RESEARCH REPORT

Needed Skills in the Transportation Workforce, in the Context of New and Emerging Technologies and Approaches

January 2022

Prepared for
The Center for Transportation Workforce Development
Office of Innovative Program Delivery
Federal Highway Administration
United States Department of Transportation

UCLA Institute of Transportation Studies

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UCLA ITS-LA2116	N/A	N/A

4. Title and Subtitle	5. Report Date
Needed Skills in the Transportation Workforce, in the Context of New and Emerging Technologies and Approaches	January 2022
	6. Performing Organization Code
	UCLA ITS
7. Author(s)	**8. Performing Organization Report No.**
Teo Wickland, https://orcid.org/0000-0001-8351-9251	UCLA ITS-LA2116
9. Performing Organization Name and Address	**10. Work Unit No.**
UCLA Institute of Transportation Studies 337 Charles E. Young Drive East Public Affairs Building 3320 Los Angeles, CA 90095-1656	N/A
	11. Contract or Grant No.
	693JJ32145219
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
U.S. Department of Transportation Federal Highway Administration Talent Development Division 1200 New Jersey Avenue, Southeast Washington, D.C. 20590	Final report (April 2021 – January 2022)
	14. Sponsoring Agency Code
	FHWA

15. Supplementary Notes

DOI:10.17610/T6GG6H

16. Abstract

The United States' transportation workforce is currently at a skills deficit in key areas. New and innovative transportation technologies and approaches threaten to exacerbate this situation. Yet, transportation workers need more than skills to implement new technologies: they need the skills to critically determine which technologies are likely to support a thriving nation and under what conditions. Additionally, transportation workers need the skills to support non-technology-focused solutions to the nation's transportation challenges, including cultural, political, and social change.

17. Key Words		18. Distribution Statement	
transportation workforce, emerging skills, technology		no restrictions	
19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**21. Price**
unclassified	unclassified	43	N/A

Form Dot F 1700.7 (8-72)

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Acknowledgments

This material is based upon work supported by the Federal Highway Administration under Agreement #693JJ32145219. Dr. Wickland wishes to thank the UCLA Institute of Transportation Studies' Dr. Brian D. Taylor, Juan Matute, Whitney Willis, and Jacob L. Wasserman; UCLA Luskin School of Public Affairs administrators Danielle Lacob Maris and Kathy Sekine; and Karen Bobo and Chrisy Currier of the FHWA for their support, feedback, and contributions to this project.

The UCLA Institute of Transportation Studies acknowledges the Gabrielino/Tongva peoples as the traditional land caretakers of Tovaangar (the Los Angeles basin and So. Channel Islands). As a land grant institution, we pay our respects to the Honuukvetam (Ancestors), 'Ahiihirom (Elders) and 'Eyoohiinkem (our relatives/relations) past, present and emerging.

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Project ID: UCLA ITS-LA2116
DOI: 10.17610/T6GG6H
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EXECUTIVE SUMMARY

Executive Summary

This report identifies emerging skillsets needed in the transportation workforce, in the context of new and innovative transportation technologies and approaches. To understand what is needed, this report uses the lens of “a thriving nation” to conceptualize the goals the transportation system must serve.

This report finds that technology can be helpful for supporting transportation for a thriving nation, but is not a savior and can be a distraction. Likewise, although skills which enable the development and implementation of technologies may be useful, these are not the most urgently needed. More urgently, the transportation sector requires workers with the skills to effectively question and analyze whether and under what conditions particular technologies can serve the goal of a thriving nation. More generally, the United States transportation sector is in need of skills which are not specific to new technologies, many of which are nonetheless emerging either as new skillsets or as older skillsets which are newly being revalued.

This report identifies the follow emerging skillsets as those most needed for the transportation workforce:

- Adaptability skills
- Advocacy skills
- Communications skills (including listening skills)
- Consensus-building skills (including negotiation and conflict resolution)
- Creative imagination skills
- Critical thinking skills
- Diversity skills (including skills to engage and value people from diverse backgrounds, with diverse ways of thinking)
- Ethical analysis skills
- Emotional intelligence skills (including self-awareness, self-regulation, social skills, empathy, and motivation)
- Historical analysis skills (relating to deep cultural, environmental, social, political, and technological histories)
- Interdisciplinary and transdisciplinary data collection and analysis skills (enabling thinking in multiple ways from multiple perspectives)
- Managerial and leadership skills
- Planning and organizing skills
- Problem solving skills
- Public outreach skills
- Systems thinking and more-than-human thinking skills (skills to think about the world as networked systems and/or as cooperative and entangled communities including humans and nonhumans)
- Teamwork and team-building skills
- Technological literacy, analysis, and programming skills (especially for understanding and modifying information and communications technologies related to transportation)
- Training skills
- Visioning skills

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Introduction

Background

This is the final report for the Department of Transportation's Dwight David Eisenhower Transportation Fellowship Program 2020 Grants for Research Fellowship (funding opportunity 693JJ318NF5229), Project E, "Emerging Skills in the Transportation Workforce." This project was awarded to the University of California, Los Angeles (UCLA), to be completed by student designee Teo Wickland, now a doctoral graduate of the Department of Urban Planning at UCLA. Grant 693JJ32145219 was funded from April 5 to October 5, 2021. This final report is due 90 days after the grant termination date.

The purpose of this project was to identify the emerging technical skills needed in the transportation workforce, in the context of new and innovative transportation technologies and approaches. This analysis could have been pursued through a focus on the system: what new technologies and approaches are likely to be adopted by various components of the existing transportation system (planners and policymakers, infrastructure providers, transportation operators, mobility consumers, etc.). However, such an approach would have neglected the purpose and outcomes of the transportation system. The United States has not developed a sophisticated and complex transportation system in order to have a sophisticated and complex transportation system. Rather, the United States has conceived and developed a sophisticated and complex transportation system in pursuit of desired outcomes, which could be summarized as "a thriving nation." Specifically, the transportation system should help the economy to thrive, it should help society to thrive, and it should help the environment to thrive (This definition holds true even for those who value the economy above all else: a thriving society is necessary for a thriving economy, and neither a thriving society nor a thriving economy can exist without a thriving geo-ecological environment in which people can live and work.).

