CENTER OF EXCELLENCE

on New Mobility and Automated Vehicles

Research Regarding the Impacts of New Mobility and Highly Automated Vehicles

Report to the

Federal Highway Administration

Office of Safety and Operations Research and Development

pursuant to under the terms of Agreement No. 693JJ32350027

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The Center of Excellence on New Mobility and Automated Vehicles (Mobility COE) was authorized by the 23 U.S. Code section 503(c)(6) and funded through a cooperative agreement with FHWA. The Mobility COE collects, conducts, and funds research on the impacts of new mobility and highly automated vehicles on land use, urban design, transportation, real estate, equity, and municipal budgets.

www.mobilitycoe.org

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Introduction

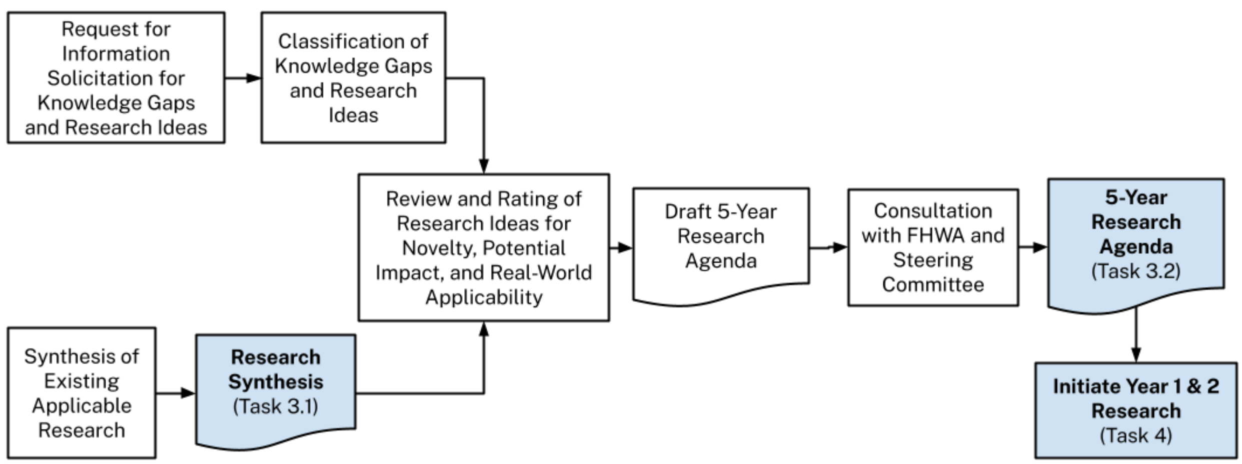
This report details the activities and research outcomes of the first year of the Center of Excellence on New Mobility and Automated Vehicles ("Mobility COE"). Established through cooperative agreement 693JJ32350027 between the Federal Highway Administration (FHWA) and UCLA, the Mobility COE researches and disseminates research on the impacts of new mobility and highly automated vehicles on land use, urban design, transportation, real estate, equity, and municipal budgets.

The success of the Mobility COE is built on strong partnerships with leading institutions. Our core partners — Carnegie Mellon University (CMU), National Renewable Energy Laboratory (NREL), Shared-Use Mobility Center (SUMC), University of Alabama (UA), and MetroLab Network — bring together a diverse array of expertise and resources crucial for advancing the Mobility COE's mission. These partnerships enable us to leverage cutting-edge research, extensive industry connections, and robust administrative capabilities to address the multifaceted challenges of new mobility technologies.

UCLA, as the primary host institution, provides a solid administrative foundation and extensive experience in managing large-scale transportation research initiatives. CMU contributes significant expertise in AI/ML, network simulation, and optimization methodologies, supported by a history of federal and state funding and strong industrial partnerships. UA offers valuable insights from its work in deploying new technologies in suburban, small city, and rural areas, ensuring that our research addresses the needs of often-underserved populations. NREL brings comprehensive research capabilities in energy system analysis, vehicle electrification, and transportation modeling, emphasizing equitable and sustainable mobility. SUMC, with its nationally recognized expertise in shared mobility and public-private partnerships, enhances our ability to evaluate and implement new mobility technologies. MetroLab Network plays a critical role in promoting civic research and facilitating collaborations between government, academia, and communities. This will ensure the COE engages with extensive external stakeholders.

The Mobility COE Steering Committee (SC), chaired by FHWA, plays a pivotal role in guiding the center's initiatives. Comprising experts from government, industry, and academia, the SC ensures that all relevant perspectives are integrated into the research and activities of the Mobility COE. The diverse expertise of SC members spans core technological and service areas essential for new mobility solutions, including land use, urban planning, systems analysis, optimization, equity, health, and society. Their guidance ensures that the research agenda aligns with strategic goals, remains relevant, and addresses the evolving needs of the transportation ecosystem. Another important charge of the SC is to leverage their extensive networks to expand the Mobility COE's partnerships to enhance the center's reach and impact. This collaborative approach ensures that the Mobility COE remains at the forefront of innovation, addressing the most pressing needs in new mobility technologies and their implications for society.

The diagram below outlines the systematic process the Mobility COE has followed in its first year of activities.



The process begins with a Synthesis of Existing Applicable Research to establish a foundational understanding and identify known knowledge gaps. This synthesis is formalized in the Research Synthesis (Task 3.1) report. Based on this analysis, the COE developed the [Request for Information (RFI) Solicitation for Knowledge Gaps and Research Ideas](), which involves gathering input from a wide range of stakeholders. These submissions are then subjected to a Classification of Knowledge Gaps and Research Ideas, organizing them based on thematic relevance and research potential. Subsequently, the Mobility COE and FHWA jointly review and rate ideas on novelty, potential impact, and real-world applicability. This step ensures that only the most promising and impactful ideas are selected for further consideration. Following this, the COE will draft a Five-Year Research Agenda, outlining the long-term research objectives and priorities of the Mobility COE. This draft agenda will then be further developed in consultation with the FHWA and Mobility COE Steering Committee, incorporating feedback and ensuring alignment with broader strategic goals .The Mobility COE has assembled a Steering Committee comprising 10 distinguished individuals from the public, private, academic, and non-profit sectors. These members represent various communities and diverse perspectives related to land use, urban design, transportation, real estate, equity, and municipal budgets. The finalized agenda becomes the Five-Year Research Agenda (Task 3.2), which guides the COE's research efforts over the next five years. Finally, the COE proceeds to initiate Year 1 & 2 Research (Task 4), kicking off the prioritized research projects identified in the agenda.

This structured approach ensures a comprehensive, stakeholder-informed research process that aligns with the Mobility COE's mission to advance new mobility and automated vehicle technologies that support improved land use, urban design, transportation, real estate, equity, and municipal budgets.

Concurrently, the Mobility COE is engaged in Outreach and Engagement to establish connections with and educate stakeholders and knowledge users about research related to the Mobility COE's core themes.

Overall, in its first year, the Mobility COE has engaged in various research activities, outreach efforts, and stakeholder engagements to fulfill its mission. This report provides an overview of these efforts and a summary of corresponding results, outlined in four sections: the synthesis of existing research, the results of the Request for Information (RFI) process, outreach and engagement initiatives, and the development of research roadmaps.

Synthesis of Existing Research on New Mobility and Highly Automated Vehicles

Purpose

Cooperative Agreement Task 3.1 requires the COE to synthesize existing research on the effects of emergent technologies and new mobility services as those technologies are deployed at scale. The primary objective of synthesizing existing research is to compile and analyze current knowledge on the positive and negative impacts of new mobility and automated vehicles. This effort aims to establish a foundational understanding to guide future research and policy development. By examining the early effects of emergent technologies and new mobility services, this synthesis will identify research gaps and inform the development of a comprehensive five-year research program to understand impacts when these technologies are deployed at scale. Additionally, it will guide the selection of research projects funded by the Mobility COE, ensuring alignment with the most pressing needs and opportunities in the field.

Process

The COE research team has reviewed nearly 400 academic publications, reports, and other forms of expert-produced content regarding the impacts of new mobility and highly automated vehicles. The resulting synthesis of applicable literature will be published to the Mobility COE's website before September 27, 2024 at https://www.mobilitycoe.org as separate sections that can be linked individually or compiled into a customized literature review. Publishing in this modular fashion will make the literature review more useful than a single PDF file for government agencies and media organizations that may wish to use or link to the content. This report provides a summary of key results and conclusions from this review.

We focused our review on 11 mobility services and technologies and 8 types of impacts.

Mobility services and technologies	Types of impacts
Vehicle Technology:	1. Safety

1. Automated Vehicles 2. Connected and Automated Vehicles 3. Connected Vehicles Emerging Passenger Mobility Options: 4. Micromobility: docked and dockless bicycles and electric scooters 5. Ride-hail/Transportation Network Companies 6. Carsharing 7. Demand- responsive transit and microtransit Emerging Freight/Goods Movement Options: 8. Heavy Duty Applications of Automated Vehicles 9. On-Demand Delivery Services Business Models: 10. Mobility-as-a-service and related business models 11. Universal basic mobility	2. System Efficiency 3. Social Equity 4. Municipal Budgets 5. Land Use 6. Education and Workforce 7. Energy and Environment 8. Health

The summary of synthesis results is provided for each of the 8 impact areas in Appendix A. For purposes of this synthesis, Energy, Environment, and Health are combined into a single subsection.

Request for Information

Purpose

Cooperative Agreement Task 3 requires the Mobility COE to define a research agenda in collaboration with the steering committee. To solicit a range of ideas from knowledge producers and users, the Mobility COE conducted a public Request for Information (RFI) process. The first RFI issued by the Mobility COE in March and April of 2024 aimed to perform a thorough gap analysis via direct engagement with stakeholders to identify unexplored areas that can significantly benefit from further study. This analysis is crucial for crafting a dynamic five-year research agenda that will undergo annual reviews to adapt to the rapid evolution of mobility technologies. The primary intent of the RFI is to engage with a diverse range of stakeholders, including public agencies, industry, academic institutions, non-profit organizations, and advocacy groups, to identify potential research gaps and solicit detailed project ideas or proposals. These contributions will help shape the first round of funded projects, which will be executed either by the existing six COE core members or external contracted researchers. Also, the RFI also identifies external collaborators who are interested in working with the COE, including researchers who perform the research and public and private entities who have identified and solicited collaboration in certain research areas of urgent needs.

Participants are encouraged to focus their research ideas on key areas such as Land Use, Urban Planning, and Policy; Systems Analysis and Optimization; Equity, Health, and Society; or other relevant topics. For more detailed information, please visit the Mobility COE RFI page at RFI - Mobility COE.

Process:

The RFI process involves several steps designed to gather and evaluate stakeholder inputs effectively:

- **Issuance of RFI**: The RFI was issued as the first annual RFI to be issued over the coming years to continuously engage with stakeholders and gather fresh insights as mobility technologies evolve.
- **Submission Formats**: Participants submitted their ideas in three formats: Knowledge Gaps, Initial Ideas, and Developing Ideas. Each format caters to different stages of idea development and allows participants to provide input regardless of the maturity of their concepts.

- **Stakeholder Engagement:** A diverse range of stakeholders were engaged through this RFI. These can include public agencies seeking to leverage COE expertise, academic researchers looking to secure funding, and organizations interested in collaborative research efforts.
- **Critical Dates and Webinars:** The RFI process was structured around key dates, including the release of the RFI, a webinar to discuss its contents, and deadlines for submission. This first RFI was released on March 6, 2024, with a webinar on March 19, 2024, and a submission deadline on April 26, 2024.
- **Evaluation and Selection:** Submissions were reviewed by a selection committee formed by the COE Leadership and FHWA. Selected ideas were further developed with the submitters, and in some cases, multiple ideas were combined to form comprehensive research projects to create synergistic research activities and collaboration by developing research teams of diverse backgrounds.
- **Collaboration and Project Launch:** The COE emphasizes a collaborative approach, working closely with stakeholders to refine and initiate projects. Selected projects are expected to commence in sequence when the research plan is approved. All projects funded by Year 1 and Year 2 COE funding will initiate before November 2024.

By following this structured process, the Mobility COE aims to build a robust research agenda that addresses the most pressing issues and opportunities in the realm of new mobility and automated vehicles. For additional details on the RFI process and submission instructions, please visit the Mobility COE RFI page at RFI - Mobility COE.

RFI Focus Areas

The RFI outlined several focal areas critical to understanding and optimizing the impacts of new mobility and automated vehicles. This section provides a summary of the three primary research thrusts and their respective areas of interest. Detailed information on these areas, including additional research gaps and example projects, can be found on the RFI website at RFI - Mobility COE.

