Mobility Futures

Four scenarios for the Dutch mobility system in 2050

Atasoy, B.; Caesar, Holger; Ellerbroek, Joost; Hiemstra-van Mastrigt, S.; Maknoon, M.Y.; van Oort, N.; Psyllidis, A.; van der Spek, S.C.; Snelder, M.; Triggianese, M.

Publication date
2025

Mobility Futures

Four scenarios for the Dutch mobility system in 2050

TU Delft

Foreword

At TU Delft, we develop technology that has a high impact on society. It's simply our mission: to create impact for a better society. And while it is a privilege to be able to do so, that privilege comes with a responsibility. Because success does not take place in isolation. Only by connecting with society can we develop technology that makes sense.

A sustainable society then, is our point on the horizon, but the how we get there is still uncertain. Mobility is just one of a number of complex and interconnected challenges along that road. And while mobility is undergoing a transition, it touches on other societal transitions: the energy transition, the digital transition, the transition to a circular economy – movements that are sometimes mutually reinforcing, sometimes getting in each others' way.

One thing is certain: mobility must become sustainable. It must be emission free, but still affordable and accessible to all. So how do we make transport more sustainable, how do we fit mobility into the available public space, how do we ensure that mobility remains accessible to everyone? Trying to answer these questions, we must take into account that materials and public space are limited resources, and so of course is funding.

All in all, shaping the future of our mobility system will be no easy task. It is what we call a wicked problem: it consists of many challenges with complex interdependencies. An effort to solve one aspect of a wicked problem may reveal or create other problems. Besides, the system is in continuous flux, meaning that requirements will change, and new challenges will arise with each decision we make.

Nobody can accurately predict the long-term future. But thinking about possible futures helps making more informed decisions. This is where our team of Mobilisers come into their own. They created a canvas for exploring the future by sketching out four possible scenarios. These can help us explore transformative possibilities and can promote strategic discussions about the future of mobility in the Netherlands.

These scenarios are not a final result, but a starting point – and an invitation – for practitioners and academics to exchange ideas, explore future challenges, stress-test strategies, and identify "no-regret" policy interventions.

Here, we proudly present the results of our Mobilisers: a multidisciplinary team of TU Delft researchers: twelve mobility researchers and six experts in strategy, innovation, communication and support. Together, they developed four scenarios for the Dutch Mobility System in 2050, looking at the Netherlands' position as part of Europe and its role as an international hub.

I consider it a major achievement, but at the same time it is just a stopover on our journey towards sustainable mobility. Will you join us?

Prof. ir. Tim van der Hagen Rector Magnificus, TU Delft

Executive Summary

Mobility is vital for societal wellbeing, economic growth, social inclusion, and access to essential amenities. However, the current system faces significant challenges, including environmental impact, unequal access, and safety concerns.

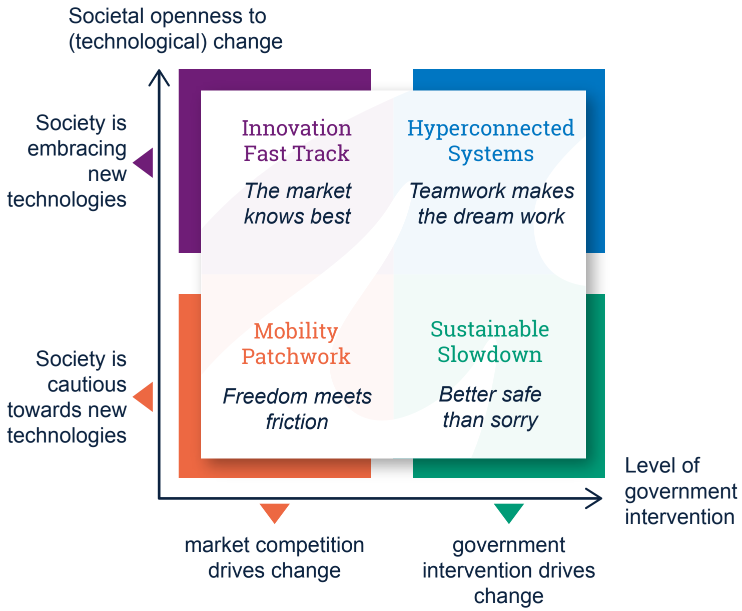
To address these pressing issues and navigate future uncertainties, TU Delft's multidisciplinary team of mobility researchers, The Mobilisers, has created four scenarios for the Dutch mobility system in 2050. Far from predictions, they are tools to inspire stakeholders in government, business, and academia to think long-term and make informed decisions today.

You are welcome to join TU Delft's "Future Mobility Workshops," where the scenarios are used as tools for discussion and collaboration. These workshops bring together practitioners and academics to exchange ideas, explore future challenges, stress-test strategies, and identify "no-regret" policy interventions—visit www.tudelft.nl/mobility-futures for more information.

The scenarios serve as a canvas to explore varying levels of government intervention and technology adoption, offering insights into future complexities and opportunities. When government intervention in the economy is low, society relies on market-driven solutions to societal problems, emphasising free-trade agreements, private enterprise, protection of intellectual property rights, and entrepreneurship. When government intervention is high, we see government-orchestrated solutions aiming to achieve broad prosperity goals.

When society is cautious towards new technologies, there is a focus on ethical considerations and societal implications, preferring proven technologies over emerging ones to safeguard societal values and reduce uncertainty. Conversely, when society embraces new technologies, there is enthusiasm for technological progress and encouragement of engineering education and careers to advance society. To be clear, a society that is cautious towards new technologies is not equal to one that rejects technology completely; it is simply much slower in adoption, and due to limited demand, innovation will move slower.

Combining different levels of government intervention and societal attitudes towards emerging technologies creates a canvas for sketching out four future scenarios:



The tables below summarise the characteristics of each scenario and can be a useful reference while reading the report.

Scenario Highlights	**Innovation Fast Track** *The market knows best*	**Hyperconnected Systems** *Teamwork makes the dream work*	**Sustainable Slowdown** *Better safe than sorry*	**Mobility Patchwork** *Freedom meets friction*
Dimensions	Society embraces new technologies, and market competition drives change.	Society embraces new technologies, and government intervention drives change.	Society is cautious towards new technologies, and government intervention drives change.	Society is cautious towards new technologies, and market competition drives change.
Context	The Netherlands is a hub of rapid technological advancement, fuelled by market competition and a strong entrepreneurial spirit. Society eagerly embraces new technologies, prioritising the benefits, convenience, and prosperity they bring. Technological innovation is widely regarded as essential for economic growth.	The Netherlands thrives under a synergy of technological enthusiasm and proactive government intervention. Society eagerly embraces new technologies, with the government playing a pivotal role in steering these advancements toward the public good, emphasising responsible entrepreneurship, sustainability, and societal wellbeing.	The Netherlands prioritises broad prosperity with a cautious approach to technology, focusing on sustainability, equity, and community engagement. Society adopts proven technologies deliberately, ensuring they align with societal and environmental goals while minimising potential risks.	The Netherlands experiences a fragmented service landscape shaped by minimal government intervention and cautious attitudes toward technology. Innovation proceeds slowly, and societal needs are often overlooked in favour of profit-driven priorities, creating disparities between regions and communities.
Innovation Strategy	Strengthen economic growth and Dutch competitiveness by advancing mobility innovations and rapidly adopting advanced technologies.	Create equitable and efficient mobility services for society through government-led integration of advanced technologies.	Build a sustainable mobility system by prioritising environmental and societal wellbeing over rapid technological adoption.	Facilitate efficient and affordable mobility services for society through market-driven competition.
Mobility Sector	Strong business ecosystems and high innovation rates, startups are thriving due to minimal regulation—potentially concentrated economic benefits in profitable areas.	Public-private partnerships foster coordinated innovation, creating stable opportunities for businesses to flourish within a government-supported framework.	Business potential centers on meeting societal and environmental goals. Innovation is slower but targeted, focusing on green technologies and long-term sustainable solutions.	Local businesses and innovation develop organically, but the lack of coordination creates uneven opportunities. Fragmentation limits scalability and broader economic impact.

Scenario Highlights	**Innovation Fast Track** *The market knows best*	**Hyperconnected Systems** *Teamwork makes the dream work*	**Sustainable Slowdown** *Better safe than sorry*	**Mobility Patchwork** *Freedom meets friction*
Values & Beliefs	Market competition is the most effective way to drive innovation and deliver solutions efficiently. Minimal regulation accelerates technology diffusion and leads to societal and economic benefits.	Government intervention is necessary to ensure technological advancements serve the public good. A technology-enabled, data-driven system can enhance societal welfare and wellbeing.	Strong government oversight is essential to ensure balance and avoid unchecked market forces. Emerging technologies should be cautiously adopted, with thorough consideration of their societal and environmental impacts.	Market-driven approaches prioritise flexible, localised solutions, adapting to diverse needs and contexts. Letting end-users choose technologies and data to share is key to addressing risks and fairness.
Challenges	Limited oversight risks neglecting public values like security, privacy, equity, and sustainability as market players prioritise profit.	Administrative complexity and slow decision-making risk hindering innovation and reducing flexibility.	Slow technological progress and over-regulation risk stagnation, reducing competitiveness and scalability.	Limited coordination and oversight risk creating fragmented systems, leaving rural and low-demand areas with reduced access and growing equity gaps.
Keywords	# Rapid technological innovation # Minimal government intervention # Economic growth # Entrepreneurship # Competition # Cost-efficiency and convenience # Personal Freedom # Social disparities # Unintended side effects	# Technology for the collective good # Government-orchestrated innovation # Sustainability # Collaboration # Data Sharing # Broad prosperity # Long-term strategies # High public investments # Bureaucracy	# Proven technologies # Government-led initiatives # Community engagement # Equality # Governance and control # Behaviour change # Limitations # Slow innovation # Less is more	# Fragmented services # Market-driven choices # Minimal government intervention # Freedom of choice # Vehicle ownership # Lack of trust in authorities # Infrastructure decline # Mobility inequality

Broad Prosperity Goals	**Innovation Fast Track** *The market knows best*	**Hyperconnected Systems** *Teamwork makes the dream work*	**Sustainable Slowdown** *Better safe than sorry*	**Mobility Patchwork** *Freedom meets friction*
Sustainability & Living Environment				
Sustainability	Broad mix of sustainable mobility options, (often) with undesired side-effects. Carbon-capture solutions and carbon trading help mobility providers reduce the mobility system's carbon footprint to achieve carbon-neutral mobility.	Highly sustainable mobility system with high public investments in infrastructure, technology, and renewable energy generation. Government-led, data-driven orchestration is key to optimising the mobility of people and goods.	Mostly sustainable mobility options with limited freedom of choice in the type of mobility, when, and how much to travel. Behaviour change and non-mobility alternatives are key to becoming more sustainable.	A mix of mobility options with different levels of sustainability. End users enjoy freedom of choice without personal consequences; the government is tasked with offsetting mobility-related carbon emissions.
Accessibility				
Accessibility Principle	Utilitarianism: Solutions maximise accessibility for the largest number of people, aligning with overall societal wellbeing.	Sufficiency: Governments ensure a baseline of mobility for all, using localised services and a polycentric, proximity-driven city planning approach	Egalitarianism: Focuses on reducing accessibility disparities through integrated, subsidised transport.	Pragmatism: Decisions vary by context, optimising for different priorities case by case.
Affordability	Affordability of modes varies, depending on automation, demand, and economies of scale.	Affordable mobility for end users, however, with high public costs.	Affordability of modes varies, depending on societal and environmental impact.	Affordability of modes varies, depending on demand. Main traffic corridors are well-served with affordable solutions.
Inclusivity & Equity	High inequality, resulting from profit-driven mobility providers offering highly personalised non-integrated mobility.	Low inequality resulting from public investments to make mobility accessible for everyone, physically and digitally.	Moderate inequality resulting from bottom-up community-focused initiatives and travel restrictions.	High inequality despite targeted interventions for disadvantaged groups.
Resilience	Fast recovery through market-driven innovation, primarily in profitable areas, but with uneven resilience and slower recovery in underserved regions.	Proactive and coordinated resilience driven by centralised systems, but vulnerable to cascading failures due to high interdependence.	Localised robustness to small-scale shocks but limited capacity to adapt to large-scale disruptions at the national level.	A fragmented and fragile system with slow recovery, deep regional inequalities, and heavy reliance on personal preparedness.

Broad Prosperity Goals	**Innovation Fast Track** *The market knows best*	**Hyperconnected Systems** *Teamwork makes the dream work*	**Sustainable Slowdown** *Better safe than sorry*	**Mobility Patchwork** *Freedom meets friction*
Safety and Security				
Physical Safety	Variety of safe mobility options with limited regulatory frameworks.	Safe mobility system with intelligent traffic management and strong restrictions.	Safety of mobility is achieved through roadway design and limited mobility options.	Diverse mobility options with limited regulation create an unsafe mobility mix.
Cybersecurity	High variety in security levels amongst mobility providers; high speed of innovation leads to new vulnerabilities.	Secure mobility system with strong government oversight and compliance checks; however, high connectivity level increases exposure to attacks.	Vulnerable legacy systems, however, low automation levels limit the impact of security breaches.	High variety in security levels amongst mobility providers; legacy systems are especially vulnerable.
Health				
Healthy Lifestyle	Sufficient active mobility options are available, with many consumers preferring light electric vehicles.	Active modes are promoted and further stimulated by limiting access for specific types of vehicles to certain areas.	Active modes are the default mode for local mobility, strongly driven by government-enforced restrictions.	Limited active mobility due to a preference for privately owned vehicles and limited public transport in low-demand regions.

Mobility of People	**Innovation Fast Track** *The market knows best*	**Hyperconnected Systems** *Teamwork makes the dream work*	**Sustainable Slowdown** *Better safe than sorry*	**Mobility Patchwork** *Freedom meets friction*
Local Mobility	Automated and light electric vehicles dominate urban areas, with various shared services catering to high-demand zones. However, poor interoperability among providers leads to inefficiency and clutter in public spaces.	Integrated, multimodal mobility hubs form the backbone of the mobility network. Active modes like walking and cycling are prioritised, with seamless connections to other modes. Automated shared vehicles complement public transport.	Local mobility is centred on proximity and community. Walking and cycling are strongly promoted, supported by extensive car-free zones and green urban spaces, improving the liveability of neighbourhoods. Essential services are (also) digitally accessible.	Competition among private operators leads to fragmented, inconsistent services. Dense areas are well served with multiple travel options, while less dense areas face accessibility challenges, relying on car ownership.
Regional/ National Mobility	Frequent and fast mobility services focus on profitable routes, connecting major urban and suburban centres but leaving rural areas underserved. Shared mobility solutions are concentrated around hubs in densely populated areas.	A well-coordinated, green-electric public transport network spans the country, supported by automated shuttles for less dense areas. Integrated hubs ensure smooth connections and convenience for travellers.	Public transport services are reliable but limited in scope due to budget constraints. Priority is given to traditional buses and trains, often manually operated. For many people, public transport is subordinate to car use.	Private operators focus on profitability, resulting in selected high-quality lines but also in uneven service levels and limited coverage. Mobility options are scattered, and transfers are unregulated.
International Mobility	Multiple international rail operators offer services on high-demand routes. Aviation is still growing, and the first hyperloop routes are operational. Flights up to 1,000km are electric; longer flights use (a mix of) carbon-based fuels.	Rail and hyperloop compete with short-haul flights. Public investments in sustainable aviation drive the adoption of electric and hydrogen planes for short and regional flights. Regulation reduces intercontinental carbon-based aviation.	Rail services are limited; international mobility remains dependent on fossil-fuelled aviation. Heavy taxes reduce demand, and new intercontinental hubs emerge at the edge of the EU.	International rail struggles to compete due to fragmented systems and high costs. Aviation focuses on low-cost options without significant reduction in environmental impact.

Transport of Goods	**Innovation Fast Track** *The market knows best*	**Hyperconnected Systems** *Teamwork makes the dream work*	**Sustainable Slowdown** *Better safe than sorry*	**Mobility Patchwork** *Freedom meets friction*
Last-Mile Logistics	Automated delivery robots and drones are widely used, but competition among service providers results in inefficiency and crowded streets. High-tech solutions dominate urban areas, but accessibility varies across regions.	Harmonised multimodal logistics systems use electric cargo bikes, vans, and automated vehicles. Regulations ensure efficient coordination and reduce environmental impact, even in high-density zones.	Electrified logistics vehicles and manual labour dominate the last mile; pick-up points are omnipresent. Government regulations incentivise shared infrastructure, but automation remains limited, raising costs.	Last-mile logistics rely on traditional vehicles; there is little innovation. Private companies operate independently, resulting in congested urban areas and inconsistent service levels.
Regional/ National Logistics	Logistics hubs are market-driven, prioritising efficiency for high-demand corridors. Automated technologies improve profitability but fail to address sustainability comprehensively.	Government-developed automated logistics hubs ensure seamless coordination between road, rail, and water-based transport. Investments in green energy drive the decarbonisation of logistics chains.	Logistics systems are coordinated by government policies, focusing on electrification. Subsidies are essential for maintaining coverage in less profitable areas.	Market forces shape decentralised logistics. Private operators prioritise profitable regions, leaving underserved areas with outdated and inefficient logistics solutions.
International Logistics	International logistics rely on advanced automated solutions along highly profitable corridors. Weak governance hampers the widespread adoption of sustainable practices.	A highly regulated system integrates green shipping, rail, and aviation. Cross-modal coordination ensures efficiency and environmental responsibility.	Fossil fuel dependency persists in international shipping and aviation. Rail focuses on dependable, low-risk operations supported by government incentives.	Traditional shipping and aviation methods dominate, with fossil fuels still playing a central role due to low investment in green technologies.

This report presents the results of a strategic foresight process conducted throughout 2024, offering a snapshot of findings as of January 2025. Over time, additional mobility researchers will contribute their visions, which will be available on the project's website www.tudelft.nl/mobility-futures

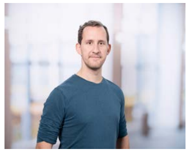
Table of Contents

Mobilisers

A multidisciplinary team of TU Delft mobility researchers called the Mobilisers embarked on a journey to explore the future of mobility embedded in various socio-technological contexts. They developed four scenarios for the Dutch Mobility System in 2050, considering the Netherlands' position as part of Europe and its role as an international hub. The Mobilisers comprise of twelve mobility researchers and six experts in strategy, innovation, communication and support.

