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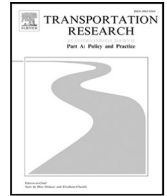
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The Hitchhiker's Guide to challenges in transport policy research: Towards ANSWERing questions regarding life, mobility, and everything

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ABSTRACT

Transport policy research has been developed systematically since the second half of the 20th century, when urban planning and transportation systems became critical components of economic development and urbanization. The field has evolved through a wealth of diverse publications and scholarly contributions. Our comprehensive guide synthesizes the state of the art in 20 major categories of transport policy research, identified based on a data-driven categorization. Each category is represented by a leading expert in the field, providing a rigorous assessment of the state of the art on an area together with an identification of challenges to

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inform future research and policymaking. Aggregated analysis reveals six major trends in policy research, namely: Adaptability, Network Integration, Sustainability, Wireless Connectivity, Equity, and Resilience — combined to form the word ANSWER, with each component being crucial to understanding and addressing the field's multifaceted challenges. Our guide aims to provide answers to pressing challenges and serve as an essential, accessible reference regarding transport policy research for academics, policymakers, and industry stakeholders alike.

1. Introduction

Transport policy research has undergone striking evolution since the 1960s, beginning with the post-war era's emphasis on infrastructure development and urban planning to accommodate rapidly growing populations and emerging automobile usage (Alpkokin, 2012; Tolley and Turton, 2014; Divall and Hine, 2017). During the 1960s and 1970s, the field began to incorporate more systematic approaches to traffic management and public transit planning, driven by the rising concerns of congestion and environmental impacts (Hillman, 1982; Hart, 1992). In 1979, the inaugural issue of 'Transportation Research Part A' was published under the editorship of Frank A Haight, addressing transportation policy and related issues (Modak et al., 2019). The 1980s and 1990s saw the advent of sophisticated modelling techniques and the integration of economic theories, reflecting a shift towards understanding transportation's socio-economic implications (Metz, 2002; Pflieger et al., 2009). The turn of the century introduced digital innovations and data analytics, leading to significant improvements of the precision and scope of research and the materialization of policy transfer ideas (Marsden and Stead, 2011). Contemporary transport policy research often encompasses a holistic view, addressing complex, multi-disciplinary challenges, continuously adapting to societal needs and technological advancements (Carreira et al., 2013; Schweikert et al., 2014; Marsden and Reardon, 2017; Tsoi et al., 2021; Wandelt and Zheng, 2024; Mehdizadeh et al., 2024).

Given the importance of informed and effective transport policy making, the number of studies on transport policy in the literature is enormous. Unfortunately, these studies are often scattered across various scientific venues because the subject intersects with multiple scientific domains, each offering unique perspectives and methods. For instance, studies on sustainable transport policy in environmental science journals, financial implications of transportation investments/pricing policies in economic journals, advancements in autonomous vehicles or infrastructure planning in engineering and technology-focused venues, and research on how active transportation policies impact community health outcomes in public health journals. This wide distribution across disciplines like urban studies, economics, environmental science, and public health reflects the complexity of transport policy, making it essential to integrate insights from various fields to address contemporary transportation challenges comprehensively. Numerous review papers in the literature explore diverse factors, impacts, and methodologies in transport policy research. For instance, Berg et al. (2017) examine how transport investments influence growth, inclusion, and sustainability, particularly in developing countries, highlighting economic gains and social impacts. The Special Interest Group 10 of the World Conference on Transport Research Society, as summarized by May et al. (2003), presents foundational research addressing diverse global transport policy concerns. Metz (2003) explores policies for supporting mobility among ageing populations, emphasizing accessibility and health. Möser and Bamberg (2008) provide a meta-analysis on soft transport policy measures, compiling data from 141 studies to evaluate the effectiveness of various non-infrastructure approaches. Marsden and Stead (2011) review the transferability of transport policy lessons across cities, underscoring the challenges and enablers of policy adaptation in new contexts. Urbanek (2019) synthesizes the role of data-driven approaches in urban transport policy, noting how data analytics can enhance urban mobility solutions. van Burgsteden et al. (2024) focus on transport policies aimed at improving community well-being, examining the social benefits of inclusive transportation systems. Fontoura and Ribeiro (2021) review the use of system dynamics in sustainable urban transportation policies, detailing how this methodology aids in policy development and implementation. Ryley et al. (2020) address climate change impacts on aviation, documenting industry responses to mitigate and adapt to environmental challenges. Lastly, Glaser et al. (2022) synthesize insights on learning and adaptation in transport policy, identifying the factors that enable effective policy transfer and learning. Together, these studies provide a comprehensive look at transport policy's complex landscape, from infrastructure investments and social inclusion to data-driven decision-making, sustainability, and policy transfer. Nevertheless, they are lacking connections to broader trends across the entire transport policy landscape. We believe an overarching review that synthesizes insights from all major transport policy areas to identify shared challenges and interrelated trends is an important contribution to the community.

Our study, coined the **The Hitchhiker's Guide to Challenges in Transport Policy Research**, presents such an overarching review. As a first step, we have used a data-driven classification paradigm to derive 20 major directions within the transport policy subject. The classification of the subject is based on a collection of more than 8,000 abstracts from three prominent journals with focus on transport policy: 'Transportation Research Part A: Policy and Practice', 'Transport Policy', and 'Case Studies in Transport Policy' - obtained via Elsevier's ScienceDirect platform.¹ The obtained clusters are visualized in Fig. 1. Our data-driven approach provides a detailed overview of the research landscape and key areas of focus in the field.

¹ The abstracts underwent preprocessing using a word-to-vector embedding (Goldberg and Levy, 2014) and t-Distributed Stochastic Neighbour Embedding (Van der Maaten and Hinton, 2008), a powerful technique for reducing the dimensionality of high-dimensional data while preserving the essential structure and relationships. This preprocessing step facilitates the visualization and analysis of abstract content in a two-dimensional space. Subsequently, clustering techniques (Kanungo et al., 2002) were employed to identify 20 distinct topics within the abstracts, revealing the underlying themes in transportation policy research, as represented by the three leading journals.

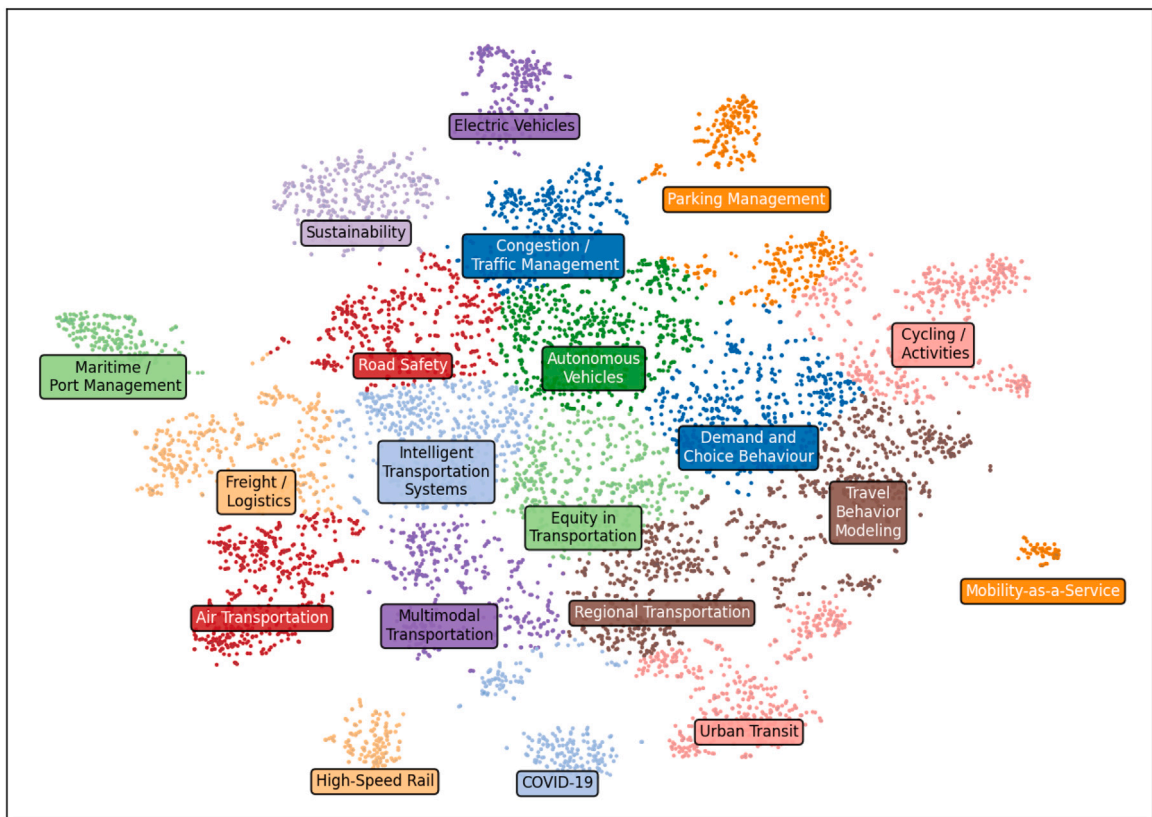


Fig. 1. Twenty major categories of transportation policy publications.

A group of twenty international experts was formed, each of which represents one of the subjects; the selection of experts mainly took place via the identification of prolific authors on the 20 categories — measured in terms of the number of indexed publications, using Web of Science and Google Scholar searches with related keywords. Each expert provided a summary of the state of the art together with a set of 2–3 important challenges in an area.² Afterwards, a structured approach was implemented to ensure consistency and cohesion across each subject; a central editorial team reviewed all sections to identify overlapping concepts, gaps, or inconsistencies. This iterative process led to a comprehensive and coherent study that captures the depth and interconnectedness of each topic within the broader field of policy research. Our review is systematic in using all papers published in the three leading transportation policy journals (TRA, TP, and CSTP) for deriving a data-driven characterization of the extant literature. On the other hand, the individual 20 sections of our paper could be best classified as a structured narrative, since the selection of citations was done subjectively. The six identified key trends of challenges in transport policy are – Adaptability, Network Integration, Sustainability, Wireless Connectivity, Equity, and Resilience – combined to form the word **ANSWER**, each piece being crucial to understanding and addressing the field’s multifaceted challenges.

The remainder of this study is structured as follows. Section 2 reviews the state of the art and major policy-related challenges regarding the 20 identified categories, each drafted by an expert on the subject. Section 3 dissects a collection of six research trends which the authors have collectively identified on the conjoined version of all 20 subject summaries. We believe that these six trends, despite not all of them are present in each of the 20 categories, require special attention from researchers and policymakers alike. Section 4 concludes this study with a brief summary.

2. Review of the 20 subjects on transport policy research

This section discusses the state of the art and major policy-related challenges regarding each of the 20 categories identified earlier. These categories represent distinct yet interconnected domains that respond to different scales, technological advances, and policy objectives. For the sake of clarity, these categories are discussed in alphabetical order, starting with air transportation and ending with urban transit.

² Note that the three core transport policy-related journals were used for the identification of categories only; all reviews and discussions of challenges cover references from all scientific outlets.

2.1. Air transportation

The world airline industry has received a great deal of attention from scholars in a number of different disciplines: economics, management, political science, engineering, and so on. The sustained interest in this industry is due in part to its fundamental importance as a contributor to exchange, development, and economic growth. The global air passengers grew ten times between 2019 and 1970. While the industry is vulnerable to shocks of various types, traffic typically resumes the pre-shock growth trajectory within a short period. An important contributor for the robust growth is public policy reforms. For example, the United States deregulated its domestic markets in 1978, which started a worldwide move away from government regulation towards liberalization of air services. The liberalized environment has unleashed airline competition over fares, frequency, scheduling and networks, and led innovations in business models such as the development of low-cost carriers. For reviews of the policies, operations, and interactions between the aviation sector and economic development and environment, see, e.g., [Zhang et al. \(2010\)](#), [Zhang and Graham \(2020\)](#), [Wandelt et al. \(2024a\)](#).