Research regarding the impacts of new mobility and highly automated vehicles

Thrust 1: Land Use, Urban Planning, and Policy

This thrust investigates how new mobility technologies, such as connected and automated vehicles (C/AVs), impact urban development. Key areas include:

- **Land Use:** Examining the potential of new mobility to stimulate mixed-use developments and reshape land use patterns for sustainability.
- **Real Estate:** Analyzing the effects on parking demand, real estate pricing, and the configuration of buildings and blocks.
- **Urban Design:** Assessing the demands on urban design, including curb usage, green spaces, and pedestrian areas.
- **Public Investments and Costs:** Evaluating the impact of new mobility on public infrastructure investments and municipal budgets.
- **Reversed Focus:** Considering how changes in land use planning can facilitate the adoption of new mobility technologies.

Thrust 2: Systems Analysis and Optimization

This thrust focuses on enhancing system-level efficiencies, travel demand management, energy use, and the resilience and security of transportation systems. Key areas include:

- **System-level Efficiencies:** Exploring the impact of C/AVs and transportation network companies (TNCs) on demand, congestion, and energy consumption.
- **Travel Demand and Energy Use:** Assessing shared mobility platforms' influence on travel demand and energy use.
- **System Security:** Evaluating responses to hazards, disasters, and cyberattacks.
- **System Safety, Resilience, and Reliability:** Examining safety impacts on pedestrians, cyclists, and other road users.
- **Commercial and Freight Operational Tools:** Investigating how C/AV may improve access to goods and services.

Research regarding the impacts of new mobility and highly automated vehicles

- **Mode Switching and Transfers:** Determining the potential role of C/AVs in multimodal networks.
- **Policy/Context Case Studies:** Understanding policy frameworks supporting new mobility solutions.
- **Data Strategy/Data Quality:** Exploring data requirements for analyzing system impacts.

Thrust 3: Equity, Health, and Society

This thrust aims to ensure that new mobility technologies promote equitable benefits across all societal segments. Key areas include:

- **Equitable Use of New Mobility/Automated Vehicles:** Designing accessible and user-friendly systems for all, focusing on individuals with disabilities and disadvantaged groups.
- **Equitable Access to New Mobility/Automated Vehicles:** Ensuring availability and accessibility of services, especially in underserved areas.
- **Equitable Impacts from New Mobility/Automated Vehicles:** Understanding broader societal impacts, including on workforce dynamics and community well-being.
- **Economics, Service Provision, Politics, and Governance:** Investigating the economic development, service provision, and governance frameworks supporting equitable urban mobility.

Participants were encouraged to propose research ideas and projects that address these focal areas, considering the broader impacts of new mobility technologies on societal structures, urban and rural landscapes, environmental health, and organizational frameworks. The RFI also emphasized the interest in ideas and proposals related to the impacts and solutions when new mobility and automated vehicles are deployed at scale or strategies for transitioning into that stage. For detailed information on these focus areas and additional research gaps, please visit RFI - Mobility COE.

RFI Results

The RFI was preceded by an internal gap assessment activity (multiple online working sessions in January 2024) to support the RFI development:

- Ran an internal gaps assessment in January and February to aid in scoping the Request for Information. Received a total of 64 knowledge gaps and research ideas from sources internal to the COE.
- Received 61 knowledge gaps and research ideas from the Request for Information process between March 6th and April 26, 2024. Submissions came from individuals working at federal government agencies, academic institutions, cities, metropolitan planning organizations, transit agencies, disability advocates, and mobility providers.

The submissions to the Mobility COE RFI showcase a broad range of research interests and priorities. Automation emerged as the most frequently mentioned core competency, indicating a strong focus on the development and deployment of automated vehicle technologies. Other significant areas of interest include research and collaboration, connectivity (V2X), electrification, and energy efficiency. The involvement of a diverse group of 78 unique contact persons highlights the collaborative and inclusive nature of the RFI process.

Below are some statistics of research ideas submitted to Mobility COE RFI:

Number of Ideas

COE Partners	64
RFI External Submissions	61
Total	125

Percentage of ideas related to each topic

Automation	45.6%
Connectivity, V2X	13.6%
Health	7.2%
Land Use and Urban Design	16.8%
Micromobility	12.0%
Mobility Equity	18.4%
Planning, Analysis, and Optimization	16.8%
Policy and Regulatory Guidance	33.6%
Real Estate	2.4%
Ride-hail/Transportation Network Companies	11.2%
Safety	18.4%
Universal Access/People with Disabilities	7.2%
Workforce	3.2%

Percentage of RFI external submissions by submitter's affiliation

Public Agency	36%
Industry	18%
Academia	44%
Others	2%

Types of submissions

Knowledge gap	85
Initial research idea	7
Developing Idea	33

Overall, the data reflects a vibrant and dynamic research landscape, with stakeholders eager to explore various aspects of new mobility and automated vehicle technologies. The insights gained from these submissions will be instrumental in shaping the COE's research agenda, i.e., five-year roadmap and ensuring that it addresses the most pressing concerns of various stakeholders.

Year 1 & 2 Project Plan Summary

The COE has developed an ambitious and comprehensive research project plan for Years 1 and 2, reflecting its commitment to addressing the multifaceted challenges of new mobility and automated vehicle technologies and services. Through extensive stakeholder engagement, rigorous evaluation, and strategic prioritization, the COE has curated a diverse portfolio of projects that collectively advance our understanding of the technological, social, economic, and infrastructural impacts of emerging mobility solutions.

At the core of this research project selection is to better understand the pathways for technological innovation and at-scale deployment, particularly in vehicle-to-everything (V2X) communication and highly automated vehicle integration. Projects like "Scalable V2X Options into the Future" and "Risk-based Assessment of V2X-enabled Traffic Systems" aim to enhance the scalability, safety, and effectiveness of V2X technologies.

The project plan also places emphasis on the significant implications of AVs and shared mobility on urban planning and land use. One project "Shifting Spaces: Understanding Land Use and Zoning Adaptations for the Autonomous and Shared Mobility Era" is exploring how zoning regulations and urban spaces must evolve to accommodate the shift from traditional auto-serving facilities to those needed for fleet services and AV support. Similarly, a project related to "Parking Charges for AVs" investigates the economic and equity implications of parking policies in a world increasingly dominated by highly automated vehicles, aiming to develop sustainable financial structures for parking management.

Additionally, the COE is focusing on the integration of AVs into local jurisdictions through projects like "Developing a Safety-Centric Framework for the Integration of Highly Automated Vehicles in Local Jurisdictions". This project aims to create a framework that local governments can use to safely and effectively integrate AVs into their transportation networks, ensuring that safety remains a top priority in the deployment of these technologies.

In the realm of equity and accessibility, the COE is funding projects like "Catalyzing Equitable Mobility in Rapidly Developing Suburban Landscapes" and "Evaluation of Universal Basic Mobility Program Deployments". These initiatives explore how new mobility solutions can be deployed to enhance access and opportunity for underserved populations, particularly in rapidly developing suburban areas and low-income urban neighborhoods. These projects are essential for ensuring that technological advancements do not exacerbate existing social inequalities but rather contribute to a more inclusive transportation ecosystem.

Data utilization is another cornerstone of the project selection focus, with projects such as “Data for Autonomous Transportation Awareness (DATA)” and “AV Insights: Helping Cities Understand and Assess Street Conditions and Uses”. These projects focus on how data collected from AVs and other mobility technologies can be used to inform policy and operational decisions, improving city management of urban infrastructure and enhancing the safety and efficiency of transportation systems.

Moreover, the project plan is placing a strong emphasis on stakeholder engagement and international collaboration. One project named “Stakeholder Engagement Campaign and International Collaboration” is designed to facilitate meaningful dialogue among cities, private companies, and international research partners.

Projects such as “Modeling and Simulation Testbeds: A Sandbox for Analysis of New Mobility Deployed at Scale” are setting the stage for future research by developing advanced tools and frameworks to evaluate new mobility solutions in simulated environments. These testbeds provide a safe and controlled space for experimenting with different mobility scenarios, offering insights that can be translated into real-world applications. These resources will be available to the stakeholders and public through the COE clearing house.

The diverse range of projects funded in Years 1 and 2 exemplifies the COE’s holistic approach to addressing the challenges and opportunities presented by new mobility technologies. By tackling issues from multiple angles — technology, urban planning, equity, data, and collaboration — the COE is laying a strong foundation for the future of mobility research and policy. These projects are not only advancing knowledge but also paving the way for practical solutions that will shape the transportation systems of tomorrow.

Year 1 Special Research Project

Background

The Vehicle-to-Everything (V2X) programs, including various safety pilot programs (e.g., connected vehicle testbeds) and state deployments, has produced valuable data on the direct impacts of V2X applications on safety under specific testbed scenarios. These scenarios, however, are limited to controlled environments and do not fully capture the diverse range of conditions encountered in real-world deployments. To address this gap, it is essential to develop capabilities that allow for the evaluation of generic benefits of V2X applications under various scenarios. Such tools will enable different agencies to assess the benefits and costs of deploying V2X technology within their unique infrastructure contexts.

The primary focus of many pilot programs has been on safety. Despite these promising results, there remains a critical need to extend the evaluation framework to include generic mobility benefits beyond safety. These include enhancements in energy efficiency, reductions in emissions, and overall improvements in transportation system efficiency at both facility and network levels. By broadening the scope of evaluation, agencies can make more informed decisions about the deployment of V2X technologies. This comprehensive approach will facilitate the adoption of V2X by providing a clearer understanding of its wide-ranging impacts, thereby supporting investments in smart infrastructure that promote safer, more efficient, and environmentally friendly transportation systems. The development of robust evaluation tools is a crucial step in realizing the full potential of V2X technologies and ensuring their benefits are maximized across different urban and rural settings.

Process

The Mobility COE initiated the Year 1 project in response to an urgent need identified by the FHWA in February 2024. One of the current agency priorities is leveraging connectivity (i.e., interoperable V2X technologies) to enhance safety, efficiency, and sustainability across the transportation system. FHWA communicated this priority to the COE, specifically the urgent need to continue development of a quantitative methodology to derive safety, risk, and reliability requirements for V2X technology and integrate the methodology into an easy-to-use tool (to be posted on the COE clearinghouse) for agencies or industry to understand the benefit-cost analysis when deploying such technologies. The COE swiftly developed a comprehensive research plan in collaboration with the Turner Fairbank Highway Research Center and the Volpe Center. This rapid response exemplifies the COE's capacity and agile nature to address critical research needs promptly, thereby contributing significantly to the advancement of the state of practice and the optimal allocation of USDOT resources.

Project Introduction

This project is entitled as “Risk-based Assessment of V2X-enabled Traffic System and Corresponding System Requirements”. This project addresses the critical need for improved cost-benefit analysis (CBA) methods for V2X technologies and the development of a decision support tool for deployment by various stakeholders. V2X technology, which encompasses both vehicle-side (On-Board Units – OBUs) and infrastructure-side components, relies on sensor data, wireless connectivity, and real-time calculations to enhance traffic safety and efficiency.

The project aims to develop a methodology for quantifying safety, risk, and reliability impacts when deploying V2X technology. This methodology may be adapted for various technologies, applications, and contextual factors. While traditional metrics focus on crash and delay reduction, this project also considers emissions, reliability, and the rate of unsafe interactions to provide a more comprehensive assessment of deployment benefits. Key components and progress include:

- **Development of a General Approach**: Leveraging model-based system analysis tools to estimate the safety and traffic impacts of different V2X technology configurations on different road segments.

- **Selection of Use Cases:** Identifying relevant reliability, safety, and traffic-related parameters and contextual factors (e.g., road types, weather conditions) that prospective cost-benefit analysts may modify based on their own decision-making contexts.

- **Risk Reduction Estimations:** Approach enables analysts to provide preliminary impact estimates based on available data, model assumptions, and technology effectiveness. The approach is flexible enough to adapt and incorporate new data sources as systems become more mature and more widely deployed, and more data is available. In turn, this will reduce uncertainties and sensitivities in safety impacts.

The current project focused on quantitative impact methodology will be completed by the end of 2024. Potentially, the next phase will develop a Cost-Benefit Analysis tool.

- **System Requirements Design**: Deriving operational and design-level requirements based on identified safety-critical parameters.
- **Improvement of Risk Assessment Framework:** Enhancing contextual representation, expanding scenario analyses, and refining uncertainty analysis tools.
- **Cost-Benefit Analysis:** Incorporating cost analysis to assess the adoption of infrastructure-side V2X technology, estimating benefits from risk reduction, and calculating net present value (NPV).
- **Data Collection Initiatives**: Identifying critical data needs for future model improvements, including V2X technology reliability, operational conditions, and collision data.