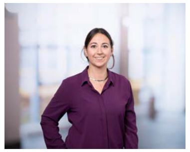
Mobility Researchers

Bilge Atasoy
Associate Professor Transport & Logistics
Expert perspective: Multimodal City Logistics
Faculty of Mechanical Engineering
Email address: B.Atasoy@tudelft.nl



Holger Caesar
Assistant Professor Intelligent Vehicles
Expert perspective: Automated vehicles
Faculty of Mechanical Engineering
Email address: H.Caesar@tudelft.nl

Joost Ellerbroek
Assistant Professor Air Traffic Management
Expert perspective: Small electrical aviation
Faculty of Aerospace Engineering
Email address: J.Ellerbroek@tudelft.nl



Suzanne Hiemstra-van Mastrigt
Director of the Seamless Personal Mobility Lab & Assistant Professor
Expert perspective: User-centred mobility services
Faculty of Industrial Design Engineering
Email address: S.Hiemstra-vanMastrigt@tudelft.nl

Yousef Maknoon
Assistant Professor Transport and Logistics
Expert perspective: Intercity logistics
Faculty of Technology, Policy and Management
Email address: M.Y.Maknoon@tudelft.nl

Niels van Oort
Associate Professor Public Transport and Shared Mobility & Co-director of the Smart Public Transport Lab
Expert perspective: Public transport
Faculty of Civil Engineering and Geosciences
Email address: N.vanOort@tudelft.nl

Achilleas Psyllidis
Assistant Professor of Urban Mobility & Director of the Urban Analytics Lab
Expert perspective: Active transport and micro-mobility
Faculty of Industrial Design Engineering
Email address: a.psyllidis@tudelft.nl

Stefan van der Spek
Associate Professor of Urban Design & Director of the VR – BK lab
Expert perspective: Public space
Faculty of Architecture and the Built Environment
Email address: S.C.vanderSpek@tudelft.nl

Maaike Snelder
Associate Professor & Co-director Sustainable Urban Multimodal Mobility Lab
Expert perspective: Automated vehicles
Faculty of Civil Engineering and Geosciences
Email address: M.Snelder@tudelft.nl

Manuela Triggianese
Assistant Professor of Architecture/ Complex Projects
Expert perspective: Transit Hubs & Mobility Experience
Faculty of Architecture and the Built Environment
Email address: m.triggianese-1@tudelft.nl

Wijnand Veeneman
Professor Governance of Infrastructure & Mobility
Expert perspective: Governance and integration
Faculty of Technology Policy and Management
Email address: W.W.Veeneman@tudelft.nl

Roelof Vos
Associate Professor
Expert perspective: Aviation
Faculty of Aerospace Engineering
Email address: R.Vos@tudelft.nl

Strategy, Innovation, Communication, Support

Serge Hoogendoorn
Professor Traffic Operations and Management & Director of the TU Delft | Transport & Mobility Institute
Expert perspective: Data, AI & Smart Mobility
Faculty of Civil Engineering and Geosciences
Email address: s.p.hoogendoorn@tudelft.nl

Sascha Hoogendoorn-Lanser
Director Mobility Innovation Centre Delft
Expert perspective: Data & AI
Impact & Innovation Centre
Email address: S.Hoogendoorn-Lanser@tudelft.nl

Deborah Nas
Professor of Strategic Design for Technology-Based Innovation & Team Lead of the Mobilisers
Expert perspective: Mobility Innovation Ecosystem
Faculty of Industrial Design Engineering
Email address: d.n.nas@tudelft.nl

Nicole van Nes
Professor of Human-Centered Design for Smart Mobility & Director Delft Design Lab on Automated Mobility
Expert perspective: Automated vehicles
Faculty of Industrial Design Engineering
Email address: C.N.vanNes@tudelft.nl

Karlijn Spoor
Strategic communication and press
Corporate Communication department
Email address: k.spoor@tudelft.nl

Maaike Swarte
Executive Secretary of TU Delft | Transport and Mobility Institute
Faculty of Civil Engineering and Geosciences
Email address: m.p.swarte@tudelft.nl

Introduction

Moving Society Forward

Mobility plays a key role in society, enabling economic growth by facilitating trade and supply chain operations and providing access to jobs, education, healthcare, and more while fostering social inclusion, cultural exchange, and community connections. By connecting people, goods, and places, mobility is a vital force for societal progress.

The way we implemented mobility, however, also introduced serious downsides. Excluding international air and sea travel, the mobility sector accounts for 21% of all carbon/greenhouse gas emissions in the Netherlands (CBS, 2024). Besides, traffic accidents resulted in 684 deaths in 2023 (CBS, 2024), and the space required for mobility causes significant organisational and liveability challenges (KiM, 2019). Mobility options remain unevenly distributed, with 113,000 to 270,000 households at risk of transport poverty in the transition to sustainable mobility (Knoope et al., 2024).

Did you know? Out of the total 30.6 megatonnes of CO_2 emissions produced by the mobility sector in the Netherlands—excluding international air and maritime traffic—in 2023, petrol cars were the largest contributors, accounting for 12.0 megatonnes. Diesel cars contributed 2.4 megatonnes, goods transport added 10.4 megatonnes, and mobile machinery accounted for 3.3 megatonnes (CBS, 2024).

While accessibility remains a core objective of the mobility system, the focus for designing the Dutch mobility system has evolved significantly over the past decades. This reflects a growing recognition that mobility is not just about moving people and goods efficiently but about creating sustainable, affordable, inclusive, equitable, safe, and resilient systems that promote liveable cities and healthy lifestyles. Achieving this is a complex challenge, as the mobility system is deeply intertwined with major societal issues such as climate change, urbanisation, demographic shifts, inequality, and geopolitical tensions.

- → We want our mobility system to be *sustainable*, but we are limited by an overloaded energy network, limited availability of sustainable energy sources, dependence on other countries for critical materials and scarcity of skilled labour.
- → We want our mobility system to be *affordable*, but transitioning to a sustainable mobility system is expensive, and a growing labour shortage drives wages up.
- → We want our mobility system to be *inclusive and equitable*, but we see a growing reliance on digital solutions while not everyone in society has the right digital skills, and we have an ageing population with special needs.
- → We want our mobility system to be *safe*, but forecasts predict that our roads and cities will become busier.
- → We want our mobility system to be *resilient*, as climate change is introducing more extreme weather events, COVID-19 revealed the vulnerability of our supply chains, and geopolitical tensions force us to consider the resilience of our infrastructure and the need for strategic autonomy in times of conflict.
- → We want to reduce the impact of mobility on the *liveability of cities*, but urban areas are rapidly densifying.
- → We want our mobility system to promote a *healthy lifestyle*, but as more people become overweight, they are less likely to choose active modes of travel.

Solving the diverse challenges of the mobility system presents a wicked problem: it consists of many challenges with increasingly complex interdependencies. Efforts to solve one aspect of a wicked problem may reveal or create other issues. Moreover, the mobility system is in continuous flux, meaning that requirements keep on changing, and new challenges arise with each decision we make. Since decisions to change elements of the mobility system play out over long periods—sometimes decades—we must adopt a long-term perspective when developing mobility solutions and interventions.

Did you know? The percentage of people in the Netherlands with overweight will increase to 64% in 2050, up from 50% in 2022. The percentage will increase for every age group, but the 18–44 age group will see the most significant increase (Rijksinstituut voor Volksgezondheid en Milieu, 2024). Research shows that people who are overweight make fewer trips and engage less in active modes (de Haas, 2022).

Did you know that 56% of all bicycles sold in the Netherlands in 2023 were e-bikes? (RAI Vereniging & BOVAG, 2024). KIM estimates a growth of 20% more km travelled by bicycle in 2028 compared to 2019, mostly resulting from increased use of electric bicycles (in 2028 +132% compared to 2019). The use of regular bicycles, though, declines (in 2028 -15% compared to 2019) (Kennisinstituut voor Mobiliteitsbeleid, 2023).

Did you know? Adding infrastructure to a traffic network does not always improve its performance. In fact, *removing* infrastructure—like closing roads—can sometimes enhance operations. This counterintuitive phenomenon, known as the Braess paradox (Braess et al., 2005), has been observed in real-world cases, such as road closures in Seoul, New York, and Stuttgart, where traffic flow and congestion improved. In the DIT4TraM project (www.dit4tram.eu), this principle was applied in Barcelona's SuperBlocks. By closing just 0.4% of the roadway network, traffic congestion decreased by 14%, and pollution dropped by 8%. The Braess paradox underscores the importance of thoughtful network design in achieving sustainable and efficient mobility systems.

Exploring the Future of Mobility

A multidisciplinary team of TU Delft mobility researchers, called the Mobilisers, embarked on a journey to explore the future of mobility and how it is embedded in various socio-technological contexts. They developed four scenarios for the Dutch Mobility System in 2050, considering the Netherlands' position as part of Europe and its role as an international hub. The year 2050 is intended as a signpost for the long term rather than focusing on the exact year. These scenarios are not predictions nor desired futures; they serve as thinking frameworks to help stretch the imagination. They are created to inspire stakeholders in government, business, and academia to think about mobility with a long-term perspective and help them make better-informed decisions today. More importantly, the scenarios serve as a tool to facilitate collaborative future explorations, bringing together various areas of expertise and bridging the gap between academia and practice.

Each scenario includes a general description, followed by a projection of how the mobility system impacts broad prosperity goals (see Appendix I for a definition) and the trade-offs central to this scenario. To shed light on what the different elements of the mobility system might look like, the Mobilisers present their perspectives on the scenarios for their respective areas of expertise. These perspectives are mode-related, like public transport, active modes, or automated vehicles, or take a more overarching perspective, like multimodal logistics, the transit stations (hubs), the public domain, the mobility experience, governance, or the innovation ecosystem. Perspectives serve as illustrative examples of how the future might unfold.

The future is highly uncertain, shaped by unforeseen 'black swan' events, looming 'grey rhinos', and breakthrough technological innovations. Some of these events and their potential impacts on the mobility system are explored in Appendix II. This exploration will be expanded over time and incorporated into the Future Mobility Workshops to support further investigations.

Like mobility, the scenarios are not an end but a means to an end. The aim is to inspire you and stretch your thinking. They can be used as a discussion tool in settings where practitioners and academics exchange knowledge and ideas while exploring the future, stress test strategies and (ideas for) policies, and identify 'no regret' interventions. You are welcome to join the "Future Mobility Workshops" to think beyond your area of expertise, exchange knowledge with TU Delft mobility researchers, and, by broadening your horizons, make better-informed decisions for the mobility system of the future. For inquiries, please contact Deborah Nas: d.n.nas@tudelft.nl.

Exploring the Future Through Four Scenarios

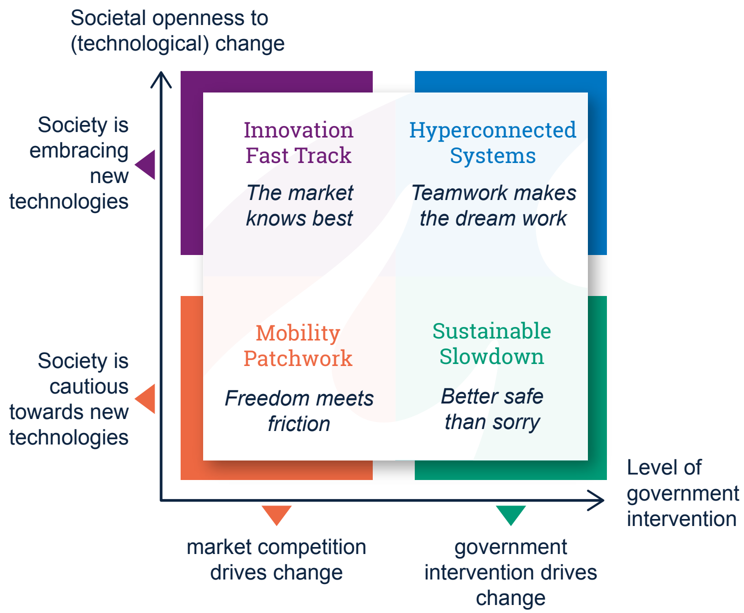
The Dutch mobility system of 2050 will have evolved within a complex socio-technological landscape influenced by local, national, and international forces. This chapter explores four distinct scenarios for the mobility system in 2050, not as exact predictions but as signposts to guide long-term strategic thinking. These scenarios were developed through a rigorous process called strategic foresight, analysing signals of change across political, economic, social, technological, environmental, and legal domains. Signals of change were evaluated to determine their likelihood and transformative potential, forming the basis of a canvas to explore diverse futures. These futures are characterised by two dimensions: the level of government intervention and societal openness to new technologies. For details on the methodology and process, including justification of choices made, see Appendix III.

When government intervention in the economy is low, society relies on *market-driven solutions to societal problems*, emphasising free-trade agreements, private enterprise, protection of intellectual property rights, and entrepreneurship. When government intervention is high, we see *government-orchestrated solutions* emphasising sustainability, broad societal welfare and wellbeing, and responsible entrepreneurship.

When society is cautious towards new technologies, there is a focus on *ethical considerations and societal implications*, preferring proven technologies over emerging ones to safeguard societal values and reduce uncertainty. Conversely, when society embraces new technologies, there is *enthusiasm for technological progress and encouragement of engineering education and careers* to advance society.

A society that is cautious towards new technologies is not equal to a society that rejects technology completely; it is simply much slower in adoption, and due to limiting demand, innovation also moves slower.

Combining different levels of government intervention and societal attitudes towards emerging technologies creates a framework for envisioning four future scenarios:



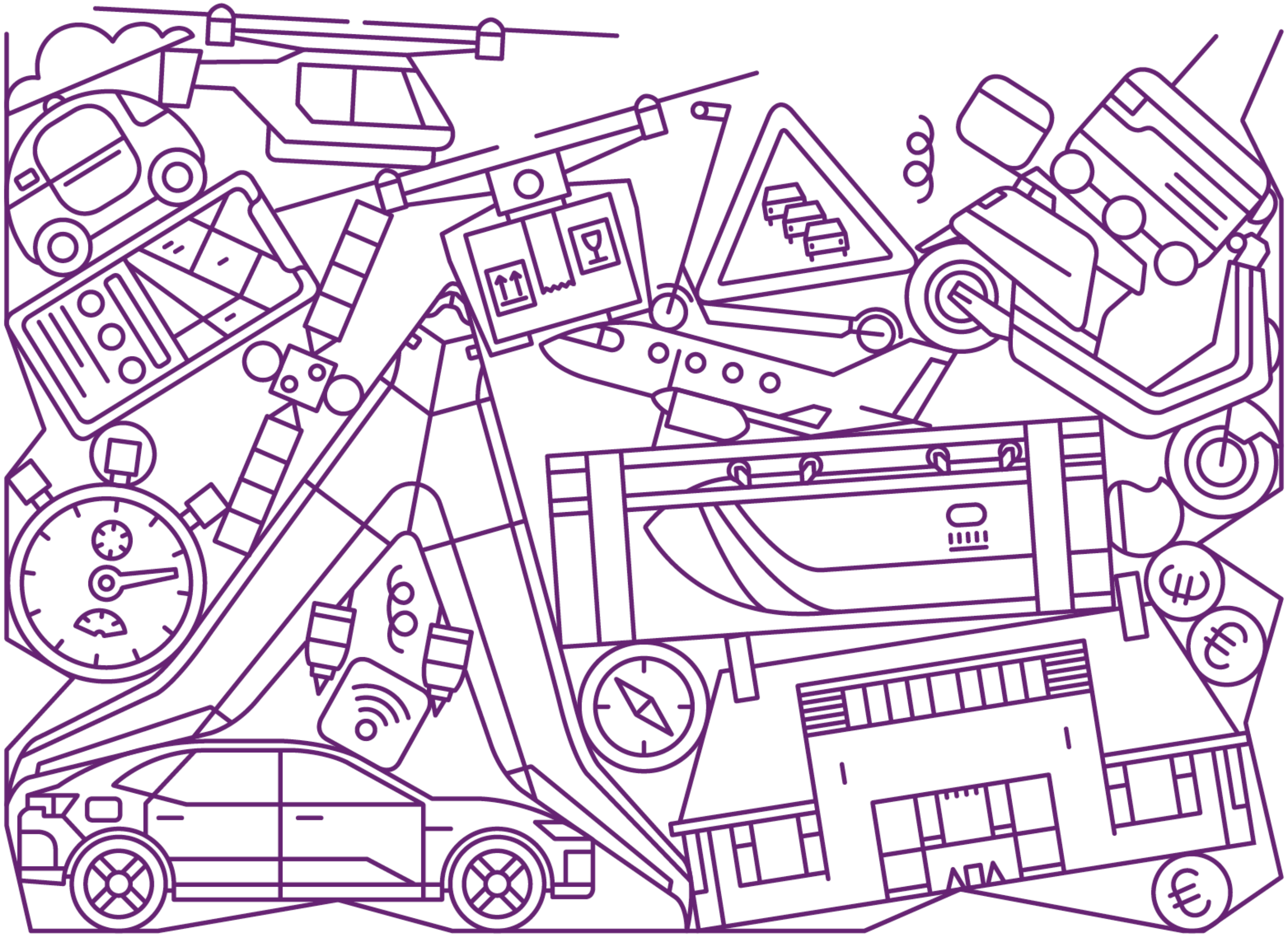
While these four scenarios are distinct, they are not mutually exclusive. Elements of one scenario may overlap with another, as no system operates in extremes. For instance, market-driven systems still include some regulation, and government-led approaches often involve market dynamics. Besides, sustainability is an important theme in each scenario as the trajectory of the Netherlands is closely tied to its European context. Achieving EU carbon neutrality targets by 2050 underpins all scenarios, though the pathways and degrees of success differ.

This chapter describes each scenario, offering insights into:

- **Their general characteristics:** a broad description of the mobility system, highlighting its defining features. The descriptions in this chapter are intentionally kept general. Specific solutions are detailed in the Mobilisers' perspectives on the scenarios for their respective areas of expertise (Chapter 3).
- **The (mis)alignment with broad prosperity goals:** how the mobility system impacts the Dutch Ministry of Infrastructure and Water Management's broad prosperity goals (see Appendix I for a definition of these goals).
- **The main trade-offs:** key choices and compromises necessary to navigate limited resources and competing priorities.

Innovation Fast Track

The market knows best



Keywords: Rapid technological innovation – Minimal government intervention – Entrepreneurship – Competition – Cost-efficiency and convenience – Economic growth – Personal freedom – Social disparities – Unintended side effects

In 2050, the Netherlands thrives as a hub of rapid technological advancement, driven by market competition and a strong entrepreneurial spirit. A significant portion of society eagerly embraces new technologies, prioritising the benefits, convenience, and prosperity they bring. Technological innovation is seen as essential for economic growth, and social disparities resulting from this rapid progress are commonplace.

The government adopts a hands-off approach, allowing free market dynamics to drive innovation with minimal intervention. This laissez-faire environment fosters a culture where startups and large tech companies flourish. Competition accelerates progress, and market-driven mobility solutions prevail. However, a more commercial approach also influences public transport, making it unevenly distributed as companies focus on profitable main transit corridors and routes.