There are still a number of issues that will likely receive a great deal of scholarly (as well as public policy) interest in the coming years. First, the COVID-19 pandemic, the most recent major shock, was devastating to the airline industry. At the same time, air transportation is also a main facilitator of virus spread. How to design an aviation system and corresponding policies resilient to future disruptions, which have been on the rise over the decades, cyber-attacks, and climate-change induced shocks remains a major challenge to the industry, governments and international organizations, as well as research community (e.g., [Wandelt et al., 2023a](#)). The second issue is with regard to the international regulatory regime. Unlike many other industries, international air transportation overall remains heavily regulated, in the form of a huge number of bilateral air service agreements. While several “open skies” agreements (OSAs) have emerged among countries since the 1990s, OSAs still fall well short of establishing completely free trade in air transport services. A recent study by [Tan et al. \(2024\)](#) investigated the question of whether U.S. travellers would benefit from entry by foreign airlines, by simulating the effect of cabotage based on low-cost carrier competition in the U.S. and EU markets. Their simulation shows that an EU low-cost carrier’s entry in U.S. markets would generate a modest \$1.6 billion annual welfare gain to travellers. The analysis is based on a case of unilateral cabotage (only the U.S. granted cabotage rights to foreign airlines). While U.S. travellers gain, it is not sure about the impact on U.S. carriers’ profit, nor would the impacts on other countries be. More studies on the assessment and implementation are needed. Here, it is worth noting that because of (bailout) subsidies during the COVID-19 crisis, governments with large stakes in airlines might not want to see their carriers facing major competition until they get their subsidies back. Thus, there might be a real danger that the decades of progress on regional/international liberalization would be pushed backwards. This is an important issue that warrants vigilant and careful monitoring by policymakers as well as researchers. Third, sustainability has gradually become one of the top priorities for air transportation and relatedly, we start to see more research on the topic, especially CO₂ or greenhouse gas (GHG) emissions, e.g., [Zhang and Wan \(2024\)](#). Government policies and regulations play crucial roles in mitigating GHG emissions, and public concerns over the potentially significant impacts of aviation on climate have pressured regulators to control GHG emissions from air transport. As a result, sustainability, particularly climate change, will remain an important research area, including fuel tax, cap-and-trade, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), Sustainable Aviation Fuels (SAF) and other new technologies. Finally, air cargo represents an oft neglected area of air transport, as passenger transport has often taken precedence both in terms of policy and scholarship. Yet air cargo has substantially grown over the past decades and its relative importance with respect to passenger transport has accordingly increased. Concerning our ANSWER framework, air transport has dominantly challenges regarding network integration, sustainability, and resilience.

2.2. Autonomous vehicles

Autonomous Vehicles (AVs) are often portrayed as one of the most transformative potential innovations in modern transportation systems. While certain Driver-Controlled Assistance Systems (DCAS) – such as adaptive cruise control, lane-keeping assistance, and automated emergency braking – are already widely deployed, these technologies operate under the continuous supervision of a human driver, who remains fully responsible for vehicle operation. In contrast, Automated Driving Systems (ADS), which refer to systems capable of performing the entire dynamic driving task without human input under specific conditions, remain largely in the developmental or pilot phase and are not yet commercially deployed at scale. Advances in sensors, artificial intelligence, and connectivity have enabled experimental ADS to handle more complex driving tasks. However, it is important to emphasize that these systems are not yet mature or broadly implemented, and much of the public and policy discourse remains speculative. Autonomous Vehicles (AVs) – particularly those incorporating Automated Driving Systems (ADS) – are frequently promoted as innovations that could enhance road safety and expand mobility for individuals facing transportation barriers, such as the elderly and persons with disabilities ([Fagnant and Kockelman, 2015](#)). While the accessibility benefits of AVs are widely acknowledged, claims of reduced congestion or improved environmental performance remain highly contested, with recent evidence suggesting that AVs may significantly increase travel demand, generate zero-occupancy trips, and lead to unintended environmental burdens ([Luo et al., 2024](#); [Silva et al., 2022](#)). The current evidence base supporting these broader systemic impacts is limited and often based on modelling under idealized conditions ([Martínez-Buevas et al., 2022a](#)). In practice, fully autonomous ADS remain at the experimental stage, and many jurisdictions have launched pilot programs to test these technologies and gather data to inform future policy. For example, adaptive testing protocols in Queensland, Australia, have allowed controlled AV trials while contributing to the iterative development of governance frameworks ([Kaye et al., 2019](#)). Despite these efforts, significant challenges persist, including infrastructure readiness, regulatory fragmentation ([Li et al., 2019](#)), and public scepticism—often amplified by high-profile incidents

during testing phases (Hemphill, 2020). Additionally, social equity concerns are increasingly shaping the discourse, with attention to how AVs might reinforce or mitigate existing inequalities in access to transportation (Martínez-Buelvas et al., 2022a).

A central policy challenge for AVs is the development of cohesive regulatory frameworks that clearly define liability and safety responsibilities. As AV technologies evolve, it becomes increasingly important to determine who is accountable in the event of an accident—whether it is the manufacturer, the software developer, or the vehicle operator (Li et al., 2019). Current legal frameworks, primarily designed for human drivers, do not adequately address these complexities, leading to uncertainties that hinder AV adoption. Additionally, cross-jurisdictional collaboration is crucial to ensure consistency in regulations, as fragmented laws across regions can stifle innovation and complicate AV deployment (Hemphill, 2020). Ensuring equitable access to AV technology and its benefits is another significant challenge. AVs have the potential to improve mobility for underserved populations, but if policies are not carefully crafted, they could exacerbate existing inequalities (Martínez-Buelvas et al., 2022a). Without affordable access to AVs or reliable public AV systems, low-income communities risk being left behind, creating a “mobility divide” (Emory et al., 2022). Moreover, as Jiang et al. (2023) emphasize, promoting shared AVs and public transport options could foster more sustainable and equitable outcomes, but this requires careful coordination of policy interventions. As AV systems grow increasingly connected and data-intensive, cybersecurity has become a key regulatory concern. However, existing legal and institutional frameworks are ill-equipped to govern cyber risks that span technical, geographic, and jurisdictional boundaries (Khan et al., 2023b). Policy efforts remain fragmented, with limited coordination across sectors, making it difficult to establish clear responsibilities for risk management, liability, and data governance (Llorca et al., 2025). These challenges are further compounded by the integration of increasingly autonomous AI systems into AV operations, raising complex questions about institutional accountability, algorithmic transparency, and regulatory legitimacy. Failing to recognize AI as an actor requiring its own governance logic – rather than a neutral technical layer – risks undermining safety, oversight, and public trust. This perspective has been reinforced in recent work highlighting how large language models used in autonomous decision-making demand frameworks that can account for ethical reasoning, unpredictability, and responsibility attribution (Xu et al., 2025). Without cohesive cybersecurity and AI governance frameworks, both system resilience and public acceptance of AVs remain at risk. Policy gaps aside, how AV technologies are governed – from design through deployment – plays a critical role in shaping public trust and legitimacy. Understanding the perspectives of diverse stakeholders, particularly around safety, ethics, and equity, is not only essential for fostering public acceptance but also for informing the design of both AV systems and their regulatory frameworks (Martínez-Buelvas et al., 2024). As AVs begin to operate in complex, mixed-traffic environments, co-designed policies that specifically account for the needs of vulnerable road users (VRUs) – including pedestrians and cyclists – are vital to ensuring safe and equitable mobility (Afghari et al., 2021). Without early and meaningful engagement, AV policy risks overlooking key social concerns, increasing the likelihood of public resistance and policy failure. Within the ANSWER framework, autonomous vehicles primarily raise challenges related to network integration, wireless connectivity, equity, and resilience.

2.3. Congestion/traffic management

Congestion is an inevitable side effect of modern societies, where the strive for specialization and agglomeration benefits increases both urbanization and transport volumes (Anas et al., 1998). Congestion tends to increase faster than proportionally to urban population and urban density (Chang et al., 2017). The task of urban transport planners is hence not to eliminate urban congestion altogether, which would be futile, but to provide high accessibility and liveable environments despite the scarcity of urban land, and to balance the benefits of transportation against its social costs. An efficient and equitable way to do the former is to provide good accessibility with public transport, walking and cycling, and to strive for dense and diverse urban planning — but the direct effects of such strategies on road congestion are limited at best (Duranton and Turner, 2011; Echenique et al., 2012; Ewing and Certero, 2010; Handy, 2005; Stopher, 2004; Wardman et al., 2018). Attempting to reduce congestion through increased road capacity is offset by induced traffic — at least to some extent. In fact, consistent with empirical observations, many studies have concluded that expanding road capacity does not reduce congestion at all in the long run (“Down’s paradox”), since road traffic will increase in direct proportion to road capacity (Duranton and Turner, 2011). However, other studies (Anas, 2024; Ossokina et al., 2023) have argued that this extreme result is due to simplistic measures of congestion (vehicle kilometres divided by lane kilometres, rather than excess travel time), and concluded that increasing road capacity does in fact reduce congestion — even if the inherent scarcity of urban land puts a limit to this strategy. Through adaptive signal control strategies, using real-time data from sensors and vehicles, scarce road space can be used more efficiently, thereby reducing congestion (Ampountolas et al., 2017; Keyvan-Ekbatani et al., 2012; Le et al., 2015). While efficient traffic engineering and attractive non-auto transport modes can improve overall accessibility, and to some extent reduce congestion, bringing road congestion down to its optimal level can only be done through congestion pricing. This is because roads will be underpriced, and hence overused and over-congested, as long as transport costs do not reflect each trip’s marginal contribution to congestion. With proper congestion pricing, transport volumes will be optimal in the sense that only those transports where benefits outweigh total societal transport costs will be undertaken (Eliasson, 2021). The theory of congestion pricing is old and well developed, and several successful examples around the world show that it also works in practice (Börjesson and Kristofferson, 2018; Eliasson, 2014; Eliasson et al., 2009; Olszewski and Xie, 2005; Rotaris et al., 2010; Santos et al., 2008).

The fundamental strategies for efficient accessibility in large urban regions rely on space-efficient transport modes (transit, walking, cycling), and dense, diverse spatial planning. But even if there is a broad consensus about this in principle, the many complex and multi-directional linkages between congestion and road capacity, urban form and non-auto accessibility are still not well understood on a detailed level. Still, road transport will continue to be an important component of urban transport systems, and it is hence necessary to ensure that scarce road space is used as efficiently as possible. Adaptive signal control using real-time data

holds a vast potential, especially when linked to recent advances in microscopic and macroscopic congestion modelling (Aboudolas and Geroliminis, 2013; Geroliminis and Daganzo, 2008). Despite the wealth of theoretical and empirical evidence of the effectiveness of congestion pricing, it is still rarely used since it is often met with public or political resistance. The two most important obstacles seem to be political power struggles between different levels of governments, and that losses tend to be more salient than gains; even if total social gains vastly exceed total social losses, losers tend to be easy to identify, while winners tend to be more dispersed and perhaps only exist in the future (Eliasson, 2021). In addition, most real-world pricing systems and proposals are still relatively crudely designed. Designing implementable and cost-efficient congestion pricing systems, which balance system costs versus traffic benefits, is still a difficult and under-researched problem. Concerning our ANSWER framework, congestion/traffic management challenges are dominantly related to adaptability and equity.

2.4. COVID-19

The COVID-19 pandemic profoundly impacted transportation systems and policy making globally, triggering an unprecedented re-evaluation of mobility and public health (Budd and Ison, 2020; Gkiotsalitis and Cats, 2021; Sun et al., 2022). Earlier epidemic outbreaks were mostly contained at the regional scale, e.g., SARS (Lau et al., 2003; Lee and McKibbin, 2004; Colizza et al., 2007) and MERS (Hilgenfeld and Peiris, 2013; Bialek et al., 2014). Based on the experience with these outbreaks, various models have put a particular emphasis on the role of air transportation (Colizza et al., 2006), transportation hubs (Browne et al., 2016) as well as the importance of the so-called probabilistically motivated effective distance, contrary to the geographical distance (Brockmann and Helbing, 2013). These models were able to predict related arrival times of a contagion in different cities, given the location of an outbreak, even in absence of other epidemiological parameters. Despite the existing knowledge, it seems as if the COVID-19 pandemic caught governments off-guard in its early development; the explanations for this observation are neither simple nor straightforward (Bosa et al., 2022). The COVID-19 pandemic required at various stages an unprecedented trade-off between (a) enforcing measures that significantly restrict individual liberties in democratic systems and (b) the need to mitigate the global spread of the contagion; affecting transportation systems at all scales, e.g., public transit (Tirachini and Cats, 2020), railway (Tardivo et al., 2021), air transportation (Sun et al., 2021b), bicycling (Buehler and Pucher, 2021), and walking (Park et al., 2022); each of which came with significant challenges regarding equity and fairness (Sadeghvaziri et al., 2024; Nolte and Schaefer, 2024).