Below are potential outcomes:

- A tool for analyzing various V2X configurations and their safety benefits on different road segments
- Methodologies for deriving safety, reliability, and connectivity requirements.
- Targeted data collection strategies to support estimations of safety impact assessment.

This project not only addresses an urgent need identified by USDOT but also demonstrates the COE's ability to rapidly respond to critical research demands. The results and tools developed through this project are expected to significantly advance the state of practice and contribute to the efficient and effective allocation of USDOT resources for public benefit.

Outreach and Engagement

Purpose

Outreach and engagement activities are essential for disseminating research findings, engaging with stakeholders, and fostering collaboration. These efforts are critical for building a broad base of support and ensuring that the Mobility COE's work remains relevant and impactful. Effective outreach and engagement help to bridge the gap between research and practice, enabling the application of new insights to real-world challenges in mobility and transportation. These activities also facilitate the continuous exchange of ideas, feedback, and expertise among researchers, practitioners, policymakers, and the public, thereby enhancing the overall quality and impact of the COE's initiatives.

Steering Committee

Cooperative Agreement Task 2 required that the Mobility COE assemble a Steering Committee composed of 5 - 10 individuals representing diverse perspectives. The Mobility COE has assembled a Steering Committee comprising 10 distinguished individuals from the public, private, academic, and non-profit sectors. These members represent various communities related to land use, urban design, transportation, real estate, equity, and municipal budgets. The Steering Committee provides strategic input for the COE, helps reach out to core stakeholders, and offers guidance for the selection of projects funded by the COE.

Name	Position	Organization	Category
Danielle Chou (Chair)	Enabling Technologies Program Manager	Federal Highway Administration	Government - Federal
Mark Arizmendi	Managing Partner	Northwestern Capital Partners LLC	Private - Real Estate
Alan Berger	Professor	Massachusetts Institute of Technology	Academic - Land Use
Tilly Chang	Executive Director	San Francisco County Transportation Authority	Government - Local
Arielle Fleisher	Policy Development and Research Manager	Waymo	Private - Automated Personal Mobility
Andrew Glass Hastings	Executive Director	Open Mobility Foundation	Nonprofit - city consortium
Susan Shaheen	Professor	University of California at Berkeley	Government - Air Quality & Academic - New/Shared Mobility
Kim Williams	Chief Innovation Officer	Metropolitan Transit Authority of Harris County (Houston Metro)	Government - Transit Agency
Candice Xie	CEO & Co-Founder	Veo Micromobility	Private - Personal Micromobility
Kevin Gay	Head of Safety - Autonomous Mobility & Delivery, Uber	Uber	Private - Automated Personal Mobility

All the COE steering committee members have been engaged in individual meetings with the COE leadership between April and May of 2024. The first in-person committee meeting of the COE Steering Committee was at the 2024 Transportation Research Board

(TRB) annual Automated Road Transportation Symposium (ARTS 2024) in San Diego. The steering committee discussed selected COE-funded projects using Year 1 and Year 2 funding, as well as provided comments on the five-year research agenda.

Website and Clearinghouse

In order to serve as a hub for information related to the COE and to disseminate research produced by the COE, the Mobility COE has established a website at https://www.mobilitycoe.org. This website meets the requirements of Cooperative Agreement Task 5.2. On this website, the COE has established a clearinghouse of reports, plans, regulations, websites, academic publications, and government documents related to automated vehicles and new mobility and implications for one or more of: energy, health, land resource management, mobility equity, operations/efficiency, resilience/reliability, safety, security, V2X/connected infrastructure, and workforce equity. As of June 24, 2024, twenty-two resources are available, with plans to add more resources in the future. Below is a current list of categories of resources to be developed by the COE.

- **Research Repository:** A searchable and categorized database of research papers, studies, and analyses, including advanced search functionalities. Subcategories should include reports, papers, projects, data, tools, and training/courses.
- **Data Center:** Access to datasets, visualization tools, and guides on data use and interpretation.
- **Tools:** Access to open source or online tools available for use; this could be linked to an additional website/webpage (such as Github), web tools, or online sand box/playground
- **Training and Education:** Details about online courses, webinars, workshops, and educational materials for different levels of expertise.

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- **Topics:** Dedicated pages for key topics in mobility and AV, including articles, multimedia resources, and related research; this page will be a hub with all information linked to all internal and external resources for the most critical selected topics
- **Resources and Links:** A compilation of external resources, reading lists, toolkits, and guidelines.

As of June 27, 2024 the Mobility COE has attracted 1,900 website users, 204 mailing list subscribers, and 413 LinkedIn Followers.

Webinars and Events

Cooperative Agreement Task 5.3 expects the Mobility COE to hold or participate in public events to discuss and disseminate research with potential stakeholders. In March 2024, the COE initiated the Mobility COE webinar series, and, as of June 2024, the Mobility COE held two webinars and was involved in one in-person event.

This webinar series aims to foster a robust discussion of critical (or even controversial) issues, emerging trends, and challenges shaping the future of mobility. Through structured webinars, the COE seeks to facilitate dialogue, encourage collaboration, and promote innovative solutions within the mobility landscape. Another primary objective of the webinar series is to explore issues identified in the gap analysis that pose challenges for resolution due to limitations in COE resources or their inherent complexity. These webinars will provide opportunities to gather insights from top experts and guide research directions in those specific areas.

Date	Topic	Webinar Participants	YouTube Views
3/19/24	Introducing the Mobility COE & RFI Information	74	20

5/22/24	Cityscapes Transformed: The Road Ahead for Highly Automated Vehicle Integration	52	24
7/25/24	Reimagining Real Estate: The Impact of New Mobility and Autonomous Vehicles (tentative)	–	–
September	Scalable or not: V2X and Infrastructure Solutions for AV (tentative)	–	–
November	The Multimodal Mix: AVs in Public Transit Ecosystems (tentative)	–	–

Mobility COE leadership and researchers have also identified core conferences and events to perform broader stakeholder engagement via invited presentations and panel discussion, workshop/technical session organization, and conference posters. The COE has designed and printed handouts for distribution at these events. Below is a selected examples of the events that the COE leadership and researchers supported in the first year:

- Attended 104th Annual Meeting of the Transportation Research Board (TRB) in Washington, DC in January 2024 and shared information about the COE and Request for Information (RFI).
- Attended Automated Road Transportation Symposium (ARTS) 2024. Participated in multiple technical sessions and presented at a poster session.
- Attended and introduced the COE at the United Nations ESCAP Regional Meeting on “Enhancing Social Inclusion and Innovations in Urban Transport Systems in Asia-Pacific Cities” in Bangkok and online on 18 and 19 June 2024
- Collaborated with FHWA on a technical session at SAE World Congress 2024 entitled, “Transportation is a part of real estate, not apart from real estate.”

To sum up, the Mobility COE engaged with stakeholders through one-on-one meetings, participation in conferences, and collaborative workshops. These engagements have been and will be crucial for building relationships, gathering feedback, and ensuring that the Mobility COE's research addresses real-world needs and challenges.

Conclusion

In its first year, the Mobility COE has made significant strides in understanding the impacts of new mobility and automated vehicles. Through comprehensive research, stakeholder engagement, and strategic planning, the COE has established a strong foundation for its ongoing work. The findings and insights gathered in Year 1 will inform future research efforts and support evidence-based policy decisionmaking by policymakers, contributing to the effective integration of new mobility technologies into the transportation system. The Mobility COE is committed to continuing its mission and advancing the state of knowledge in this rapidly evolving field.

Appendix A: Literature Review Summary of Results

Safety

Vehicle Technology: AVs equipped with Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS) functions have demonstrated significant safety benefits. For instance, lane departure warning (LDW) and lane departure prevention (LDP) systems could potentially prevent 28 to 32% of road departure crashes in the United States [1]. Recent studies utilizing naturalistic data comparing ADS vehicle operations with human benchmarks have concluded that ADS vehicles are generally safer than human drivers, though additional data from various ADS vendors are necessary for a comprehensive safety analysis [2,3]. Moreover, for at-scale deployment analysis, it is essential to consider system operational safety throughout the lifecycle of ADS deployment and operations, beyond the traditional ADS functional safety analysis [4]. Connectivity through vehicle-to-everything (V2X) technology enhances safety by enabling real-time communication and data sharing between vehicles and infrastructure. While extensive research has already confirmed the safety benefits of various CV applications, a gap remains in achieving large-scale deployment. This includes utilizing different V2X technologies, developing additional use cases or business models for deployment, and ensuring interoperability among multiple CV technologies. Connected and Automated Vehicles (CAVs) offer further safety benefits, such as reducing pedestrian injury crashes by up to 95% and decreasing traffic conflicts at high penetration rates [5,6]. However, most evaluations have relied on traffic simulations, and more real-world testing is needed to demonstrate safety at scale [7].

Emerging Passenger Mobility Options: Micromobility options, including bicycles and electric scooters, present safety concerns, especially in areas lacking dedicated infrastructure. Users often resort to sidewalks, creating conflicts with pedestrians, particularly older adults and children [8,9]. Additionally, regular cyclists tend to take longer detours to avoid dangerous routes [10]. Payment structures, such as per-minute pricing, may also encourage unsafe behaviors like speeding [11]. Infrastructure policies that separate travel networks or slow motorized traffic can improve safety for micromobility users [12]. Ride-hail services have mixed safety impacts. They can reduce drunk driving incidents, contributing to a decrease in severe traffic-related injuries [13,14]. However, safety concerns may deter some users, particularly women, from using these services [15]. Ride-hail trips may also result in more minor injury crashes compared to taxis, possibly due to driver distractions and less experience [16,17]. Carsharing services may offer safety benefits through user screening processes, but more research is needed to compare safety differences among users and determine the factors promoting safer driving [18,19]. Demand-responsive transit and microtransit services can enhance safety by offering door-to-door services in areas with unsafe walking routes [20]. However, the effectiveness of algorithms in selecting safe stops and ensuring driver competency remain concerns, particularly in pilot programs using private contractors [21].

Emerging Freight/Goods Movement Options: Vehicle automation in heavy-duty applications can reduce crash risks related to driver fatigue, impairment, and distraction. Higher levels of automation (Levels 4 & 5) could further enhance safety, but more testing is needed before commercial deployment [22]. Inspection of automated trucks can be much more efficient as compared to previous practices due to information sharing and data-driven preventative monitoring [23]. Vehicle platooning, where trucks travel in groups, is a potential intermediary step [22]. Research is needed to understand the impacts of higher levels of automation and platooning on safety and crash rates using field data. On-demand delivery services increase curb space demand, leading to congestion and associated safety impacts [24,25]. Limited observations of robotic delivery services suggest few incidents, but larger-scale deployment remains a challenge, especially when these small delivery vehicles shares the same right of way with vulnerable road users.

Business Models: Mobility-as-a-service (MaaS) business models rely on collecting personal and financial data, raising privacy and safety concerns [26]. There is little research on how MaaS impacts safety in practice. Universal Basic Mobility (UBM) aims to ensure access to essential transportation services, potentially enhancing safety and equity. However, implementing UBM at scale requires significant investment and coordination, with gaps in understanding the safest and most efficient methods.

Systems Operations and Efficiency

Vehicle Technology: AVs have been extensively studied using demand modeling and agent-based simulations to assess their effects on transportation system operations and efficiency, such as congestion and vehicle miles traveled (VMT). Most studies agree that AVs may increase VMT and congestion due to increased trip-making and empty travel from SAVs [27,28]. Future research opportunities include simulating AVs considering heterogeneous populations and incorporating parking to estimate AVs' impact on system operations and land use [29]. Again, connectivity has been proved by extensive research that they can optimize traffic flow and reduce congestion. However, connecting simulation and pilot testing to wide at-scale deployments and providing state and local agencies with the necessary resources and tools for early deployment applications in diverse operational environments remains a challenge [30].

Emerging Passenger Mobility Options: Micromobility, such as bikes and electric scooters, presents mixed results regarding sustainability and efficiency. McQueen et al. [31] found that micromobility could reduce greenhouse gas emissions (GHG) when substituting car trips but could increase GHG when complementing them. Perceptions of micromobility as a pleasant experience, especially for e-bikes, and integration with public transportation to improve first/last mile access and network efficiency are areas of interest [32,33]. Carsharing increases system efficiency by allowing multiple individuals to access a single vehicle, which uses less parking space. It works well in communities with low vehicle ownership rates or areas with mobility constraints [34,35]. However, more research is needed to determine specific pricing conditions and sustainability models for carsharing. Demand-responsive transit and microtransit systems can enhance efficiency by providing flexible, on-demand transportation, which can reduce the need for personal vehicles and improve access to public transit.