Project Focus and Research Questions

Following the above line of reasoning, this project was executed following an outcomes-oriented approach rather than a systems-based approach. The project focus was organized into three overarching research questions.

The first research question of this outcomes-oriented project was:

1. *What innovations, technologies, and approaches are needed for the United States transportation system to support a thriving nation and have the potential to be absorbed in the transportation industry in the next decade?*

In addition, this project addressed all major technologies and approaches that are likely to impact the transportation sector, regardless of whether or not they will help to support a thriving nation. Thus, the second research question:

2. *What major technologies and approaches are likely to impact the transportation sector in the next decade?*

Finally, these two research questions point to the heart of this project. On the one hand, what skills are needed to support the innovations, technologies, and approaches that can help the United States transportation system to support a thriving nation? On the other hand, what skills are needed to manage the effects of other major technologies and approaches that are likely to impact the transportation sector? These lines of inquiry are summarized in the third research question:

3. *What emerging skills are needed in the transportation workforce for a transportation system that will support a thriving nation?*

Each of the above research questions was researched and analyzed using multiple methods as described below.

Methodology

Each of this project's research questions were analyzed via a trans-disciplinary literature review, comparative analysis, emerging issues analysis, causal layered analysis, futures mapping, and four-quadrant mapping.

This project's trans-disciplinary literature reviews included surveys of trade, expert, and scholarly literature across multiple disciplines. Disciplines surveyed include many of the transportation-related academic disciplines identified by the Center for Transportation Workforce Development as part of its Universities and Grants Programs, such as architecture, environmental science, economics, civil engineering, and urban and regional planning. Some disciplines not identified as transportation-related academic disciplines for the purposes of Universities and Grants Programs were also surveyed, including history, geography, anthropology, ethnic studies, and science and technology studies. Additionally, work from non-academic disciplines such as industrial trade journalism is included. The insights provided by these other fields provide greater context and a more well-rounded understanding of the opportunities and challenges facing the transportation sector.

In addition to literature review, this project conducted comparative analyses between the United States transportation system and transportation systems in other times and places. Additionally, it included comparative analyses between the transportation sector and other policy sectors.

Finally, a set of futures studies methodologies were also used. These include emerging issues analyses, causal layered analyses, futures mapping, and four-quadrant mapping. Emerging issues analysis is an approach to anticipating new innovations, challenges, and opportunities before they are missed or become unwieldy (Molitor, 2003 and Dator, 2018). Causal layered analysis is a method for examining underlying causes behind litanies of problems which are commonly cited (Inayatullah, 1998 and Riedy, 2008). Futures mapping is a method of mapping futures based on histories, the present, views of the future, drivers of change, barriers to change, and multi-level future landscape analysis (Inayatullah, 2008). Futures mapping is often implemented through four-quadrant mapping (Slaughter, 2003) or futures archetypes (Dator, 2009).

Definitions

This report uses certain key terms according to the following definitions (See **Table 1**):

Table 1. Definitions

Term	Definition
"A thriving nation"	A large body of closely interacting people whose social relations, economic activities, and environmental conditions ensure shared and collective flourishing
Approach	A way of thinking, organizing, or acting with respect to a particular question, problem, or possibility
Facilitate	To make more likely; to encourage; to make easier
Innovation	The process of transforming something previously established
Infrastructure	Any physical or organizational structure which facilitates processes, like a roadway, transportation agency, car, or computer
Machine	A piece of infrastructure whose components each serve a predefined purpose and which interact using cause-and-effect logic
Norm	Standard or established modes of thinking, organizing, and acting
Regulate	To control thought, organization, and action by establishing or enforcing norms
Technology	Knowledge about how to create effects through machines, tools, and infrastructures or the physical things produced with this knowledge
Tool	Anything used to help accomplish a goal or facilitate a process
Transform	To change radically or dramatically
Transportation	An act, practice, or means of moving (oneself or something else) from one physical place to another
Transportation industry	The interacting ensemble of organizations which work to regulate, facilitate, or transform transportation in a specified time and place
Transportation sector	Synonym for transportation industry
Transportation system	The interacting ensemble of infrastructures, vehicles, tools, norms, and actions which regulate, facilitate, or transform transportation in a specified time and place
Vehicle	A piece of physical infrastructure which transports itself along with passengers or cargo

Acronyms

The following acronyms appear in this report (See **Table 2**):

Table 2. Acronyms

Acronym	Meaning
AI	Artificial intelligence
ICT	Information and communications technologies
ITS	Intelligent transportation systems

Report Outline

This report will proceed with analyses in response to each of the three research questions in turn. Part 3 concludes with a summary analysis and recommendations.

1. Needed Technologies and Approaches

This section addresses the question of what innovations, technologies, and approaches are needed for the United States transportation system to support a thriving nation. It focuses on those innovations, technologies, and approaches that have the potential to be absorbed in the United States transportation sector in the next decade.

A Historical Context of Technology-focused Transportation Change

The transportation system of the United States has long emphasized modern technology. From the development of railroads (Schivelbusch, 1977) to the rise of the automobile (Foster, 1979) and demise of the trolley (Jackson, 1985), from the proliferation of freeway-based transportation (Seiler, 2003) to mass air transportation (Budd, 2011), high-tech transportation security apparatuses (Adey, 2009), and fare collection systems (Petrie, 2014), many of the most obvious developments in the nation's transportation system have depended on new technologies.