The COVID-19 pandemic has vanished from the conscious parts of most peoples' lives. Nevertheless, challenges remain, particularly regarding the preparedness for future epidemic outbreaks. Informed and timely response coordination during outbreaks is one of the most critical challenges in the future. Specifically, the ability to swiftly implement travel restrictions, quarantines, and social distancing measures is essential to curbing the spread of infectious diseases, despite inherent complexities such as systems spanning multiple jurisdictions and involving various stakeholders (Ding et al., 2021; Liu et al., 2024). Policymakers must also balance public health priorities with economic and logistical considerations, as travel restrictions can have significant impacts on trade, supply chains, and the mobility of essential workers. Moreover, rapid response coordination requires transportation systems to be flexible and adaptable, capable of scaling operations up or down as the situation evolves; a property particularly relevant for air transportation (Sun et al., 2024). This includes adjusting service frequencies, reallocating resources, and implementing new safety protocols on short notice; coordinated across airports within a region (Wu et al., 2023). The ability to quickly mobilize resources, such as additional vehicles, personnel, or emergency supplies, is also crucial. Without accurate and up-to-date information, policymakers may struggle to implement the most effective measures, potentially leading to further spread of the disease and greater disruption to transportation systems (Weible et al., 2020; Sturmberg et al., 2022). Relatedly, equity and accessibility during epidemic outbreaks or pandemics present significant challenges, as these crises have a significant potential to exacerbate existing disparities in access to transportation as well as healthcare (Chen et al., 2021). Clearly, vulnerable populations, such as low-income communities, the elderly, and individuals with disabilities, are disproportionately affected by disruptions in transportation services (Brough et al., 2021; Benitez et al., 2020). Disruptions or restrictions to public transit have more pronounced implications on these groups during a pandemic, due to a lack of alternatives. The reduction or suspension of public transit routes can isolate these communities, making it difficult for residents to access necessary resources or receive timely medical care (Marlow et al., 2021). Addressing these disparities requires targeted policies that ensure continuity of service in vulnerable areas and the provision of alternative transportation options, such as subsidized rideshares, community transport programs, as well as support for the vulnerable groups (Cochran, 2020; Ivaldi and Palikot, 2023). This requires proactive planning, targeted interventions, and inclusive communication strategies to prevent exacerbating existing inequalities and to promote a fair and effective public health response.

2.5. Cycling/activities

Cycling, and more generally, *active mobility*, has been understood and is considered a critical element in the fight against the twin problems of congestion and lack of sustainability plaguing urban areas since the 1950s (Beckmann, 2001; Whitelegg, 2020). Urban planners, policymakers, transportation professionals, and researchers play a crucial role in this fight. Together with efforts to make people aware of (and internalize) the damaging transport externalities inherent to the private car (accidents, delays, noise and atmospheric pollution), such as *congestion pricing* (Eliasson, 2008; Börjesson and Kristoffersson, 2015; Grisolia et al., 2015; Börjesson et al., 2016; Lehe, 2019; Cipriani et al., 2019) and much longer-term policies associated with *land-use changes* (Cervero, 1991; Pinjari et al., 2011; Stevens, 2017; Ibraeva et al., 2020), the welcome increase in active mobility offers some hope for the future (Ortúzar, 2019). There is a vast empirical literature on the advantages for cities and their citizens to embrace active mobility, particularly cycling, to replace trips recurrently made by car (Brand et al., 2021; Neves and Brand, 2019; Ortúzar et al., 2000; Pritchard et al.,

2019; Rosas-Satizábal and Rodríguez-Valencia, 2019; Rossetti et al., 2018; Vecchio et al., 2021). These advantages are particularly clear in the case of movements of less than 7 km in length (a threshold distance which, even in large conurbations, is exceeded by less than 50% of the total trips), as in that range, the bicycle is almost unbeatable in terms of travel time and cost (Berrill et al., 2024; Gutiérrez et al., 2020b). The now universal move towards greater use of active mobility – among other things for the substantial impacts on both health and the economy (Hobbs and Frost, 2024) – was initiated in Europe with a radical effort that incorporated extensive cycleway networks of high standard, and urban measures combining good design with social campaigns and systematic education of citizens since the school age (Dekker, 2022).

The main challenges preventing an increasing use of the bicycle as a commuting mode are discussed as follows. The strong habit and latent attachment perceptions to the private car by its users, which are extremely difficult to overcome (Ramos et al., 2020; Moody and Zhao, 2019; Kalter et al., 2020; Van et al., 2014). The increasing use of motorcycles as a highly convenient commuting mode, particularly in Asia and Latin America (Chu et al., 2022; Rodríguez et al., 2015) — which brings even worse environmental problems and externalities than the private car. The lack of well-designed and extensive infrastructure for bicycles (Godefrooij et al., 2009; Global Designing Cities Initiative, 2016), particularly in North and South America, and several parts of Asia (Clean Air Asia Center, 2013). Note that by the word infrastructure, we refer not only to adequate cycle lanes but also to safe bike-parking facilities, showers, and other facilities at destinations, particularly in hot/humid environments (Gutiérrez et al., 2020a). Note also that the lack of these facilities goes against helping to reduce the final challenge. The potential fears by users of the dangers associated with using bicycles for regular trips; these include the fears of being mugged, of suffering accidents, and – mainly among women – the fear of not being able to solve a mechanical failure (Gutiérrez et al., 2020b). Addressing these challenges, particularly the first two requires a dedicated effort by planners to convince policymakers of the need to act (as the measures are well-known); here, it is undoubtful that a political champion may be required (i.e., somebody like Ken Livingstone in London or Enrique Peñalosa in Bogota). The last two challenges require only the will of politicians, as solutions are comparatively low-cost (building cycle facilities and educational campaigns), and there is already good information about how to proceed. Concerning our ANSWER framework, cycling /activities challenges are dominantly related to adaptability, sustainability, and equity.

2.6. Demand and choice behaviour

The interactions of demand and supply determine the operation of the transportation system and provide a key input to evidence-based transport policy. Therefore, the estimation and prediction of demand flows has been a crucial research direction. Travellers face a large number of short-term choices in their daily travels, including (i) mode, (ii) route, (iii) destination, and (iv) departure time, but also linked mid-term choices, such as whether to own a car (and how many), a mobility provider subscription, e.g. public transport card and MaaS (Mobility-as-a-Service) subscription, but also longer-term choices, such as residential and workplace location. While these choices are very complex in themselves, it is their joint nature that makes modelling them particularly daunting. In fact, even the sequence at which they occur is often not straightforward, and part of the modelling process. Recent research directions include simultaneously modelling multiple choices (Schmid et al., 2023) and also considering more advanced modelling techniques, such as hybrid choice models (Ben-Akiva et al., 2002; Abou-Zeid and Ben-Akiva, 2024). While random utility theory (McFadden, 1974; Train, 2009) is the dominant methodological approach in the field of choice behaviour, alternatives have been proposed, such as random regret minimization (Chorus, 2012). Advances in computing resources, but also in powerful software for developing discrete choice models, such as Apollo³ (Hess and Palma, 2019) and Biogeme⁴ (Bierlaire, 2016) have enabled more researchers and practitioners to specify and estimate increasingly more powerful models. Demand and choice behaviour is being used extensively to support evidence-based policy. For example, techniques like Technology Acceptance Modelling are being introduced to forecast the policy impacts of emerging and future modes, such as for Urban Air Mobility (Al Haddad et al., 2020). Attention is also being given into distinguishing and explicitly considering and modelling the different needs of special segments of the population, such as tourists (Bursa et al., 2022), older travellers or children.

One can argue that demand and choice behaviour is a particular hard aspect of transport policy, as human behaviour is not only very multifaceted, heterogeneous and volatile, but we can still only observe -at best- a small fraction of the relevant factors. One of the biggest challenges limiting the impact of demand and travel behaviour models in transport policy relates to the limited available data. In fact, the specification and estimation of choice models has traditionally been hampered by the high cost of obtaining data, as well as the -often- low quality and high biases associated with such data. The incorporation of emerging data into travel behaviour analyses is one of the great challenges and opportunities. One of the techniques to improve this situation has been the joint consideration of stated preference and revealed preference data (Ben-Akiva et al., 1994; Lizana et al., 2021). Technological advancements have considerably altered the data landscape, and this is being exploited by demand and choice behaviour analyses to advance policy insights. For example, smartphone apps (Cottrill et al., 2013; Prelicpean et al., 2018; Marra et al., 2019) have been used to collect not only passive data (e.g. trips, modes and activities), but also integrate active measures, such as survey questions, to both validate these observations, and also collect richer behavioural data. The power of such approaches, which allow for the unobtrusive continuous data collection from large populations at relatively low costs, was demonstrated very well from the rapid repurposing of an existing such app for COVID-19 data collection (Hintermann et al., 2023). A further related development is the opportunistic use of data collected for other purposes to act as a proxy for capturing traveller demand and behavioural patterns.

³ <http://www.apollochoicemodelling.com>

⁴ <https://biogeme.epfl.ch>

For example, Lu et al. (2024a) used Google Popular Times data to analyse the impact of the 9-Euro ticket during the summer of 2023 in Germany, while Lu et al. (2024b) used Foursquare check-in data from Tokyo, Japan, to infer origin–destination flows. The second challenge relates to the difficulties associated with estimating the more advanced models that are needed to answer the ever more complex transport policy questions of interest. The data revolution has enabled the use of methodological advances, including the consideration of machine learning techniques. Machine learning is currently omnipresent, as – after several decades of doubtful results – it seems to be making a resurgence, following the success of large language models (LLMs), among others. Many researchers have been attempting to take advantage of machine learning models in improving our ability to better model demand and choice behaviour. Two main directions are currently pursued: (i) using machine learning classifiers in place of discrete choice models and (ii) combining machine learning and discrete choice models to develop more powerful hybrids, which also retain the interpretability and other benefits of discrete choice models. Concerning our ANSWER framework, cycling/activities challenges are dominantly related to adaptability, network integration, and equity.

2.7. Electric vehicles

Electric vehicles (EVs) have emerged as a vital component in addressing environmental sustainability concerns that have escalated since the mid-20th century (Kumar and Alok, 2020; Yong et al., 2015). As urban planners, policymakers, and transportation experts increasingly recognize the detrimental externalities associated with conventional vehicles – such as greenhouse gas emissions, air pollution, and noise – there is a concerted push towards integrating electric mobility into urban transportation systems (Sanguesa et al., 2021). Policies such as subsidies for EV purchases, infrastructure development for charging stations, and incentives for manufacturers have been implemented to foster the adoption of electric vehicles. The potential benefits of EVs for urban environments are profound, including reductions in urban air pollution, lower operational costs compared to internal combustion engines, and contributions to meeting climate targets (Alanazi, 2023). Studies demonstrate that EVs can significantly contribute to sustainable urban mobility, particularly when combined with renewable energy sources (Zhang et al., 2020; Wu and Lin, 2021). Furthermore, EVs can enhance urban livability by promoting quieter streets, as electric motors operate with significantly less noise than traditional vehicles. This shift not only improves the quality of life for residents but also encourages outdoor activities and social interactions in public spaces. Additionally, the rise of shared electric mobility services, like e-scooters and ride-hailing, represents a transformative shift in urban transport dynamics. As cities worldwide adopt comprehensive strategies to integrate electric vehicles, the prospect of more sustainable, efficient urban transport systems becomes increasingly feasible.