Emerging Freight/Goods Movement Options: Automated trucks can optimize fuel efficiency, reduce emissions, and lower operational costs through precise control of speed, braking, and acceleration. These vehicles also mitigate driver fatigue and improve overall safety by reducing human error. Additionally, the ability of automated trucks to operate for longer hours without breaks can increase the throughput of goods and improve the reliability of supply chains. Truck platooning, where trucks travel in groups, has received attention for its potential to improve fuel efficiency and reduce congestion. Studies have shown that connected eco-driving systems and truck platooning can smooth speed profiles, improve safety, and reduce fuel consumption [36,37]. On-demand delivery services impact system efficiency positively by reducing shopping trips and energy consumption but negatively by increasing delivery vehicle congestion and competition for curb space [38–40]. Robotic delivery services are still new, with limited empirical evidence on their impact. Studies show mixed results about AVs' effects on traffic flow efficiency, depending on modeling conditions [41].

Business Models: MaaS potentially reduces private vehicle use and ownership, encouraging shifts to active travel modes and public transit [42–44]. Simulation studies suggest that MaaS can reduce emissions by up to 54% and decrease transport-related energy consumption by introducing car-sharing and bike-sharing services [45,46]. However, more research is needed to explore user incentives for MaaS adoption, model the integration of multi-travel modes, and understand the collaborative mechanisms between public and private sectors in the MaaS ecosystem. Universal Basic Mobility (UBM) programs, which provide monetary assistance for transportation, have been piloted in several U.S. cities, offering positive preliminary results. Participants reported greater travel flexibility and increased use of various transportation modes [47,48]. However, most studies focus on survey-based analyses, highlighting a gap in understanding actual (revealed) preferences and how UBM affects system-level efficiency, accessibility, and equity. More research is needed to design tailored UBM programs that improve efficiency and equity for diverse population groups.

Social Equity

Vehicle Technology: AV technologies hold significant promise for benefiting vulnerable populations and bridging urban-rural disparities. Numerous studies highlight the potential of AVs to improve mobility for people with disabilities, elderly individuals, and low-income populations by offering accessible and affordable transportation options [11,49–52]. AVs provide safe and reliable transportation through advanced sensors and navigation systems, incorporating user-friendly interfaces and assistive technologies, such as wheelchair ramps and voice-activated controls, empowering individuals with disabilities to travel independently and participate more fully in their communities

[53,54]. Geographically, AV deployment can address "transportation deserts" in small urban, rural, or remote areas, offering on-demand mobility options and connecting residents to essential services and opportunities previously out of reach [55,56]. However, careful planning and implementation are necessary to ensure AV technologies do not exacerbate existing inequalities, addressing concerns like the digital divide, affordability, and infrastructure limitations in rural and small urban areas [57–59]. Community engagement and inclusive planning processes are critical to ensure the deployment of AV technologies is responsive to diverse community needs [60,61].

Emerging Passenger Mobility Options: Micromobility programs have mixed social equity impacts. Studies in developed countries often find that bikeshare and scooter share riders are relatively privileged in terms of income, education, youth, or able-bodied status [62]. Docked micromobility systems tend to be unequally distributed geographically compared to dockless systems [63]. Agencies may impose equity requirements in shared micromobility programs to address these imbalances [64]. Although low-income travelers are less likely to adopt bikeshare, those who do may use them more intensively for various trip purposes [65,66]. Shared micromobility options offer an alternative to private driving, expanding access to jobs and improving health outcomes for underserved populations [67,68]. However, more research is needed on the social determinants of access to micromobility and the factors predicting ridership beyond existing demographics [69,70]. Ride-hail companies can alleviate high car ownership costs and reduce mobility gaps across socioeconomic divides by providing car trips on an as-needed basis. Most ride-hail users utilize the service occasionally, rather than for regular travel. While ride-hail users' socioeconomic characteristics vary by region, they often have higher incomes than the typical resident [71]. Evidence from California suggests heavy users of ride-hail services, who are more likely to be low-income and car-free, benefit significantly from these services [72]. Ride-hail services may also address racial bias in traditional taxi services, offering more equitable service quality [73]. However, access gaps remain, particularly in rural areas [74]. Carsharing offers benefits by shifting mobility costs to a per-trip basis, aiding both those with and without cars. Carshare users tend to be car-less but relatively affluent [75]. Carshare stations are often located in higher-income neighborhoods, which can limit access for lower-income populations [76,77]. Public subsidies enabling reduced rates for low-income residents can help expand carshare access and benefits [78]. Demand-responsive transit and microtransit programs address geographic, temporal, economic, and social equity. These services expand transit access in lower-density areas, fill gaps in transit timetables, provide cost-effective commuting options, and improve mobility in disadvantaged neighborhoods [20,79]. However, studies are mixed on whether microtransit enhances transit ridership or simply replaces it, depending on specific demands and existing transportation alternatives [80].

Emerging Freight/Goods Movement Options: Heavy-duty AVs have the potential to reduce emissions and improve social equity by decreasing residents' exposure to pollutants from diesel exhaust, which disproportionately affects low-income communities and communities of color living near major goods movement corridors [81–83]. Automation can facilitate regulations like truck route operations and restrictions on truck parking and engine idling, leading to more equitable environmental impacts. However, heavy-duty AVs may also displace low-wage jobs, such as truck drivers, creating new layers of employment-related social exclusion [84–86]. Policymakers must develop robust retraining programs to prevent these workers from being replaced by higher-wage tech employees [87]. Further research is needed on the environmental and job market impacts of heavy-duty AVs, as well as their potential benefits and risks to different socioeconomic groups.

Business Models: MaaS applications may have mixed impacts on social equity. Digital apps facilitating ride-hail services lowered transportation inequities for seniors in Japan but maintained rural-urban disparities in Finland [88,89]. Unbanked users, those without smartphones, and non-native English speakers may face barriers to using MaaS, exacerbating existing mobility challenges [90]. Market dominance by private MaaS companies could lead to monopolization and price discrimination, impacting those most reliant on public transportation [90]. Overall, MaaS can improve job accessibility but requires targeted policy measures to enhance social equity [91]. Universal Basic Mobility (UBM) pilot programs have successfully enrolled low-income people of color and increased transit use [47]. Ongoing research evaluates UBM programs' economic, social, and environmental impacts, but more research is needed to assess their effectiveness in addressing transportation inequality compared to alternatives like free or reduced fare transit programs [92,93].

Municipal Budgets

Vehicle Technology: AV adoption has significant implications for municipal budgets. Studies suggest that AVs could reduce municipal parking revenues and tax receipts from gasoline and diesel fuels, parking, traffic violations, and other revenues by 3-51% across various AV/EV/Shared scenarios in different cities [94,95]. Additionally, AVs could reduce operating costs for municipal services, such as trash collection, by 32-63% [96]. Connectivity through vehicle-to-everything (V2X) technology may increase expenses for conduits and signals needed for connected infrastructure systems [94]. Platooning behavior could increase vehicle density on bridges, necessitating additional inspection, retrofitting, or new design approaches to accommodate increased weight [97]. However, V2X technology also presents new revenue opportunities, such as a vehicle miles traveled (VMT) fee based on vehicle class enabled by V2I data transmission [97]. Also, there is no recommended solution in the literature regarding how state and local agencies can scale up the deployment of connected infrastructure that are needed for V2X and CAV applications, and research is urgently needed in this area.

Emerging Passenger Mobility Options: Micromobility impacts municipal budgets through permits, operating licenses, and fines for improper use. Initial regulatory responses to shared dockless micromobility often constrained operations rather than generating revenue [98]. Municipalities may need to subsidize riders, especially low-income users [69]. While micromobility can enhance quality of life and access to mobility [99], the focus has been more on mitigating externalities like improper parking [100] rather than enhancing tax revenue. Ride-hail services present a mixed impact on municipal budgets. A taxonomy of taxation regimes for ride-hail services shows varying levels of municipal power to tax these services, often limiting the ability of cities to leverage these services for direct social benefits [101,102]. Carsharing's impact on municipal budgets largely revolves around tax revenue from carshare reservations. Studies indicate that sales tax revenue from carshare typically exceeds the nominal sales tax rate of the city, potentially leading to a net drop in social benefit [103]. Excessive taxes on carsharing may boost short-term municipal budgets but raise concerns about long-term sustainability and growth of the sector [104]. Demand-responsive transit and microtransit can be a cost-effective alternative to fixed-route services in rural areas with dispersed populations. These services can flexibly meet the needs of a small group of riders better than larger bus services on fixed schedules [105]. However, in urban areas with dense populations, microtransit can bloat transit agency budgets without scaling efficiently [106].

Emerging Freight/Goods Movement Options: Research on the effects of heavy-duty AVs on municipal budgets is sparse. However, a study at the University of Oregon suggests that using AVs for waste collection could result in significant cost savings [96]. Heavy-duty AVs may also affect municipal expenses related to infrastructure maintenance and labor costs.

Business Models: MaaS impacts on municipal budgets are not well-researched, largely due to varying definitions and models of MaaS. Successful MaaS implementation requires balancing public and private providers sustainably [107,108]. Current research focuses on economic spillovers from global deployment rather than direct impacts on specific municipalities [109]. The recent failure of MaaS Global highlights the need for a viable path to sustainability in this sector [110]. Universal Basic Mobility (UBM) programs in the U.S. have primarily been funded through grants from municipal transit organizations, state programs, or corporate giving. For instance, Oakland's UBM pilot received a $243,000 grant for 500 residents, while LADOT's pilot is estimated at $18,000,000, funded through city transit subsidies, corporate giving, and state funding [111,112]. The sustainability of these programs post-grant funding remains uncertain, and more research is needed to evaluate their long-term implications on municipal budgets and financial sustainability of transit organizations.

Land Use

Vehicle Technology: AVs are expected to significantly impact urban land use. By lowering travel expenses, AVs could lead to urban sprawl, with more pronounced horizontal city spread. For example, Moore et al. [113] predicted a 68% increase in the horizontal spread of cities in the Dallas-Fort Worth Metropolitan Area due to AVs. AVs can also increase trip lengths and promote suburban and exurban development, as shown in studies like Nadafianshahamabadi et al. [114] and Gelauff et al. [115]. This shift could result in lower density and increased travel demand in these areas. Additionally, AVs have the potential to densify existing urban areas by reallocating space from parking to residential, economic, and leisure activities [116]. Zakharenko [117] noted that reduced daytime parking needs could allow for denser economic activity in downtown areas. However, the overall impact on land use is complex, with studies indicating both positive and negative outcomes, such as increased parking space on the outskirts [118–120]. Future research should focus on AVs' long-term effects on urban land-use patterns and infrastructure adaptation to accommodate new traffic dynamics and parking needs. Zoning laws will need to adapt. Scenario-based analyses indicate that increased capacity from CAVs could result in varied impacts, including lower travel times and increased urban sprawl if not managed properly [121].

Emerging Passenger Mobility Options: Micromobility, such as bikeshare and scootershare, thrives in well-connected and dense urban environments with a mix of establishments and residences. These areas shorten trip distances and times, facilitating micromobility trips [122]. A meta-analysis found that ridership increased with population density, employment density, bus stops, metro stations, and bike infrastructure [123]. However, low-density neighborhoods with fewer young people and zero-car households have less access to micromobility services [63]. In the long run, micromobility could impact land use by extending the reach of shared transportation services [124]. Ride-hail services are more prevalent in dense urban areas where parking is scarce, and public transit use is higher. Ride-hail can alleviate curb congestion if a sufficient number of car trips are replaced [125]. However, those freed up spots may quickly be taken up by drivers who would otherwise have parked elsewhere, parked at a different time, or not made the trip by private vehicle at all. Ride-hail drivers compete for curb access, temporarily congesting the curb. In lower-density areas, ride-hail users tend to have higher incomes compared to urban users [126]. Carsharing is particularly effective in dense urban areas with scarce parking, mixed land uses, and close proximity to transit hubs. It benefits users who need a car occasionally but do not want to own one [35]. In lower-density areas, carsharing is more challenging due to abundant parking and higher car ownership rates [127]. Demand-responsive transit and microtransit services are designed to offer flexible, point-to-point transportation. These services are cost-effective in low-density suburban and rural areas where fixed-route services are inefficient [128]. In urban areas, microtransit can complement fixed-route transit by providing first-last mile solutions and expanding the service area during off-hours [129]. However, the impact on transit ridership in cities is mixed [130].