We have become so used to technology-focused transportation solutions that many Americans now assume technology is the best or only solution to transportation changes. Everyone from the trucking industry (Vaughn, 2021) to internet startups (Cramer and Krueger, 2016) and billionaire visionaries (Fannin, 2020 and Harris, 2020) is pursuing technology-based solutions for the nation's transportation system. In a context where technology has long been held up as the key to development (Hess, 1995 and Ullrich, 2019), Americans remain optimistic about the power of government investment in technology (Alvarez et al., 2021), including infrastructural transportation technologies like upgraded roads, bridges, and ports (Boak and Fingerhut, 2021).

What this breathless enthusiasm for technology often overlooks is that technology is not a cure-all. For example, in 2013, tech entrepreneur Elon Musk proposed a "hyperloop" system which would whisk travelers between Los Angeles and San Francisco via magnetic-levitation vacuum tubes (Kolawole, 2013).[1] Supposedly, this technological solution would resolve the issues which have delayed the construction of California's high-speed rail system. However, a closer look reveals that California high-speed rail has not been delayed due to limitations of high-speed rail technology but rather due to political and organizational issues. Substituting hyperloop technology for high-speed rail technology does not resolve those issues. Building the hyperloop would still require the sorts of easements and land acquisitions which have bedeviled the development of high-speed rail between Los Angeles and San Francisco. Similarly, any organization which would oversee construction of the hyperloop would risk the same managerial challenges as California's High-speed Rail Authority: the substitution of one transportation technology for another does not resolve the risk of institutional problems.

Many other types of challenges which face the nation's transportation system cannot be resolved wholly or even primarily by technological intervention. For example, transportation technologies which have been deployed to resolve the cultural problem of racism (Henderson, 2006), the social problem of access to opportunity (Stehlin, 2019), and the engineering problem of capacity limitations (Hansen, 1995) have all had perverse effects. In

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1. Technically, hyperloop tubes would operate at very low pressure, rather than as true vacuums.

general, new transportation technologies risk exacerbating problems such as equity, environmental injustice, and even lack of safety (Guo et al., 2020).

In sum, development of the nation's transportation system has long emphasized technological solutions. However, such solutions are not cure-alls and can often be counter-productive. The nation's transportation system does not only face technological challenges. The transportation system and its project of supporting a thriving nation is also confronted with social, cultural, and political problems that cannot be solved by technology.

More than Technology: Four Futures

Numerous approaches could transform the transportation system either without or in complement to technological change. Some relatively unsurprising examples might include education campaigns to encourage walking and bicycling or beautification schemes for public transit. Some less predictable examples could range from integrating storytelling into participatory planning processes (Bulkens, Minca, and Muzaini, 2015 and van Hulst, 2012) to cultural renewal programs that support culturally-specific ways of moving around (Hamilton, 2019 and Rau and Jones, 2019).

In order to organize and analyze such widely varying approaches, this project engaged futures studies methodologies, including emerging issues analysis, causal layered analysis, futures mapping, and four-quadrant mapping (These four methods are discussed in the Introduction to this report.). The results of these analyses are summarized in the four possible futures discussed below and illustrated in **Figure 1**.

Future A most closely resembles the status quo trajectory. This transportation future will be ensured by following ideals of progress (like reliability or faster speeds) grounded in values of conquest (expansion of political and capitalist empires, extraction of valuable resources).[2] The military models of Future A are currently embedded in everything from engineering paradigms (Karwat, 2020 and Walls, 2021) to technological excitement (Irani, 2018 and Lane, 2015). Because we are so used to militarism (Martin and Steuter, 2010), we may not notice how it combines with transportation systems to enable destructive resource extraction which harms humans as much as nonhumans (Klein, 2014 and Ross, 2011). This future would lead to mass death of disfavored groups before systemic collapse finally forced transformation among privileged groups (Adams, 2013; Klein, 2010, 2014; Mitchell, 2002; and Robinson, 2020).

Future B could be attained if current policy efforts to improve equity are followed to their logical conclusions. Because these efforts do not challenge capitalism (e.g., Sprunt, 2020), and rarely consider more-than-human relations, a transportation system in this future would support equity without challenging the extractivist ideas also seen in Future A (Hine and Grieco, 2003). Therefore, this future would only avoid the collapse of Future A by equitably distributing harm such that the system would become untenable some time before collapsing.

Future C is currently being modeled by some social movements which appropriate transportation infrastructure (Badger, 2016 and Jilani, 2017) and could be supported by scholarly ideas around social transportation (Bonera et al., 2020; du Toit et al., 2007; and Fink, 2012). This future represents a steady state in which power and counter-power groups engage in sustainable agonism (Castells, 2012 and Mouffe, 2013).

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2. For an in-depth exploration of the intertwinement of progress and conquest, refer to the modernity/coloniality research program (Escobar, 2007; Maldonado-Torres, 2007; and Mignolo, 2011).

Figure 1. Mapping Transportation Futures on Sustainability and Equality Axes

Sustainability

C. Transportation for social struggle

- Social movement models and metaphors guide transportation development
- Transportation system emphasizes social interaction
- Strong transportation-based community networks are evenly matched with centers of power
- Transportation system is a site of continual political struggle

D. Transportation to nurture a thriving nation

- Transportation understood through models of care and deep relation
- Transportation system supports spiritual development and healthy more-than-human social relations
- Transportation infrastructures attend to hyperlocal needs and creativities, de-emphasizing long-distance movement
- Transportation enables transformation of values and culture

Inequality

Equality

A. Transportation for domination and attempted supremacy

- Transportation driven by militaristic models and metaphors
- Transportation system optimized for resource extraction and unequal wealth accumulation
- Transportation system accelerates direct environmental harms and indirect human harms
- Transportation-destabilized climate, ecology, and society and extractive ideology lead to mass death and then systemic collapse

B. Transportation for inclusive extraction

- Transportation changes conditioned by models of participation and inclusion
- Transportation system optimized for distribution of costs, resources and opportunities
- Transportation perpetuates existing extraction-and-consumption socioeconomic model with less inequality
- Resource limits and equitably-distributed externalities eventually cause system failure

Unsustainability

Finally, Future D represents a transformation in our understandings of transportation (Ingold, 2011). This future aligns with a broader process of social transformation, sometimes referred to as a new stage in human evolution, which is currently ongoing (Ateljevic, 2013). This future transportation system valorizes care (Puig de la Bellacasa, 2017 and Jon, 2020) and love (hooks, 2000 and Porter, Sandercock, and Umemoto, 2012), which are not opposed to economic activity but rather different ways of understanding it (Gibson-Graham, 2006 and M. Meyer, 2013). The transportation system of Future D would diversify our modes of relating and imagining (Wickland, 2021).