Promoting EVs faces several significant challenges that hinder their widespread adoption: Safety issues related to EVs can be a major concern for potential users (Sun et al., 2020). Many consumers worry about the risk of battery fires or accidents, fuelled by high-profile incidents in the media. Addressing these fears requires manufacturers to enhance safety standards and improve communication about the rigorous testing EVs undergo to ensure their reliability and safety. Range anxiety concerns still remain critical, despite having much improved in recent years (Pevce et al., 2019). Educating consumers about advancements in battery technology, which have significantly extended range capabilities, is essential. Additionally, developing and distributing more fast-charging options can alleviate these worries. The lack of charging stations is a significant obstacle, particularly in rural and underserved urban areas (Liu et al., 2012; Jensen et al., 2014). Inadequate charging infrastructure can deter consumers from considering EVs, as the convenience of refuelling is a key factor in vehicle selection. To overcome this challenge, robust investment in charging networks is necessary, with strategic placement of stations in high-traffic areas and near major highways. Public–private partnerships can play a vital role in this infrastructure development, ensuring that charging stations are accessible and sufficient in number. Here, an important question is to what extent public investments and support is needed — at least in the first phase of EV introduction. The perception that charging an EV takes longer than filling a gasoline vehicle adds to consumer hesitation. Promoting the convenience of home charging and highlighting how many EV users charge overnight can help shift this perception. Addressing societal attitudes towards EVs is crucial (Manca et al., 2020). Many consumers still view traditional gasoline vehicles as the norm, and a cultural shift is needed to foster acceptance of electric mobility. Engaging in educational campaigns that emphasize the environmental benefits of EVs, along with financial incentives and subsidies, can help cultivate a more positive image of electric vehicles. Concerning our ANSWER framework, electric vehicle challenges are dominantly related to network integration, wireless connectivity, equity, and resilience.

2.8. Equity in transportation

While there is no consensus on the definition of transport equity, several features are worth highlighting. Firstly, equity is primarily about social considerations and is normative. Hence, transport equity in one context may not be applicable universally (Guzman et al., 2017; Liu, 2024a; Vecchio et al., 2020; Zhang and Zhao, 2021). As a normative concept, value judgments are involved. Secondly, transport equity deals with the distribution among different groups in society. Basically, it boils down to two groups: the vulnerable or disadvantaged group and the non-vulnerable or advantaged group. Each group may be further divided into sub-groups, such as “the most vulnerable among the vulnerable”. Common classification criteria include age (e.g. the very young and very old as vulnerable), gender (e.g. females as vulnerable), race (e.g. minority as vulnerable), income (e.g. low-income as vulnerable), physical ability (e.g. people with disabilities as vulnerable), location (e.g. remote areas as vulnerable) and type of road users (e.g. pedestrians and cyclists as vulnerable). As such, the literature on transport equity is very diverse. Thirdly, there is this question of “what is being distributed?”. Again, to simplify, there are essentially two types: the distribution of benefits and the distribution of costs. Key transport benefits include improved accessibility due to new/improved transport infrastructure or services (measured by a range

of attributes from fare, travel time, frequency, safety to comfort). Public transport, for instance, provides accessibility to jobs and essential services but its coverage has been focused on urban areas which do not directly benefit the most needed and vulnerable population living in remote or spatially disadvantaged areas (Wang and Loo, 2024). By far, studies about transport equity have most commonly used public transport accessibility indicators (Deboosere and El-Geneidy, 2018; Farber et al., 2014; Neutens, 2015; Qi et al., 2020; Welch, 2013). Transport costs encompass various environmental (e.g. pollution and noise), social (e.g. traffic injury) or economic (e.g. time cost associated with congestion) transport externalities. Finally, transport equity suggests that more (public) resources should be spent to support the vulnerable population so that they can overcome their disadvantages. Explicit policies and resource commitments are involved. No wonder, theoretical explorations of the concept are related to theories in political philosophy concerning rights and justice (Pereira et al., 2017).

In view of the climate change emergency, a big challenge in transport policy research is related to the differential impacts or burdens of more extreme environmental conditions on vulnerable transport users (such as health stress to pedestrians and cyclists). This research thread is also closely related to environmental justice. Partly related to the above, new transport policies, such as more stringent emission standards and carbon reduction mandates, have been introduced worldwide. However, they can have differential impact on the population (Lucas and Pangbourne, 2014; Pahle, 2023; Plötz et al., 2019). Conversely, new technologies, like autonomous vehicles, zero-emission vehicles and new transport modes, do not benefit all sectors of the society equally (Plötz et al., 2019; Camilleri et al., 2023; Dianin et al., 2021; Guan et al., 2024; Guo et al., 2024). Over the last two decades, many studies have been conducted to evaluate how transport policies (e.g. different transport fare schemes) and plans may affect the achievement of transport equity (Yen et al., 2020; Doran et al., 2021; Farber et al., 2014; Guzman and Oviedo, 2018; Rubensson et al., 2020; Rye and Wretstrand, 2019; Hosking et al., 2022). Nonetheless, they remain relatively theoretical. More efforts in using scientific research to inform policies from conceptualization, implementation to evaluation is needed to overcome the policy-implementation gap (Tsoi and Loo, 2021). On the way forward, research needs to focus more on people-oriented and place-based policies to support the vulnerable population effectively and in ways that they value and see the interventions as relevant. Equity is one cornerstone of our ANSWER framework.

2.9. Freight/logistics

Freight/logistics operations concern the efficient movement of goods through supply chain management/logistics planning, while reduce costs (Blauwens et al., 2006; Cui et al., 2015; Meersman and Van de Voorde, 2019). Traditional subjects in this area focused mainly on costs and efficiency (Archetti et al., 2022), infrastructure development (Winkelhaus and Grosse, 2020; Cedillo-Campos et al., 2022), regulatory compliance, and network optimization (Crainic, 2000; Wiebermeit, 2008). In recent years, transport policy-related research has increasingly focused on decarbonization (Meyer, 2020; Ghisolfi et al., 2022) and supply chain resilience (Tukamuhabwa et al., 2015; Ribeiro and Barbosa-Povoa, 2018), particularly during the COVID-19 pandemic. Lockdowns, factory closures, and labour shortages led to supply chain bottlenecks, creating delays and shortages of goods across industries (Spieske and Birkel, 2021; Ozdemir et al., 2022). The effects of labour shortages, particularly in trucking and warehousing, are also a major focus, as policymakers seek solutions to workforce challenges while considering automation and its impacts on jobs. Meanwhile, the surge in e-commerce demand put immense pressure on last-mile logistics, challenging delivery networks and highlighting inefficiencies in urban freight systems (Macioszek, 2018; Lyons and McDonald, 2023).

Various challenges remain for freight/logistics sector — especially on the way towards increased long-term sustainability. A major one is the reduction of Greenhouse Gas emissions, through the implementation of cleaner fuel standards, promotion of EVs, and encourage modal shifts in freight and logistics; see also Section 2.7. To achieve that, policymakers must adopt comprehensive approaches, including stricter emissions regulations that gradually phase out high-polluting fuels, incentivizing the adoption of cleaner alternatives such as biofuels or renewable diesel. Similarly, subsidies or tax breaks can be provided to accelerate the deployment of electric trucks and other zero-emission vehicles, while investing in the necessary charging infrastructure across key freight corridors. Another policy challenge is the support of innovation and encouraging the adoption of cutting-edge technologies such as blockchain, Internet of Things (IoT), and artificial intelligence (AI), all of which can enhance efficiency, transparency, and real-time tracking in supply chains. However, policymakers must also ensure that industry standards are established to promote interoperability across different systems and platforms. An absence of such harmonized standards and technological fragmentation inevitably leads to inefficiencies and creates barriers to seamless data. While automation, particularly the use of drones for last-mile delivery, offers the potential to reduce congestion and expedite shipments, the incorporation of autonomous vehicles raises logistical, regulatory, and safety concerns. Airspace management in cities is already congested, and adding drones or other small aircraft necessitates new regulations to prevent collisions and manage traffic flows. Moreover, noise pollution, limited payload capacity, and the need for specialized infrastructure, such as vertiports, further complicate the adoption of urban air mobility for freight. Coordinating with existing ground-based logistics networks and ensuring compliance with local, national, and international aviation standards present additional hurdles. Concerning our ANSWER framework, major challenges are related to network integration, sustainability, and resilience.

2.10. High-speed rail

High-speed rail (HSR) has fundamentally transformed our understanding of mobility by redefining the concept of distance and time in transportation. Japan's introduction of the Shinkansen in 1964, became boilerplate for Europe's adoption of HSR in the

1980s and 1990s, with France's TGV and Germany's ICE, as well as China, which has rapidly developed the world's largest high-speed rail network since the early 2000s, revolutionizing domestic travel and setting a precedent for infrastructure development. There is a vast empirical literature on the effects of HSR on the economy/population, covering aspects such as positive effects on social welfare (Chen et al., 2016), economic growth (Jia et al., 2017), productivity (Wetwitoo and Kato, 2017), enhanced accessibility (Diao, 2018), population mobility (Wang et al., 2019), and GDP development (Cascetta et al., 2020). HSR is widely regarded as a more environmentally friendly transport mode, and many studies have investigated the impact of HSR on the environment, e.g., spatial spillovers of industrial populations (Li and Guo, 2021), the impact of HSR on carbon emissions by replacing air transportation (D'Alfonso et al., 2016; Strauss et al., 2021; Avogadro et al., 2021; Li et al., 2024). Finally, there exist various research studies on the interactions between HSR and other transport modes, predominantly focusing on HSR and aviation (Givoni and Dobruszkes, 2013; Sun et al., 2017; Jiang et al., 2021). Various studies have found that competition from HSR has exerted a downward pressure on airfares, flight frequencies, capacities (Wan et al., 2016), and air traffic (Dobruszkes, 2011; Dobruszkes et al., 2014). In addition, Jiang and Zhang (2016) found that when HSR enters the trunk market, the airline will have a greater incentive to cover more regional markets if the trunk market is large. In addition to air-HSR competition, an emerging body of literature focuses on air-HSR cooperation (Givoni and Banister, 2006; Socorro and Viegas, 2013; Li and Sheng, 2016; Liu et al., 2019).

HSR development in the context of environmental concerns is a crucial challenge for transport policy making, given the growing urgency to reduce carbon emissions and mitigate climate change (Chapman, 2007; Creutzig et al., 2015). While HSR offers a lower-carbon alternative to air and road travel, particularly for medium-distance routes, which can significantly decrease the overall environmental footprint of transportation, the construction and expansion of HSR networks can lead to significant environmental impacts, such as land use changes, habitat disruption, and resource consumption (Campos and De Rus, 2009; De Rus, 2011). Policymakers must carefully balance the long-term environmental benefits of HSR with the short-term ecological damage caused by construction activities. For instance, it has been shown recently that the introduction of short-haul flight bans has the potential to reach net-zero 10 years after construction, within an integrated modal life cycle assessment, compared to 60 years without bans (de Bortoli and Féraïlle, 2024). Additionally, integrating HSR into existing transportation networks requires careful planning and optimization to ensure efficient operations and minimal disruption to communities (Dai et al., 2021; Xu et al., 2024). Ensuring that HSR development is sustainable involves not only minimizing immediate environmental damage but also considering the long-term resilience of the infrastructure in the face of climate change (Lin et al., 2021). Maintaining and updating HSR infrastructure presents a significant challenge for transport policy making given the complex nature of these projects. High initial capital investments, coupled with the need for long-term financial commitment, make HSR projects politically sensitive and economically demanding. Additionally, the planning and construction of HSR networks often involve intricate coordination across multiple jurisdictions, including local, regional, and national levels, complicating the decision-making process. Land acquisition, environmental concerns, and the need for advanced technology integration further add layers of complexity (Sun, 2015; Gong and Li, 2022). Furthermore, existing HSR infrastructure requires continuous upgrades to keep pace with technological advancements and to maintain safety and efficiency standards, necessitating ongoing investment and innovation (Bugalia et al., 2023). Balancing these two challenges with the imperative to provide sustainable, efficient transportation solutions makes HSR development a critical element of modern transport policy. Concerning our ANSWER framework, major challenges are related to network integration, sustainability, and resilience.