Pervasive connectivity, enabled by advanced digital infrastructures, and the convenience of automated vehicles reshape living and working patterns. Remote working and seamless long-distance commutes drive suburban expansion, while local centres emerge around transit hubs. Affluent citizens increasingly opt for larger homes located farther from city centres.

City centres evolve into vibrant, mixed-use spaces prioritising pedestrians, cyclists, light electric vehicles, and shared transport. However, the liveability of cities is negatively impacted by the volume of mobility and the lack of interoperability between (shared) mobility providers.

Living Environment and Sustainability

Urban Space Constraints

The fast-paced adoption of new technologies transforms urban landscapes, with cities filled with diverse (shared) mobility options, including automated vehicles and automated public transport, with the exception of specific zones. While this competitive market spurs innovation, reduces consumer prices, and offers freedom of choice, it also results in fragmented fleets and inefficient use of public spaces.

Cost and Efficiency Over Sustainability

Despite advancements in vehicle technology improving efficiency, the focus on convenience and economic growth increases energy consumption and resource use. While many consumers express a desire for sustainable options, their choices are predominantly driven by financial and convenience considerations. Similarly, most companies adopt sustainable practices only when economically advantageous and choose to offset through carbon capture or carbon trading to meet their carbon targets if financially more attractive.

Did you know? Starting in 2035, all new cars and vans registered in the EU must be zero-emission. However, existing combustion engine vehicles can still be used, and discussions are ongoing to allow new ones to be registered after 2035 if they run exclusively on CO_2-neutral fuels, such as e-fuels. E-fuels, also known as CO_2-neutral fuels, are synthetic fuels produced using renewable energy sources, water, and CO_2. They release approximately the same amount of CO_2 during combustion as was captured during their production. They can be used in existing internal combustion engines without modifications, making them a "drop-in" replacement for conventional fuels. However, it is important to note that producing e-fuels requires significant additional energy compared to the direct use of electricity due to the energy-intensive steps involved in fuel synthesis, making it an expensive solution.

Limited Coordination

With limited government oversight, there is little regulation to enforce data sharing among operators or to manage public spaces effectively. Efforts to create privately-owned-car-free urban zones and enhance liveability are undermined by the circulation of empty automated vehicles, avoiding parking fees. Lack of coordination and a preference for market solutions over public planning hinder significant progress.

Accessibility

Utilitarian approach

The government prioritises solutions that improve accessibility for large groups of people, maximising overall wellbeing and aligning with utilitarianism principles.

Regional Disparities

Automated metros, light rail and/or buses connect main residential locations with city centres and other main attractions. Most suburban and rural areas face limited, underfunded public transport services, forcing residents to rely on less efficient options, personal vehicles, or commercial automated services. The competitive market prioritises profitability, exacerbating mobility inequalities based on location and income. While digital connectivity offers some alternatives, access to essential services and jobs remains uneven.

Convenience for the Affluent

Advanced technologies provide unparalleled convenience for affluent users. Highly automated vehicles offer significant comfort, allowing travel time to be repurposed for work or leisure. As travel time becomes less of a burden, traffic congestion worsens. However, increased levels of digital accessibility mitigate part of it, facilitating teleworking and e-commerce. Drone taxi services, a status symbol for the wealthy, enable rapid regional travel. Shared mobility services are concentrated in profitable, high-demand areas.

Infrastructure limitations

The separation in mobility and spatial planning intensifies accessibility challenges as basic facilities are unevenly distributed. Climate change disruptions strain the system and funding for innovation shifts from mitigation to adaptation, reflecting the growing need to address the impacts of climate change.

Did you know? Global estimates suggest that adapting the transportation system to cope with the impacts of a 2°C warmer world could cost between \$70 billion and \$100 billion annually by 2050 (World Bank, 2015). These investments are crucial to safeguarding infrastructure against rising sea levels, extreme weather events, and other climate-related challenges. Even though mobility significantly contributes to carbon emissions and the resulting need for climate-resilient infrastructure, climate adaptation costs are considered external costs and are therefore excluded from business cases for sustainable mobility systems.

Safety and Security

Technological Safety Advancements

Advancements in vehicle technology, such as Advanced Driver-Assistance Systems, enhance traffic safety on highways. However, safety improvements remain limited as intense competition forces the car industry to design cars with a minimal sensor setup to reduce costs. Safer, higher-level automated vehicles remain a luxury product.

Fragmentation Challenges

The lack of standardisation and regulation results in a fragmented mobility system with inconsistent technologies. The proliferation of apps for shared mobility services creates usability barriers, especially for less digitally savvy users. Additionally, competition for road space with vulnerable road users exacerbates safety risks, particularly with the growing presence of compact electric vehicles.

Cybersecurity Threats

The expansion of connected mobility services and high speed of innovation, combined with a wide variety in security levels amongst mobility providers and a lack of standardisation, brings significant cybersecurity risks. With minimal oversight, mobility infrastructure and user data are vulnerable to attacks, posing risks to privacy and system reliability.

Health

Strong Differences in Activity Levels

Convenient mobility options like electric scooters, microcars, light electric vehicles, and automated vehicles are now widely accessible. While e-bikes have replaced some car trips, the primary shift has been from walking and traditional cycling to light electric vehicles, reducing physical activity and negatively affecting public health for a large part of society. People who predominantly use active mobility do so because of lifestyle or cost considerations.

Divide in Access and Wellbeing

For those who can afford it, the convenience of automated vehicles, widely available multimodal travel solutions in urban regions, and the freedom to choose between travel options reduce commuting stress. For those who cannot, the stress of limited access to mobility services, reduced social interactions, and restricted access to opportunities can negatively impact mental health.

Trade-Offs

Free Market Dynamics Comes with (New Forms of) Environmental Impact

The lack of coordinated efforts to address environmental concerns means technological advancements do not necessarily lead to sustainable mobility solutions, potentially exacerbating climate change.

Focus on Profitability Comes with Growing Inequality

Rapid, market-driven innovation fosters economic growth and convenience for affluent users but increases social disparities and mobility inequalities, as access to advanced solutions is uneven. In addition, public transport providers only bid for profitable routes, leaving low-demand areas underserved.

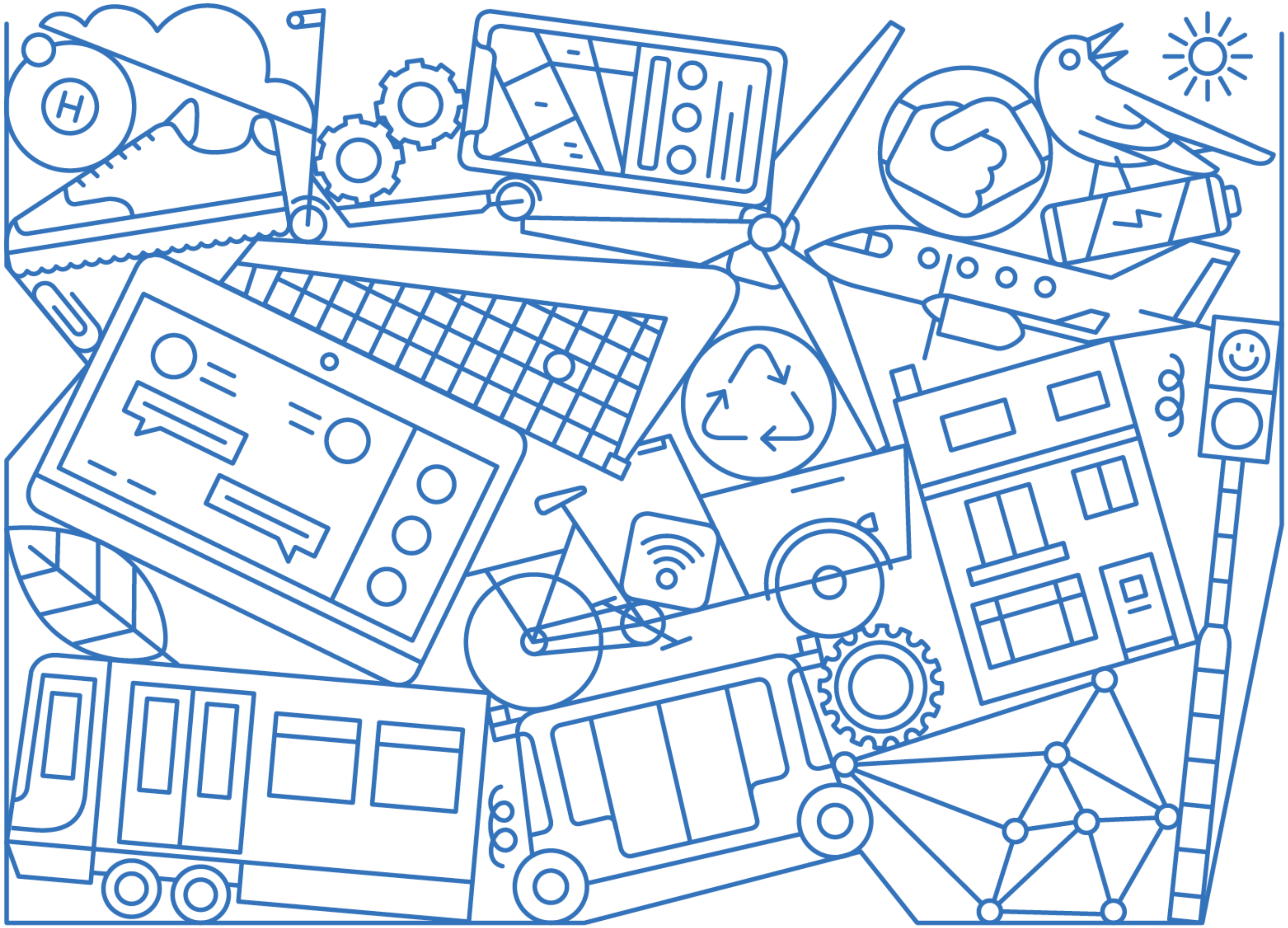
Lack of Regulation Comes with Unexpected Side Effects

Without proper regulation, innovations in mobility can lead to unintended consequences, such as public disturbances and inefficient use of public space. Companies seek to maximise profit, leading to a focus on high-demand areas and periods and non-uniform prices, adding to inequality.

Did you know? Early shared e-scooters had a lifespan of just 6 to 12 months, contributing to significant environmental concerns due to frequent replacements and resource consumption (Severengiz, Schelte, & Bracke, 2021). However, the industry is making strides—making their new models last longer, thereby reducing costs, waste and the carbon footprint associated with production and disposal.

Hyperconnected Systems

Teamwork makes the dream work



Keywords: Technology for the collective good – Government-orchestrated innovation – Sustainability – Collaboration – Broad prosperity – Long-term strategies – High public investments

In 2050, the Netherlands thrives under a synergy of technological enthusiasm and proactive government intervention. Society is eager to embrace new technologies, with the government playing a pivotal role in steering these advancements toward the public good. Massive investments in sustainable infrastructure, efficient transport, and smart traffic management systems are accompanied by an integrated urban planning approach, contributing to liveable cities. Policies emphasise responsible entrepreneurship, sustainability, and societal wellbeing. Circularity and life cycle aspects are included in assessing solutions' sustainability score.
Technological innovation is widely seen as an effective solution to address complex societal challenges, and it is accepted that government funding is often necessary to bring about these advancements. The government has a clear vision of how technology can address societal challenges and actively guides its development through policies and regulations that promote societal welfare, manage natural resources, and address pollution. Companies collaborate under these regulations, safeguarding their own benefits within the broad prosperity framework. Trust in regulators and experts from government and science is key to social acceptance of government intervention and sustaining progress within social and planetary boundaries.

Living Environment and Sustainability

Carbon-Neutral Mobility

By 2050, the Dutch mobility system is highly sustainable, driven by a strong can-do mentality and a shared sense of community. Massive investments in wind and solar energy, as well as small modular reactors, power a large part of the mobility system, and green hydrogen production and synthetic fuels enable the decarbonisation of most heavy trucks, ships, and long-haul flights. Carbon capture solutions offset the remaining carbon footprint. This transformation, though successful, has also led to significant national debt, which will be a major theme in the decades ahead.

Did you know? Comparing the well-to-wheel energy consumption of battery electric, hydrogen fuel cell, and e-fuel vehicles is highly complex due to numerous factors. These include variations in production methods, technological advancements, infrastructure efficiency, vehicle design, and driving conditions. Additionally, the definition of system boundaries significantly impacts the results, making it challenging to offer a single, definitive comparison.

Battery electric vehicles are generally the most energy-efficient, with well-to-wheel efficiency estimated at 70–90%. Hydrogen fuel cell vehicles are less efficient, achieving only 25–35% due to energy losses during hydrogen production and fuel cell conversion. E-fuel vehicles using a traditional combustion engine require additional synthesis steps on top of green hydrogen production and exhibit the lowest well-to-wheel efficiency, well below that of hydrogen fuel cell vehicles.

Urban Transformation

Urban areas have undergone significant changes. In highly urbanised regions, specific zones are designated exclusively for public transport and shared mobility vehicles. The mandatory interoperability among shared mobility services and logistics service providers via mobility hubs ensures efficient use of public spaces and resources, reducing redundancy, optimising vehicle distribution, and freeing up space in cities. Extensive car-free areas, limited parking options, and high taxes on private vehicle ownership have reshaped cities, creating more green and blue (water) spaces. However, these changes have also accelerated gentrification, creating inequalities.

Resilience and Digital Infrastructure

An integrated approach to mobility and urban design, coupled with intelligent infrastructure and mandatory data sharing, enables real-time system analysis and enhances resilience against disruptions. However, despite the increased presence of green and blue spaces, cities still face resilience challenges posed by extreme weather events. During such crises, advanced digital infrastructure supports effective traffic management and enables companies to transition smoothly to remote work, reducing the reliance on physical mobility. The reliance on digital infrastructure comes with new challenges, though. Power outages–mainly due to extreme weather events and cyberattacks-result in regular disruptions of the mobility system. To be more resilient against these new challenges, the government takes a centralised approach to investing in and developing digital solutions and adopts a modular approach to implementation.

Sustainable Procurement and Innovation

Public procurement processes incorporate circularity and lifecycle sustainability criteria, ensuring mobility solutions contribute to long-term environmental goals. Digital innovations and artificial intelligence are leveraged to enhance energy efficiency and optimise logistics, making the mobility system as effective as possible.

Accessibility

Sufficiency principle

The government ensures a baseline level of mobility-based accessibility through interventions aligning with sufficiency principles. Most cities have adopted polycentrism as their planning approach, adhering to Green Transit-Oriented Development (Cervero, R. 2011) and a proximity-driven city planning approach to ensure that all residents have easy access to essential services. Local planning authorities have strategically located basic services and enhanced digital connectivity, ensuring comprehensive access for everyone.

Financial Accessibility

Financial instruments and subsidies are implemented to make sustainable and public transport options affordable for lower-income populations, reducing economic barriers to mobility. The widespread acceptance and promotion of remote work have also contributed to reducing overall mobility demand, supporting sustainability efforts and improving work-life balance.

Inclusive Mobility Services

To promote inclusivity, mobility services are designed with features like voice control and remote assistance, making them accessible to individuals with limited digital skills. Automated transport solutions are widely available, particularly catering to those with mobility challenges, thereby ensuring equitable access to transportation.

The Digital Divide

As mobility services increasingly operate without personnel, travel depends heavily on digital user interfaces. While these systems are efficient for digitally skilled users, they exclude individuals with limited digital literacy, reducing equality. However, if technologies such as seamless check-in and check-out systems and reliable voice control are well-implemented, they could significantly enhance inclusivity.

Did you know? Approximately 2.5 million Dutch citizens aged 16 or older have difficulties writing and/or counting, resulting in difficulties navigating the digital world. (Durand & Zijlstra, 2020; Van Oort et al, n.d.)

Did you know? The impact of two additional days of teleworking on environmental costs is modest, ranging from 4% to 7% in an optimistic scenario, excluding potential rebound effects. Quantifying the overall environmental impact of teleworking is challenging due to the interplay of complex factors. While teleworking can reduce commuting trips and associated emissions, this can be (partly) offset by increased energy consumption at home and the potential for rebound effects (European Environment Agency, 2024). Reduced traffic and the flexibility of remote work may encourage people to accept jobs farther from home, resulting in longer commutes when travel is necessary, or people may use the time and money saved from commuting for additional travel. Additionally, reduced congestion might encourage more car use among other workers.

Safety and Security

Advanced Traffic Safety through Connectivity

Advances in connectivity have revolutionised traffic safety by enabling seamless communication between vehicles, roadside infrastructure, and other vehicles. This has given rise to an advanced automated vehicle network, significantly reducing accidents, casualties, and material damage.

A key feature of these advancements is Intelligent Speed Adaptation, where vehicles are equipped with systems that automatically adjust speeds to meet zone-specific safety requirements. This dynamic speed regulation enhances traffic safety across land and water, playing a critical role in minimising accidents and ensuring safer travel for everyone.

Dedicated Cybersecurity Measures

To address the growing risks of cybercrime, a specialised government mobility cybersecurity centre safeguards mobility infrastructure and user data, enhancing both traffic safety and the perceived safety of individuals and groups.

Social and External Safety

Safety goes beyond traffic and cybersecurity. Measures are in place to enhance the perceived safety of individuals at specific locations and to protect group safety within public spaces. Location-based and group-related risks are closely monitored to ensure social safety. Although these initiatives are implemented in a privacy-secure way, aiming to make everyone feel safe, whether travelling alone or as part of a group, there is a continuous tension between safety and surveillance.

Health

Physical Health

Extensive initiatives–from the government and employers–encourage walking and cycling, supported by urban design and incentivisation programs. The emphasis on active transportation and creating safer, more sustainable environments helps reduce exposure to unsafe situations and negative environmental impacts.

Did you know? In the past, active mobility referred to human-powered modes of transportation, with walking and cycling being the core components. However, the definition has evolved to include certain types of Personal Mobility Devices (PMDs), like e-scooters, and Electrically Power Assisted Cycles (EPACs), like e-bicycles, given the growing importance of these modes in urban transportation.

Mental Health

Promoting autonomy and reducing stress are key components of urban planning and mobility policies. Integrating green spaces, providing opportunities for exercise, relaxation, and social interaction, and the availability of active transportation options contribute to a healthier mental state, giving individuals more control over their mobility choices and reducing the stresses associated with urban living.

Trade-Offs

Sustainable Mobility for All Comes with High Public Investments

Environmental and social outcomes are improved by making significant public investments in sustainable energy sources, mobility infrastructure, and advanced technology. However, these investments may also increase national debt, potentially compromising long-term fiscal health, slowing economic growth, and limiting the government's ability to fund other critical programs.