Needed Skills

As illustrated by the four futures analysis above, a wide variety of possibilities are feasible for the future of the nation's transportation system. The differences between these are much more than technological, and therefore navigating among these futures requires more than technical skills.

Any one of these futures will require skills training. Therefore, the skill of training (i.e., the ability to convey skills to others) will certainly be crucial. There is already a lack of qualified staff to train transportation professionals on needed skills (Puentes et al., 2019, p. 1). Developing training skills should be a key priority.

Beyond training skills, many skills related to "planning, environmental/cultural protection, and multimodalism," as well as "managerial and leadership" skills, are insufficiently represented in at least some parts of the transportation sector (Puentes et al., 2019, p. 2). Employees will need to be trained in such "critical" skills as communications, management, teamwork, and leadership (Puentes et al., 2019, p. 8). New approaches such as leadership development programs are already emerging to address this issue (Puentes et al., 2019, p. 40); however, a more "diverse array" of educational offerings is also needed (Puentes et al., 2019, p. 9). Indeed, while current STEM offerings may be too difficult for some, in other cases, they are not relevant to students' interests and career goals (Kennedy, Hefferon, and Funk, 2018). Such offerings often lack training in attitude, behavior, and motivation skills and fail to tie learnings to student interests in areas such as social and environmental benefits (Puentes et al., 2019, pp. 9–10).

The terrain the transportation sector must navigate to support a thriving nation is of vast complexity. To face this challenge, transportation workers will require skills in interdisciplinary and transdisciplinary thinking. These could be facilitated by emerging approaches of transdisciplinary peer-to-peer knowledge transfer (Puentes et al., 2019, pp. 2, 40). Additionally, creative approaches will be needed to allow for whole thinking across such varied knowledges (Fazey et al., 2018).

Generally, these futures will also require public outreach and consensus-building skills (Puentes et al., 2019, p. 10). They will also require additional creativity to deal with changing budgetary and policy environments, as is already happening, for example, following "budgetary challenges due to declining revenue from oil and gas extraction" (Puentes et al., 2019, p. 40).

Technologies for Four Futures

Each of the four futures described above (See **Figure 1**) has different requirements with respect to transportation technologies.

Future A relies on speedy, high-capacity transportation capable of projecting military and economic power and of carrying vast quantities of resources from extraction sites to places where they can be profited from. Our current transportation system already exceeds these technological needs, meeting not only these requirements but also contributing to resource demand and capital accumulation directly (For example, the car system burns fossil fuels and requires individuals to purchase costly vehicles.). However, future technologies could further facilitate Future A. For example, technologies which allow for more vehicles to operate efficiently in congested areas could encourage more vehicle purchases and operation by those with the means to do so, while further isolating those without means.

Future B relies on a transportation system which equitably distributes costs, resources, and opportunities. In contrast to our present transportation system and the requirements of Future A, Future B could be produced either by a high-capacity, long-distance transportation system or by a transportation system with more moderate capacities that facilitates shorter-distance movements. The essential quality of technologies for Future B would be their capacity to be deployed equitably: are there sufficient resources to provide those technologies to everyone who needs them? Secondarily, these technologies would have to rely on socially sustainable resource extraction: do the people where the required resources are produced agree to their extraction and distribution?

Future C relies on a transportation system that facilitates social interaction. This could be facilitated by certain technologies, such as mass-transit systems that encourage on-board interaction and community. However, as recent events have shown, social movements are perfectly capable of appropriating existing technologies like roadways and freeways to make them spaces of social interaction. This could further be facilitated by information and communications technologies that allow for distributed planning of social interactions using the existing transportation system. This future relies on an absence of technologies of power (e.g., police surveillance and deployment technologies) that would prevent such social mingling.

Future D requires a transportation system that supports physical, creative, and spiritual development while facilitating intimate relations with local environments. This sort of transportation paradigm could be facilitated by locally specific technologies. For example, local communities might lead and participate not only in roadway design processes but also in the physical construction of roads using local materials and ideas. Rather than reproducing cookie-cutter freeways in every community, this model would lead to smaller-capacity roads whose materials carry meaning to the people who use them. Roads in one area might be pedestrian ways made of wood; in another, they might be bikeable stone paths surfaced with salvaged concrete. A benefit of such technologies which might go unremarked by someone from Future A is that their embedding of local knowledge in diverse ways will lead to further diversification and creativity.

Summary: Needed Technologies and Approaches

A number of transportation skillsets will be needed in any foreseeable future, including training, planning, environmental and cultural protection, management, leadership, teamwork, communications, attitude and behavior, interdisciplinary thinking, and creative approaches. Needed and useful technologies vary with possible futures. Based on the analysis of this report, no new technologies would be strictly required, except for the local development of locally specific technologies in Future D.

2. New and Impending Technologies and Approaches

This section addresses the question of what major technologies and technological approaches are likely to impact the transportation sector in the next decade. It will include discussions of technologies and approaches identified as needed in Section 1. It will also include discussions of technologies and approaches not identified in Section 1 and which may have mixed or negative impacts with respect to the transportation sector's objective of supporting a thriving nation.