2.11. Intelligent transportation systems

The origins of Intelligent Transportation Systems⁵ (ITS) can be traced back to the mid-20th century, when transportation planning was largely focused on building and expanding physical infrastructure (Sussman, 2008). Once these approaches reached their limits, there was a growing consensus of the need to focus on more efficient management of existing infrastructure. This marked the beginning of a shift from infrastructure-centric policies to those that leveraged technology to optimize the use of existing infrastructure instead (Wootton et al., 1995). With the start of mass-computerization in the 1980s and 1990s, ITS was formally conceptualized as a field, with a focus on integrating information technology and communication systems into transportation (Kanninen, 1996; Weiland and Purser, 2000). Governments and industry stakeholders started to explore the potential of these technologies mainly to improve traffic flow (Hua and Faghri, 1994; Figueiredo et al., 2001; Boukerche et al., 2020); leading projects at this time include Intermodal Surface Transportation Efficiency Act (United States), the Dedicated Road Infrastructure for Vehicle Safety program (Europe), and the Vehicle Information and Communication System (Japan); see Catling (1988), Lyons (1995), Ishihara et al. (1998). By the early 2000s, ITS had gained substantial momentum, particularly in the context of smart transportation, and many governments started to guide the development/deployment of these systems; a period characterized by the establishment of dedicated agencies, funding programs, and regulatory frameworks (Dimitrakopoulos and Demestichas, 2010; Guerrero-Ibanez et al., 2015; Bıyık et al., 2021).

The deployment and integration of ITS present numerous pressing policy challenges that policymakers must address to ensure these technologies effectively contribute to modern transportation systems. As ITS technology becomes more advanced and ubiquitous, the amount of data generated and collected is increasing exponentially (Zhu et al., 2018). This includes not only real-time traffic and vehicle data but also personal information related to travel habits, locations, and potentially even biometric data. Ensuring the privacy and security of the vast amount of user data will become increasingly critical. As cyber threats evolve, so

⁵ The meaning underlying this term has evolved from focusing primarily on traffic management and infrastructure efficiency to encompassing advanced technologies like real-time data analytics, autonomous vehicles, and integrated mobility solutions for sustainable and user-centric transportation.

must cybersecurity measures that protect ITS infrastructure (Khan et al., 2023a). Moreover, with the growing integration of ITS into other smart city initiatives, the interconnectivity of systems will create more complex security challenges, requiring continuous innovation in data protection strategies. Autonomous vehicles, drone deliveries, and other emerging ITS technologies will challenge current legal standards, particularly regarding liability, safety, and ethical considerations (Wandelt and Zheng, 2024). The rapid pace of technological advancement in ITS will likely outstrip existing policies, necessitating a continuous evolution of regulations to keep up with new developments; the recent developments are large language models can serve as a prime example (Liu, 2024b). Accordingly, governments will need to create flexible and adaptive regulatory frameworks that can evolve alongside technological innovations, ensuring that regulations do not stifle innovation while still protecting public safety and welfare (Docherty et al., 2018). The challenge will be to craft policies that are forward-looking and capable of addressing the unforeseen consequences of new ITS technologies. International coordination also becomes critical as ITS development is a global endeavour, since inconsistent regulations across countries can create barriers to innovation and deployment, necessitating international collaboration to harmonize policies and standards for effective cross-border ITS operations (Zacher and Sutton, 1996). Additionally, legal and liability issues pose a significant challenge, particularly in accidents involving automated or semi-automated systems (Fard et al., 2023). Clear legal frameworks must be established to define liability and responsibilities among manufacturers, operators, and users, as well as to address data breaches and cybersecurity incidents (Wandelt et al., 2023b). Concerning our ANSWER framework, major challenges are related to adaptability, network integration, wireless connectivity, and resilience.

2.12. *Maritime/port management*

Shipping has a very long history since the ancient times when ships were propelled by wind. Correspondingly, ports were needed to transfer cargo between ships and shores. Shipping and ports have evolved along with human civilization till the modern era. Given the fact that maritime transport is a key trade facilitator, maritime and port management is much associated with enhancing the infrastructure, operations, and policies of shipping and ports to improve global trade efficiency (Shi and Li, 2017; Zhang et al., 2024b). Analysing the efficiency of shipping companies and ports has drawn a lot of interests (Cullinane et al., 2004; Panayides et al., 2011). Related to that, there exist a vast body of literature on competition, competitiveness, and performance of shipping companies (Chou and Liang, 2001; Progoulaki and Theotokas, 2010), ports, and terminals (Haralambides, 2002; Heaver et al., 2001; Yap and Lam, 2006). Concerning operations, an important aspect of maritime and port management is safety and security, such as evaluating human factors affecting shipping accidents (Hetherington et al., 2006), safety climate (Lu and Tsai, 2008), accidental oil spill (Yip et al., 2011), piracy in shipping (Fu et al., 2010), port security policy (Yeo et al., 2013), geopolitics of maritime security (Germond, 2015). Researchers have also linked shipping and ports to transport chain (Song et al., 2016; Talley and Ng, 2013; Van Der Horst and De Langen, 2008), network (Ducruet and Zaidi, 2012), logistics, and supply chain management (Carbone and Martino, 2003; Lee et al., 2003), as maritime transport is seen as a node in a transport/supply chain. Furthermore, the maritime industry is subject to high volatility. Shipping investors and operators are vulnerable to various sources of uncertainty and disruption. Research studies investigated freight rate volatility and market interactions (Kavussanos and Visvikis, 2004; Xu et al., 2011) to understand about shipping market behaviours.

Simultaneously attaining environmental and economic sustainability is a major challenge in maritime and port management. Due to the need for mitigating negative impacts caused by pollution and climate change, there are more policies to monitor and regulate the maritime sector's environmental performance in recent years. Among many initiatives regionally and internationally, the two policies that can be highlighted here are the International Maritime Organization (IMO) 2020 global sulphur cap and the Greenhouse Gas (GHG) emission reduction strategy. "IMO 2020" limits the sulphur content of marine fuels used by ships globally to 0.50% since January 2020 (Zis and Cullinane, 2020). The IMO GHG Strategy aims to reduce CO₂ emissions per transport work from international shipping by at least 40% by 2030, compared to 2008; and achieve net-zero GHG emissions by or around 2050 (Bilgili and Ölçer, 2024). Compliance leads to fundamental changes in shipping operations, higher fuel costs, retrofitting older ships, and investment in new ships (Lagouvardou et al., 2023). Ports also strive to be green and sustainable ports as required by more stringent national climate targets (Lam and Notteboom, 2014). Particularly, the quest for maritime decarbonization is driving transformations in both ports and shipping. **Maritime Autonomous Surface Ships (MASS)** is relatively a new development which presents another key challenge owing to its complexity. There are four degrees of autonomy, and each affects shipping safety, security, and seafarers differently (Fonseca et al., 2021). Besides, ship-to-ship and ship-shore communications will be changed drastically, thereby affecting ports and public authorities. Other concerns include accountability and liability in case of an accident, cybersecurity risk, and ethical issues (Kim et al., 2020). The technology of autonomous ships is in rapid advancement. It is crucial to establish a comprehensive regulatory framework of MASS to keep pace with new technology development (Ringbom, 2019). However, while seeking sustainability and MASS bring challenges, they also generate tremendous opportunities for growth and innovation in the maritime industry. Concerning our ANSWER framework, major challenges are related to network integration and resilience.

2.13. *Mobility-as-a-service*

Mobility-as-a-Service (MaaS) is an emerging concept aimed at transforming transportation markets by providing flexible, efficient, user-centric, and personalized services. It integrates existing transport options, selecting the most suitable mode for each journey based on customer preferences and real-time transport network conditions at the time of the request (Ho et al., 2020). Key features of MaaS include one-stop travel solutions and on-demand services, with mobility service products enabling these functionalities.

The ultimate goal of a MaaS platform is to seamlessly integrate various transportation modes, reduce dependence on private vehicles, alleviate traffic congestion, and decrease greenhouse gas emissions. The MaaS concept has been piloted in various forms in different countries, such as Finland (Giesecke et al., 2016), Sweden (Strömberg et al., 2018), the Netherlands (Ebrahimi et al., 2018), Italy (Ambrosino et al., 2016), Germany (Brendel and Mandrella, 2016), the UK (Kamargianni and Matyas, 2017), and the US (Frei et al., 2017).

Despite the active involvement and enthusiasm of many regions, MaaS is still in its early stages. Developing one-stop travel and on-demand transportation systems poses new challenges compared to traditional transportation models. Key challenges include the following. How can we accurately and promptly capture and characterize travel demand for one-stop travel and on-demand transportation systems? Current demand analysis methods focus on aggregate deterministic or disaggregate preference-based studies for traditional systems. However, these approaches do not adequately address the time-sensitive nature of one-stop and on-demand travel. Factors such as personalization, responsiveness, end-to-end service integration, and the use of multi-source demand data require significant improvements in current theories (Xiong et al., 2020). There is a need to analyse the unique characteristics of travel demand in MaaS systems, uncover new patterns of individual demand, and develop advanced forecasting methods. Another important challenge is how can we manage the relationship between travel services and personalized, end-to-end travel demand in one-stop travel and on-demand transportation systems? The diversity, unpredictability, and time-sensitive nature of personalized travel places higher demands on system responsiveness and complexity (Liu et al., 2020). The volume and variability of available data far exceed traditional control models, necessitating the development of systems capable of omnipresent sensing and precise monitoring to dynamically match travel demand and supply in real-time. Addressing these challenges requires advancing several technological and managerial approaches. Research focuses on one-stop travel services, integrated travel routes, travel chain simulation and optimization, and smart travel solutions. To meet the rising demand for comfort, personalization, and multidimensional travel in MaaS systems, there must be progress in the construction technologies supporting these services. On the management side, fast optimization models for multimodal, multi-objective travel optimization are needed, while on the supply side, research should focus on optimizing the spatio-temporal allocation of travel resources. From the user perspective, real-time responsiveness and personalization must be enhanced to meet the unique needs of diverse traveller groups. Concerning our ANSWER framework, major challenges are related to adaptability and network integration.

2.14. Multimodal transportation

As transportation demand becomes increasingly diversified and complex, traditional unimodal transport systems struggle to meet the needs of modern society. Multimodal transportation concerns the coordination and integration of different modes of transport to create seamless and efficient travel experiences (Tirachini and Hensher, 2012; Jiang et al., 2017a; Meng et al., 2020). Understanding traveller attitudes and preferences towards multimodal transportation is crucial for the successful implementation of such systems. While multimodality theoretically enhances transport adequacy and accessibility, research indicates that the public often perceives it as more of a burden than a benefit (Fu and van Lierop, 2024). Psychological barriers, such as trust and safety concerns, particularly regarding AVs in last-mile transport, hinder their adoption. Promoting AVs as a premium last-mile service could address these concerns effectively (Yap et al., 2016). Moreover, dissatisfaction with transfers between different modes is a significant deterrent to the adoption of multimodal systems. Effective promotion of sustainable travel behaviours requires policies tailored to the specific characteristics of different traveller groups (Molin et al., 2016). Liao et al. (2020) conducted stated preference experiments simulating various travel scenarios, revealing that optimizing transfer experiences – by reducing transfer times and improving station facilities – can significantly enhance the attractiveness of multimodal systems, encouraging greater public transport use. Recent years have seen substantial technological and methodological advancements in multimodal transportation networks. For example, van der Gun et al. (2016) introduces a comprehensive approach to simulate multimodal networks' response to emergencies. This research underscores the importance of considering the interactions between different modes during emergency planning, as a disruption in one mode (e.g., road congestion) can have cascading effects on others (e.g., public transport). Agent-based simulation models have also advanced the optimization of multimodal systems. Čertický et al. (2015) developed a fully agent-based approach to simulate the daily travel behaviour of millions of urban residents, including various modes such as cars, public transport, walking, and cycling. This model allows agents to switch between different modes based on real-time conditions and personal preferences, thus addressing the limitations of previous models and providing more dynamic and realistic decision-making processes. Additionally, the application of space–time prism (STP) models in multimodal networks has evolved. Qin and Liao (2021) offers a robust method for measuring spatio-temporal accessibility in large-scale multimodal networks. By systematically reducing the complexity of travel chains, this model enables efficient construction of STPs, making it feasible to apply STP modelling in real urban scenarios.