Emerging Freight/Goods Movement Options: Heavy-duty AVs could lead to the development of transfer hubs near interstate highways where automated trucks drop trailers for human-operated trucks [131,132]. This change in logistics could impact land use patterns near these hubs, although specific implications are still emerging and require further research. On-demand delivery services, such as ghost kitchens and dark stores, have created new real estate opportunities by dispersing firms away from traditional retail districts [133,134]. These changes can impact land use by shifting commercial activities to less central locations.

Business Models: MaaS can influence urban land use by bundling multiple transportation modes into one interface, potentially inducing mode shifts and generating new trips [45], which has implications for urban land use, particularly parking demand. Early research suggests that MaaS users are often frequent public transit users [135]. Price structures, such as discounted rides and geofencing, can impact user mode choice, influencing congestion and parking demand. MaaS schemes that encourage switching from private cars to public transit may ease parking demand, while those promoting ride-hail or carshare could exacerbate congestion [136]. Additionally, MaaS may shift users from active transportation modes like biking and walking to public transit and ride-hail, with unclear implications for congestion and infrastructure use [42]. Universal Basic Mobility (UBM) programs, while addressing transportation equity, have limited research on their impact on land use. Future studies should explore how UBM can influence urban development and infrastructure planning.

Workforce and Education

Vehicle Technology: Understanding shifts in job roles and responsibilities is crucial for developing targeted training programs and workforce development initiatives [45]. Automation will cause widespread substitution of machines for labor, increasing inequality in the short run but potentially beneficial in the long run. While automation substitutes for labor, it also complements it by increasing per-worker productivity, which can boost earnings and raise labor demand [137,138]. The workforce shift related to AVs depends on their acceptance and deployment timelines, influencing transportation-related jobs and necessitating accurate AV deployment schedules for effective public policies and workforce planning [139,140]. CAVs have the potential to revolutionize road maintenance and transportation operations. Successful deployment and operation of these technologies depend largely on a knowledgeable, trained, and skilled workforce [141,142]. Workforce development is crucial for CAV deployment, maintenance, and repair. Caltrans emphasized the importance of addressing labor challenges and fostering state efforts to recruit and retain a skilled workforce for CAV deployment [143]. The most significant expense associated with CV deployment is labor for installation/deployment and personnel training, which accounts for a substantial portion of the costs [144].

Emerging Passenger Mobility Options: Early operations of shared e-micromobility services heavily relied on independent contractors, with substantial operational costs associated with collecting, charging, and distributing dockless e-scooters and bikes [145]. Legislation like California's AB5 reclassified independent contractors, shifting the labor market toward third-party companies. Technological advances in transportation necessitate diversified skillsets, requiring education and workforce development to adapt. Workforce development recommendations include partnerships with industry and academia, increased investment in workforce development, integration of training into pre-apprentice and apprentice programs, and data collection to inform policies [146,147]. Ride-hail drivers, often classified as gig workers, lack legal protections on labor rights and employment benefits available to traditional employees [148]. Research shows that ride-hail drivers come from diverse backgrounds, with many being people of color and immigrants [148]. Drivers are attracted to gig work due to schedule flexibility and additional income [149]. There is limited research on the interests and capabilities of current workers to develop effective workforce development programs. Current suggestions include workforce development tools for individuals outside the gig workforce and strategies for self-advocacy, such as business planning, leveraging platform competition, activism, and using technology to manage the workforce [150]. Carsharing has evolved with shared autonomous vehicles, increasing the need to understand drivers, barriers, and future shifts [151]. Literature explicitly related to education and workforce development in carsharing is sparse, revealing a significant research gap. No specific literature was found on workforce development for demand-responsive transit and microtransit. The general concern is that low-skilled and low-wage workers will be affected by technological substitution, requiring skill transfer management.

Emerging Freight/Goods Movement Options: Studies indicate that automation may first affect long-haul trucking, impacting over-the-road drivers who travel on federal interstates and highways [152]. Assessing job displacement potential by examining alternative positions with similar skill requirements is crucial. A survey found that drivers believe automated trucks will reduce the size of the truck driving workforce [153]. The introduction of additional technologies in trucking could lead to a shift towards younger drivers rather than older drivers. Ghost kitchens can reduce overhead costs from front-of-house staff and single-facility expenses, affecting demand for hospitality workers and food service establishments [154]. A concern for gig economy workers is the risk of exploitation if they become overly dependent on a single platform. Delivery service workers can increase revenues by switching between services and repositioning to high-demand areas [155]. On-demand delivery services provide an alternative platform for gig work, with ride-hail and delivery platforms competing for workers [156].

Business Models: A review of the literature using Google Scholar and ProQuest yielded no applicable research, indicating a probable gap in the literature. Increased access to education and job opportunities are cited as benefits of Universal Basic Mobility, based on robust existing research demonstrating the relationship between mobility and access to opportunity and early research on UBM pilot programs [47,157]. Research assessing how effectively Universal Basic Mobility policies and programs improve access to education and job opportunities is sparse.

Energy, Environment and Health

Vehicle Technology: AVs equipped with Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS) can significantly impact energy consumption, environmental sustainability, and public health. By optimizing driving patterns and reducing human error, AVs can improve fuel efficiency and decrease emissions. However, these benefits are contingent upon the market penetration rates and connectivity of AVs. Studies indicate that while a network of connected AVs could reduce CO2 emissions by up to 5%, isolated AVs in dense traffic might increase emissions by 11% due to reduced speeds [158]. The potential for AVs to induce demand due to easier travel and the necessity for empty travel in shared AV fleets can lead to an overall increase in vehicle miles traveled (VMT), which might offset some energy savings [159,160]. In terms of public health, AVs present a mixed picture. Potential increased emissions can be a public health concern. While they can potentially reduce crashes, there is concern that an increase in automobile use might detract from healthier alternatives like walking and biking. Public health advocates emphasize the need for community input and consent in the deployment of AVs to ensure that these technologies do not exacerbate existing inequalities in health (e.g., exposure to pollutants), especially for vulnerable populations such as the poor, disabled, and rural residents [161]. Connectivity makes it possible for AVs to enhance energy efficiency and environmental sustainability through various technologies such as Cooperative Adaptive Cruise Control (CACC), platooning, and eco-driving strategies. These technologies can moderate AV movements, optimize routing, and reduce emissions significantly. For instance, dynamic multi-objective eco-routing strategies for CAVs have shown potential reductions in greenhouse gas (GHG) and NOx emissions by 43% and 18.58%, respectively [162]. Despite these benefits, real-world implementation challenges and the need for large-scale deployment pathways remain.

Emerging Passenger Mobility Options: Micromobility options like e-bikes and e-scooters offer both energy and environmental benefits by potentially reducing car trips and emissions. However, the actual impact depends heavily on the modes of transport they replace. While personal e-scooters and e-bikes generally reduce CO2 emissions, shared counterparts might increase emissions due to the infrastructure and maintenance required [163,164]. Health benefits include increased physical activity and improved air quality from reduced car trips. However, safety concerns, such as injuries from collisions, highlight the need for designated infrastructure [165,166]. TNCs can reduce emissions by promoting pooled rides and providing alternatives to private vehicle ownership. However, studies show that most TNC trips are not pooled, and a significant portion involves deadheading, leading to additional emissions [167]. The mixed impact on public transit use and the potential to reduce alcohol-related collisions are notable. Yet, driver health remains a concern, with risks such as stress and fatigue compounded by job insecurity [168,169]. Carsharing can reduce net private automobile travel and emissions by replacing more polluting private fleets with cleaner shared fleets. Electric carshare programs further reduce tailpipe emissions and expose users to cleaner vehicle types, potentially influencing future car purchases [78,170]. However, carshare vehicles also contribute to fine particulate emissions from tire friction. The COVID-19 pandemic highlighted carsharing as a safer alternative to public transit for those who could not afford a private car, demonstrating its role in public health [171,172]. Demand-Responsive Transit and Microtransit services can enhance energy efficiency by pooling passengers and reducing emissions relative to private vehicle trips, especially if they use zero-emission vehicles. However, empty vehicles and deadheading can offset these benefits [173]. Microtransit can improve accessibility for underserved populations, providing a door-to-door service that traditional public transit cannot always offer [79]. More research is needed to understand their full environmental and public health impacts.

Emerging Freight/Goods Movement Options: Automated heavy-duty vehicles, particularly when electrified, can significantly reduce fuel consumption and emissions. Automated diesel trucks can cut GHG emissions by 10%, while automated electric trucks can achieve a 60% reduction compared to conventional trucks [174]. However, the increased mineral intensity of electric trucks' battery manufacturing presents environmental trade-offs. Research is needed to assess the environmental impact of different fuel sources and vehicle designs. On-demand delivery services can reduce shopping trips and energy consumption but may increase delivery vehicle congestion and competition for curb space [175]. The energy efficiency of these services varies; meal delivery by vehicle is highly energy inefficient compared to bicycle delivery [176,177]. Robotic delivery services show mixed results, with energy consumption and emissions depending on factors like delivery distance and electrification [50,178].

Business Models: The environmental impact of MaaS depends on service implementation and operator incentives. MaaS schemes with shared mobility have the potential to reduce energy consumption significantly, but the benefits diminish if ride-hailing is prioritized over public transit and bike-shares [179]. Public transport operators may focus more on public benefits, including reduced environmental impact, compared to private operators focused on maximizing revenue [180]. Initial studies suggest that UBM can increase transit use and reduce personal vehicle travel, thereby decreasing environmental harms [92]. However, more research is needed to understand the full extent of these reductions and their implications for public health and environmental sustainability.

References Cited

[1] Scanlon JM, Kusano KD, Sherony R, Gabler HC. Potential Safety Benefits of Lane Departure Warning and Prevention Systems in the U.S. Vehicle Fleet, 2015.

[2] Scanlon JM, Kusano KD, Fraade-Blanar LA, McMurry TL, Chen Y-H, Victor T. Benchmarks for Retrospective Automated Driving System Crash Rate Analysis Using Police-Reported Crash Data 2023.

[3] Flannagan C, Leslie A, Kiefer R, Bogard S, Chi-Johnston G, Freeman L, et al. Establishing a Crash Rate Benchmark Using Large-Scale Naturalistic Human Ridehail Data. UMTRI; 2023. https://doi.org/10.7302/8636.

[4] Correa-Jullian C, Ramos M, Mosleh A, Ma J. Operational safety hazard identification methodology for automated driving systems fleets. Proc Inst Mech Eng Part O J Risk Reliab 2024:1748006X241233863. https://doi.org/10.1177/1748006X241233863.

[5] Detwiller M, Gabler HC. Potential Reduction in Pedestrian Collisions with an Autonomous Vehicle, 2017.

[6] Papadoulis A, Quddus M, Imprialou M. Evaluating the safety impact of connected and autonomous vehicles on motorways. Accid Anal Prev 2019;124:12–22. https://doi.org/10.1016/j.aap.2018.12.019.

[7] Han X, Xu R, Xia X, Sathyan A, Guo Y, Bujanović P, et al. Strategic and tactical decision-making for cooperative vehicle platooning with organized behavior on multi-lane highways. Transp Res Part C Emerg Technol 2022;145:103952. https://doi.org/10.1016/j.trc.2022.103952.

[8] Yang Y, Wu X, Zhou P, Gou Z, Lu Y. Towards a cycling-friendly city: An updated review of the associations between built environment and cycling behaviors (2007–2017). J Transp Health 2019;14:100613. https://doi.org/10.1016/j.jth.2019.100613.

[9] Sikka N, Vila C, Stratton M, Ghassemi M, Pourmand A. Sharing the sidewalk: A case of E-scooter related pedestrian injury. Am J Emerg Med 2019;37:5. https://doi.org/10.1016/j.ajem.2019.06.017.

[10] Shah NR, Cherry CR. Different safety awareness and route choice between frequent and infrequent bicyclists: findings from revealed preference study using bikeshare data. Transp Res Rec 2021;2675:269–79.

[11] Milakis D, Gedhardt L, Ehebrecht D, Lenz B. Is micro-mobility sustainable? An overview of implications for accessibility, air pollution, safety, physical activity and subjective wellbeing. Handb. Sustain. Transp., Edward Elgar Publishing; 2020, p. 180–9.

[12] Wegman F, Zhang F, Dijkstra A. How to make more cycling good for road safety? Accid Anal Prev 2012;44:19–29. https://doi.org/10.1016/j.aap.2010.11.010.