Vehicular Communications and Intelligent Transportation Systems

The categories of vehicular communications and intelligent transportation systems are quite vast: all the ways communications could happen in relation to vehicles and ways in which transportation systems could embody intelligence. However, scholarly discourse on these keywords has defined them much more narrowly. "Intelligent transportation systems" (ITS) are defined by the Institute of Electrical and Electronics Engineers as "those systems utilizing synergistic technologies and systems engineering concepts to develop and improve transportation systems of all kinds" (IEEE Transactions on Intelligent Transportation Systems, 2022). In practice, "ITS" is often applied even more particularly to refer to transportation systems which integrate information and communications technologies (Gharehbaghi and Myers, 2019 and Lei et al., 2017). "Information and communications technologies" (ICT), in turn, is an umbrella term for all technologies of information or communication (Graham and Marvin, 2001, p. 426). However, here again, "ICT" is often used more narrowly: to refer to "electronic means of capturing, processing, storing, and communicating information" (Heeks, 1999). In the context of transportation systems, ICTs may encompass specifically those <u>tele</u>communications and information technologies which have been used by the transportation sector since the mid-1980s (Giannopoulos, 2004). In sum, there is a slippage between the universal possibility implied by sweeping terms like "vehicular communications" and "intelligent transportation systems" and the very narrow (and potentially myopic) use of these terms to refer specifically to the integration of computer electronics and electric telecommunications into transportation systems via systems engineering methods. This slippage ignores and erases the possibility of using more diverse, profound, or creative approaches.

Recent efforts at development of ICT-based vehicle communications and ITS technologies have focused on using computer-based telecommunications to improve automobile fuel economy and safety and add entertainment capabilities (Elhoseny and Hassanien, 2019) or increase efficiency (Yang, Guler, and Menendez, 2016). These engage varied "vehicle-to-X" computer communications models (vehicle-to-vehicle, vehicle-to-infrastructure, vehicle-to-pedestrian, "vehicle-to-everything") to route vehicles effectively, manage separation between vehicles, keep speeds more constant, and allow gaming, video, and other entertainment communications either among vehicles and/or between vehicles and the broader internet (Elhoseny and Hassanien, 2019; Miucic, 2019; and Shladover, 2018). These models use a number of electronic sensor and telecommunications technologies, including cellular data, radio-frequency identification (RFID), intelligent traffic lights, roadside and roadbed sensors, and the Global Positioning System (GPS) (An, Lee, and Shin, 2011 and Baras et al., 2017).

This research focus in ITS and vehicle telecommunications discourses is reflected in the top keywords in the field (Xu et al., 2019, p. 2897):

1. Road traffic
2. Traffic control
3. Road vehicles
4. Traffic engineering computing
5. Global Positioning System
6. Road safety
7. Vehicle dynamics
8. Driver information systems
9. Automated highways
10. Object detection

Technologies such as machine type communication, internet of things traffic, and cloud services and virtualization may be implemented in concert with “vehicle-to-X” models to make computer-based vehicular telecommunications more efficient and powerful (Camacho, Cárdenas, and Muñoz, 2018). These are complemented by technologies which focus on vehicle operators and passengers, such as driver assistance functions (McCall and Trivedi, 2006) or even emotion monitors (Healey and Picard, 2005). Finally, the algorithms which determine how to route and manage vehicles are also constantly being refined (P. Veres, Bányai, and Illés, 2017). All of the above may be augmented by machine learning, whereby transportation systems integrate artificial intelligence and autonomously refine and improve themselves over time (Boukerche and Wang, 2020 and M. Veres and Moussa, 2020).

Vehicle communications and ITS development efforts have increasingly noted the potential of their integration into the “smart city,” which is a strategy to use ICTs to help manage complex urban centers and tackle problems like over-crowding, energy and resource overconsumption, poverty and inequality, and unemployment (Trombin et al., 2020). Thus, ITS development could potentially become more closely coordinated with or integrated into smart city research and development through the lens of “smart mobility.” However, this is not a purely technological endeavor: as Trombin et al. point out, “smart mobility...needs both high technologies and virtuous people behaviors” (Trombin et al., 2020, p. 165).

Transit Priority Technologies

Technologies to give priority to public transit include some ICT-based ITS and vehicle telecommunications technologies and additional technologies which may not rely on ICTs. These have long included both “passive” technologies like bus-only lanes, signal optimization, and bus bulbs and “active” technologies like signal pre-emption or real-time traffic routing and capacity optimization (Skabardonis, 2000). As Skabardonis (2000) notes, individual passive and active technologies can also be categorized as either facility design or traffic control approaches.

Recent technological efforts in transit priority have included the development of new algorithms to optimize provision of transit priority infrastructures (Mesbah et al., 2011), transit priority signal settings (Stevanovic et al., 2008), or both at once (Ma, Head, and Feng, 2014). Other innovations include the development of transit priority strategies coordinating multiple transit routes (Lin et al., 2013) or across variable demand scenarios (Ghaffari, Mesbah, and Khodaii, 2020).

Travel Planning, Tracking, and Sequential Mobility Sharing Technologies

Enhanced trip planning capabilities have long been a key aspiration of intelligent transportation systems (Wootton, García-Ortiz, and Amin, 1995). Relatively recent efforts have developed real-time trip scheduling (Fu, Liu, and Calamai, 2003) and multimodal travel planning with real-time information (Li et al., 2012).

However, in this area, the pace of development of commercially-available consumer technology has far exceeded that of scholarly research and planning technologies. Even news reports and product documentation have proven unable to keep up with the rapid cadence of new product updates and feature launches. Therefore, the best contemporary references are the products themselves.

Hundreds of innovative trip-planning websites, applications, and vehicle functions are currently available. These range from platforms like Google Maps, the most popular trip-navigation software (Panko, 2018), with a website, smartphone app, and various integration schemes (Google, 2021), to services like HERE, which integrates into automobiles to provide on-board trip planning and navigation (HERE, 2022), to Waze, which dynamically routes automobiles based on crowd-sourced travel conditions (Waze, 2021), to Uber, which allows for real-time trip scheduling and routing through its ride-hailing platform (Uber Technologies, 2022), to Transit, which plans trips using real-time data from multiple sources include transit operators, ride-hailing services, and light-vehicle sharing schemes (Transit App, 2022).