A Systems Approach to Mobility Comes with Increased Risks from Data Collection and Storage and Consequent Public Mistrust

By leveraging AI-powered systems and large-scale data to improve efficiency and decision-making in mobility, we achieve greater accessibility and optimisation but risk public mistrust, potential misuse of personal data, bias in decision-making, and heightened cybersecurity vulnerabilities.

Government-Orchestrated Innovation Comes with Bureaucratic Challenges

By prioritising an active role for the government in driving innovation, we ensure alignment with societal goals. However, the requirement for transparency in innovation processes to maintain the trust of companies and citizens can lead to delays caused by lengthy procedures. Additionally, this approach carries the risks of accusations of corruption or favouritism and slower outcomes due to the long-term nature of transformative initiatives.

Sustainable Slowdown

Better safe than sorry

Keywords: Proven technologies – Government-led initiatives – Community engagement – Equality – Behaviour change – Governance and control – Limitations – Slow innovation – Less is more

The Dutch government takes a central role in guiding societal change with policies prioritising environmental protection, community wellbeing, and social equity. Social innovation and behaviour change play a central role in addressing societal challenges while technological adoption proceeds deliberately, focusing on proven solutions and thorough assessments of potential impacts.
Urban planning focuses on creating liveable, proximity-based communities, adhering to the principles of polycentric development and the 15-Minute City. Active modes of transport like walking and cycling are strongly promoted, supported by extensive car-free zones and green spaces. Public transport is heavily subsidised while its reliability is affected by labour shortages. The widespread implementation of pick-up points alleviates traffic congestion associated with last-mile logistics by reducing individual home deliveries and enabling more efficient consolidation of goods.
The government collaborates with private entities but sets clear boundaries to ensure that developments contribute positively to society.

Did you know? According to the BREVER law (Behoud van Reistijd En VERplaatsingen/ Conservation of Travel Time and Movements), people tend to spend a consistent 70 to 90 minutes travelling daily. This principle has been observed across different cultures and time periods (Ahmed & Stopher, 2014). What changes over time is the distance people travel as greater infrastructure capacity or faster modes allow for longer trips within the same timeframe. It also applies to a reduction in travel capacity: reducing capacity means people travel shorter distances, which naturally decreases demand.

Living Environment and Sustainability

Community-Focused Urban Design

Urban areas feature extensive car-free zones and abundant green spaces, promoting walking, cycling, and the use of light electric vehicles under strict safety regulations. Incentive programs nudge residents to exchange parking spaces for communal green areas, improving the liveability of neighbourhoods and enhancing resilience to extreme weather.

Sustainability Through Behaviour Change

Municipalities actively support shared mobility to reduce the number of vehicles and prioritise green spaces in urban design. The widespread use of pick-up points relieves last-mile logistics traffic. Policies incentivise sustainable behaviour through subsidies, rewarding citizens for low-impact mobility choices, and putting restrictions and taxes on less-sustainable mobility. Despite efforts, “hard-to-decarbonise” modes like aviation and long-haul freight still rely on fossil fuels due to limited availability and high prices of alternative sustainable fuels.

Slow Transformation

While sustainability is a key goal, the cautious stance toward new technologies and the absence of subsidies stimulating technology-enabled sustainable solutions means that the mobility sector evolves slowly. Innovations are carefully evaluated for environmental and social impacts before widespread implementation, ensuring that changes are beneficial and aligned with societal values.

Did you know? Even during COVID-19 lockdowns, there was quite some traffic remaining. On average, traffic congestion decreased by approximately 35% in the second quarter of 2020 compared to the same period in 2019. At its lowest point (late March), traffic demand had dropped by about 40%. Freight traffic showed relatively little decline in demand at the national level: only 10%. This decline occurred quite abruptly following the introduction of the “intelligent lockdown.” Just over three months later, at the end of the second quarter, traffic demand had almost returned to pre-crisis levels (Nationaal Dataportaal Wegverkeer, 2020).

Accessibility

Egalitarian Approach to Inclusivity

Shared mobility services are well-integrated and subsidised, with municipalities ensuring seamless transitions between different modes of transport. The government prioritises reducing disparities in accessibility in line with egalitarian principles. However, labour shortages in public transport may exacerbate service gaps between areas.

Proximity-Centred Accessibility

Cities are optimised to ensure that most essential services are close by, adhering to Transit-Oriented Development and proximity-focused urban planning principles.

Economic and Spatial Divides

Efforts are made to minimise economic disparities in access to mobility. However, the high cost of car use in urban areas—driven by heavy taxation and limited parking facilities designed to discourage private vehicle use—disproportionately impacts lower-income individuals, particularly in areas with underdeveloped alternative transport options.

Safety and Security

Enhanced Traffic Safety

Strict enforcement of speed limits and car-free zones significantly reduce traffic accidents in urban areas. Proven technologies like intelligent speed adaptation are mandated for all vehicles, enhancing safety on roads and waterways. Automated vehicles are regulated and primarily used in shared services on specific routes, highways, and regional roads, ensuring controlled and safe deployment.

Digital Security Challenges

Public transport systems face challenges in modernising their digital infrastructure, leaving them vulnerable to cyberattacks. While there is a focus on cybersecurity, limited resources and cautious technological adoption slow the implementation of comprehensive protective measures. However, limited digital connectivity limits the impact of cybersecurity attacks on a systems level.

Health

Promotion of Active Lifestyles

Active transportation is strongly encouraged through urban design that favours pedestrians and cyclists. The emphasis on proximity and the availability of safe, accessible routes leads to increased physical activity, improving public health outcomes.

Mental Wellbeing

Green spaces and community-focused urban planning contributes positively to mental health. Reduced noise pollution, lower traffic congestion, and a stronger sense of community enhance overall quality of life.

Trade-Offs

Environmental Protection Comes with Restrictions on Individual Freedom

The government effectively promotes sustainability by implementing strict regulations and limitations on travel to reduce environmental impact. However, these measures can restrict personal freedom of movement and individual choice, potentially leading to public dissatisfaction among those who value personal mobility and autonomy.

Universal Travel Limitations Affect Vulnerable Populations

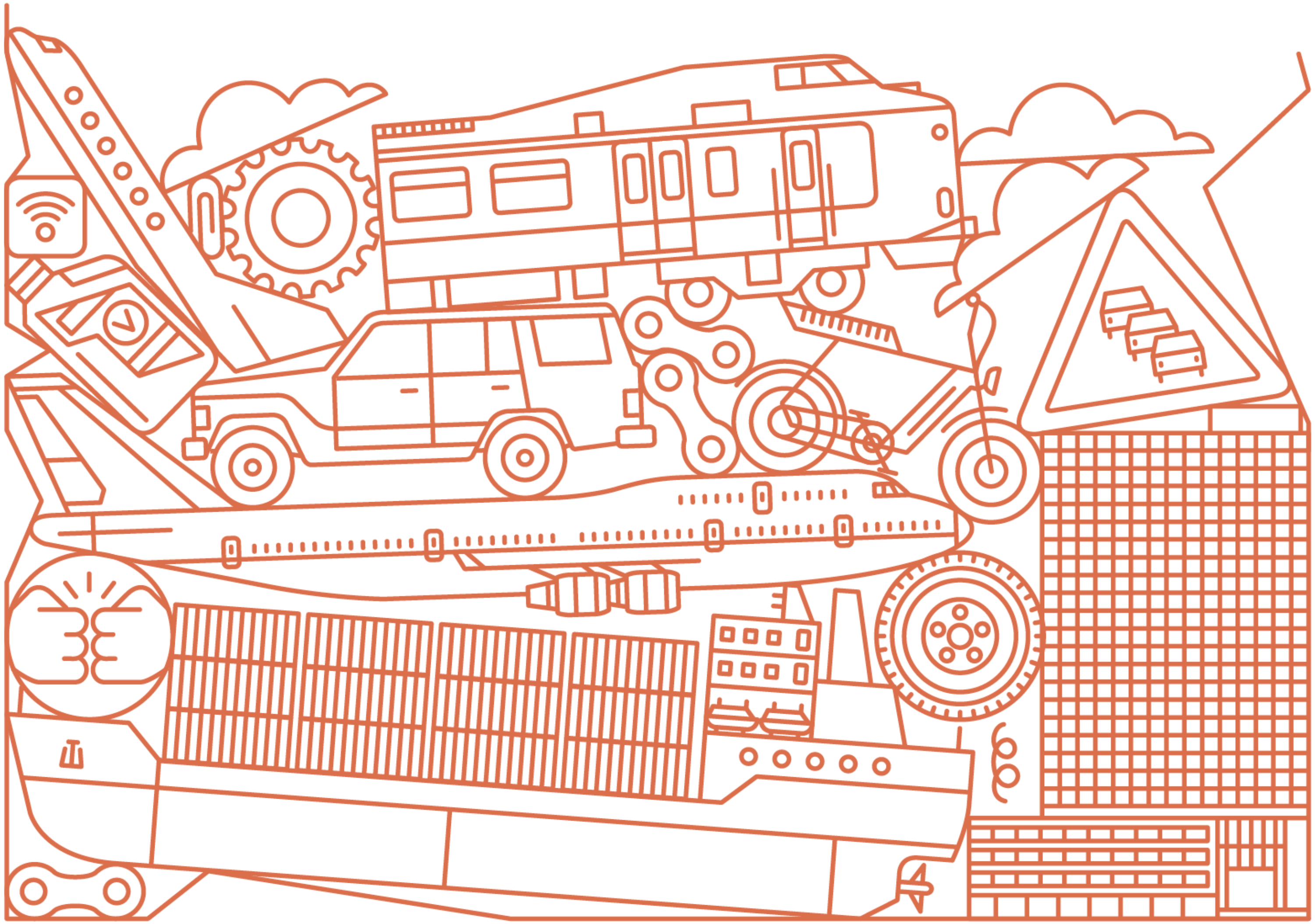
Enforcing universal policies simplifies implementation and supports environmental goals, but it may disproportionately impact vulnerable groups. Without tailored provisions, these measures can hinder access to essential services for low-income individuals, seniors, and those in remote areas, exacerbating existing social inequalities.

Cautious Innovation Slows Addressing Societal Challenges

The deliberate approach to adopting new technologies ensures that technological innovations align with community wellbeing and safety. At the same time, it can slow the adoption of new, efficiency-enhancing technologies, potentially hindering economic growth and delaying solutions that could address environmental challenges more effectively.

Mobility Patchwork

Business as usual



Keywords: Fragmented services – Market-driven choices – Minimal government intervention – Freedom of choice – Vehicle ownership – Scepticism – Infrastructure decline – Mobility inequality

By 2050, the Netherlands experiences a fragmented mobility landscape marked by minimal government intervention and a cautious societal stance toward new technologies. Market competition drives change without strong regulatory frameworks, leading to freedom of choice and unlimited mobility for those who can afford it. Private companies dominate the sector, focusing on profitability over sustainability or social equity. Technological innovation proceeds slowly due to public scepticism and limited adoption.

Urban areas grapple with congestion as competing mobility operators deploy overlapping services without coordination. Public transport is underfunded and unreliable, especially in rural regions, prompting reliance on personal vehicles. Environmental concerns are sidelined, with fossil fuels and e-fuels being prevalent and green technology adoption lagging.

Living Environment and Sustainability

Urban Congestion and Clutter

The lack of regulation results in inefficient use of public spaces. Multiple mobility providers operate independently, leading to cluttered streets in high-demand areas filled with various vehicles and shared mobility options that are not interoperable.

Environmental Neglect

The Netherlands follows rather than leads in adopting green technologies, relying on foreign advancements for electrification and other sustainable practices. A successful car lobby, combined with a shortage of critical materials for electrification, moved Europe's 2035 zero-emission new car regulation backwards. The surge in sales of hybrid cars just before the delayed regulation kicked in and a flourishing second-hand market made that fossil fuels are still widely used.

Did you know? As of 1 January 2024, there were 9.1 million passenger cars in the Netherlands, a 7.4% increase compared to 2019. Of these, 88% are privately owned, while 12% are company-owned (CBS, 2024). Among the fleet, 5% are fully electric, and 9% are hybrids (RAI Vereniging, 2024).

With an average car age of 9.23 years, the Netherlands ranks third in the European Union for oldest car fleets, following Spain (9.86 years) and Finland (9.69 years) (European Environmental Agency, 2024). Notably, approximately 65% of cars in the Netherlands are nine years or older, and 27% are 15 years or older (CBS, 2024).

Accessibility

Pragmatic Decision Making

Without clear guidelines on accessibility principles, pragmatic decision-making takes precedence. This approach varies—sometimes optimising for the largest groups, at other times arguing for minimal accessibility standards or focusing on reducing disparities. Decisions often hinge on whichever argument is most compelling at the moment. Significant differences between regions and cities emerge, shaped by their political governance and priorities.

Fragmented Services and Complexity

Mobility providers focus on profitable urban markets, leaving less dense regions underserved. The lack of interoperability among operators means users must manage multiple apps and payment systems, complicating access to services, especially for those with limited digital proficiency.

Inequitable Mobility Access and Economic Disparities

The lack of coordinated policies created significant disparities in mobility services between urban and rural areas. Urban residents enjoy access to various mobility options, albeit fragmented, while rural populations often rely heavily on personal vehicles due to limited public transport availability. Economic disparities further compound these geographic inequalities. Wealthier individuals can afford high-end automated vehicles and benefit from a broader range of mobility services. At the same time, lower-income populations face restricted options and higher costs, exacerbating social inequalities and limiting access to essential opportunities.

Infrastructure Decline

The lack of substantial investment in maintenance and new technologies to more effectively deal with maintenance backlog leads to deteriorating infrastructure. Shortages of technical personnel exacerbate the issue, leading to unreliable services and increased safety risks across the mobility network. All in all, cities are ill-prepared for climate-related disruptions.

Safety and Security

Limited Safety Advancements

Technological improvements enhance safety on highways through driver assistance systems. However, on urban and rural roads, increased heterogeneity in traffic, e.g., cars, microcars, and various forms of light electric vehicles, can lead to unsafe situations.

Cybersecurity Vulnerabilities

Fragmented mobility services struggle with cybersecurity due to underinvestment and lack of coordination. Operators are ill-prepared for cyberattacks, leading to vulnerabilities that undermine public trust in shared mobility and public transportation systems.

Health

Reduced Physical Activity

The prevalence of light electric vehicles and reliance on personal cars diminish opportunities for physical activity. Walking and cycling decline as people opt for motorised transport, even for short distances, negatively impacting public health through increased sedentary lifestyles. People who predominantly use active mobility do so because of lifestyle or cost considerations.

Air Quality Concerns

Although continuous improvements are made, continued use of fossil fuels and slow adoption of cleaner technologies still contribute to poor air quality. Pollution levels remain significant, affecting respiratory health and increasing the incidence of pollution-related illnesses.

Trade-Offs

Maximising Market Efficiency Comes with Compromised Ethical Standards

By allowing aggressive market strategies to maximise profits, companies may engage in practices that compromise ethical standards, such as unfair pricing or monetising personal data. This might lead to potential exploitation, unfair competition, and neglect of social responsibilities.

Preserving Traditional Mobility Practices Slows Technological Advancement

Maintaining the status quo in mobility preferences supports familiar practices but hinders the adoption of new, beneficial technologies, limiting improvements in efficiency, sustainability, and overall system modernisation. Besides, it could impact economic growth and international market standing.

Market Competition Comes with Mobility Inequality

Intense market competition drives innovation as companies focus on profitable segments but results in unequal access to mobility services, leaving underserved populations with limited options.

Perspectives on the Future of Mobility

This chapter provides detailed Mobilisers' perspectives on how the system might evolve by 2050, building on the general descriptions of the scenarios outlined in the previous chapter. These perspectives span various aspects of mobility, ranging from specific modes such as public transport, active mobility, and automated vehicles to broader themes like multimodal logistics, transit hubs, mobility experience, governance, and the public domain. Together, they offer tangible examples of how different elements of the mobility system could interact and develop within each of the four scenarios.

The perspectives reflect the diversity of expertise within the Mobilisers and are firmly rooted in academic freedom, which fosters critical thinking and embraces varied viewpoints. While the team collaborated closely to align their analyses, differences in interpretation or emphasis on specific details naturally emerged. These divergences are not only acceptable but also serve to enrich the exploration of future possibilities, providing a nuanced and comprehensive understanding of potential outcomes.

Each perspective envisions potential futures for specific aspects of the mobility system, informed by insights from past and current research, and concludes with key research questions to guide future mobility-related investigations. These questions aim to inspire ongoing inquiry and innovation in this evolving field.

This document captures the perspectives developed by the Mobilisers as of January 2025. Recognising that mobility is a dynamic and multifaceted domain, additional insights and perspectives will be published on the project's website over time, further expanding and deepening this exploration. www.tudelft.nl/mobility-futures

Active Transport & Micro-Mobility

Bio

Achilleas Psyllidis is an Assistant Professor of Urban Mobility and the Director of the Urban Analytics Lab at Delft University of Technology. He also leads the Social Urban Data Lab at Amsterdam Institute for Advanced Metropolitan Solutions and is an LDE Center for BOLD Cities affiliate. His research explores the interplay between land use, human perception, and the design of built environments, focusing on their impact on active mobility behaviour and accessibility for diverse populations. He has developed novel methods for analysing human mobility and accessibility and (co-)leads numerous projects on sustainable urban mobility, environmental exposures, and well-being. His research is funded by the EU, NWO, KNAW, SSHRC Canada, and FAPESP Brazil. He serves on the Executive Board of Computational Urban Planning and Urban Management (CUPUM). Achilleas earned an Engineering Diploma (Summa Cum Laude) in Architectural Engineering and a Master's in Spatial Planning (Summa Cum Laude, Highest GPA) from the National Technical University of Athens and holds a PhD in Spatial Data Science from Delft University of Technology. He is a recipient of scholarships from the Onassis Foundation, the European Social Fund, the Greek State Scholarships Foundation, the Foundation for Education and European Culture, and the A.G. Leventis Foundation.

Email address: a.psyllidis@tudelft.nl

Four Scenarios

Top left: Innovation Fast Track
Society embraces new technologies and market competition drives change

"Micro-Mobility Revolution"

Private sector innovations drive active transport (e.g., various electrically powered personal mobility devices, such as e-bikes and speed pedelecs), particularly cycling and goods delivery technologies. Companies compete to develop advanced micro-mobility solutions, including ultra-light e-bikes, weather-protective bike pods, and modular, shared cycling services. A sophisticated app ecosystem supported by AI aids navigation for all ages and abilities, ensuring seamless connections with transit networks in urban and peri-urban areas.

While automated delivery robots are increasingly utilised, active transport – such as electrically powered, lightweight vehicles – remains important for first- and last-mile goods delivery, driven by innovative private-sector solutions. Government regulations are limited to strategically locating local logistics hubs to balance efficiency and align with land use, making active transport deliveries feasible and attractive for providers.