[13] Kirk DS, Cavalli N, Brazil N. The implications of ride-hailing for risky driving and road accident injuries and fatalities. Soc Sci Med 2020;250:112793. https://doi.org/10.1016/j.socscimed.2020.112793.

[14] Dills AK, Mulholland SE. Ride-Sharing, Fatal Crashes, and Crime. South Econ J 2017. https://doi.org/10.2139/ssrn.2783797.

[15] Siddiq F, Taylor BD. A gendered perspective on ride-hail use in Los Angeles, USA. Transp Res Interdiscip Perspect 2024;23:100938. https://doi.org/10.1016/j.trip.2023.100938.

[16] Zhai G, Xie K, Yang H, Yang D. Are ride-hailing services safer than taxis? A multivariate spatial approach with accommodation of exposure uncertainty. Accid Anal Prev 2023;193:107281. https://doi.org/10.1016/j.aap.2023.107281.

[17] Lefcoe AD, Connelly CE, Gellatly IR. Ride-Hail Drivers, Taxi Drivers and Multiple Jobholders: Who Takes the Most Risks and Why? Work Employ Soc 2023:09500170231185212. https://doi.org/10.1177/09500170231185212.

[18] Butler L, Yigitcanlar T, Paz A. Barriers and risks of Mobility-as-a-Service (MaaS) adoption in cities: A systematic review of the literature. Cities 2021;109:103036. https://doi.org/10.1016/j.cities.2020.103036.

[19] Dixit V, Rashidi TH. Modelling crash propensity of carshare members. Accid Anal Prev 2014;70:140–7. https://doi.org/10.1016/j.aap.2014.03.005.

[20] Volinski J. Microtransit or General Public Demand-Response Transit Services: State of the Practice. Washington, D.C.: Transportation Research Board; 2019. https://doi.org/10.17226/25414.

[21] Ghimire S, Bardaka E, Monast K, Wang J, Wright W. Policy, management, and operation practices in U.S. microtransit systems. Transp Policy 2024;145:259–78. https://doi.org/10.1016/j.tranpol.2023.10.011.

[22] Bhoopalam AK, Van Den Berg R, Agatz N, Agatz N, Chorus CG. The Long Road to Automated Trucking: Insights from Driver Focus Groups. Soc Sci Res Netw 2021. https://doi.org/10.2139/ssrn.3779469.

[23] Schaefer W. North American Standard Level VIII Electronic Inspection Basics 2022.

[24] Jaller M, Rodier C, Zhang M, Lin H, Lewis K. Fighting for Curb Space: Parking, Ride-Hailing, Urban Freight Deliveries, and Other Users 2021. https://doi.org/10.7922/G22N50JJ.

[25] Shaheen S, Martin E, Cohen A, Broader J, Davis R. Managing the Curb: Understanding the Impacts of On-Demand Mobility on Public Transit, Micromobility, and Pedestrians. Mineta Transp Inst Publ 2022. https://doi.org/10.31979/mti.2022.1904.

[26] Casadó RG, Golightly D, Laing K, Palacin R, Todd L. Children, Young people and Mobility as a Service: Opportunities and barriers for future mobility. Transp Res Interdiscip Perspect 2020;4:100107. https://doi.org/10.1016/j.trip.2020.100107.

[27] Yan H, Kockelman KM, Gurumurthy KM. Shared autonomous vehicle fleet performance: Impacts of trip densities and parking limitations. Transp Res Part Transp Environ 2020;89:102577. https://doi.org/10.1016/j.trd.2020.102577.

[28] Zhang W, Guhathakurta S, Khalil EB. The impact of private autonomous vehicles on vehicle ownership and unoccupied VMT generation. Transp Res Part C Emerg Technol 2018;90:156–65. https://doi.org/10.1016/j.trc.2018.03.005.

[29] Millard-Ball A. The autonomous vehicle parking problem. Transp Policy 2019;75:99–108. https://doi.org/10.1016/j.tranpol.2019.01.003.

[30] Ma J, Jullian CC, Ramos M, Xia X. Risk Assessment for Remotely Operation of Level 4 Automated Driving Systems in Mobility as a Service Transport 2023. https://doi.org/10.7922/G23N21QC.

[31] McQueen M, Abou-Zeid G, MacArthur J, Clifton K. Transportation Transformation: Is Micromobility Making a Macro Impact on Sustainability? J Plan Lit 2021;36:46–61. https://doi.org/10.1177/0885412220972696.

[32] Liu L, Miller HJ. Measuring the impacts of dockless micro-mobility services on public transit accessibility. Comput Environ Urban Syst 2022;98:101885. https://doi.org/10.1016/j.compenvurbsys.2022.101885.

[33] Barnes F. A Scoot, Skip, and a JUMP Away: Learning from Shared Micromobility Systems in San Francisco 2019. https://doi.org/10.17610/T6QP40.

[34] Celsor C, Millard-Ball A. Where does carsharing work? Using geographic information systems to assess market potential. Transp Res Rec 2007;1992:61–9. https://doi.org/doi.org/10.3141/1992-08.

[35] Hu S, Chen P, Lin H, Xie C, Chen X. Promoting carsharing attractiveness and efficiency: An exploratory analysis. Transp Res Part Transp Environ 2018;65:229–43. https://doi.org/10.1016/j.trd.2018.08.015.

[36] Lee S, Oh C, Lee G. Impact of Automated Truck Platooning on the Performance of Freeway Mixed Traffic Flow. J Adv Transp 2021;2021:1–13. https://doi.org/10.1155/2021/8888930.

[37] Wang M, Van Maarseveen S, Happee R, Tool O, Van Arem B. Benefits and Risks of Truck Platooning on Freeway Operations Near Entrance Ramp. Transp Res Rec J Transp Res Board 2019;2673:588–602. https://doi.org/10.1177/0361198119842821.

[38] Visser J, Nemoto T, Browne M. Home Delivery and the Impacts on Urban Freight Transport: A Review. Procedia - Soc Behav Sci 2014;125:15–27. https://doi.org/10.1016/j.sbspro.2014.01.1452.

[39] Liu J, Ma W, Qian S. Optimal curbside pricing for managing ride-hailing pick-ups and drop-offs. Transp Res Part C Emerg Technol 2023;146:103960. https://doi.org/10.1016/j.trc.2022.103960.

[40] Liu X, Qian S, Teo H-H, Ma W. Estimating and Mitigating the Congestion Effect of Curbside Pick-ups and Drop-offs: A Causal Inference Approach 2022. https://doi.org/10.48550/ARXIV.2206.02164.

[41] Narayanan S, Chaniotakis E, Antoniou C. Chapter One - Factors affecting traffic flow efficiency implications of connected and autonomous vehicles: A review and policy recommendations. In: Milakis D, Thomopoulos N, van Wee B, editors. Adv.

Transp. Policy Plan., vol. 5, Academic Press; 2020, p. 1–50. https://doi.org/10.1016/bs.atpp.2020.02.004.

[42] Feneri A-M, Rasouli S, Timmermans HJP. Modeling the effect of Mobility-as-a-Service on mode choice decisions. Transp Lett 2022;14:324–31. https://doi.org/10.1080/19427867.2020.1730025.

[43] Durand A, Harms L, Hoogendoorn-Lanser S, Zijlstra T. Mobility-as-a-Service and changes in travel preferences and travel behaviour: a literature review 2018. https://doi.org/10.13140/RG.2.2.32813.33760.

[44] Jittrapirom P, Marchau V, Van Der Heijden R, Meurs H. Future implementation of mobility as a service (MaaS): Results of an international Delphi study. Travel Behav Soc 2020;21:281–94. https://doi.org/10.1016/j.tbs.2018.12.004.

[45] Labee P, Rasouli S, Liao F. The implications of Mobility as a Service for urban emissions. Transp Res Part Transp Environ 2022;102:103128. https://doi.org/10.1016/j.trd.2021.103128.

[46] Becker H, Balac M, Ciari F, Axhausen KW. Assessing the welfare impacts of Shared Mobility and Mobility as a Service (MaaS). Transp Res Part Policy Pract 2020;131:228–43. https://doi.org/10.1016/j.tra.2019.09.027.

[47] Rodier C, Tovar A, Fuller S, D'Agostino M, Harold B. A Survey of Universal Basic Mobility Programs and Pilots in the United States. University of California Institute of Transportation Studies; n.d.

[48] Beibei L, Branstetter L, Mobility21 CMU. Evaluating Pittsburgh's Universal Basic Mobility Pilot Program. 2022.

[49] Fagnant DJ, Kockelman K. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transp Res Part Policy Pract 2015;77:167–81. https://doi.org/10.1016/j.tra.2015.04.003.

[50] Simoni MD, Kutanoglu E, Claudel CG. Optimization and analysis of a robot-assisted last mile delivery system. Transp Res Part E Logist Transp Rev 2020;142:102049. https://doi.org/10.1016/j.tre.2020.102049.

[51] Millonig A. Connected and Automated Vehicles: Chances for Elderly Travellers. Gerontology 2019;65:571–8. https://doi.org/10.1159/000498908.

[52] Wu X, Cao J, Douma F. The impacts of vehicle automation on transport-disadvantaged people. Transp Res Interdiscip Perspect 2021;11:100447. https://doi.org/10.1016/j.trip.2021.100447.

[53] Klinich KD, Manary MA, Orton NR, Boyle KJ, Hu J. A Literature Review of Wheelchair Transportation Safety Relevant to Automated Vehicles. Int J Environ Res Public Health 2022;19:1633. https://doi.org/10.3390/ijerph19031633.

[54] Brewer R, Ellison N. Supporting People with Vision Impairments in Automated Vehicles: Challenge and Opportunities. University of Michigan, Ann Arbor, Transportation Research Institute; 2020.

[55] Douma F, Petersen E. Scenarios and Justification for Automated Vehicle Demonstration in Rural Minnesota 2019.

[56] Dowds J, Sullivan J, Rowangould G, Aultman-Hall L. Consideration of Automated Vehicle Benefits and Research Needs for Rural America 2021. https://doi.org/10.7922/G2B27SKW.

[57] Velaga NR, Beecroft M, Nelson JD, Corsar D, Edwards P. Transport poverty meets the digital divide: accessibility and connectivity in rural communities. J Transp Geogr 2012;21:102–12. https://doi.org/10.1016/j.jtrangeo.2011.12.005.

[58] Wadud Z. Fully automated vehicles: A cost of ownership analysis to inform early adoption. Transp Res Part Policy Pract 2017;101:163–76. https://doi.org/10.1016/j.tra.2017.05.005.

[59] Liu Y, Tight M, Sun Q, Kang R. A systematic review: Road infrastructure requirement for Connected and Autonomous Vehicles (CAVs). J Phys Conf Ser 2019;1187:042073. https://doi.org/10.1088/1742-6596/1187/4/042073.

[60] Chng S, Kong P, Lim PY, Cornet H, Cheah L. Engaging citizens in driverless mobility: Insights from a global dialogue for research, design and policy. Transp Res Interdiscip Perspect 2021;11:100443. https://doi.org/10.1016/j.trip.2021.100443.

[61] Kaplan L, Rupprecht S, Grosso M, Thomopoulos N, Backhaus W, Raposo MA, et al. Ensuring Strong Public Support for Automation in the Planning Process: From Engagement to Co-creation. In: Meyer G, Beiker S, editors. Road Veh. Autom. 9, Cham: Springer International Publishing; 2023, p. 167–83. https://doi.org/10.1007/978-3-031-11112-9_13.

[62] Brown A, Howell A, Creger H. Mobility for the People: Evaluating Equity Requirements in Shared Micromobility Programs. Transportation Research and Education Center (TREC); 2022. https://doi.org/10.15760/trec.277.

[63] Chen Z, Van Lierop D, Ettema D. Dockless bike-sharing systems: what are the implications? Transp Rev 2020;40:333–53. https://doi.org/10.1080/01441647.2019.1710306.

[64] Brown A, Howell A. Mobility for the people: Equity requirements in US shared micromobility programs. J Cycl Micromobility Res 2024;2:100020. https://doi.org/10.1016/j.jcmr.2024.100020.

[65] Winters M, Hosford K, Javaheri S. Who are the ‘super-users’ of public bike share? An analysis of public bike share members in Vancouver, BC. Prev Med Rep 2019;15:100946. https://doi.org/10.1016/j.pmedr.2019.100946.

[66] Mohiuddin H, Fitch-Polse DT, Handy SL. Does bike-share enhance transport equity? Evidence from the Sacramento, California region. J Transp Geogr 2023;109:103588.