These technologies have several things in common. They are all computer-based technologies which regularly integrate new features based on software updates. They rely on the Global Positioning System (GPS), supplemented with secondary data, such as wireless network triangulation, to locate devices (and, by extension, users and vehicles) on the Earth’s surface. And they rely on internet connectivity to share and access real-time data. Conversely, this sample of trip-planning technologies also illustrates certain diversities. These technologies run on different computers, from desktop and laptop PCs to smartphones to the integrated onboard computers of automobiles. Some, like Waze, focus on automobile travel (including, in Waze’s case, both individual driver and carpool travel). Others, like Transit, emphasize mode choice, including route planning and trip tracking for fixed-route public transit, walking, ride-hailing, and bicycle- and scooter-sharing. Still others, like Uber, allow for integrated billing and electronic payment of dynamically priced trips.

The rapid development and deployment of varied functionalities into trip-planning technologies reveals, on the one hand, the unpredictability of this sector and, on the other hand, the breadth of relevant skills that may be implicated. This is especially true in trip planning because trip planning can change independent of government policymaking (in contrast to, say, transit priority technologies) and because trip-planning functions can be updated based on software changes (as opposed to, say, battery power storage technology, for which major changes require hardware updates).

Some aspects of trip-planning functionality offered by such applications do depend on government coordination, especially as relates to public transit. For example, Google Maps requires regularly updated transit schedule data from transit agencies. Apple Wallet, an electronic payments platform, requires both hardware capability and software integration with transit systems to allow for electronic fare payment. Services like Transit, which hope to make public transit more appealing to travelers, will be most successful if inter-jurisdictional coordination for transit is prioritized by transit operators.

Electric Vehicles and Battery Power Storage

Electric vehicles have a long history, and rail electric vehicles in particular have been common in many countries for decades. However, automobile electric vehicles have only recently begun to enter into the mainstream (Jensen et al., 2017). Rapid technological development of automobile electric vehicles has been motivated in part by desires to reduce dependence on oil and to alleviate environmental harms like air pollution and greenhouse gas emissions (Sun et al., 2020). The most prominent technologies of automobile electric vehicles are pure battery-electric vehicles, hybrid electric vehicles, and fuel cell electric vehicles. Of these, pure battery-electric technologies are currently receiving the greatest interest and investment (Sun et al., 2020).

Although the development of automobile electric vehicles has been motivated by desires to reduce environmental harms, the shift from gasoline internal combustion to electric power does not necessarily reduce air pollution or other environmental harms. Often in the United States, transitioning from internal combustion to electric vehicles merely shifts emissions from local gasoline combustion to coal- and natural-gas-burning power plants slightly further afield (Holland et al., 2016). Switching to so-called "green" electricity technologies like solar panels and wind turbines also moves environmental problems around rather than eliminating them. Firstly, they rely on resource-extraction and manufacturing processes which produce significant environmental harms, including greenhouse gas emissions (Uddin and Kumar, 2014 and Ziemińska-Stolarska, Pietrzak, and Zbiciński, 2021). Second, their installation and operation also produces environmental harms, such as destroying ecosystems to clear land for solar farms (Turney and Fthenakis, 2011), or the noise, wildlife-killing, and local climate impacts of wind farms (Leung and Yang, 2012). These technologies' relatively short lifespans also create significant ongoing issues related to waste and recycling, including emissions produced by recycling the materials they contain (Uddin and Kumar, 2014 and Ziemińska-Stolarska, Pietrzak, and Zbiciński, 2021).

Battery-electric vehicles also raise the particular problem of the battery power storage itself. The heretofore emphasis on lithium-ion batteries requires lithium mining, which carries significant adverse impacts to the environment, biodiversity, and human health (Kaunda, 2020 and Wanger, 2011). Although increased lithium recycling could partially alleviate this issue, sharp reductions in demand for lithium-ion batteries would be necessary to actually minimize environmental harm (Nilsen and Marsh, 2021 and Wanger, 2011). These environmental impacts also imply social impacts,[3] often affecting Indigenous groups on whose lands mining occurs (Hancock, Ralph, and Ali, 2018 and Wanger, 2011; see also: Liboiron, 2021).

Automated Vehicles

As with electric vehicles, automated vehicles have been common for decades in some sectors, notably fixed-guideway mass transit. Like electric vehicles, much recent technological development for automated vehicles has focused on small vehicles, including automobiles (Clements and Kockelman, 2017).

Automated public transit aspires to improve safety and efficiency and to reduce driver labor costs (Liu, 2016). However, automated train operation systems have repeatedly been implicated in crashes (e.g., National Transportation Safety Board, 1996, 2010), and, in some cases, transit drivers continue to be paid to operate trains

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3. The distinction between environmental and social impacts is debatable, because people are part of the environment (Cronon, 1996; de la Cadena, 2019; and Tsing, 2015) and nonhumans are also social (Haraway, 2003; Scott, 2020; and Wohlleben, 2016). Some scholars have argued that environmental impacts are social and vice versa (e.g., Ross, 2011; Liboiron, 2021; and Pulido, 2016).

that are nominally automated (Friedlander, 1974). Recent experiments which have successfully launched automated transit services are often on smaller, specialized operations, like airport-specific transit lines or miniature transit vehicles operating at tourist destinations.

Automobile automation addresses the possibility both of automated personal vehicles (to replace manually operated, individually owned automobiles) and of automated shared vehicles (to replace manually operated taxi, demand-response, and ride-hailing services) (Alessandrini et al., 2015). Potential benefits include possible reductions in personal vehicles and parking needs and increased accessibility and inclusion for groups such as children, the elderly, and people with disabilities (Alessandrini et al., 2015).

Automated vehicles also bring unique risks, ranging from the potential for automated systems to produce crashes that would be avoided by human operators (Goodall, 2014) to their particular vulnerability to cyberattacks (Petit and Shladover, 2015).