Private-sector green innovations, such as electric vehicle charging infrastructure, shared micro-mobility services, and zero-emission vehicle technologies, are incentivised to advance environmental goals and promote sustainable transport adoption. While the abundance of micro-mobility providers ensures widespread availability and competitive pricing, it also leads to challenges like clutter, inefficiencies, and limited system integration. Competitive market dynamics encourage diverse and accessible mobility options, while regulatory measures ensure these innovations are not only environmentally effective but also support compact urban planning, reduce car dependency, and foster walkable, sustainable neighbourhoods.

Top right: Hyperconnected Systems

Society embraces new technologies and government intervention drives change

"Sustainable Mobility Heaven"

Public investment prioritises extensive networks of pedestrian routes and protected bike lanes connecting essential services. Technological advances also enhance pedestrian comfort, with surface temperature regulators in sidewalks to make walking more appealing in extreme weather. At the same time, most strategic government funding is focused on encouraging a shift toward more sustainable mobility behaviours.

Active modes, including electrically powered, lightweight vehicles, seamlessly complement automated delivery solutions for efficient first- and last-mile goods transport. Government funding ensures these projects remain fiscally responsible, while private companies offer affordable, rentable mobility aids for all ages and abilities, making active transport accessible without burdening public resources.

The government promotes active transport through strategic investments on two fronts. First, land-use regulations foster polycentric neighbourhoods, placing essential services close to home, school, and work. Second, transport behaviour change is actively promoted through subsidised educational programs aimed at late adolescents in schools. These programs focus on fostering sustainable mobility habits and equipping young individuals with the knowledge and skills to make environmentally conscious travel choices. This age group, at a pivotal transitional stage, benefits from learning sustainable mobility habits as they transition from education to work and civic engagement.

An advanced AI-driven app ecosystem developed by public and private partnerships offers real-time updates on path conditions and environmental factors along walking and cycling routes to minimise long-term exposure to health hazards. Data is optimised to enhance user experience, with strong privacy protections in place through decentralised storage and user consent controls. Citizens actively manage their mobility data, ensuring it is used only for services they select.

Bottom right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

"Active Communities"

Active mobility modes like walking, cycling, and micro-mobility are central to a society where sustainability, community engagement, and digital alternatives shape the urban landscape. Cities are organised around 15-minute neighbourhoods, where essential services are strategically located near homes, schools, workplaces, and transit hubs.

Travel credits are introduced to cap excessive travel and reduce emissions, with additional allowances and subsidies provided for vulnerable populations. Community-driven initiatives, such as shared bike pools and neighbourhood-led mobility hubs, are rising. The large penetration of digital connectivity significantly reduces the need for physical travel. Remote work, virtual classrooms, and remote health consults are largely encouraged.

Walking, cycling, and micro-mobility options are central to urban and peri-urban mobility, supported by strategic governmental investments in large-scale travel-behaviour change campaigns and initiatives. Efforts to promote shifts toward sustainable transport modes take precedence over investments in new infrastructure. Freight mobility is similarly localised and relies on active modes, including electrically powered, lightweight vehicles supported by locally integrated logistics hubs.

Bottom left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"Mobility Mishmash"

Walking, cycling, and micro-mobility options are widely available, but the landscape is shaped by competing forces of profit-driven companies and limited government efforts to ensure some level of access inclusivity. Freedom of choice is central to mobility design. Users can select from various active and micro-mobility options tailored to their affordances, needs, and convenience preferences. For example, premium e-bikes equipped with advanced AI navigation cater to those prioritising comfort, while low-cost manual bicycles and shared scooters provide affordable, eco-friendly options accessible to a broad segment of the population.

Private companies compete to develop efficient and sustainable solutions. Government oversight is limited to ensuring ethical practices, such as transparent pricing and privacy-preserving data use. Targeted subsidies focus exclusively on underserved groups, such as low-income families and rural populations, to make access to micro-mobility options more affordable. These measures encourage more sustainable first- and last-mile travel, enabling these communities to travel longer distances efficiently.

Freight hubs are strategically located near active mobility corridors, enabling seamless transfer of goods to active modes. Proven, sustainable technologies are prioritised, balancing efficiency with reliability, while small subsidies support access for underserved areas.

Questions for Future Research

- How can we improve and maintain society's accessibility levels without compromising ecosystem limits or increasing mobility demand?
- How can we meet sustainability and climate goals while ensuring equitable access to essential services and goods?
- How do built environment design, land-use distribution, and human perceptions influence active travel behaviour and social encounters?
- What are acceptable active travel times to essential services, and how do these differ among population groups?
- What factors shape pedestrian and cycling accessibility and the adoption of active transportation? How can objective measures and subjective experiences be balanced?
- How do environmental exposures affect the extent to which active transport is adopted?

Public Transport

Bio

Niels van Oort is an associate professor of Public Transport and Shared Mobility at the Delft University of Technology and co-director of the Smart Public Transport Lab. He has been involved in public transport projects and research for over 20 years and aims to make an impact with his academic work in practice. He collaborates closely with the (public) transport industry via joint research projects and advisory boards. His main fields of expertise are public transport planning and (data-driven) design, focusing on the passenger perspective and societal impacts related to, for instance, inclusiveness, land use and sustainability. His work also involves shared mobility and first/last mile solutions. In addition to teaching Bachelor's and Master's courses, Niels provides trainings and workshops both in the Netherlands and abroad. He frequently speaks at academic and industry events and publishes articles in (international) journals and general media. Until 2024, he successfully supervised 8 PhD students and over 120 MSc students.

Read more about Niels' expertise on his weblog or his personal page.

Email address: N.vanOort@tudelft.nl

Four Scenarios

Top left: Innovation Fast Track
Society embraces new technologies and market competition drives change

"Fast and Modern"

Public transport services are concentrated in dense areas, offering fast and efficient services to/from city centres and main activity centres on national, regional and local levels. Due to automated technology, dependency on labour is reduced, and reliable services are offered, with short but frequent pods. Most vehicles are driven by green electricity. New concepts, such as the trackless tram, have arrived on the streets. Less dense areas, such as suburbs, towns and rural zones, are less or not served. Due to a high level of teleworking, services concentrate on peak hours on Tuesdays and Thursdays. Multiple operators are able to offer competing services on (inter)national, regional and local levels, which reduces ticket prices and enhances service. Public transport operators also offer integrated first and last-mile services, e.g., shared bicycles, e-scooters, e-bikes, and automated shuttles. Active mobility is, therefore, reduced. Due to new technology, no tapping in or out is needed. Ridership and travel patterns are continuously monitored to optimise fleet and service levels. In case of limited patronage, on-demand services are offered, applying optimised shared routes. Within

Niels van Oort

one operator, the integration of services, payment and information is maximised, but between operators, it is limited. Shared mobility is offered anywhere in the city, creating high coverage and low prices but also nuisance and limited integration. Automated cars offer heavy competition for public transport. Musk sponsored a Hyperloop connection from Amsterdam to Madrid via Paris and Barcelona as a potential start of a European network.

Top right: Hyperconnected Systems

Society embraces new technologies and government intervention drives change

"Connected and Inclusive"

All public transport is powered by green electricity and offers services in all areas and at all times. Due to automated technology, dependency on labour is reduced, and reliable services can be offered with short but frequent pods. New concepts, such as the trackless tram, have arrived on the streets. Less dense areas, such as suburbs, towns and rural zones, are served by on-demand, automated shuttles and cars. Ticket prices are medium, but many subsidies are needed. Anyone is able to travel. Special transport is integrated with public transport, and first- and last-mile services are seamlessly connected via shared bicycles, e-scooters, e-bikes, and automated shuttles. Active mobility is stimulated by the government over passive mobility. Most trips consist of bicycle+transit. Nationwide, all payment and information are integrated for door-to-door journey convenience, and due to new technology, no tapping in or out is needed. Mobility hubs are located in cities and regions, combining mobility services and facilities. Primary schools and day cares are located near hubs to promote chain trips. Shared automated cars are part of public transport networks, and the government heavily stimulates public transport usage over car usage.

Did you know? Train services in the Netherlands are amongst the densest and most efficient around the world, being ranked second in Europe after Switzerland. The world top is dominated by Asian countries. On the other side, the Dutch public transport system is also amongst the most expensive ones, being ranked 2nd worldwide after Switzerland (Landgeist, 2021; Compare the Market, 2023)

Bottom right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

"Accessible and Safe"

Public transport is operated by bus (including BRT), tram/light rail, metro and trains and is mainly powered by green electricity. Only fully isolated lines, e.g., metros, are automated, but all other services are manually operated, thereby enhancing social security. For the same reason, all stations have a crew. Less dense areas are served by a mix of traditional buses, vans operated by volunteers, and carpool services that enable anyone to travel anywhere in the country. Due to the prime focus on national services, international rail services are limited and low quality compared to the airline network. First and last miles services are limitedly integrated regarding payment and integration. Operations costs are high, and thus, much funding is needed. Ticket prices also rise. In city centres, cars are restricted, and public transport plays a major role in addition to active mobility. New, dense residential areas have high-level services from the start. Overall, the main mode is the integrated bicycle+transit mode and OV fiets is still the best innovation in the public transport domain. In the suburbs and rural areas, public transport faces challenges to offer competitive services to the car. Due to net congestion and charging problems, the reliability of services is under pressure.

Did you know? The most used shared (micro)mobility service in the Netherlands is OV-fiets, the shared bicycle scheme, operated by NS (national railway operator). As of 2024, OV-fiets includes almost 22,000 bicycles available at 300 locations throughout the country. In that year, a total of 5.9 million trips were made by OV-fiets. The system exists for over 20 years and shows a positive societal benefit-cost ratio for that period, with 10-150% more benefits than costs (NS, 2025; van Oort et al, n.d.)

Bottom left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"Frequent and Multimodal"

The focus of public transport networks is serving dense areas. Multiple operators are allowed on the major train and bus lines, enhancing frequencies and prices, but due to limited integration, the impact of disturbances on passengers is high. Networks and lines are changed regularly to reduce costs and maximise profit. Metro and tram networks remain as they are and are the backbones of cities, but new residential areas suffer from a lack of new infrastructure and connections. BRT lines are serving areas without rail connections. In low-demand areas and times, no services are offered, and people must rely on cars and bicycles. Transport poverty has increased substantially in these areas. In dense areas, ticket prices are low. International rail is flourishing due to multiple operators on the main routes, enabling low ticket prices. Shared mobility is offered anywhere in the city, creating high coverage but also nuisance. New residential areas are only served when completed, and thus, when most households already have multiple cars. Due to net congestion and charging problems, reliability is under pressure. Existing technologies enabling individual on-demand services (e.g., Uber-like services) offer serious competition to public transport and create congestion, besides passenger convenience.

Questions for Future Research

- How to design and operate a public transport network, consisting of fixed and flexible lines, maximising user and societal impacts while minimising (societal) costs?
- How to optimise coordination and integration of public transport and (shared) micromobility from multiple perspectives, e.g., accessibility, efficient space usage, inclusiveness and sustainability?
- What is the best (multi-objective) design of public and shared mobility (networks and services) for new residential areas?
- What are the impacts and opportunities to plan, operate and maintain trackless trams?
- How are specific groups excluded from mobility (in time and space) for different networks and services, and how to mitigate?
- What are suitable (and new) methods and data sources to evaluate and predict passenger behaviour?
- How does (or could) AI impact public transport planning and operations?

Automated vehicles

Bio

Dr. Maaike Snelder is an associate professor at the Department of Transport and Planning, Civil Engineering at the Delft University of Technology and a principal scientist at TNO. Her research focuses on impact assessment and design of multimodal transport systems with a special interest in the resilience of networks and the impact of new mobility concepts like automated vehicles and shared mobility. Maaike is co-director of the Sustainable Urban Multimodal Mobility Lab (SUM Lab) and has led the NWO research programs XCARCITY (co-lead) on the design of car-low areas, SUMMALab on living lab experiments for sustainable mobility, ToGRIP on combined logistics and traffic management, and STAD (co-lead) on the Spatial and Transport impacts of Automated Driving. Maaike is Editor-in-Chief of the European Journal of Transport and Infrastructure Research (EJTIR). She completed her PhD research on robust road network design in 2010 (Cum Laude) and completed her study Econometrics in 2003.

Dr. Holger Caesar is a tenured Assistant Professor in the Intelligent Vehicles group of TU Delft in the Netherlands. Holger's research interests are in the area of Autonomous Vehicle perception and prediction, with a particular focus on the scalability of learning and annotation approaches. Previously, Holger was a Principal Research Scientist at an autonomous vehicle company called Motional (formerly nuTonomy). There, he started three teams with 20+ members that focused on Data Annotation, Autolabeling and Data Mining. Holger received a PhD in Computer Vision from the University of Edinburgh in Scotland under Prof. Dr. Vittorio Ferrari and studied in Germany and Switzerland (KIT Karlsruhe, EPF Lausanne, ETH Zurich). He is best known for developing the influential autonomous driving datasets nuScenes and nuPlan, as well as his contributions to the real-time 3d object detection method PointPillars.

Prof. Nicole van Nes is a Full Professor of Human-Centered Design for Smart Mobility at the Faculty of Industrial Design Engineering. Her two main research interests are the design of sound and seamless human-technology interactions and how to steer the transition towards higher levels of automated mobility toward our societal goals. Nicole investigates these topics in collaboration with stakeholders from industry and policy in a national and international context. Among others, she initiated and coordinated the large European-funded project MEDIATOR about human factors challenges in designing interaction with intermediate levels of vehicle automation. Nicole is director of the Delft Design Lab on Automated Mobility and board member of the TU Delft Transport and Mobility Institute (TMI).

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies and market competition drives change

"The Self-Driving Race"

Market competition fuels the rapid development and adoption of automated mobility, driven by profitability and business continuity. Technological progress focuses on cost reduction, resulting in minimal sensor setups and Level 3 to 4 automation, where human intervention or remote assistance is required. Privately owned automated vehicles (AVs) and automated drones have emerged as luxury products for affluent consumers. Simultaneously, automation is leveraged to cut costs, such as replacing pilots in low-cost carriers.

Governments adopt a permissive stance, with limited regulation and no communication standards, leading to slower V2X deployment. This leads to increased following distances between road vehicles, reduced road capacity, and increased congestion. Shared services remain limited to niche applications, such as campuses or airports, while the business case for widespread shared mobility remains weak.

The design priority focuses on commercially successful solutions tailored to profitable markets. Usability takes a back seat, as systems are influenced more by purchase preferences than actual user needs. Safety measures prioritise primary users, leaving others to adapt. Despite rapid innovation, adoption remains uneven, and broader societal challenges, such as inclusivity and sustainability, are inadequately addressed. The result is a fast-paced rollout that benefits select groups while leaving others behind.

Did you know? Over the past decade, many developments have taken place in the field of automation of cars, trucks and public transport. Driver assistance systems (level 1) are readily available. The penetration rate of Level 2 partially automated vehicles in mixed traffic is increasing, and Level 3 conditional automation on motorways is now supported by EU legislation. In 2021, about 1.5 million cars were sold with level 3 features, which is expected to increase to 3.5 million in 2025 (AUTO2X, 2024). In August 2023, a Californian commission allowed two self-driving car companies to commercially operate Level 4 automated taxis 24 hours a day on all roads in San Francisco (The Guardian, 2023). China has a fast-growing fleet of robot taxis as well. Although the automated taxis are a success, General Motors recently announced that they will refocus on private instead of shared automated vehicles (General Motors, 2024). Level 5 fully automated vehicles are not yet available.

Level 0: No Driving Automation
Level 1: Driver Assistance
Level 2: Partial Driving Automation
Level 3: Conditional Driving Automation
Level 4: High Driving Automation
Level 5: Full Driving Automation

For a more detailed overview of levels of automation, see SAE International. (2021)

Top Right: Hyperconnected Systems

Society embraces new technologies and government intervention drives change

"Self-Driving for All"

Government-led initiatives drive automated mobility, aligning it with goals of equity, sustainability, and efficiency. Embraced by a tech-positive society, innovations like Level 5 automated vehicles, high-speed trains, robot taxis and on-demand shuttles are rolled out under strict regulatory oversight, ensuring safety and public trust. Policies incentivise shared and public transport while minimising environmental impacts and reclaiming urban spaces.

Inner cities are transformed into car-free zones, prioritising pedestrians, cyclists, and light electric vehicles. On-demand automated shuttles provide last-mile connectivity and flexible services for remote areas or people with disabilities. Exemptions are made for logistic services and good delivery. In rural regions, government-subsidised shared services adapt to local needs. Governments mandate electric and hydrogen-powered vehicles, investing heavily in charging and communication infrastructure, including dedicated AV lanes and V2X networks.

The design priority focuses on intuitive, user-friendly systems that foster trust and ensure adoption across diverse populations. Usability is critical to integrating automation seamlessly into daily life, supporting equitable mobility solutions.

This scenario achieves sustainable, shared mobility while advancing societal needs. Automation enhances liveability, reduces environmental harm, and improves traffic flow. With cohesive policies and infrastructure, automation contributes to a greener, more inclusive transportation system.

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

"Safe but Slow Self-Driving"

Government oversight and societal caution shape a measured, safety-driven approach to automated mobility. Level 2 automation, with advanced driver assistance systems, becomes standard, but higher levels face regulatory and societal barriers. Progress is slow, and automated mobility remains focused on low-risk solutions, such as motorways and regional roads.

Governments emphasise sustainability and equity, encouraging walking, cycling, and rail travel over automation. Urban policies prioritise liveability, with car-free zones, reduced parking, and mobility hubs that integrate shared services like electric bikes, e-scooters, and cars. Shared vehicle providers must meet minimum service quotas, with subsidies ensuring accessibility in non-profitable areas.

Design priorities focus on societal relevance, such as automated taxis offering mobility for elderly or disabled individuals. However, innovation is limited, and societal scepticism hinders widespread adoption. Infrastructure investments remain focused on traditional transport systems, leaving AV technologies underdeveloped. While this approach minimises environmental and safety risks, it slows the realisation of automation's full potential. Mobility becomes more localised, sustainable, and inclusive, but gaps remain in transport accessibility. The cautious adoption delays innovation, preventing significant societal transformation.

Bottom Left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"Self-Driving for the Few"

Societal caution toward automation, combined with market-driven development, results in a fragmented and uneven adoption of automated mobility. Advanced AV technologies primarily serve affluent groups, while most people rely on traditional transport due to scepticism and affordability concerns.

Governments take a limited role, providing minimal regulation or infrastructure support. Without cohesive policies, automation stalls at intermediate levels, and V2X communication remains undeveloped. Infrastructure investments focus on vehicle-based technologies, leading to localised, inconsistent solutions with varying success. The design priority emphasises business cases for selective markets that embrace automation. As safety concerns and public scepticism persist, usability and transparency are critical design challenges to earning the much needed trust. Automated mobility solutions are niche, catering to specific locations or high-demand areas. This fragmented approach limits automation's benefits, excluding large portions of society and intensifying inequalities. Road congestion increases as traditional vehicles dominate, while infrastructure quality declines due to underinvestment. Safety and operational risks are managed commercially, leaving road users to adapt.