The integration of new transportation modes/technologies, such as drones, autonomous vehicles, and flying cars, presents a significant challenge for the future of multimodal transportation systems (Du et al., 2022b). These innovative modes of transport offer promising solutions to urban congestion, last-mile connectivity, and overall mobility. However, their integration into existing transportation networks is complex. Firstly, the operational coexistence of these new modes with traditional transportation methods (e.g., buses, trains, and private cars) requires careful planning and regulation. Airspace management for drones and flying cars, road-sharing protocols for autonomous vehicles, and the development of necessary infrastructure are critical areas that need addressing. Secondly, public acceptance and regulatory frameworks must evolve to accommodate these new modes, ensuring safety, reliability, and minimal disruption to existing systems. The challenge lies in creating a cohesive, multimodal transportation ecosystem where these new modes complement rather than compete with traditional transportation options. The complexity of travel choice behaviour is a significant challenge in understanding and predicting user behaviour within multimodal transportation systems (Fu and Zimm,

2024). With the increasing diversity of transportation modes, individuals' travel choices are influenced by a myriad of factors, including time cost, monetary cost, comfort, safety, and environmental impact. Traditional travel behaviour models often assume rational decision-making by users; however, travel choices are frequently shaped by factors such as emotions, habits, and social norms. Additionally, the substitutability and complementarity between different modes add further complexity to behavioural prediction. For instance, travellers may dynamically switch between modes based on real-time traffic conditions, making accurate modelling of travel behaviour more challenging. Future research must delve deeper into the drivers of travel choice behaviour and leverage big data and machine learning techniques to develop more precise predictive models, thereby supporting the optimization and management of multimodal transportation systems. Concerning our ANSWER framework, major challenges are related to network integration and resilience.

2.15. Parking management

Parking management refers to the policies and measures which are utilized to bring about an improvement in the efficient utilization of parking provision (Shoup, 2005). The aim of parking management differs according to who is responsible for the parking provision (Json and Mulley, 2014). Public authorities manage parking to disincentivise car use and encourage alternative modes, address congestion and its related emissions, and raise revenue (Marsden, 2006). Commercial organizations on the other hand, whether in the public or private sector, may use parking management to free up constrained locations and obtain revenue, which then may or may not be hypothesized for specific transport related projects. Parking policies can be considered as second-best options when compared to road user charging not least since they impact on the point of destination rather than directly at the point of use of the road. In saying this, they tend to be easier to implement and have higher levels of public acceptance, and as such have been widely used, most notably in urban areas, as a traffic demand management measure. Parking management addresses both public on-street or off-street parking, be that via pricing or direct control, and impacts private non-residential parking (PNRP) via measures including a workplace parking levy (WPL), such as that introduced in the city of Nottingham, UK (see Dale et al., 2017a,b; Flack et al., 2022). There is growing interest in this measure as a means of addressing the provision of parking at the workplace. As a form of dynamic pricing, San Francisco implemented SFpark, a programme by which on street parking prices adjust on a two to three monthly basis in response to changing occupancy rates which are monitored via sensors (Pierce and Shoup, 2018). This technological solution is designed to increase parking space availability in order to meet demand whilst reducing the time spent searching for parking (see Brooke et al., 2018 for detail of the issues relating to parking search). Both the WPL and SFpark seek to optimize the use and availability of parking spaces in urban areas. Transport economics on parking supply and parking pricing has been increasingly explored in the literature (Inci, 2015; Zakharenko, 2016; Eliasson and Börjesson, 2022).

Parking management is a complex and problem rich area. Two specific challenges relate to the advent of AVs and ageing car parking infrastructure. The development and adoption of AVs as part of the transport network will impact on parking management, in terms of efficiency, capacity, utilization and urban planning. Overall, as the use of AVs becomes more widespread, the impact on demand for on and off-street parking, multi-story car parking provision, residential or PNRP will need to be considered. Since AVs will gradually be able to drop off their occupants and either move to remote parking, cruise until required, or return to the owner's residence (assuming private car ownership is still the preferred model) then the supply of car parking provision in urban areas could be freed for alternative uses yet increased cruising could worsen congestion and result in safety and air quality implications (Levin et al., 2020). As well as new technologies, a second key challenge in parking management relates to the age of historical parking infrastructure. Contemporary parking management thus may involve substantial investment in retrofitting and reinforcing ageing infrastructure. This is especially true of multi-story car parks built in the 1960s/70s which may be nearing the end of their intended service life and which are now too small to accommodate the increase average size and weight of private cars. Since the situation for the foreseeable future will comprise conventional vehicles alongside AVs then the retrofitting of car parks will involve equipping them with sensors and charging stations in order to support AVs. In addition, an ageing population and increase in the number of motorists with disabilities presents another important research challenge with respect to parking management. Concerning our ANSWER framework, major challenges are related to adaptability and sustainability.

2.16. Regional transportation

Regional transportation plays a central role in linking urban centres with surrounding areas and multiple urban centres with each other (Handy, 2008; Li et al., 2016; Russo and Rindone, 2021). By providing efficient and integrated connections between cities, suburbs, and rural areas, regional transportation systems help to balance urban growth, reduce congestion, and support sustainable development (Handy, 2008; Guerra, 2016). Effective regional transportation policies are crucial for facilitating the movement of people and goods, improving labour market access, and reducing environmental impact by encouraging public transit and reducing car dependency (Blum, 1982). Policymakers focus on creating cohesive regional transportation networks that consider diverse community needs, environmental goals, and economic priorities, often involving complex coordination across government levels and sectors (Berman et al., 2005; Du et al., 2022a). In recent years, a strong shift towards sustainability, digitalization, and integrated mobility can be observed. Many regions are prioritizing green transport initiatives, such as expanding electric and hydrogen-powered public transit fleets, which require supportive policies on infrastructure development and emissions standards (Li, 2016; Shah et al., 2021). Additionally, digital technologies are transforming regional transportation systems with demand-responsive transit options, necessitating updated policies on data privacy, cybersecurity, and digital inclusivity (Uchimura et al., 2002; Itani

et al., 2024). Finally, the integration of various transport modes, from rail and buses to bike-sharing and micro-mobility, aimed at creating seamless, multimodal transport networks is important.

One major challenge for regional transportation is the development of effectively metropolis systems supported by better coordinated transportation, which comes with various policy-related challenges. For instance, achieving coherent policy frameworks across municipal, regional, and national levels, often faces differing priorities and budgets which can lead to fragmented planning and investment (Kigochi, 2024). Policymakers must also address issues of funding allocation and long-term financial sustainability, often complicated by competing infrastructure projects or shifts in political agendas (Schank and Rudnick-Thorpe, 2011; Garrett, 2016). Additionally, regulatory challenges arise from the need to harmonize standards and regulations across different transportation modes, which may involve public-private partnerships with varying objectives and compliance requirements (Zhou, 2016; Veekman et al., 2017). Ultimately, solving these challenges requires a shared vision, flexible yet unified policy frameworks, and continuous collaboration across sectors and jurisdictions. Another challenge in this context is the transition towards autonomous regional air mobility. Compared to urban air mobility, which is in the news for a while now, the increased operational range and complexity involved in regional operations are significant. Major sub-challenges include navigating varied airspace regulations across larger geographical areas, in controlled and uncontrolled airspaces, as well as managing the integration of autonomous vehicles with traditional aircraft and air traffic control systems in less congested regions (Wandelt et al., 2023b; Sun et al., 2021a; Jin et al., 2024). This integration needs to take place while ensuring safety over longer distances (Wandelt et al., 2024b). Additionally, regional air mobility must tackle issues related to passenger demand and acceptance, economic viability, and environmental concerns, particularly in integrating sustainable practices for longer flights compared to shorter urban routes (Babetto et al., 2023). Concerning our ANSWER framework, major challenges are related to network integration, wireless connectivity, and resilience.

2.17. Road safety

Road safety remains a critical global issue (Loo et al., 2005; Nikolaou and Dimitriou, 2018; Ziakopoulos and Yannis, 2020), with approximately 1.19 million people dying annually as a result of road traffic crashes, imposing significant public health, social and economic burdens on societies (Ameratunga et al., 2006; Nankunda and Evdorides, 2023), particularly in low- and middle-income countries (Dhibi, 2019), where the risk of traffic-related deaths is three times higher despite having less than 1% of the world's motor vehicles (WHO, 2023). Since the seminal work of Haddon (1972), a rich academic literature has emerged based on a modern systematic framework for crash prevention with multidisciplinary dimensions of engineering, psychology, technology and policy. Research has moved from a reactive to a proactive approach, shaping the direction of public policy, urban planning and transport systems (Elvik et al., 2009). A significant proportion of studies have focused on the role of infrastructure design in significantly reducing the likelihood of crashes (Soltani and Roohani Qadikolaei, 2024), through well-designed road environments (Daniels et al., 2010), incorporating road elements that can directly influence driver behaviour (Bobermin et al., 2021), or prioritizing urban road design for non-motorized vulnerable road users such as cyclists (Caicedo et al., 2023) and pedestrians (Asadi-Shekari et al., 2015). Understanding driver behaviour remains an important issue for improving road safety. Factors such as distracted driving (Oviedo-Trespalacios et al., 2016, 2019), speeding (Aarts and van Schagen, 2006), driving under the influence of alcohol and drugs (Qin et al., 2019), fatigue (Jiang et al., 2017b), and violation of traffic rules (Hsiao et al., 2018) are common contributors to driver misjudgments that affect decision making and reaction times. Strategies based on public awareness campaigns, or stricter legislation and traffic law enforcement (Castillo-Manzano et al., 2015) play a crucial role in compliance and prevention of these traffic violations (Wegman, 2017), which are also promoted by automated systems (Wang et al., 2020) and technological advances in vehicle safety (Furlan et al., 2020). More recent studies have broadened the scope to include systemic and integrated approaches, emphasizing transport systems as complex and interconnected networks (Duggal et al., 2021), particularly in European countries, applying transport policy frameworks such as the revolutionary Swedish Vision Zero or the Dutch Sustainable Safety Initiative (Hyder et al., 2022).

Despite significant achievements over the last decade, traditional methods yield increasingly limited results (Ehsani et al., 2023), and two key challenges for future road safety research and policy development stand out. First, the integration of emerging technologies such as artificial intelligence (AI) (Torbaghan et al., 2022), autonomous vehicles (AVs) (Martínez-Buevas et al., 2022b; Hosseinian and Mirzahosseini, 2024), and smart infrastructure (Castro-Nuño and Arévalo-Quijada, 2018), which presents both opportunities and challenges for road safety management (Bathla et al., 2022), including the development of new standards for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, and the adaptation of road design and traffic management systems (Dey et al., 2016). While these technologies have the potential to significantly reduce accidents by improving vehicle control, enhancing traffic management and providing real-time data for predictive analytics, they may also introduce new risks and uncertainties (Verma et al., 2024). For example, the safety implications of AVs are not yet fully understood and require further research into regulatory frameworks and testing (Zhang et al., 2024a); in particular, interactions between them and human drivers and non-motorized road users (Pyrialakou et al., 2020) and ethical concerns (Sonko et al., 2024). Second, promoting equity in road safety interventions and policies is another pressing challenge (Hyder et al., 2022), particularly given the disproportionate burden of road crashes on different population groups and vulnerable users such as pedestrians, cyclists, motorcyclists, the elderly and women (Abebe et al., 2024) and those in low-income communities (Ameratunga et al., 2006). This disparity is exacerbated by factors such as poor infrastructure, limited access to safety education and enforcement, and socio-economic inequalities that may influence behaviour and risk exposure (Roll and McNeil, 2022). Equity-focused research should examine how road safety interventions, including urban planning, access to public transport and enforcement strategies, can be adapted to protect vulnerable populations (Karner et al., 2023). As technological and infrastructural innovations advance, interdisciplinary research is needed to address social, economic and ethical dimensions (Guo et al., 2020). Concerning our ANSWER framework, major challenges are related to wireless connectivity and resilience.