Travel Substitution and Virtual Travel

Information and communications technologies may interact in various ways with transportation. Telecommunications have long been theorized as a possible substitution for physical travel; however, telecommunications can also complement physical travel (Salomon, 1985). These range from mail and package deliveries to phone calls, television, fax machines, and teleconferencing to e-mail, internet, telecommuting, video chat, social media, and internet file sharing. The COVID-19 pandemic has vividly illustrated both the application and limits of new technologies for travel substitution and virtual travel. For example, Zoom calls allow for long-distance connection but lead to user fatigue (Ramachandran, 2021). To take another example, virtual reality can substitute for tourist travel during and after the COVID-19 pandemic, which could actually encourage additional physical travel by stimulating wanderlust (Sarkady, Neuburger, and Egger, 2021). Given the rapid pace of software technology development, we can expect the continual release of new technologies which seek to alleviate some of the challenges of using ICTs for travel substitution or virtual travel. The effects these technologies will have after the COVID-19 pandemic remain to be seen.

Transportation Data Collection

A final area of notable technological development is in transportation data collection. Recent and emerging technological interventions allow for automated data collection from intelligent transportation systems, trip-planning and payment systems, electronic hailing platforms, automated vehicle records, and ICT logs.

Innovative technologies may be used for the collection of data related to transportation systems. For example, Hipp et al. (2013) proposed using crowd-sourcing and webcams to measure active transportation activity. Further creative approaches may allow for new and novel ways to collect transportation data. For example, intelligent transportation systems might integrate surveys and other methods for general data collection about needs and desires in the smart city (Trombin et al., 2020).

Secondary Effects of Impending Technologies

The above discussions have summarized key new and impending technologies and technological approaches, and some of their direct effects. However, these technologies will also inevitably have secondary effects, and indeed, already are.

> "**Technology-related influences on travel are impacting virtually all recognized travel characteristics that influence travel decisions.** Cost in time and money, safety, convenience, reliability, comfort, flexibility, environmental impact, personal privacy and identity security, awareness of opportunity, image, and social interaction opportunities are influenced by the changes technologies are having on transportation options.
>
> **Technologies are enabling a transformation of the historic business models and economic structure of transportation.** Technology enables fundamentally different business structures and cost structures for travel with the prospect of sequentially and/or simultaneously sharing vehicles, reducing capital and operating costs, and transitioning transportation expenditures from high fixed and low variable costs characteristic of personal auto ownership to a fully-allocated per-trip cost structure. These technology-enabled changes are hypothesized to profoundly influence travel behavior" (Polzin, 2016, p. 2; emphasis original).

Additionally, actual or potential technologies can also have effects on planning and policy activity (Polzin, 2016, pp. 18–19).

One aspect of such secondary effects could be summarized as "introducing new stories": the new technology tells new stories about where and how we can travel and what that means. These stories are sometimes fulfilled and sometimes not (e.g., a story of quick travel is fulfilled when a driver speeds down the freeway but betrayed if that driver is stuck in gridlock).

Another aspect of such secondary effects are the material effects, those that exist whether or not we tell stories about them. For example, if new technologies allow for more automobile travel, that could lead to more air pollution and greenhouse gas emissions. Whether we measure these or not, the technologies would produce death as a material effect.

Summary: New and Impending Technologies and Approaches

A vast array of transportation technologies are currently emerging. The most celebrated examples, reviewed in this report, heavily emphasize information and communications technologies. Among transportation-related ICTs, software technologies see the fastest pace of development, while hardware technologies are developing at a relatively slower pace. In some cases, hardware technologies under long-term development are superseded or rendered less relevant by rapidly deployed software technologies. For example, intelligent transportation systems efforts have long envisioned automobiles which would integrate hardware technologies to automatically re-route based on changing roadway usage. However, freely available smartphone mapping software now updates driving directions in real-time based on changing conditions, reducing the need for previously envisioned ITS hardware.

3. Needed Emerging Skills

This section addresses the question of what emerging skills are needed in the transportation workforce, for a transportation system that will support a thriving nation. This section relates to the two prior report sections as follows: on the one hand, what skills are needed to support the innovations, technologies, and approaches that can help the United States transportation system to support a thriving nation? On the other hand, what skills are needed to manage the effects of other major technologies and approaches that are likely to impact the transportation sector?

Reconciling the Gap between Needed Approaches and Impending Technologies

Why are highly educated scholars pushing forth with new technologies while ignoring voluminous research on the adverse effects of the technological development model they are pursuing? One reason is because even these highly educated scholars have not been educated on this transdisciplinary research. Another reason is that these scholars are not aware of or do not focus on alternative paradigms. There is a gap in skills and knowledge which reaches to the highest levels of transportation education in the United States, failing to educate even sophisticated transportation leaders about systemic injustices and alternatives.

There is an urgent need for skills to produce and disseminate knowledge which relates the nation's transportation system to cultural and political histories spanning centuries or more and which contextualizes the work of the contemporary transportation sector in these histories (e.g., Sheller, 2018). Such skillsets will allow workers and leaders in the transportation sector to better understand the implications of their actions. It will also allow for thoughtful deliberation about which technologies and innovations are needed for which objectives, and better awareness of the possibilities which are available to us.

Managing Impending Technologies

Far from a panacea, technological "solutions" may malfunction or simply move problems around. For example, as mentioned earlier in this report, innovations to increase roadway efficiency could encourage more automobile use, producing more pollution and accelerating climate change. To cite another example, the artificial intelligence (AI) integrated in many plans for intelligent transportation systems, such as self-driving cars, raises a raft of safety and ethics concerns which may be difficult to resolve once widely deployed (Santoni de Sio, 2021).