With limited room for innovation and no cohesive policies, automation struggles to deliver widespread benefits. Unequal access and stalled development leave automated mobility's promise largely unrealised, confined to select groups and applications.

Questions for Future Research

- How can different levels of government intervention (or lack thereof) shape the adoption of automated vehicles and their integration into urban mobility systems?
- How to steer the transition to higher levels of automation towards our societal goals? How can automated mobility contribute to the safety, sustainability and inclusivity of our mobility system? How to design and create business and societal relevant use cases?
- What is the best way to define and standardise V2X communication protocols?
- Which sensors should be used for AVs that prioritise either safety or low cost?
- For the intermediate levels, when a vehicle is partly automated, a particularly challenging research question is: How to design a safe and seamless interaction between human driver and automation? How to design, from a user perspective, high quality transition of control routines, task load variations, mode awareness?
- How do tiered pricing models based on automation levels and data-sharing preferences impact consumer behaviour and the adoption of automated vehicles?
- What are the expected penetration rates of different levels of AVs in 2050 and what are the expected societal impacts? (see Snelder et al., 2025).
- How can mobility systems of urban areas best be designed such that personal preferences regarding comfort and travel time and societal goals such as liveability, sustainability, accessibility, health, safety and security are balanced? (see www.XCARCITY.nl)
- How to design a safe and seamless coexistence of automated vehicles and other road users such as pedestrians, cyclists and human-operated vehicles?

Transit Hubs & Mobility Experience

Bio

Manuela Triggianese is an Assistant Professor in the Department of Architecture at Delft University of Technology, where she coordinates research in the Section Building Knowledge and MSc education in the Complex Projects Group. She contributes to the Future (proof) Urban Infrastructure program led by DIMI, and she is a member of the Transport and Mobility Institute. An architect by training, she holds her PhD from IUAV in Venice, focusing on high-speed railway station design and development. Her research centres on co-creation in architecture for an integrated building project, using the architecture of mobility spaces – stations - as a testbed. She explores how design fosters dialogue by integrating multidisciplinary expertise, diverse data, and stakeholder perspectives. The scope is to align architectural design with transitions in sustainability, digital transformation, and social innovation. Formerly at the Dutch firm KAAN Architecten, Manuela has held research positions at Beijing Technical University as Marie Curie fellow and at the Amsterdam Institute for Advanced Metropolitan Solutions, where she led the Stations of the Future project and AMS-Mid City. She leads the NWO-funded project Walk-In and the open access book series City of Innovations (TU Delft). Read more about her work in stories of science.

Email address: m.triggianese-1@tudelft.nl

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies, and market competition drives change

“The Demand-Adaptive Hub”

Society is increasingly tech-driven, with AI, automation, IoT, and MaaS reshaping daily life. Mobility hubs like transit stations prioritise efficiency and cost-effectiveness, using digital platforms for personalised travel. Competition among private providers fosters innovation, reducing costs and overshadowing public transit. Digital twins predict and manage congestion, ensuring smooth operations and controlled maintenance. Hubs now feature flexible, modular designs that reconfigure in real-time, optimising operations and enabling a decentralised, sprawled urban fabric. Major hubs such as airports and central stations, including hyperloops for long-distance travel, accommodate automated vehicles,

offering on-demand services that cut wait times and improve efficiency. The shift from predetermined shuttle routes to more dynamic systems aligns with car-free streets and residential zones. Small hubs, strategically placed in these areas, become essential for providing convenient and efficient access to mobility services, ensuring that people and goods can move seamlessly within these pedestrian-friendly environments without relying on private cars or fixed transit schedules. Goods distribution relies on micromobility, drones, and automated systems. Urban air mobility solutions serve as premium services in congested centres, transforming hubs into high-tech innovation centres but raising concerns about affordability and inclusivity. While these advancements maximise space and efficiency, they risk prioritising data providers' interests over public welfare. The real-time reconfigurations demand significant energy, and the increased modularity risks rendering existing stations obsolete, necessitating retrofitting to avoid abandonment.

Top Right: Hyperconnected Systems

Society embraces new technologies and government intervention drives change

"The Seamless Hub"

Stations are multimodal hubs facilitating seamless travel between trains, buses, micromobility, and automated vehicles. Rooted in governmental urban mobility plans and strategic spatial development, these hubs form a polycentric network shaping urban areas. Dense, mixed-use neighbourhoods emerge around stations, enhanced by electrified and automated micromobility, enabling mid-low-rise developments instead of high-rises, with expanded green and open spaces. Governments prioritise sustainability, investing in infrastructure tied to environmental and social goals, such as high-efficiency trains and zero-emission buses. This ensures stations drive urban regeneration, avoiding gentrification and displacement. Transit hubs are designed as carbon-neutral (BSbm, 2024), regenerative spaces to reduce urban carbon footprints. Suburbs shrink into ecological green belts exclusive to non-motorised mobility, with Park and Ride hubs facilitating smooth urban-rural connections. These hubs, acting as "urban batteries," harness renewable energy from solar and wind sources to power stations, electric vehicles, and local systems. The resilient dimension plays a crucial role in this scenario. Highly complex, connected transport systems are more fragile to disruptions, such as climate events. While centralised coordination and connectivity bring benefits, they also risk inefficiencies like bottlenecks, higher costs, or underutilisation of resources. Inner cities evolve into car-free zones, emphasising active transport, light electric vehicles, and shared mobility. Automated taxis integrate into transit networks with designated drop-off points, while varied hub sizes ensure accessible options in car-reduced zones. Shared mobility facilities, including bike parking and on-demand services, are conveniently located within a 5-10 minute walk or bike ride of main stations. Urban Air Mobility is deprioritised due to its high energy demand and reliance on non-preferable data practices. These interconnected hubs foster sustainable, energy-efficient urban mobility, prioritising people and environmental goals while transforming cities into greener and more accessible spaces.

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

"The Eco-Conscious Hub"

In a technology-cautious society, the government drives change by investing in mobility hubs that prioritise safety, inclusivity, and social cohesion. These hubs, designed with community input, blend traditional transit services with facilities like day-care centers, libraries, and co-working spaces. Accessibility is central, catering to all, from families with strollers to older adults requiring assistance. Sustainable construction features renewable energy sources and low-rise, human-scale architecture that integrates into the urban landscape. Hubs address growing vulnerabilities, such as heat-related challenges, while supporting the shift to public transport through investments in urban, suburban, and rural mobility nodes. Suburban stations, with park-and-ride (P&R) facilities, connect highways to public transit, enhancing accessibility and encouraging car-free city centres. Governments also promote circular approaches, low-tech solutions, and renewable energy, balancing efficiency with societal concerns like data privacy. Private car use faces heavy taxation, reduced parking, and restrictions in city centres, with allowances for logistics. Environmental and car-low zones, combined with nature-based climate adaptation measures for stations (BSbm, 2023), further promote sustainable mobility. Challenges include housing deficits and integrating new dwellings near stations while maintaining a polycentric urban fabric. Despite fewer mobility options, improved quality and comfort in public transport are prioritised. This strategy ensures equitable access and supports sustainable, low-carbon urban development, embedding hubs seamlessly into urban environments to foster resilience and cohesion.

Bottom Left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"The Competitive Hub"

In a technology-sceptical society where market competition drives change, transit hubs adopt technology cautiously, with gradual improvements spurred by competition among mobility providers. Stations blend traditional and modern mobility solutions, with hubs of varying sizes present in urban, peri-urban, and rural areas. However, mobility choices are scattered, transfers are unregulated, and modal splits are disorganised. In cities, competing services increase congestion due to a lack of network integration. Duplicate routes from private operators exacerbate traffic jams and inefficient road use. Minimal collaboration between private and public transport networks results in fragmented, non-seamless travel options. Urban densification around stations, combined with limited space, leads to districts that appear overcrowded and unsafe. A strong focus on densification and real estate development limits space for mobility growth in the future and puts pressure on the quality of the living environment (CRa and BSbm, 2023). Market-driven development around stations prioritises economic competition, impacting hub attractiveness. This approach risks gentrification and inequality while failing to ensure cohesive planning. Smaller hubs for shared mobility options, such as electric vehicles, are located near car-free streets and residential areas, but the fragmented mobility space lacks quality public infrastructure. While market-driven efficiency improves cost and speed, it does so at the expense of liveability, sustainability, and the seamless user experience. Public spaces remain disjointed, with limited positive developments in mobility space quality or urban cohesion. Overall, this scenario underscores the challenges of balancing economic competition with inclusive and sustainable transport systems.

Questions for Future Research

- How to design and adapt transit hubs responding to new challenges, e.g. climate change, scarcity of materials, and carbon footprint, while enhancing users' experience and comfort?
- How does the design of transit hubs influence the mobility experience of commuters and what design strategies can enhance accessibility and users' satisfaction?
- How can design and technology embody and express cultural and shared values - e.g. local heritage - of transit hubs, meeting people's needs and sense of belonging?
- How can design and technology facilitate conversations among different stakeholders to look for solutions together for an attractive, sustainable and inclusive mobility hub? Which tools and methods?
- How can design and technology balance hubs as transit nodes in the network with the creation of liveable spaces, well integrated into their urban surroundings, promoting wellness, connectivity, and community?
- How can design and technology align slow development of the built environment with rapid tech advances to maintain mobility hubs still vibrant and efficient?

User-centred Mobility Services

Bio

Dr.ir. Suzanne Hiemstra-van Mastrigt is an Assistant Professor at TU Delft's faculty of Industrial Design Engineering and the director of the Seamless Personal Mobility Lab. In this Delft Design Lab, students and researchers work closely together with (public) transport and mobility companies and organisations, as well as local and national governments, to design solutions that match the needs of travellers and different stakeholders.
Suzanne's academic journey started with a focus on mobility product design, specifically vehicle seating and interiors, and has since evolved to include mobility services and systems design. She has over 15 years of experience in the mobility domain and a unique background that combines design research and consumer behaviour, with a usability, user-centred and human factors systems approach. She wants to design future mobility systems that enhance both the well-being of people and our planet. Therefore, her main research interest is how design can accelerate the behavioural shift towards more sustainable mobility. For example, in the EU project TULIPS, she investigates behavioural interventions to encourage shifts from airplane to train travel.

Email address: S.Hiemstra-vanMastrigt@tudelft.nl

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies and market competition drives change

"Individual Sub-Systems"

Many new sustainable transport modes and travel services are emerging, accompanied by a high adoption of new technologies. While seamless technologies, such as facial recognition to access vehicles, are available, different seamless sub-systems operate independently and do not form an integrated system. The market is largely dominated by a few big players, creating a Big Tech monopoly that fosters unfair competition and significantly influences politics, governance and regulations. A seamless experience will primarily be accessible to those who can afford individual transport, leaving others having to rely on inefficient and unattractive public transport services, characterised by high prices, lots of transfers and long waiting times due to the lack of integration between the different modes of transport. Another option to travel seamlessly would be to stay within the—monopolised—system of

one platform. People who are digitally illiterate will find themselves increasingly being excluded from mobility and, by extension, from society. The strong emphasis on individual mobility contributes to increasing congestion and pollution, with society depending on compensatory measures for the negative effects of mobility, such as carbon capture solutions. If there is no vision or direction from the government, there will be hardly any investments in new infrastructure and very limited new or improved public transport connections.

In the international travel sector, we see incremental improvements in sustainability in the aviation sector since the business case for scaling up sustainable aviation fuels (SAF) and hydrogen is tough without investments from the government. Hyperloop is starting to introduce its first routes, promising sustainable, fast, and safe travel; however, these higher average speeds will also lead to longer distances travelled and Amsterdam-Paris is soon becoming the new average commuting distance. Using automated vehicles makes it possible to use travel time as work time, thereby also increasing the commuting distance.

Top Right: Hyperconnected Systems

Society embraces new technologies and government intervention drives change

"Seamless Multi-Modal"

A variety of new sustainable transport modes and travel services are introduced, with government efforts focused on ensuring their seamless integration in planning and information, payment systems, ticketing, subscriptions, and travel rights. Mobility operators use open standards and data sharing and enable users to maintain control over their own data rather than depending on Big Tech companies. The government plays a crucial role in ensuring affordable mobility options for all while also implementing measures to limit excessive use of mobility, for example, by introducing a personal carbon budget. Tailored mobility packages are available to support multi-modal travels, and strategically located physical hubs ensure easy access for all travellers. Additionally, highly efficient Bus Rapid Transit (BRT) Systems equipped with automated buses enhance connectivity between regions. Automated vehicles are not allowed in city centres but will be integrated into the public transport system by transfer hubs on the edge of the city. This contributes to rural areas being better served.

Significant investments are being made in high-speed rail networks, making the international train more and more an attractive alternative to flying. Furthermore, the aviation sector is supported in investing in electrification of smaller airplanes, sustainable aviation fuels (SAF), and hydrogen-powered aircraft. We see the introduction of small, electrified airplanes that are primarily designed for business travel to hard-to-reach areas.

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

"Public Mobility Network"

Active mobility options, such as walking and cycling, along with shared mobility, are thriving as the government invests in 15-minute neighbourhoods and enhances the accessibility of public facilities such as schools and hospitals. Many cities have implemented car-free zones to promote a healthier living environment. The mobility system is optimised for collective societal goals, with most of the mobility organised through Commons, such as Mobility-as-a-Commons (MaaC). This integrated approach combines public transport with shared mobility solutions, creating a cohesive public mobility network.

Traveller privacy is prioritised, ensuring that users will feel secure when using these services. The market experiences minimal competition, resulting in limited incentives for improving mobility services. Consequently, few new services are introduced, and mobility costs remain high, reflecting true prices to include environmental impacts. In order to support those who cannot afford these prices, the government provides financial assistance. This can, however, lead to very high –almost unbearable- public costs. The need for mobility is critically questioned, embracing the idea that "less is more", and encouraging the use of non-mobility solutions such as remote working.

International travel is discouraged, with very limited options available. When necessary, sustainable modes of transport are prioritised to minimise environmental impact, reinforcing the commitment to a more sustainable future.

Bottom Left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"Fragmented Mobility Landscape"

The mobility landscape is highly fragmented, requiring users to navigate numerous apps, identifications, and subscriptions to be able to access different mobility services. This complexity adds to slow user adoption, and many users continue to rely on existing solutions. Mobility service offerings are particularly limited in areas with low market potential, such as less populated regions, where services are often very expensive and highly demand-driven. Moreover, there is a lack of digital connectivity between different modes of transport, with no open standards such as APIs, preventing integration and data sharing with government entities. This disconnection leads to an expensive and inefficient mobility system. Additionally, physical connections between different transport modes are inadequate, as there will be little investments in transport hubs to facilitate seamless transfers. We might see a deterioration of the current infrastructure, if not maintained. While there are some high-speed train connections available, sustainable options for international travel remain very limited, and the aviation industry strongly relies on fossil fuels.

Questions for Future Research

- How can we encourage a behavioural shift towards more sustainable transportation modes, including the adoption of Mobility-as-a-Service (MaaS) systems, and a transition from air to rail travel?
- How can we increase the (potential) user adoption of new, emerging sustainable transportation modes, such as Bus Rapid Transit (BRT), shared automated vehicles (SAVs), electric vertical take-off and landing vehicles (eVTOLs) and hyperloop?
- How can we make public transport the default option for travellers and make and keep mobility services accessible for everyone in terms of financial, cognitive, and physical barriers?
- How can we design and evaluate interventions to reduce our need for mobility?
- How can we ensure multi-modal integration of mobility services for door-to-door journeys, including transaction/ticketing, reservation, information and planning (TRIP)?
- How can we use user-centred development to bridge the gap between technology and users?

Multimodal City Logistics

Bio:
Bilge Atasoy is an associate professor at TU Delft, Mechanical Engineering in the Department of Maritime and Transport Technology. She develops methodologies towards adaptive transport and logistics systems. Her research lies at the intersection of operations research, behavioural modelling and learning algorithms. Her application areas cover various transport and logistics systems with a focus on multimodality. She is the recipient of ERC Starting Grant on Adaptive Transportation and Logistics Systems and runs other national and international projects, including the NWO project TRiLOGy focusing on multimodal city logistics. Prior to joining TU Delft, Bilge was a research scientist at the Intelligent Transportation Systems Lab at MIT where she managed projects on real-time optimisation as well as choice-based optimisation for various transport systems. Bilge received her PhD from EPFL as part of the Transport and Mobility Lab, and prior to that, she studied at Bogazici University, Türkiye, for her MSc and BSc degrees.

Email address: B.Atasoy@tudelft.nl

City logistics stands at the intersection of technological innovation and regulatory frameworks. Integrating waterways into urban transportation systems offers a promising solution to alleviate city road congestion. However, realising this potential requires advanced autonomy of vehicles both over water and land to keep costs down, advanced automated coordination between water and land supported by automated logistics hubs, and robust government regulation to ensure effective coordination between different delivery solutions.

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies and market competition drives change

"Robots are Moving our Goods(!)"

Even though the technology for automated electric boats/vessels is mature, it is not taken advantage of for logistics activities and is used mostly by those who can afford it for personal leisure activities. Automated delivery robots are a reality on the streets and are used by

various service providers as last-mile delivery solutions, which lead to crowded streets and pavements. These high-tech last-mile delivery companies are competing, and some have profitable businesses in isolation. The competition leads to cheaper and faster logistics solutions at locations and times that are profitable but not uniformly spread across the city.

The coordination between automated systems across different modalities is limited as there are no incentives to develop and manage automated logistics hubs to facilitate transfer across modalities. Technological advancements are, therefore, not making use of their full potential.

Lack of coordination across modalities entails that logistics activities in the cities mostly rely on roads. There are some logistics hubs developed for increasing the efficiency of last-mile delivery companies limited to land side. Waterways are only used for transporting materials and equipment for large-scale construction projects as the roads are not viable in historic city centres. Therefore, roads are still somewhat congested.

The high-tech solutions for the last mile delivery mostly come with electrification for small vehicles but as the government intervention is limited, the electrification is not widely spread across modalities. The heavy-duty trucks and vessels used in the cities are mostly running on fossil fuels.

Top Right: Hyperconnected Systems
Society embraces new technologies and government intervention drives change

"City Logistics in Harmony"

Automated electric boats/vessels are working in real-time coordination with automated land-based logistics systems supported by automated logistics hubs. Thanks to autonomy and electrification, different times of the day can be used to spread the transport peaks. Personnel costs are reduced due to autonomy, and noise is avoided as well.