[67] Yu W, Chen C, Jiao B, Zafari Z, Muennig P. The Cost-Effectiveness of Bike Share Expansion to Low-Income Communities in New York City. J Urban Health 2018;95:888–98. https://doi.org/10.1007/s11524-018-0323-x.

[68] Qian X, Niemeier D. High impact prioritization of bikeshare program investment to

improve disadvantaged communities' access to jobs and essential services. J Transp Geogr 2019;76:52–70.

[69] Delbosc A, Thigpen C. Who uses subsidized micromobility, and why? Understanding low-income riders in three countries. J Cycl Micromobility Res 2024;2:100016. https://doi.org/10.1016/j.jcmr.2024.100016.

[70] Sanguinetti A, Alston-Stepnitz E. Using emerging mobility data to advocate equitable micromobility infrastructure in underserved communities. Transp Res Part Transp Environ 2023;117:103613. https://doi.org/10.1016/j.trd.2023.103613.

[71] Feigon S, Murphy C, McAdam T. Private Transit: Existing services and emerging directions. 2018.

[72] Lazarus JR, Caicedo JD, Bayen AM, Shaheen SA. To Pool or Not to Pool? Understanding opportunities, challenges, and equity considerations to expanding the market for pooling. Transp Res Part Policy Pract 2021;148:199–222.

[73] Brown AE. Ridehail Revolution: Ridehail Travel and Equity in Los Angeles. UCLA, 2018.

[74] Grahn R, Harper CD, Hendrickson C, Qian Z, Matthews HS. Socioeconomic and usage characteristics of transportation network company (TNC) riders. Transportation 2020;47:3047–67. https://doi.org/10.1007/s11116-019-09989-3.

[75] Martin E, Shaheen S. The impact of carsharing on household vehicle ownership. Access Mag 2011;1:22–7.

[76] Jiao J, Wang F. Shared mobility and transit-dependent population: A new equity opportunity or issue? Int J Sustain Transp 2021;15:294–305.

[77] Tyndall J. Where no cars go: Free-floating carshare and inequality of access. Int J Sustain Transp 2017;11:433–42.

[78] Paul J, Pinski M, Brozen M, Blumenberg E. Can Subsidized Carshare Programs Enhance Access for Low-Income Travelers? A Case Study of BlueLA in Los Angeles. J Am Plann Assoc 2023:1–14.

[79] Liezenga AM, Verma T, Mayaud JR, Aydin NY, van Wee B. The first mile towards access equity: Is on-demand microtransit a valuable addition to the transportation mix in suburban communities? Transp Res Interdiscip Perspect 2024;24:101071. https://doi.org/10.1016/j.trip.2024.101071.

[80] Martin E, Shaheen S. Synthesis Report: Findings and Lessons Learned from the Independent Evaluation of the Mobility on Demand Sandbox Demonstrations. Federal Transit Administration; 2023.

[81] Clark LP, Millet DB, Marshall JD. Changes in Transportation-Related Air Pollution Exposures by Race-Ethnicity and Socioeconomic Status: Outdoor Nitrogen Dioxide in the United States in 2000 and 2010. Environ Health Perspect 2017;125:097012. https://doi.org/10.1289/EHP959.

[82] Nguyen NP, Marshall JD. Impact, efficiency, inequality, and injustice of urban air

pollution: variability by emission location. Environ Res Lett 2018;13:024002. https://doi.org/10.1088/1748-9326/aa9cb5.

[83] Rosofsky A, Levy JI, Zanobetti A, Janulewicz P, Fabian MP. Temporal trends in air pollution exposure inequality in Massachusetts. Environ Res 2018;161:76–86. https://doi.org/10.1016/j.envres.2017.10.028.

[84] Khogali HO, Mekid S. The blended future of automation and AI: Examining some long-term societal and ethical impact features. Technol Soc 2023;73:102232. https://doi.org/10.1016/j.techsoc.2023.102232.

[85] Groshen EL, Helper S, MacDuffie JP, Carson C. Preparing U.S. Workers and Employers for an Autonomous Vehicle Future. W.E. Upjohn Institute; 2018. https://doi.org/10.17848/tr19-036.

[86] Nikitas A, Vitel A-E, Cotet C. Autonomous vehicles and employment: An urban futures revolution or catastrophe? Cities 2021;114:103203. https://doi.org/10.1016/j.cities.2021.103203.

[87] Fleming KL. Social Equity Considerations in the New Age of Transportation: Electric, Automated, and Shared Mobility. J Sci Policy Gov 2018;13.

[88] Chinbat T, Fumihiko N, Mihoko M, Shinji T, Ryo A. Impact assessment study of mobility-as-a-service (MaaS) on social equity through nonwork accessibility in rural Japan. Asian Transp Stud 2023;9:100109. https://doi.org/10.1016/j.eastsj.2023.100109.

[89] Eckhardt J, Nykänen L, Aapaoja A, Niemi P. MaaS in rural areas - case Finland. Res Transp Bus Manag 2018;27:75–83. https://doi.org/10.1016/j.rtbm.2018.09.005.

[90] Committee for Review of Innovative Urban Mobility Services, Policy Studies, Transportation Research Board, National Academies of Sciences, Engineering, and Medicine. Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services. Washington, D.C.: Transportation Research Board; 2016. https://doi.org/10.17226/21875.

[91] Wang F, Ross CL, Karner A. Understanding the Influence of Mobility as a Service (MAAS) on Job Accessibility and Transportation Equity, 2019.

[92] Sanguinetti A, Alston-Stepnitz E, D'Agostino MC. Evaluating Two Universal Basic Mobility Pilot Projects in California. n.d. https://www.ucits.org/research-project/2022-20/.

[93] Los Angeles launches nation's largest UBM pilot, Lewis Center leads evaluation. UCLA Lewis Center for Regional Policy Studies.; 2022.

[94] Terry J, Bachmann C. Quantifying the Potential Impact of Autonomous Vehicle Adoption on Government Finances. Transp Res Rec 2019;2673:72–83. https://doi.org/10.1177/0361198119837218.

[95] Lewis R, Clark BY. Retooling local transportation financing in a new mobility future. Transp Res Interdiscip Perspect 2021;10:100388. https://doi.org/10.1016/j.trip.2021.100388.

[96] Clark BY. The impacts of autonomous vehicles on local government budgeting and finance: case of solid waste collection. Natl Tax J 2020;73:259–82. https://doi.org/10.17310/ntj.2020.1.08.

[97] Agbelie B. A new highway cost allocation framework in the day of connected and autonomous vehicles. Transp Res Interdiscip Perspect 2024;24:101067. https://doi.org/10.1016/j.trip.2024.101067.

[98] Fearnley N. Micromobility – Regulatory Challenges and Opportunities. In: Paulsson A, Sørensen CH, editors. Shap. Smart Mobil. Futur. Gov. Policy Instrum. Times Sustain. Transit., Emerald Publishing Limited; 2020, p. 169–86. https://doi.org/10.1108/978-1-83982-650-420201010.

[99] Shaheen S, Cohen A. Shared micromobility: policy and practices in the United States. In: Sigler T, Corcoran J, editors. Mod. Guide Urban Shar. Econ., Edward Elgar Publishing; 2021. https://doi.org/10.4337/9781789909562.00020.

[100] Brown A. Micromobility, Macro Goals: Aligning scooter parking policy with broader city objectives. Transp Res Interdiscip Perspect 2021;12:100508. https://doi.org/10.1016/j.trip.2021.100508.

[101] Lehe L, Devunuri S, Rondan J, Pandey A. Taxation of Ride-hailing. FHWA-ICT-21-029 2021. https://doi.org/10.36501/0197-9191/21-040.

[102] Lowe K, Ashton P, Kasal Q. Taxing New Mobility Providers n.d.

[103] Bieszczat A, Schwieterman J. Carsharing: Review of Its Public Benefits and Level of Taxation. Transp Res Rec J Transp Res Board 2012;2319:105–12. https://doi.org/10.3141/2319-12.

[104] Schwieterman JP, Bieszczat A. The cost to carshare: A review of the changing prices and taxation levels for carsharing in the United States 2011–2016. Transp Policy 2017;57:1–9. https://doi.org/10.1016/j.tranpol.2017.03.017.

[105] Walker J. What is “Microtransit” For? Hum Transit 2019. https://humantransit.org/2019/08/what-is-microtransit-for.html (accessed July 1, 2024).

[106] Via Transportation. Transit agencies are paying the price for inefficient paratransit 2020. https://ridewithvia.com/resources/transit-agencies-are-paying-the-price-for-inefficient-paratransit (accessed May 13, 2024).

[107] Hensher DA, Mulley C, Nelson JD. Mobility as a service (MaaS) – Going somewhere or nowhere? Transp Policy 2021;111:153–6. https://doi.org/10.1016/j.tranpol.2021.07.021.

[108] Mulley C, Nelson J. How Mobility as a Service Impacts Public Transport Business Models. Paris: OECD; 2020. https://doi.org/10.1787/df75f80e-en.

[109] Kamargianni M, Matyas M. The Business Ecosystem of Mobility-as-a-Service. Transp Res Board 2017;96. http://www.trb.org/Main/Blurbs/175528.aspx (accessed May 16, 2024).

[110] National Center for Mobility Management. Does the Collapse of Maas Global and

the Whim Travel App Signify the End for MaaS? Natl Cent Mobil Manag 2024. https://nationalcenterformobilitymanagement.org/news/does-the-collapse-of-maas-global-and-the-whim-travel-app-signify-the-end-for-maas/ (accessed May 16, 2024).

[111] Oakland Department of Transportation. Universal Basic Mobility Pilot Overview Evaluation 2022.

[112] City of Pittsburgh. Move PGH Mid-Pilot Report. 2022.

[113] Moore MA, Lavieri PS, Dias FF, Bhat CR. On investigating the potential effects of private autonomous vehicle use on home/work relocations and commute times. Transp Res Part C Emerg Technol 2020;110:166–85. https://doi.org/10.1016/j.trc.2019.11.013.

[114] Nadafianshahamabadi R, Tayarani M, Rowangould G. A closer look at urban development under the emergence of autonomous vehicles: Traffic, land use and air quality impacts. J Transp Geogr 2021;94:103113. https://doi.org/10.1016/j.jtrangeo.2021.103113.

[115] Gelauff G, Ossokina I, Teulings C. Spatial and welfare effects of automated driving: Will cities grow, decline or both? Transp Res Part Policy Pract 2019;121:277–94. https://doi.org/10.1016/j.tra.2019.01.013.

[116] González-González E, Nogués S, Stead D. Parking futures: Preparing European cities for the advent of automated vehicles. Land Use Policy 2020;91:104010. https://doi.org/10.1016/j.landusepol.2019.05.029.

[117] Zakharenko R. Self-driving cars will change cities. Reg Sci Urban Econ 2016;61:26–37. https://doi.org/10.1016/j.regsciurbeco.2016.09.003.

[118] Narayanan S, Chaniotakis E, Antoniou C. Shared autonomous vehicle services: A comprehensive review. Transp Res Part C Emerg Technol 2020;111:255–93. https://doi.org/10.1016/j.trc.2019.12.008.

[119] Clements LM, Kockelman KM. Economic Effects of Automated Vehicles. Transp Res Rec J Transp Res Board 2017;2606:106–14. https://doi.org/10.3141/2606-14.

[120] Kondor D, Zhang H, Tachet R, Santi P, Ratti C. Estimating Savings in Parking Demand Using Shared Vehicles for Home–Work Commuting. IEEE Trans Intell Transp Syst 2019;20:2903–12. https://doi.org/10.1109/TITS.2018.2869085.

[121] Stein GM. The Impact of Autonomous Vehicles on Urban Land Use Patterns 2020.

[122] NACTO. Shared Micromobility in the U.S.: 2018. New York City: NACTO; 2019.

[123] Ghaffar A, Hyland M, Saphores J-D. Meta-analysis of shared micromobility ridership determinants. Transp Res Part Transp Environ 2023;121:103847.

[124] Zhang Y, Kasraian D, van Wesemael P. Built environment and micro-mobility. J Transp Land Use 2023;16:293–317.

[125] Clark BY, Brown A. What does ride-hailing mean for parking? Associations between on-street parking occupancy and ride-hail trips in Seattle. Case Stud Transp Policy

2021;9:775–83. https://doi.org/10.1016/j.cstp.2021.03.014.

[126] Shirgaokar M, Misra A, Weinstein Agrawal A, Wachs M, Dobbs B. Differences in ride-hailing adoption by older Californians among types of locations. J Transp Land Use 2021;14. https://doi.org/10.5198/jtlu.2021.1827.