2.18. Sustainability

While sustainability is an important subject for all transportation modes, we here focus on air transport sustainability, with an added discussion on the sustainability implications of electrification and automation of vehicles; see [Shah et al. \(2021\)](#), [Alp et al. \(2022\)](#), [Shen et al. \(2023\)](#), other sections of this paper, as well as our Conclusions section for a more general discussion on sustainability. Commercial air transport has grown rapidly, from a supply of 0.2 trillion available seat kilometres (ASK) in 1960 to 10.5 trillion ASK in 2019, and an even more rapid growth in cargo, from 3 to 235 billion revenue ton kilometres ([Gössling and Humpe, 2024](#)). Air transport is generally credited with contributing to economic growth through supply chain, spillover, and feedback effects ([Zhang and Graham, 2020](#)), though economic assessments usually do not consider the scale of subsidies forwarded to the sector ([Huwe et al., 2024](#)). Air travel has transformed society through opportunities for work, education and tourism, redefining perceptions of time and space, and patterns of dwelling and citizenship ([Urry, 2012](#)). Yet, even though the global number of passengers has grown from 0.1 billion in 1960 to 4.5 billion in 2019, air transport remains an elite activity, with only 2%–4% of the world population flying between any two countries in 2018, and much transport demand falling on a small share of frequent fliers ([Gössling and Humpe, 2020, 2024](#)). Air cargo does include high-value and time-sensitive goods, but the relatively low cost of transport has also supported long-haul exports of foodstuffs (from grapes to seafood) and low-cost mass-produced consumer goods (such as fast fashion) ([Karanki et al., 2024](#)). Such low-cost ‘induced’ air transport has relevance, because aviation is associated with a range of sustainability challenges. Chief among these are contributions to climate change ([Lee et al., 2021](#)), local air pollution ([Hudda et al., 2020](#)) and noise ([Wolfe et al., 2017](#)). The necessity to develop new propulsion technology ([Su-Ungkavatin et al., 2023](#)) and growing demand for sustainable aviation fuels represent major sustainability challenges of their own ([Bergero et al., 2022](#); [Gössling and Humpe, 2024](#)). Aviation infrastructure is vulnerable to extreme weather, sea-level rise, heat waves, or wildfires ([Burbidge, 2018](#)); events that will become more frequent under scenarios of climate change. As countries worldwide seek to expand or build new airports while airlines compete on low profitability volume-growth business models, sustainability challenges will become more pronounced over time. Efficient policies are hampered by various forms of state involvement that preclude interventions: as outlined by [Huwe et al. \(2024\)](#), the state is owner, sponsor, and customer of manufacturers, airlines, and airports.

The greatest sustainability challenge for air transport is to reduce its contributions to climate change. Aviation has specific relevance for global warming, as emissions of water and NO_x cause additional warming at flight altitude ([Lee et al., 2021](#); [Teoh et al., 2024](#)). The sector is responsible for approximately 2%–3% of global carbon dioxide (CO₂) emissions, and 4% of global warming ([Klöwer et al., 2021](#)); a share that will rise as air transport growth outpaces efficiency gains ([Gössling and Humpe, 2024](#)). While various technology solutions are under development ([Su-Ungkavatin et al., 2023](#)), it remains unclear whether these will work, or if they can be upscaled in time. One of the primary challenges is cost, as SAF are significantly more expensive than traditional jet fuel. As airlines operate with marginal profitability ([Gössling and Humpe, 2024](#)) they have to reject any legislation increasing operational costs as undermining their business model. Without policies forcing the sector to adopt new technologies, aviation is on course to become a growing contributor to climate change and other sustainability challenges, complicating international efforts to meet the goals of the Paris Agreement. To overcome technical and economic hurdles will require coordinated global efforts, implemented at state level as global agreements are unlikely ([Lyle, 2018](#)). This will also require more ambitious global regulatory frameworks that need to go beyond the European Union’s ReFuelEU policy, if the sector is to align itself with the Paris Agreement ([European Commission, 2024](#)). Given these complexities, the current outlook is that without demand reductions and new business models, it will not be possible to bring air transport on track to net-zero while increasing its economic resilience. This situation represents a formidable policy conundrum ([Huwe et al., 2024](#)). Sustainability challenges of electrification and automation of vehicles are mostly related to a growing number of vehicles in circulation that require large inputs in energy and materials, also for the construction and maintenance of road systems ([Wiedenhofer et al., 2024](#)). Electrification of vehicles is otherwise recognized for its potential to reduce greenhouse gas emissions and air pollution, particularly by eliminating tailpipe emissions in battery-electric vehicles. This benefit is most significant when electricity is sourced from renewable or low-carbon grids ([Tuffour and Ewing, 2024](#)). Vehicle automation introduces additional transport system changes. Autonomous vehicles can optimize driving behaviour, reducing fuel consumption and emissions per trip. Increased convenience and accessibility may however result in higher transport demand, thus diminishing net environmental gains ([Harper et al., 2016](#)). Increased adoption of electric, automated vehicles also impacts the energy system. Electrification shifts energy demand from petroleum to electricity, potentially straining efforts to supply low-carbon electricity. Smart charging strategies and vehicle-to-grid technologies can mitigate this ([Bogdanov and Breyer, 2024](#)). Electrification and automation also intersect with urban sustainability through their effects on land use and transportation systems. Autonomous cars have the potential to reduce the need for parking infrastructure, as vehicles can drop passengers off and park remotely or remain in circulation. This could free urban space for housing, green areas, or public uses ([Milakis et al., 2017](#)). Shared autonomous electric vehicles could reduce vehicle ownership and traffic congestion. If these vehicles are privately owned and replace rather than complement public transportation, they could however also increase congestion. Policy and planning frameworks are thus needed to address potentially negative outcomes of autonomous and electric transport systems ([Creutzig et al., 2018](#)). In cities, the imperative will remain to create affordable and efficient transport systems, and to reduce vehicle numbers. Sustainability is one cornerstone of our ANSWER framework.

2.19. Travel behaviour modelling

Travel behaviour modelling examines individuals’ trip-making behaviour in terms of multiple dimensions such as trip rate, transport mode, and trip length ([Zhang et al., 2004](#); [Bamberg et al., 2011](#); [Chorus and Kroesen, 2014](#); [Ortúzar and Willumsen,](#)

2024). These dimensions are interrelated and influenced by a variety of factors. To accurately capture these complex interrelations, travel behaviour modelling began utilizing structural equation modelling (SEM) approaches around the early 1980s and has widely adopted these methods over the past two decades. SEM facilitates the examination of multiple dependent variables and the analysis of both direct and indirect effects. A notable study in this field is by Bagley and Mokhtarian (2002), which uses a structural equation system to manage nine endogenous variables, including travel behaviour, the built environment, and attitudinal variables, estimating both direct and indirect effects. Golob (2003) provides a comprehensive review of SEM applications in travel behaviour research during the early years. Mokhtarian and Cao (2008) reviewed various modelling approaches that can address this attitudinal effect, comparing their advantages and disadvantages. Based on their analysis, they recommended that longitudinal structural equations modelling with control groups is a strong approach to address the causalities or the true effects of the built environment in travel behaviour. It is more relevant and realistic to assume that policy measures may influence travel behaviour within a certain range, with such influence potentially shifting from positive to negative or vice versa. In other words, the effect of policy measures is likely to be non-linear. For this reason, the linearity assumption commonly adopted in transportation studies has been challenged (Ding et al., 2018; Yang et al., 2021). In recent years, there has been a significant increase in studies examining these non-linear effects in transport research. Moreover, traditional practices in travel behaviour modelling, particularly the use of statistical models, have faced scrutiny. Parady et al. (2021), after reviewing relevant transportation studies published between 2014 and 2018, argued that model validation practices in discrete choice models overly depend on models' goodness-of-fit and internal validation, often neglecting external validation. They recommend that validation should be a non-negotiable part of developing transport models. Furthermore, Parady and Axhausen (2023) challenge the emphasis on statistical significance in transportation studies, asserting that accurately assessing effect magnitudes is crucial for effective transportation policy design. They contend that the primary goal of transportation research is to better inform policy. Therefore, they recommend that transport research should shift its focus from statistical significance to the assessment of effect magnitudes.

The future advancement of travel behaviour modelling may encounter numerous challenges, with uncertainty from factors such as climate change and technological innovations being the most prominent one. Climate change, characterized by more frequent extreme weather – particularly extreme temperatures – could alter human mobility patterns, affecting trip rates and the usage of different transport modes due to their varying resilience to such conditions. Consequently, travel demand forecasts based on historical data may become less relevant. Moreover, there is an nearly complete uncertainty associated with long-term forecasts (e.g., regarding population, income, car ownership, etc.), so the future may not be the one considered in any scenario. The only way out is to have a “continuous planning system” (Ortúzar and Willumsen, 2024), where a plan and the models used to evaluate it are part of monitoring function, that allows to re-evaluate and change the plan with every new item of data that becomes available. The second challenge is to leverage AI for transport analysis and prediction. Traditionally, transport modelling has relied heavily on quantitative data analysis, with transport-related textual data being underutilized. LLMs present an opportunity for transport modellers to incorporate such textual data—like news articles, transport reports, social media posts, etc.—into their analyses of travel preferences, emerging issues and trends of travel behaviour, transport patterns, etc. Additionally, LLMs hold the potential for real-time predictions of traffic and travel demand, which can be invaluable for implementing adaptive transport management measures. Concerning our ANSWER framework, major challenges are related to adaptability, sustainability, and equity.

2.20. Urban transit

Public transit is a key focus in urban infrastructure development. It should serve as the backbone of a city's transport systems. And various modal choices exist in the urban setting, such as urban rail (or subway, metro), bus, mini-bus, tram. The main goal of the public transit is to design efficient supply, e.g., timetables/networks, that creates maximal accessibility for a given budget, and efficient pricing, e.g. optimal subsidy levels (Hörcher and Tirachini, 2021). Various transport policies and programs have been created to increase the attractiveness of public transit as a travel mode choice, especially in car dependent contexts, such as expanding service areas (Santos et al., 2010), increasing the number of bus routes (Buehler and Pucher, 2011), expanding rail networks (Boisjoly et al., 2018), improving frequency/punctuality (Şimşekoğlu et al., 2015), improving onboard comfort (Sukhov et al., 2022), providing real-time information systems (Chen et al., 2017), and keeping transit fares low or providing transit subsidies (Hörcher and Tirachini, 2021). Whether the ridership of public transit systems increased or decreased depends on different factors, especially the utility of urban transit compared to that of other alternative modes. Beyond the engineering perspective, there are influential factors from planning and policy perspectives. One of these factors is the coordination of transportation and land use. If the land surrounding the rail stations or bus stops become densified, then the usage and ridership is likely to increase. This is often the case in high-density cities, where the accessibility of public transport is highly valued and capitalized in land and property price (He, 2020; Higgins et al., 2025). In contrast, some cases from low-density contexts showed that newly opened public transit stations failed to attract ridership (Guerra and Cervero, 2011). The usage and ridership of public transit also depends on urban policies, such as the setting of bus dedicated lanes or bus priority lanes (Agrawal et al., 2013). In addition, there are exogenous factors such as gasoline price (Litman, 2004), weather (Tao et al., 2018), and man-made disruptions (He et al., 2024). In the near future, disruptive technologies such as autonomous vehicles (AVs) and eVTOLs are likely to transform urban and regional transport networks, which will also affect the demand for urban transit.

Urban transit has been facing various challenges, two of which are highlighted in this section. Innovative development and financing models are highly desirable to financially sustain the development and maintenance of public transport systems and upkeep the service quality. Public transport around the world often requires government subsidy (Ercan et al., 2017). From the urban economic perspective, it can be justified as public transit is considered a natural monopoly (O'Sullivan, 1996). Such economic

nature of this urban system has resulted in different development and financing models for public transport systems. One noteworthy development model is the Rail Plus Property (R+P) model adopted by the Hong Kong Mass Transit Railway (MTR), making the public listed company one of the most financially successful urban transit systems in the world (He et al., 2018). The dual role of transit operators as urban developers has also been successfully adopted in Japan, where private rail companies such as JR and Keio have significantly shaped urban development by both operating rail lines and owning and developing the land around stations (Saito, 1997; Shoji, 2001). Some other financing models have also been adopted, such as public–private partnership (Li and Love, 2020) and special loan programs with government financial institutions (Sunio et al., 2019). Continual monitoring and improving people's perception or attitudes towards public transit is critical for policy design. It has been revealed that such attitudes will affect people's car ownership choice and mode choice (He and Thøgersen, 2017), which consequently can affect the degree of motorization and congestion in a city. Conventionally, questionnaires are a common tool to collect transit users' satisfaction with transit service quality (Allen et al., 2018). In the era of smart cities, the availability of crowd-sourced data such as social media data and AI have enabled us to automate the monitoring of people's perception and attitudes (Luo et al., 2023). Another noteworthy point is that public transport usually has a social mission — to serve the mobility demand of the marginalized groups. That said, we need to pay close attention to the needs of the marginalized groups. For example, women are often the victim of sexual harassment on buses and metros/subways, especially in developing countries in South Asia and Sub-Saharan Africa (Natarajan, 2016; Vanderschuren et al., 2023). A gendered perspective should be engaged in the monitoring of transit users' experience and in the improvement of safety and overall transit service quality (Luo and He, 2021). Amid rapid technological advances, it is important to closely examine the potential impact of emerging mobilities on urban transit. Monitoring residents' adoption intentions and the actual uptake of these new travel options is essential for making timely adjustments to existing transport networks. The adaptability of urban transit infrastructure is crucial to building a resilient transport system, particularly in transit-oriented cities. Concerning our ANSWER framework, major challenges are related to adaptability and network integration.