Based on an analysis of transport flows together with various stakeholders, municipalities have a good understanding of the critical times and locations in the city, also considering how the city is connected to the whole transport chain in the country and beyond. Therefore, regulations are designed for the usage of space and time to facilitate the needed coordination (e.g., dynamic usage of space throughout the day/week across different functionalities, coordination, logistics hubs for the transfer and consolidation of cargo and communication across different modalities of transportation to serve tasks jointly). Moreover, there is a good understanding of what combination of solutions serves better the liveability and sustainability goals. As a result, cargo bikes, people carrying goods, delivery robots, electric vans, and small and large automated electric vessels are working in harmony. Yet, these developments towards sustainability and liveability entail certain compromises in efficiency (e.g., not always having the fastest solution).

Technology and regulations are working hand in hand such that technology makes it possible to have the regulations reasonable (i.e., not too restricted as we can make use of different locations and times in a coordinated way). The regulations, on the other hand, make it possible to make use of the full potential of the available resources. Coordination between different last-mile delivery companies is incentivised, and they thrive with the different solutions they offer.

The logistics burden on the streets is alleviated, as well as the congestion on the streets and waterways.

Government intervention through incentives, both for coordinating different delivery companies and for electrification, comes at a cost with increased taxes and possibly increased prices for certain undesirable solutions.

Bottom Right: Sustainable Slowdown
Society is cautious towards new technologies and government intervention drives change

"Coordinate what we have!"

Regulations lead to widespread adoption of electric modalities for logistics (e.g., boats, vans) but autonomy is limited. Manpower is still heavily involved.

The electrified transport systems, both on water and land, are coordinated through government regulations and incentives to serve mobility and logistics activities also in coordination with active modalities (e.g., cargo bikes, people carrying goods). Logistics hubs are supporting this coordination by facilitating the transfer and consolidation of cargo and serve as pick-up points. The timing of leisure activities on waterways and the use of facilities on the land are regulated to help coordinate the water and land-based transport activities.

However, due to limitations in autonomy, it is still costly to have logistics operations at off hours over water and land. Therefore, spatial and temporal resources are not used to their full potential. Logistics service providers have difficulty generating profits in these conditions and need subsidies for their sustainability actions. These subsidies come at a cost of additional taxes.

Roads are partially relieved thanks to the regulations on providing capacity for logistics activities across modalities.

Bottom Left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"Segregated Traditional Solutions"

The modalities used for logistics are similar to today: electrification is limited to small vehicles/vessels, and autonomy is limited. Manpower is still heavily involved. The use of water stays as today, i.e., used for tourism/leisure and for some large-scale logistics that are not possible over road.

Last-mile delivery companies that rely on trucks and vans pop up and disappear. There is no coordination between those companies for serving the city transportation and rather a competition. Some of these services are cheaper, and they promise short lead times due to the inherent competition. Therefore, part of the population can benefit from fast logistics services at low costs, but this is not uniform across the city.

Roads are still congested, and canals/waterways are also congested on holidays and high seasons for tourism.

Questions for Future Research

The following research questions are important in relation to the multimodal city logistics overlayed in the above scenarios, and some of these questions are investigated in research projects led by TU Delft, such as TRiLOGy, ADAPT-OR, and NOVIMOVE.

- How can we make use of the available space in cities more efficiently and sustainably through coordinating logistics activities across time and space?
- What is the right combination of different transport solutions (vessels, boats, vans, cargo bikes, roll containers, etc.) to serve the city logistics operations sustainably and efficiently?
- What are the needed characteristics of (automated) logistics hubs for a seamless transfer across modalities, e.g., water to land and vice versa, and where should they be?
- What are the right incentives to ensure collaboration across different logistics companies for shared use of resources and coordination of operations?
- What is the benefit of automation when it comes to logistics activities, i.e., automated delivery vehicles and vessels, automated logistics hubs, in terms of transport performance as well as liveability of the cities?
- What information technology and data sharing infrastructure are needed and how can they be best used for decision making, taking into account the existence of different stakeholders contributing to the system?

Intercity logistics

Bio

Yousef Maknoon is an Associate Professor in the Faculty of Technology, Policy, and Management at Delft University of Technology. He also serves as the Co-Director of the Operations Research and Behavioral Informatics (ORBIT) Lab at TPM. His research centers on the development of methodological tools for designing and planning logistics and transport systems. Before joining TU Delft, Dr. Maknoon worked as a Research Scientist at the Swiss Federal Institute of Technology Lausanne (EPFL). He holds both an M.Sc. and a Ph.D. from École Polytechnique de Montréal. Prior to that, he was an undergraduate student at Amir Kabir University, where he earned a B.Sc.

Email address: M.Y.Maknoon@tudelft.nl

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies, and market competition drives change

In this scenario, intercity logistics is driven by rapid technological innovation and market competition. Automated electric trucks dominate highways, delivering goods efficiently over long distances. Hyperloop freight systems connect key urban centres, enabling ultra-fast transport for high-value and time-sensitive goods. Electrified and semi-automated barges utilise waterways for bulk and containerised freight. Logistics hubs, managed primarily by private companies, prioritise profitability over accessibility, leaving rural and underserved areas with limited or costly services.

Environmental sustainability is deprioritised, with energy demands from automated fleets and Hyperloop systems straining infrastructure. Transportation costs decrease due to automation, driving a shift toward dedicated transport services over consolidated models. While this increases delivery speed, it reduces system-wide coordination and may increase inefficiencies.

Top Right: Hyperconnected Systems

Society embraces new technologies and government intervention drives change

In this future, intercity logistics is fully integrated and sustainable, driven by government-led investments and policies. Electrified and hydrogen-powered freight systems connect multimodal logistics hubs, seamlessly integrating road, rail, and waterways. Inspired by the principles of the Physical Internet, standardised modular containers and open data-sharing frameworks enable interoperability, real-time tracking, and optimisation across transport modes and providers.

Urban consolidation centres and regional logistics hubs minimise emissions and congestion through strict regulations and strategic deployment of automated vehicles and electric barges. Governments ensure equitable service delivery, extending robust logistics networks to rural and peri-urban areas.

Policies incentivise collaboration among logistics providers, enhancing resilience to disruptions such as extreme weather or geopolitical tensions. Circular economy principles, such as efficient resource use and waste reduction, are embedded in logistics strategies, making operations more sustainable and cost-effective.

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

This scenario emphasises a deliberate, sustainable approach to intercity logistics. Governments and industries prioritise proven technologies, such as electrified rail and hybrid freight systems, over experimental solutions. Shared logistics facilities, operated cooperatively, enable efficient consolidation and distribution of goods across regions and cities.

Behavioral shifts reduce reliance on long-haul transport, with production localised to decrease transportation needs. Electrified waterways play a critical role, with regulated access ensuring fair use of capacity and equitable service delivery. Policies incentivise small and medium-sized enterprises (SMEs) to adopt low-impact practices, such as using shared logistics hubs to streamline operations.

While this approach reduces carbon emissions and promotes community-focused logistics, slower adoption of innovative technologies limits efficiency gains. Labour shortages in the logistics sector create challenges, addressed partially by training programs and selectively automated systems. Rural areas still face accessibility issues due to high costs and limited infrastructure, prompting governments to explore targeted subsidies.

Bottom Left: Mobility Patchwork

Society is cautious towards new technologies and market competition drives change

In this scenario, governments and industries prioritise proven technologies, such as electrified rail and hybrid freight systems, over experimental solutions. Shared logistics facilities, operated cooperatively, enable efficient consolidation and distribution of goods across regions and cities.

Behavioural shifts reduce reliance on long-haul transport, with production localised to decrease transportation needs. Electrified waterways play a critical role, with regulated access ensuring fair use of capacity and equitable service delivery. Policies incentivise small and medium-sized enterprises (SMEs) to adopt low-impact practices, such as using shared logistics hubs to streamline operations.

While this approach reduces carbon emissions and promotes community-focused logistics, slower adoption of innovative technologies limits efficiency gains. Labour shortages in the logistics sector create challenges. Rural areas still face accessibility issues due to high costs and limited infrastructure, prompting governments to explore targeted subsidies.

Questions for Future Research

- How can intercity logistics systems develop standardised frameworks for containerisation and intermodal integration to improve efficiency and accessibility across diverse transport modes, including road, rail, waterways, and emerging technologies like Hyperloop?
- What strategies can be employed to mitigate the high energy demands of automated electric trucks and Hyperloop systems while meeting environmental sustainability goals in intercity logistics?
- How can policy frameworks ensure equitable logistics services for underserved rural areas while maintaining profitability in private-sector-driven logistics systems?
- What are the best practices for balancing proprietary data concerns with the need for open and transparent data-sharing frameworks in hyperconnected intercity logistics systems?
- How can intercity logistics systems enhance resilience against disruptions such as extreme weather events, supply chain bottlenecks, or labor shortages?
- How can intercity logistics systems balance the competing demands of cost efficiency, environmental sustainability, and equitable service delivery across urban, rural, and peri-urban areas?
- How can governments and industries promote behavioural shifts toward localised production and shared logistics facilities to reduce long-haul transportation needs while maintaining economic competitiveness?

Aviation

Bio

Dr. ir. Roelof Vos is an Associate Professor at the Aerospace Engineering Faculty of Delft University of Technology. His research is focused on new aircraft configurations and technologies to enable truly sustainable aviation. Amongst others, he is the lead for the Flying V project that is performed at TU Delft in collaboration with industrial partners. Vos has published 30 articles in peer-reviewed journals, presented over 90 conference papers, and holds four patents. He has worked on various projects funded by the European Commission, the Dutch Research Council (NWO), and through public-private partnerships. He teaches courses on Aircraft Design and Aerodynamic Design as well as professional classes on Aerodynamic Design and Hybrid-Electric Aircraft Design. He is also the author of the textbook "Introduction to Transonic Aerodynamics." Vos is an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA) and a member of the AIAA Aircraft Design Technical Committee. He holds a BSc (2004) and an MSc (2005) degree in Aerospace Engineering from Delft University of Technology and a PhD degree from the University of Kansas (2009) under the sponsorship of the Fulbright Program.

Email address: R.Vos@tudelft.nl

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies and market competition drives change

"Electrified Money Maker"

Regional aircraft are electrified, leading to a full-electric range of 1000 km. The low cost of electricity, their reduced noise profile, and their reduced maintenance cost make electric aircraft a commercially attractive alternative to fossil-fuelled aircraft. In addition, electrification improves the public perception of aviation, although the vast majority of the energy consumed by aviation still comes from fossil fuels.

Medium-range and long-range aircraft still operate on fossil fuels. However, the lower operational cost of electric aircraft makes it attractive to cover ranges up to 2000 km with an intermediate stop. This increases the number of take-offs and landings at airports, but due to the reduced noise profile of the aircraft, this is accepted under protest of citizens. Single-pilot operations have become the standard, which reduces the need for experienced pilots and enables the growth in air traffic.

Roelof Vos

Airports are expanding to handle more airplanes, and each gate has a fast-charging system. All airport ground vehicles are electrified, and many vehicles operate autonomously.

Top Right: Hyperconnected Systems

Society embraces new technologies, and government intervention drives change

"Costly Energy Mix"

Heavy investment from the European Commission has made hydrogen technology for aviation a safe alternative to fossil fuels. Regional aircraft use battery-electric propulsion to ensure cost-efficient travel up to 1000 km. Hydrogen is propelling medium-range aircraft, although airfare is rising significantly, which reduces the demand for air travel within Europe.

To foster change, the European Commission (EC) combines tax initiatives with subsidies and strict regulations to ensure that airlines that operate "green" aircraft can effectively compete within the European domestic market. At the same time, the EC is negotiating with non-EU countries about bilateral agreements to grow the market for "green" aircraft outside the EU, despite their much higher operating cost compared to fossil-fuelled aircraft.

European airports are undergoing a significant change. All airport vehicles are electrified, and a fast-charging infrastructure for regional aircraft is installed, as well as hydrogen fuel storage and distribution systems. While the number of electric aircraft is increasing, the number of medium-range aircraft is reducing due to the lower demand stemming from the higher airfare.

Long-range aircraft operate on a mix of fossil fuel and sustainable aviation fuel (SAF), depending on where they are operated from. While SAF is even more expensive than hydrogen, the lack of global availability of hydrogen prevents widespread adoption for intercontinental flights. Regulations in the EU enforce all departing long-range aircraft to have at least 70% of SAF.

Due to the high cost of fuel, European airports have become less attractive as hubs for intercontinental flights, and their number has reduced significantly, which further reduces local noise and emissions but also negatively impacts economic development.

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

"Subsidised Flight"

Sustainable aviation fuel (SAF) in the form of "green" synthetic kerosene is a safe alternative to fossil kerosene and requires the least adoption of existing aircraft, airports, and certification standards.

Because SAF is even more expensive than hydrogen, the European domestic market for air travel is heavily regulated. Taxation on fossil-fuelled intercontinental flights pays for the subsidised SAF-based medium-range and long-range flights from European airports. Nonetheless, the airfares are high, which reduces the demand for air travel within the EU.

Outside the EU, the global aviation market is growing, and fossil fuel is still the primary energy source. The cheaper fuel outside of the EU sparks the growth of new intercontinental hubs at the edge of the EU from which regional and medium-range airplanes are operated into the EU on a non-refuelling round trip.

Large airport hubs in the EU are reducing their capacity due to the large reduction of intercontinental flights, which reduces the noise and emissions around airports. Airport infrastructure stays largely the same, although the electrification of ground vehicles is mandated by new legislation.

Bottom Left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"Business As Usual"

Regional, medium-range, and long-range travel rely on fossil fuels. Although the public perception is that flying is a major contributor to climate change, the cheap tickets and economic benefits for society do not reduce the number of flights. On thin-haul routes, where rail does not provide a competitive alternative, the low airfare makes air travel the preferred option.

While the growth of the EU market is small, the global market for air travel is growing due to the increased wealth in developing countries. Despite steady technological advances, the contribution of aviation to global warming is steadily rising.
New technologies are developed that reduce emissions and cost, but progress is slow, and the impact is small. The global market remains unregulated, and neither tax incentives nor subsidies are used to stimulate change. Airport vehicles become fully electrified, reducing emissions and noise on the ground and improving the work environment for ground personnel.

Questions for Future Research

- What is the impact of new energy sources on aviation's contribution to global warming?
- What technologies need to be developed to enable climate-neutral aviation?
- What is the effect of new technologies on safety, operation, and airport infrastructure?

Small Electrical Aviation

Bio

Joost Ellerbroek is an assistant professor in the Control and Operations department of the Aerospace Engineering faculty of Delft University of Technology. His research is focused on complexity in aerial transportation systems and the design, analysis, and simulation of separation management systems, both for conventional aviation and small (urban) aerial transport. In his work, he emphasises the analysis and mitigation of system-wide emergent behaviour; global patterns of behaviour in multi-agent systems, that result from many individual local interactions together.

He has coordinated and collaborated in various projects funded by the European Commission, as well as industrially funded projects. He is a strong advocate of open science, open source, and open data, and has made several successful achievements, such as the development of the internationally broadly adopted BlueSky open-source ATM simulator. He teaches courses on Air Traffic Management, and programming and scientific computing in Python.

Email address: J.Ellerbroek@tudelft.nl

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies and market competition drives change

Personal electrical aircraft are used by wealthy individuals and business travellers. Commercial taxi services that use electrical aircraft are not widespread but are, for instance, employed at high-profile events to generate publicity. Electrical Vertical Take-Off and Landing (e-VTOL) vehicles are also used where previously a helicopter would be used, such as emergency medical transport, police surveillance, and personnel transport to offshore platforms. Because the cost of ownership and maintenance costs are lower for e-VTOL aircraft, it has become economically viable to base these vehicles where previously having a conventional helicopter would have been too expensive. Drones are used for emergency services, inspection, (sports) journalism, and (police) surveillance, as well as for private security for wealthy individuals and businesses. Mega-retailers dominate the market for delivery drones in specific areas where it is profitable to operate them.

Top Right: Hyperconnected Systems

Society embraces new technologies and government intervention drives change

E-VTOL aircraft are used where previously a helicopter would be used, such as emergency medical transport, police surveillance, and personnel transport to offshore platforms. Compared to conventional helicopters, e-VTOL replacements have brought down the cost of ownership and maintenance, and because of a high degree of automation, they are much easier to operate and no longer require expensive pilots. These emergency vehicles are, therefore, now also based where previously this would have been too expensive, such as smaller hospitals and more remote police stations. E-VTOL-taxi services are rare but can be used to reach remote and sparsely-populated areas when it is the most practical/economically sensible/ environmentally friendly mode of transport. Larger eVTOL vehicles also provide an efficient (shared, on-demand mobility) alternative on longer routes that still fall below conventional regional aircraft, such as travel across the North Sea. Drones are used for emergency services, inspection, (sports) journalism, and (police) surveillance.

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

Legislation for new configurations of electrical aircraft and drone applications is slow and mostly prohibitive, and a lack of societal acceptance is holding back new types of operation using these vehicles. E-VTOL aircraft slowly replace conventional helicopters where feasible. There is no public exploitation of electrical aircraft, and private use of (small) aircraft is heavily taxed and regulated, making it virtually non-existent. Drones are only used in sparsely populated areas for the inspection of crops or infrastructure. Drone use in urban areas is allowed only for emergency situations, such as medical transport.

Bottom Left: Mobility Patchwork

Society is cautious towards new technologies and market competition drives change

The development of electrical aircraft remains conservative, and their impact is small. E-VTOL concepts that do make it to operation are only used where they are economically more interesting than their fossil-fuel predecessors. As such, e-VTOL aircraft are slowly being adopted for public services such as emergency medical transport and police surveillance, as well as for personnel transport to offshore platforms. They are only rarely used for the private transport of wealthy individuals. New applications for these vehicles have not been developed. Drones are only used when there are no privacy issues and when there is a public or environmental benefit to using them, such as for crop and infrastructure inspection in remote areas.

Questions for Future Research

- What are the determining factors for the capacity of an airspace? How can we use analytical modelling and simulation to investigate these relationships?
- What makes a traffic situation complex? How can you model this, and how can you predict it?
- How predictable is air transportation? What factors affect this predictability?
- How can airspace structure and safety procedures be designed to optimise for safety, efficiency, and capacity?
- How should robust, safe, and efficient automated systems for separation management be designed?
- Is there a threshold to the (central) optimisability of flights due to limitations in predictability, communication, and demand?
- How can artificial intelligence methods contribute to the mitigation of emergent behaviour in complex multi-agent systems?