[127] Rotaris L, Danielis R. The role for carsharing in medium to small-sized towns and in less-densely populated rural areas. Transp Res Part Policy Pract 2018;115:49–62. https://doi.org/10.1016/j.tra.2017.07.006.

[128] Brown L, Martin E, Cohen A, Gangarde S, Shaheen S. Mobility on Demand (MOD) Sandbox Demonstration: Pierce Transit Limited Access Connections Evaluation Report. Federal Transit Administration; 2022.

[129] Brumfield R. Transforming Public Transit with a Rural On-Demand Microtransit Project. Federal Transit Administration; 2023.

[130] Rovira E, McLaughlin AC, Pak R, High L. Looking for Age Differences in Self-Driving Vehicles: Examining the Effects of Automation Reliability, Driving Risk, and Physical Impairment on Trust. Front Psychol 2019;10:800. https://doi.org/10.3389/fpsyg.2019.00800.

[131] Vaishnav P, Tian Y, Isaac C, Mohan A. Automation and electrification in long-haul trucking cuts urban health and environmental damages. Transp Res Part Transp Environ 2024;131:104187. https://doi.org/10.1016/j.trd.2024.104187.

[132] Dalmeijer K, Van Hentenryck P. Optimizing Freight Operations for Autonomous Transfer Hub Networks 2021. https://doi.org/10.48550/arXiv.2110.12327.

[133] Shapiro A. Platform urbanism in a pandemic: Dark stores, ghost kitchens, and the logistical-urban frontier. J Consum Cult 2023;23:168–87. https://doi.org/10.1177/14695405211069983.

[134] Talamini G, Li W, Li X. From brick-and-mortar to location-less restaurant: The spatial fixing of on-demand food delivery platformization. Cities 2022;128:103820. https://doi.org/10.1016/j.cities.2022.103820.

[135] Smith G, Hensher DA, Ho C, Balbontin C. Mobility-as-a-Service users: insights from a trial in Sydney. Eur Transp Res Rev 2023;15:40. https://doi.org/10.1186/s12544-023-00612-2.

[136] Ho CQ, Mulley C, Hensher DA. Public preferences for mobility as a service: Insights from stated preference surveys. Transp Res Part Policy Pract 2020;131:70–90. https://doi.org/10.1016/j.tra.2019.09.031.

[137] Mokyr J, Vickers C, Ziebarth NL. The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different? J Econ Perspect 2015;29:31–50. https://doi.org/10.1257/jep.29.3.31.

[138] Autor DH. Why Are There Still So Many Jobs? The History and Future of Workplace Automation. J Econ Perspect 2015;29:3–30. https://doi.org/10.1257/jep.29.3.3.

[139] Nordhoff S, Kyriakidis M, van Arem B, Happee R. A multi-level model on automated

vehicle acceptance (MAVA): a review-based study. Theor Issues Ergon Sci 2019;20:682–710. https://doi.org/10.1080/1463922X.2019.1621406.

[140] Yankelevich A, Rikard RV, Kadylak T, Hall MJ, Mack EA, Verboncoeur JP, et al. Preparing the Workforce for Automated Vehicles. Truck Platooning State Ind. 2018, American Center for Mobility; 2018.

[141] Parikh G, Duhn M, Hourdos J. How Locals Need to Prepare for the Future of V2V/V2I Connected Vehicles 2019.

[142] Noch M. Are We Ready for Connected and Automated Vehicles? Fed Highw Adm n.d. https://highways.dot.gov/public-roads/spring-2018/are-we-ready-connected-and-automated-vehicles (accessed May 15, 2024).

[143] McKeever B, Wang P, West T. Caltrans Connected and Automated Vehicle Strategic Plan 2020.

[144] Grosso M, Cristinel Raileanu I, Krause J, Alonso Raposo M, Duboz A, Garus A, et al. How will vehicle automation and electrification affect the automotive maintenance, repair sector? Transp Res Interdiscip Perspect 2021;12:100495. https://doi.org/10.1016/j.trip.2021.100495.

[145] Said C. Lime to ‘juicers’: The gig is up. San Franc Chron 2020.

[146] Wang X. Preparing the public transportation workforce for the new mobility world. Empower. New Mobil. Workforce, Elsevier; 2019, p. 221–43. https://doi.org/10.1016/B978-0-12-816088-6.00010-9.

[147] Ivey S. Inspiring the next generation mobility workforce through innovative industry–academia partnerships. Empower. New Mobil. Workforce, Elsevier; 2019, p. 317–48. https://doi.org/10.1016/B978-0-12-816088-6.00015-8.

[148] Benner C, Johansson E, Feng K, Witt H. On-demand and on-the-edge: Ride hailing and Delivery workers in San Francisco. 2020.

[149] Hall JV, Krueger AB. An Analysis of the Labor Market for Uber’s Driver-Partners in the United States. ILR Rev 2018;71:705–32. https://doi.org/10.1177/0019793917717222.

[150] Woodside J, Vinodrai T, Moos M. Bottom-up strategies, platform worker power and local action: Learning from ridehailing drivers. Local Econ J Local Econ Policy Unit 2021;36:325–43. https://doi.org/10.1177/02690942211040170.

[151] Merfeld K, Wilhelms M-P, Henkel S, Kreutzer K. Carsharing with shared autonomous vehicles: Uncovering drivers, barriers and future developments – A four-stage Delphi study. Technol Forecast Soc Change 2019;144:66–81. https://doi.org/10.1016/j.techfore.2019.03.012.

[152] Gittleman M, Monaco K. Truck-Driving Jobs: Are They Headed for Rapid Elimination? ILR Rev 2020;73:3–24. https://doi.org/10.1177/0019793919858079.

[153] Schuster AM, Agrawal S, Britt N, Sperry D, Van Fossen JA, Wang S, et al. Will automated vehicles solve the truck driver shortages? Perspectives from the

trucking industry. Technol Soc 2023;74:102313. https://doi.org/10.1016/j.techsoc.2023.102313.

[154] Li C, Mirosa M, Bremer P. Review of Online Food Delivery Platforms and their Impacts on Sustainability. Sustainability 2020;12:5528. https://doi.org/10.3390/su12145528.

[155] Allon G, Chen D, Moon K. Measuring Strategic Behavior by Gig Economy Workers: Multihoming and Repositioning 2023. https://doi.org/10.2139/ssrn.4411974.

[156] Liu Y, Li S. An economic analysis of on-demand food delivery platforms: Impacts of regulations and integration with ride-sourcing platforms. Transp Res Part E Logist Transp Rev 2023;171:103019. https://doi.org/10.1016/j.tre.2023.103019.

[157] Bhusal S, Blumenberg E, Brozen M. Access to Opportunities Primer. Ralph Goldy Lewis Cent Reg Policy Stud 2021.

[158] Makridis M, Mattas K, Mogno C, Ciuffo B, Fontaras G. The impact of automation and connectivity on traffic flow and CO2 emissions. A detailed microsimulation study. Atmos Environ 2020;226:117399. https://doi.org/10.1016/j.atmosenv.2020.117399.

[159] Liu J, Kockelman K, Nichols A. Anticipating the Emissions Impacts of Smoother Driving by Connected and Autonomous Vehicles, Using the MOVES Model. Smart Transp. Cities Nations Rise Self-Driv. Connect. Veh., Austin, TX: The University of Texas at Austin; 2018.

[160] Fagnant DJ, Kockelman KM. The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Transp Res Part C Emerg Technol 2014;40:1–13. https://doi.org/10.1016/j.trc.2013.12.001.

[161] Fleetwood J. Public Health, Ethics, and Autonomous Vehicles. Am J Public Health 2017;107:532–7. https://doi.org/10.2105/AJPH.2016.303628.

[162] Djavadian S, Tu R, Farooq B, Hatzopoulou M. Multi-objective eco-routing for dynamic control of connected & automated vehicles. Transp Res Part Transp Environ 2020;87:102513. https://doi.org/10.1016/j.trd.2020.102513.

[163] Bretones A, Marquet O, Daher C, Hidalgo L, Nieuwenhuijsen M, Miralles-Guasch C, et al. Public Health-Led Insights on Electric Micro-mobility Adoption and Use: a Scoping Review. J Urban Health 2023;100:612–26. https://doi.org/10.1007/s11524-023-00731-0.

[164] Jones TGJ, Harms L, Heinen E. Motives, perceptions and experiences of electric bicycle owners and implications for health, wellbeing and mobility. J Transp Geogr 2016;53:41–9. https://doi.org/10.1016/j.jtrangeo.2016.04.006.

[165] Glenn J, Bluth M, Christianson M, Pressley J, Taylor A, Macfarlane GS, et al. Considering the Potential Health Impacts of Electric Scooters: An Analysis of User Reported Behaviors in Provo, Utah. Int J Environ Res Public Health 2020;17:6344. https://doi.org/10.3390/ijerph17176344.

[166] Trivedi T, Liu C, Antonio ALM, Wheaton N, Kreger VC, Yap A, et al. Injuries Associated With Standing Electric Scooter Use. JAMA Netw Open 2019;2.

https://doi.org/10.1001/jamanetworkopen.2018.7381.

[167] Saleh M, Yamanouchi S, Hatzopoulou M. Greenhouse Gas Emissions and Potential for Electrifying Transportation Network Companies in Toronto. Transp Res Rec 2024:03611981241236480. https://doi.org/10.1177/03611981241236480.

[168] Bartel E, MacEachen E, Reid-Musson E, Meyer SB, Saunders R, Bigelow P, et al. Stressful by design: Exploring health risks of ride-share work. J Transp Health 2019;14:100571. https://doi.org/10.1016/j.jth.2019.100571.

[169] Saeed Jaydarifard, Krishna N.S. Behara, Douglas Baker, Alexander Paz. Driver fatigue in taxi, ride-hailing, and ridesharing services: a systematic review. Transp Rev 2023:1–19. https://doi.org/10.1080/01441647.2023.2278446.

[170] Hoerler R, van Dijk J, Patt A, Del Duce A. Carsharing experience fostering sustainable car purchasing? Investigating car size and powertrain choice. Transp Res Part Transp Environ 2021;96:102861. https://doi.org/10.1016/j.trd.2021.102861.

[171] Tirachini A, Cats O. COVID-19 and Public Transportation: Current Assessment, Prospects, and Research Needs. J Public Transp 2020;22:1–21. https://doi.org/10.5038/2375-0901.22.1.1.

[172] Wilbur M, Ayman A, Ouyang A, Poon V, Kabir R, Vadali A, et al. Impact of COVID-19 on Public Transit Accessibility and Ridership. arXivOrg 2020.

[173] Haglund N, Mladenović MN, Kujala R, Weckström C, Saramäki J. Where did Kutsuplus drive us? Ex post evaluation of on-demand micro-transit pilot in the Helsinki capital region. Res Transp Bus Manag 2019;32:100390. https://doi.org/10.1016/j.rtbm.2019.100390.

[174] Sen B, Kucukvar M, Onat NC, Tatari O. Life cycle sustainability assessment of autonomous heavy-duty trucks. J Ind Ecol 2020;24:149–64. https://doi.org/10.1111/jiec.12964.

[175] Allen J, Piecyk M, Cherrett T, Juhari MN, McLeod F, Piotrowska M, et al. Understanding the transport and CO2 impacts of on-demand meal deliveries: A London case study. Cities 2021;108:102973. https://doi.org/10.1016/j.cities.2020.102973.

[176] Fontes F, Andrade V. Bicycle Logistics as a Sustainability Strategy: Lessons from Brazil and Germany. Sustainability 2022;14:12613. https://doi.org/10.3390/su141912613.

[177] Wicaksono S, Lin X, Tavasszy LA. Market potential of bicycle crowdshipping: A two-sided acceptance analysis. Res Transp Bus Manag 2022;45:100660. https://doi.org/10.1016/j.rtbm.2021.100660.

[178] Goodchild A, Toy J. Delivery by drone: An evaluation of unmanned aerial vehicle technology in reducing CO2 emissions in the delivery service industry. Transp Res Part Transp Environ 2018;61:58–67. https://doi.org/10.1016/j.trd.2017.02.017.

[179] Tirachini A. Ride-hailing, travel behaviour and sustainable mobility: an international review. Transportation 2020;47:2011–47. https://doi.org/10.1007/s11116-019-10070-2.

[180] Surakka T, Härri F, Haahtela T, Horila A, Michl T. Regulation and governance supporting systemic MaaS innovations. Res Transp Bus Manag 2018;27:56–66. https://doi.org/10.1016/j.rtbm.2018.12.001.