3. Towards answering questions regarding transport policy research

In the previous section, we have reviewed the state of the art and challenges in transport policy research, through the eyes of 20 experts in the field. The major challenges are summarized in Fig. 2. Across different categories, a few core issues consistently arise: the demand for adaptability, network integration, sustainability, wireless connectivity, equity, and resilience in policy frameworks.

Adaptability is essential in response to rapid technological advances across all modes of transportation. The development of autonomous vehicles, intelligent transportation systems, and multimodal solutions (e.g., drones and flying cars) requires flexible regulatory frameworks that keep pace with innovation. Policymaking needs to incorporate real-time data, artificial intelligence, and predictive analytics to effectively manage evolving transportation needs, from traffic management with adaptive signal control to travel behaviour modelling with AI and large language models. **Network Integration** of various modes remains a pressing challenge. For example, multimodal transportation aims to integrate new modes like drones and autonomous vehicles with traditional transit systems, while regional transportation coordination requires unified planning to avoid fragmentation in metropolitan areas. Network integration is crucial for creating efficient, cohesive systems that support end-to-end travel demand and reduce redundancies across transport modes. **Sustainability** remains a universal concern, driving efforts to minimize environmental impact while balancing economic viability. Cleaner fuel standards, electric vehicles, and greener freight logistics are at the forefront of this effort, along with sustainable practices in maritime and high-speed rail operations. However, achieving this balance presents challenges, such as the higher costs associated with sustainable energy sources and the financial demands of maintaining infrastructure. Policy innovation is also essential to overcome technical and economic hurdles, fostering business models that support long-term sustainability. **Wireless Connectivity** will be increasingly important since transportation systems incorporate more advanced technologies, particularly for autonomous vehicles, and vehicle-to-infrastructure (V2I) communications. While being highly technical and might be considered very narrow, the turn towards ubiquitously connected transportation systems will require strong support by policymakers. Reliable wireless networks enable real-time data exchange, adaptive traffic management, and enhanced safety measures across various components of the integrated system. Addressing challenges in privacy, security, and data sharing for wireless-connected devices will be instrumental for the successful implementation of modern transportation solutions. **Equity** in transportation is another significant challenge, with a focus on reducing disparities in access and safety for underserved populations, including the elderly, low-income communities, and vulnerable users. For example, autonomous vehicle (AV) technology should benefit all, not just specific demographic groups, while cycling infrastructure and road safety policies need to be inclusive to support equitable use. Additionally, ensuring equal access to transport options during pandemics highlights the need for policies that prioritize accessibility during crises. **Resilience** is emerging as a priority for transportation systems, especially in the context of climate change and pandemics. Policies are needed to withstand disruptions and rapidly adapt to emergencies, as demonstrated by COVID-19's impact on travel restrictions and public health considerations. This emphasis on resilience extends from air transportation to high-speed rail and urban transit, which require sustainable financing models to maintain long-term operations despite external shocks.

Just as The Hitchhiker's Guide to the Galaxy reveals "42" as the ultimate answer to life, the universe, and everything, transport policy today seeks its own comprehensive ANSWER to navigate the complexities of modern mobility. The six key trends in transport policy – Adaptability, Network Integration, Sustainability, Wireless Connectivity, Equity, and Resilience – combine to form the word ANSWER, each piece crucial to understanding and addressing the field's multifaceted challenges. By properly capturing and responding to these interconnected trends, policymakers can develop strategies that ensure transportation systems are prepared for the future.

Category	Challenge
Air Transportation	Design an aviation system and corresponding policies resilient to future disruptions, climate-change and pandemics Open Skies agreements still fall well short of establishing completely free trade in air transport services
Autonomous Vehicles	Assess the impact of fuel tax, cap-and-trade, CORSIA, sustainable aviation fuels and other new technologies Development of cohesive regulatory frameworks that address liability and safety concerns with clear responsibilities
Congestion / Traffic Management	Ensuring equitable access to AV technology and its benefits for underserved populations, instead of further exacerbation Adaptive signal control using real-time data in combination with microscopic and macroscopic congestion modeling
COVID-19	Designing implementable and cost-efficient congestion pricing systems , balancing system costs and traffic benefits Informed and timely response coordination during outbreaks with swiftly revised travel restrictions and quarantines
Cycling / Activities	Ensuring equity and accessibility during pandemics, particularly of low-income communities, elderly, and disabled Overcome the existing strong habit and latent attachment perceptions to the usage of private cars by their users
Demand and Choice Behaviour	Address lack of well-designed and extensive infrastructure for bicycles , particularly in North and South America Address potential fears by users associated with using bicycles for regular trips, regarding accidents and maintenance
Electric Vehicles	Overcome high cost of obtaining data and the low quality / high biases for specification / estimation of choice models Solve difficulties associated with estimating more advanced models to answer complex transport policy questions
Equity in Transportation	Address the risk of battery fires or accidents , fueled by high-profile coverage of incidents in the media Perform a more fast coordinated, strategic and robust investment in well-integrated fast charging networks
Freight / Logistics	Overcome differential impacts of more extreme environmental conditions on vulnerable transport users Focus more on people-oriented and place-based policies to support vulnerable populations more effectively
High-Speed Rail	Support the implementation of cleaner fuel standards, promote electric vehicles, and encourage modal shifts Bring forward the innovation of technological advancements while ensuring that standards are being satisfied
Intelligent Transportation Systems	Address logistical, regulatory, and safety concerns when incorporating of autonomous vehicles raises HSR development in the context of environmental concerns to reduce carbon emissions and mitigate climate change
Maritime / Port Management	Maintaining and updating HSR infrastructure, requiring capital investments and long-term financial commitment Ensuring the privacy and security of user data, while making policy making keep up with technological innovation
Mobility as a Service	Create flexible and adaptive regulatory frameworks evolving well alongside technological innovations Simultaneously attaining environmental and economic sustainability mitigating impacts by pollution / climate change
Multimodal Transportation	Towards Maritime Autonomous Surface Ships (MASS) with four degrees of autonomy, with safety and security Capture / characterize travel demand under time-sensitive nature of one-stop travel and on-demand transportation
Parking Management	Manage the relationship between travel services and personalized, end-to-end travel demand under responsiveness Integration of new transportation modes / technologies , such as drones, autonomous vehicles, and flying cars
Regional Transportation	Better predicting user behavior within multimodal transportation systems under emotions, habits, and social norms Understand the impact on demand for on and off-street parking , multi-story car parking provision
Road Safety	Perform substantial investment in retrofitting / reinforcing ageing infrastructure , especially multi-story car parks Towards transportation coordination inside modern metropolis systems without fragmented planning and investment
Sustainability	Supporting / implementing a transition towards autonomous regional air mobility with increased operational ranges Developing new standards for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication
Travel Behavior Modeling	Ensuring equity in road safety interventions and policies regarding pedestrians, cyclists, the elderly and women Address the problem of higher costs for sustainable energy sources without undermining business models
Urban Transit	Overcome technical / economic hurdles through coordinated efforts through more ambitious regulatory frameworks Incorporate uncertainty modeling induced by factors such as climate change and technological innovations
	Leverage artificial intelligence for transport analysis and real-time prediction , specifically large novel methods Innovative development and financing models are highly desirable for maintenance and to upkeep the service quality
	Continual monitoring / improving people's perception or attitudes towards public transit through crowd-sourced data

Fig. 2. Summary of major challenges for transport policy research.

4. Conclusions

Our study reviewed the current state and challenges in transport policy research, highlighting six key trends: Adaptability, Network Integration, Sustainability, Wireless Connectivity, Equity, and Resilience (ANSWER). Adaptability is driven by rapid technological advancements such as autonomous vehicles and intelligent transportation systems. These innovations necessitate flexible regulatory frameworks capable of integrating real-time data, artificial intelligence, and predictive analytics. Such adaptability is essential for effective traffic management and modelling travel behaviour, ensuring that transportation systems can evolve alongside technological progress. Network integration is the second significant challenge, emphasizing the need for cohesive systems that seamlessly incorporate diverse transportation modes. This includes the integration of emerging technologies like drones and autonomous vehicles with traditional transit systems. Unified planning is crucial to prevent fragmentation and ensure efficient, end-to-end travel solutions, ultimately reducing redundancies and enhancing overall system efficiency. As metropolitan areas grow, the importance of a well-integrated transportation network becomes even more pronounced. Sustainability remains a universal concern, driving efforts to minimize environmental impact while balancing economic viability. Initiatives such as cleaner fuel standards, the adoption of electric vehicles, and greener freight logistics are at the forefront of this movement. However, the transition to sustainable practices presents challenges, including higher costs associated with sustainable energy sources and the financial demands of maintaining infrastructure. Policy innovation is essential to overcome these technical and economic hurdles, fostering business models that support long-term sustainability. Wireless connectivity is becoming increasingly vital as transportation systems incorporate more advanced technologies. Reliable wireless networks are essential for real-time data exchange, adaptive

traffic management, and enhanced safety measures. This technological shift requires strong support from policymakers to address privacy, security, and data-sharing challenges, ensuring the successful implementation of modern transportation solutions. Equity in transportation is a significant challenge, focusing on reducing disparities in access and safety for underserved populations, including the elderly, low-income communities, and vulnerable users. It is crucial that advancements in transportation technology, such as autonomous vehicles and improved cycling infrastructure, benefit all demographic groups. Ensuring equal access to transport options, particularly during crises like pandemics, highlights the need for inclusive policies that prioritize accessibility. Resilience is emerging as a priority for transportation systems, especially in the context of climate change and global pandemics. Policies are needed to ensure that transportation networks can withstand disruptions and rapidly adapt to emergencies. This emphasis on resilience extends across various modes of transportation, from air travel to high-speed rail and urban transit, requiring sustainable financing models to maintain long-term operations despite external shocks. Together, these research areas underscore the need for innovative, inclusive, and sustainable approaches to shape the future of transportation, ensuring that systems are adaptable, integrated, and equitable.

CRedit authorship contribution statement

Sebastian Wandelt: Writing – review & editing, Writing – original draft, Conceptualization. **Anming Zhang:** Writing – review & editing, Writing – original draft, Conceptualization. **Constantinos Antoniou:** Writing – review & editing, Writing – original draft. **Lucy Budd:** Writing – review & editing, Writing – original draft. **Mercedes Castro-Nuno:** Writing – review & editing, Writing – original draft. **Yida Ding:** Writing – review & editing, Writing – original draft. **Jonas Eliasson:** Writing – review & editing, Writing – original draft. **Stefan Goessling:** Writing – review & editing, Writing – original draft. **Sylvia Y. He:** Writing – review & editing, Writing – original draft. **Stephen Ison:** Writing – review & editing, Writing – original draft. **Changmin Jiang:** Writing – review & editing, Writing – original draft. **Jasmine Siu Lee Lam:** Writing – review & editing, Writing – original draft. **Kevin Li:** Writing – review & editing, Writing – original draft. **Zhiyuan Liu:** Writing – review & editing, Writing – original draft. **Becky P.Y. Loo:** Writing – review & editing, Writing – original draft. **Xiaolei Ma:** Writing – review & editing, Writing – original draft. **Juan de Dios Ortúzar:** Writing – review & editing, Writing – original draft. **Oscar Oviedo-Trespalacios:** Writing – review & editing, Writing – original draft, Conceptualization. **Donggen Wang:** Writing – review & editing, Writing – original draft. **Xiaoqian Sun:** Writing – review & editing, Writing – original draft, Conceptualization.

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Data availability

No data was used for the research described in the article.

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