At the same time, despite the attention and resources lavished on technological development, cultural changes can have at least as significant effects in furthering transportation objectives like improving safety (Buckley, Marfione, and Putman, 2012) or regulating transportation system use (Bamberg, Rollin, and Schulte, 2020). In this context, with respect to technological innovations, transportation workers need to ask questions of not just "can we?" or "how do we?" but "should we?" and "who is harmed?"

A Moment of Social and Cultural Transformation

The United States is currently undergoing marked social and demographic change (Shrestha, 2006). This simple fact has significant implications for the transportation sector. As the NCHRP synthesis on transportation workforce planning and development strategies has noted, “the future labor market will be more ethnically and racially diverse than the current makeup of the transportation industry,” and “the transportation industry must consider how it can better appeal to a new, more diverse candidate pool” (Puentes et al., 2019, p. 14). Women and people with disabilities are similarly underrepresented in the transportation sector. Increasing representation of such disfavored groups is both a practical necessity and a change that will pay dividends in organization effectiveness (Puentes et al., 2019, p. 14).

However, increasing diversity in the transportation workforce is not a question of simple demographic representation. Rather, people from diverse backgrounds have diverse experiences, viewpoints, and ways of knowing.[4] Instead of trying to indoctrinate those with diverse knowledges into a single standardized knowledge system, the industry would do better to create an environment where those from diverse backgrounds feel equally heard, engaged, and valued (Puentes et al., 2019, p. 15).

More broadly, a recent scholarly consensus has identified that profound social and cultural transformation is already ongoing around the world (Ateljevic, 2013; Jelinčić, 2017; and McAllum, 2016). As a part of this transformation, the world is presently on the cusp of new policy and planning paradigms (Finck Carrales, 2021; Riedy, 2020; Sebastian and Jacobs, 2020; and Vasudevan and Novoa Echaurren, 2022). Generally, these new paradigms either include or center diverse ways of knowing and relating not previously taken seriously by modern policymaking. These often come from feminist, Indigenous, Black, postcolonial, queer, crip, and other marginalized perspectives (e.g., Bates et al., 2018 and Jon, 2021). A related quality of these new policy paradigms is their questioning of values previously assumed to be universal, such as the primacy of economic growth (Victor, 2010 and Washington, 2021). Instead, values such as love (hooks, 2000 and Porter, Sandercock, and Umemoto, 2012) or care (Puig de la Bellacasa, 2017 and Jon, 2020) may be centered.

Analyzing Needed Skills

A diversity of skills are needed to facilitate transportation for a thriving nation. There is no need to fetishize skills related to cutting-edge information and communications technologies.

The NCHRP synthesis on transportation workforce planning and development strategies identified a set of fourteen skill areas which emerged from a survey asking state transportation officials what skills transportation employees would need in ten years. The synthesis categorized these into ten “power” skill areas and four “hard” skill areas (Puentes et al., 2019, p. 25):

Power skills:

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4. This point may be self-evident. However, claims that modern science and technology are “objective” sometimes deny the fact that all our knowledges are contingent on particular perspectives and ways of knowing that are far from universal (Haraway, 1988 and Turnbull, 1997). The denial of diverse knowledges is a form of supremacism (Glover, 2017; Paraskeva, 2011; Pié-Balaguer and Planella-Ribera, 2020; and Snaza, 2019). Recent efforts have explored ways in which diverse knowledges can be better valued and integrated in public debate, policy, planning, and engineering (di Norcia, 2002; Escobar, 2007; Lang, 2011; Matuk et al., 2020; Mignolo, 2007; Nightingale, 2003; and Vasudevan and Novoa Echaurren, 2022).

- Leadership
- Negotiation
- Critical thinking
- Problem solving
- Team work
- Creativity
- Flexibility
- Conflict resolution
- Communication
- Emotional intelligence

Hard skills:

- Technology
- Programming
- Quantitative analysis
- Data science

These skills are undeniably useful, and many of them are essential. However, we might categorize them differently and interrogate the values behind the labels offered in the NCHRP report. Are “power” and “hardness” the most important qualities of these skills or of needed skills in general? Perhaps what is important about some of these skill areas is rather the need for care or to tend relationships or to unlock new possibilities, rather than to project power or assert certainty.

More generally, the transportation sector is in need of diversifying skillsets which recognize and value previously neglected ways of knowing, relating, and imagining. Riedy’s (2020) analysis of the “common ground” of “alternative discourses” provides a useful summary of some of these knowledge and relational paradigms:

> “There is common ground in how alternative discourses see the world (systems and networks), their normative relationship with nature (sustainable, regenerative[,] or planetcentric) and with each other (cooperative and entangled), their goals (wellbeing, justice[,] and plurality)[,] and some of the strategies for transformation (participatory governance, a new economic system, prioritizing different human values[,] and participatory knowledge practices)” (Riedy, 2020, p. 100).

All of these qualities suggest emerging skillsets which could be cultivated for the transportation sector.

Summary of Needed Skills

Based on the analyses summarized above, this report identifies the follow emerging skillsets as those most needed for the transportation workforce:

- Adaptability skills
- Advocacy skills
- Communications skills (including listening skills)
- Consensus-building skills (including negotiation and conflict resolution)
- Creative imagination skills
- Critical thinking skills

- Diversity skills (including skills to engage and value people from diverse backgrounds, with diverse ways of thinking)
- Ethical analysis skills
- Emotional intelligence skills (including self-awareness, self-regulation, social skills, empathy, and motivation)
- Historical analysis skills (relating to deep cultural, environmental, social, political, and technological histories)
- Interdisciplinary and transdisciplinary data collection and analysis skills (enabling thinking in multiple ways from multiple perspectives)
- Managerial and leadership skills
- Planning and organizing skills
- Problem solving skills
- Public outreach skills
- Systems thinking and more-than-human thinking skills (skills to think about the world as networked systems and/or as cooperative and entangled communities including humans and nonhumans)
- Teamwork and team-building skills
- Technological literacy, analysis, and programming skills (especially for understanding and modifying information and communications technologies related to transportation)
- Training skills
- Visioning skills

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