Smart Mobility: Multimodal Traffic and Demand Management

Bio:

Prof. Dr. Serge Hoogendoorn is distinguished professor Smart Urban Mobility at TU Delft, and is currently the director of the Transport & Mobility Institute. With a strong focus on traffic flow theory, pedestrian and crowd dynamics, and intelligent transportation systems, Serge has significantly contributed to advancing knowledge in the traffic and transportation domain. His research encompasses the development of mathematical models and simulation tools to understand and improve traffic flow and pedestrian movement in urban environments. He has published extensively in academic journals and has been involved in numerous national and international research projects aimed at enhancing the efficiency and safety of transportation networks. Serge is also recognised for his work on data-driven approaches and the application of artificial intelligence in transportation systems. His efforts in integrating traditional engineering principles with innovative data science methodologies are testaments of his the pursuit for smarter, more efficient urban transportation solutions.

Email address: s.p.hoogendoorn@tudelft.nl

Multmodal traffic and demand management involves the strategic coordination of traffic flows across diverse transport modes—such as walking, cycling, public transit, and private vehicles—with the aim of maximising the efficiency of existing infrastructure while advancing key policy objectives, including sustainability, equity, and safety. This field employs a variety of tools and measures, such as adaptive traffic signals, cooperative systems, real-time traffic information, dynamic road pricing, and behaviour-influencing demand management strategies. These interventions are designed to promote modal shifts, optimise travel behaviour, and ensure the resilience of the mobility system.

Serge Hoogendoorn

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies, and market competition drives change

"Decentralised Smart Traffic Transformation"

In this scenario, society fully embraces new technologies and market competition drives rapid change. Multimodal traffic and demand management is highly adaptive, user-centric, and heavily reliant on emerging technologies. Fully connected and automated vehicles, as well as smart wearables for cyclists and pedestrians, continuously transmit and receive detailed information through apps and sensors, enabling real-time optimisation of traffic flows. Intersections are controlled by advanced cooperative systems that use AI-powered swarm-intelligence algorithms to optimise movement based on individual priorities, such as value of time (VOT) or willingness to pay.

Mobility operates as a service, with private companies offering integrated solutions through MaaS-like platforms. Instead of traditional road pricing, private providers offer a decentralised and market-regulated tradable mobility credit system. Users earn or purchase mobility credits, which they can trade or spend on prioritised travel options, such as exclusive access to high-demand routes or premium transport modes. This system dynamically balances demand, encouraging modal shifts and reducing congestion while offering users flexibility and control.

However, the market-driven nature of this approach creates significant challenges for data sharing. In the absence of regulatory incentives or requirements, manufacturers and service providers tend to retain exclusive control over their data, viewing it as a competitive asset. This lack of interoperability reduces system-wide optimisation and hinders the seamless integration of services across providers. Some providers adopt limited, bilateral data-sharing agreements to improve their offerings, but the system remains fragmented, favouring users in high-demand urban markets while rural areas and low-income groups face limited access to cutting-edge solutions and tradable credits.

Dilemma: The decentralisation and market-driven nature of this scenario drive rapid innovation but raise critical questions about equity and accessibility. Should governments intervene to mandate data sharing and expand coverage to underserved areas, or would such regulations stifle competition and slow technological progress? Balancing innovation with fairness remains a pressing challenge, as the market often prioritises profitability over inclusivity.

Top Right: Hyperconnected Systems
Society embraces new technologies and government intervention drives change

"Unified Traffic Networks"

In this government-led scenario, multimodal traffic and demand management aligns with broad societal goals such as sustainability, equity, and accessibility. A centrally managed tradable mobility credit system, administered by public agencies, replaces road pricing, ensuring fair and efficient resource allocation in line with prevailing policy objectives (i.e., broad prosperity). The government distributes mobility credits based on societal objectives, such as reducing emissions, alleviating congestion, or prioritising accessibility for disadvantaged groups. Users can trade credits within regulated frameworks, incentivising environmentally friendly travel choices and optimising demand management.

Traffic management is centralised in interconnected smart traffic centres, leveraging AI to make decisions that balance efficiency with societal goals. For example, controlled intersections prioritise pedestrians and bicycles during peak hours, while public transport enjoys exclusive rights-of-way. Cooperative systems connect all vehicles and infrastructure, but their deployment is guided by stringent privacy regulations and equity considerations to prevent misuse of personal data. Policies emphasise inclusivity, ensuring rural and underserved areas are integrated into the broader mobility network. Rural-urban equity is further supported by investments in automated, demand-responsive transport for low-density areas. Real-time traffic information is widely accessible through public platforms, supporting transparent allocation of mobility credits and equitable use of infrastructure. Smart contracts automate credit transfers for seamless travel experiences, ensuring system efficiency while reducing administrative burdens.

This approach fosters sustainability, accessibility, and equity but depends on robust governance, public trust, and significant long-term investments. Centralised control raises concerns about accountability and resilience, requiring transparent decision-making processes to maintain public confidence.

Dilemma: Centralised control enables efficiency and alignment with societal goals but poses concerns about accountability, data privacy, and public trust. How can governments ensure transparency and safeguard individual freedoms while maintaining the centralised oversight required to deliver equitable and sustainable mobility? The trade-off between centralised decision-making and the potential risks of over-reliance on government systems highlights the tension between control and trust.

Did you know? When traffic demand increases, operations become less efficient—a phenomenon known as the capacity drop. On freeways, capacity can decrease by 15-30% during congestion, particularly at bottlenecks like on-ramps. This issue worsens with spillbacks, which can lead to gridlock. Similarly, in pedestrian or bicycle flows, bottleneck capacity decreases when queuing occurs. For crowds, this creates the paradoxical “faster is slower” effect: the faster a crowd tries to exit an area, the longer it takes. These phenomena underscore the importance of traffic management to maintain system efficiency. A simple analogy? Imagine a funnel of rice: the best way to get rice through quickly is to avoid congestion at the narrowest point (Hoogendoorn, 2011).

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

“Resilient Traffic Solutions”

This scenario reflects a society that approaches technology cautiously, emphasising traditional methods and more localised solutions. Multimodal traffic and demand management relies on proven and robust technologies, such as intelligent and connected traffic signals at intersections, loop detectors, and radar systems for monitoring flows. Cooperative systems and connected vehicle technologies are used with caution, ensuring privacy and security remain uncompromised. Local traffic plans emphasise simplicity and accountability, minimising reliance on external systems.

Cities prioritise pedestrians and bicycles, redesigning urban spaces to create low-traffic zones, wider sidewalks, and dedicated cycling corridors. Road pricing is implemented to discourage car use, but it remains straightforward and transparent, avoiding complex algorithms or opaque decision-making processes. Public transport becomes the backbone of the mobility system, supported by significant investments in capacity, reliability, and accessibility to attract users away from private cars.

Traffic information systems are designed to be intuitive and universally accessible, still also communicated through roadside displays, community channels, or simple apps with minimal user data collection. Regional traffic centres focus on transparency, ensuring operators can easily understand and communicate control strategies to the public. Participatory traffic governance encourages public engagement, allowing communities to shape local mobility priorities.

This approach fosters equity, environmental benefits, and resilience in the face of technological vulnerabilities, but it may struggle to keep pace with growing urban mobility demands or adapt quickly to unexpected disruptions, such as extreme weather events or rapid urbanisation.

Dilemma: The cautious approach prioritises resilience, equity, and environmental benefits, but it risks falling behind the pace of urbanisation and mobility demands. Should investments focus on scaling proven, low-tech solutions or cautiously adopting advanced technologies to remain competitive? This scenario faces the challenge of maintaining inclusivity and environmental goals while addressing growing pressures on infrastructure and mobility systems.

Bottom Left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"Fragmented Traffic Ecosystems"

In this market-driven scenario, multimodal traffic and demand management is fragmented, dominated by private companies that prioritise profitability over societal objectives. Road pricing systems, implemented by private entities, follow a "pay-per-use" model, with fees dynamically adjusted based on demand and infrastructure costs. Controlled intersections and cooperative systems are limited to premium urban areas, where high-end services optimise traffic flows exclusively for paying customers.sTraffic management tools function independently, optimising routes for individual users without considering collective goals like equity or sustainability. Advanced navigation systems cater to paying customers, providing personalised routing and premium options for urban mobility. However, the lack of integration between these systems and broader traffic management frameworks prevents alignment with societal objectives, such as equity or environmental goals. This fragmented approach exacerbates inequalities. Low-income populations face reduced access to quality mobility services, while rural areas rely on outdated traffic management methods due to limited investments in new infrastructure or technologies. Urban-rural mobility divides deepen, with urban residents enjoying advanced mobility services while rural areas stagnate. Overall, the system prioritises economic gains over societal benefits, creating a stark contrast between urban and rural mobility experiences and neglecting environmental or equity considerations.

Dilemma: Fragmentation fosters competition and economic efficiency but widens social and geographic inequalities. Should governments intervene to bridge the growing urban-rural divide and regulate private service providers, or would such interventions stifle innovation and burden the system with inefficiencies? This tension between economic freedom and societal equity highlights the difficulty of ensuring fairness in a market-dominated ecosystem.

Did you know? User-optimal vs. system-optimal: contrary to intuition, when every traveller chooses the shortest route (user-optimal), it does not result in the best outcome for the entire network. (Wardrop, 1952) Achieving system-optimal conditions—where total travel time is minimised—requires some travellers to make sacrifices, such as taking slightly longer routes. The gap between user-optimal and system-optimal outcomes can grow with traffic demand, reaching up to 30%. Strategic interventions, like incentivising alternative routes, are crucial for improving overall efficiency and benefiting the collective.

Questions for Future Research

- How can multimodal traffic and mobility management systems be effectively integrated to optimise efficiency, equity, and sustainability?
- What governance frameworks are needed to ensure interoperability in fragmented or market-driven ecosystems?
- What are the best practices for collecting and integrating data, from roadside infrastructure to floating car data, to enhance multimodal traffic and mobility management systems?
- How can data science and AI improve predictive management capabilities in multimodal traffic and mobility management systems?
- How can decision-makers maintain autonomy and accountability in AI-driven multimodal traffic and mobility management systems?
- What ethical and governance frameworks are required to ensure public trust in AI-managed traffic systems?
- What are the trade-offs between efficiency and robustness in multimodal traffic and mobility management systems, and how can these be addressed?
- What strategies can multimodal traffic and mobility management systems use to handle exceptional events, such as infrastructure maintenance, extreme weather, or power outages?

Governance and integration

Bio

Wijnand Veeneman is a full professor of Governance of Infrastructure and Mobility. He is researching, educating and advising on infrastructure governance, with a focus on public transport organisation and management for both public transport authorities and operators. In addition, he is reaching and researching project management in large engineering projects in masters and executive programs of organisations like Delft University of Technology, Shell, Essent, Toptech and other technology companies.

His specialties are comparative analysis of governance in infrastructures and mobility and public transport, more specifically, governance models and strategies for clients, including tendering strategies: both preparing terms of reference from the principal perspective as well as bids from the agent's perspective.

He is a regular member of committees advising the government in the field. For example, he was a member of the committee preparing an advice for the Dutch Council of the Environment and Infrastructure on the relation between local and supranational decision making: between you and the Union (Tussen Brussel en de burger) and on international rail services (Changing Tracks). Another example is his membership of the Review Board of the Parliamentary Inquiry into the High Speed Train program and Parliamentary advice of a new status for ProRail, the Dutch rail network manager.

Email address: W.W.Veeneman@tudelft.nl

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies, and market competition drives change

"Market Mastery"

In case that the initiative for innovation is put at market players and strong acceptance of these innovations, what focus would governance have? In this scenario, government has a limited role in facilitating the market, not by initiating, but by providing room on infrastructure and for innovation. We would expect a double focus of government in this scenario. On the

one hand, the success of innovative services can be helped by the standardisation of technologies (in parallel of the development of 5G technology). This will often be about the interaction between the levels of the mobility stack, between service and vehicle, and between vehicle and infrastructure. Think about how standardised road design could support self-driving vehicles. But also in the supporting information infrastructure, think about standardised APIs in booking and ticketing systems. Finally, standardisation could be required in the interaction with the energy system. Think about the requirement of new service providers on vehicle to grid support of new fleets with charging needs. Or standards on inductive or plugged in charging, allowing for automation of charging. This is where government can play a role in maximising competitive strength of the market through standardisation, probably mostly on a European level.

Also, one could expect that this scenario could have downsides on certain public values. The expectation is that market parties, especially the more innovative ones, are focusing on shareholder value. That means user value and societal value might be under pressure. In this scenario, we would expect government to be market masters and regulate some consumer rights and externalities, like emissions and safety. In this scenario, government would stay away from technical regulation and would focus on economic regulation (like emission pricing) or market access limitations (like licencing), to maximise the freedom of new entrants to innovate. One would also expect a renewed interest in market regulation aimed at cornering anti-competitive behaviour. As tech-innovations have the tendency to monopolise the market, the competition is dependent on governments keeping the market open.

Top Right: Hyperconnected Systems

Society embraces new technologies, and government intervention drives change

"Procuring Pods"

In this scenario government is initiating technological innovation and adoption is high. Where in the first scenario, we expect market entrants to focus on services and vehicle; here, infrastructure innovations are also possible or even likely, with the public focus on that. In the current time, it is unlikely that the innovations initiated by government are aimed at mobility growth. We could see other focuses. Governments could focus on a better distribution of the existing capacity on infrastructure that is more in line with public goals. Or on technological systems aimed at fair or peak pricing of the use of infrastructures or for the widespread use of mobility budgets.

In addition, platform technologies like MaaS, shared modes, or newer technologies as self-driving vehicles could become part of "public transport", with regional governments providing their inhabitants with integrated services, tying these modes together in a single mobility offering to their constituents. One could also think about the introduction of new types of vehicles using infrastructure that has outlasted its original purpose, like smaller automated pods on rails.

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies, and government intervention drives change

"Constrained Trains"

In this scenario government is expanding its role as initiating mobility innovations, however, these innovations are mostly grounded in current technology, like trains and busses. New technologies are not easily adopted, the focus is on recombining existing technologies into mobility innovations. As stated in scenario Hyperconnected Systems, in the future, this probably is not aimed at facilitating mobility growth, but at societal effectiveness of the use of existing infrastructure and mobility services and efficient delivery of those services. One example could be the roll-out of high-occupancy-vehicle lanes; no new technology but more efficient use of existing infrastructure. Or the wider deployment of tax-related instruments, taxing energy (beyond fuels) or CO_2 emissions to drive efficient and clean mobility.

Broad welfare could find its way to which governments evaluate infrastructure projects priorities or procurement. Currently, the tools that are institutionalised in decision-making on mobility are highly focused on economic value of infrastructure, based on the value of accessibility: as mobility provides people easier access to more places, this provides more value to all and society. However, other values, like health and sustainability have widened the perspective with a new appreciation of the value of less mobility. Balancing these perspectives in the way that decisions are made by governments might have been solved, analytically and politically.

Bottom Left: Mobility Patchwork
Society is cautious towards new technologies, and market competition drives change

"Demand Drive"

In this scenario, the government is leaving the initiative to market parties that would work mostly with existing technologies, maybe with new applications, for mobility. An example is open access on the rail network. New entrants in the market can claim space on the network and the role of government is limited to facilitating these operators to deliver these services with infrastructure and maybe with some additional services.

The laid-back approach of government facilitates operators to seek out attractive markets, leading to a focus on the more high-demand connections, areas and times. It could very well be that government is adding some requirements to these operators in terms of their performance on other aspects than mobility provision, like safety and sustainability. Again, growth of mobility is probably not the driver, but a selection of markets, given the stricter conditioning of mobility through limitations on resources (like staff and materials) and from requirements (like emissions and norms). One could expect that more infrastructure-heavy forms of transport in this scenario are more vulnerable to the reduced impetus from long-term government investments and the short-term rent-seeking behaviour of private investors.

Questions for Future Research

- How is governance, the way that we make decisions on infrastructure and mobility, driving the mobility solutions that we get?
- How can we change governance to do justice to the major challenges that are currently demanding new and innovative solutions?
- How will we make decisions in mobility and infrastructures that do better justice to the broad prosperity requirements that society is putting forward, including rethinking the current institutions?
- How can governance be restructured to do justice to the increasing complexity and volatility of the world of mobility, from the level of societal choices, via the level of project choices, to the level of operational choices?
- How should we align our understanding of the mobility system closer to the way we make decisions about it, to the governance. Novel ways of modelling and more open governance can help deal with the inherent uncertainty of major transitions in mobility.

Public Space

Bio

Stefan van der Spek is an Associate Professor of Urban Design at TU Delft, Faculty of Architecture and Built Environment and is currently the director of VR-BK, the VR-lab within BK-Labs. Stefan received his PhD in 2003 with his thesis titled 'Connectors, the way beyond transferring'. The project called 'Intermodal Transfer Points' was part of TRAIL's 'Seamless Multimodal Mobility' programme. Today Stefan's focus is on the role of technology in Urban Design, such as tracking technologies, VR and AR as tools for design (education) and the potential of AI for improving and optimising design. This all ensembles within 'People, Movement and Public Space'.

Email address: S.C.vanderSpek@tudelft.nl

Four Scenarios

Top Left: Innovation Fast Track
Society embraces new technologies, and market competition drives change

"Fast City"

Driven by rapid technological innovation and use of AI for all services, cities transform into urban landscapes without spatial-temporal constraints, leading to more urban sprawl. Different transport modes facilitate automated and individual door-to-door transport for all ages and all users, resulting in many criss-cross movements and domination of the public domain by all kinds of vehicles. Although the air gets cleaner as combustion engines are expelled from the cities, many different modes occupy the space: Main streets are possessed by both driving and parked vehicles, leaving limited space, fragmented networks and a low-quality public space for pedestrians and active mobility modes.
Centralities appear and disappear quickly in this urban landscape: everything is in constant motion. Only a limited number of transit corridors exist, resulting in limited coverage of public transport and scarcity of central hubs. Within and around these high-density nodes, public space is assigned to people, resulting in living spaces: Gardens of Eden.

Dilemmas: fast and efficient individual transport versus overcrowding of all roads. Quick implementation of new technologies (construction by design?) versus negative collateral impact of implementations of immature innovations. Benefit for whom: End-user or company? Where is the material to build and construct the required 'hardware'?

Stefan van der Spek

Top Right: Hyperconnected Systems

Society embraces new technologies, and government intervention drives change

"City Life"

In this scenario, technological innovation is implemented in a balanced, thoughtful way. As public transport is secured on all scales, many intermodal transport hubs exist anchoring thriving places. High-speed lines connect the central nodes, while automated vehicles provide access on district scale. On a local scale, active modes, such as walking and biking flourish, creating living structures and vibrant places, resulting in liveable cities.

Public space is well-organised and accessible, providing good accommodation for active modes. Green corridors and parks create a comfortable and adjustable climate, improving air quality, temperature and noise-levels. The city is flourishing as people have low speeds. Although centres highlight higher density and mix of functions, the transport corridors result in accessible and liveable streets providing all requirements for a 15" city.

Dilemmas: investment versus return: Who pays for it? Costs of public services? Slow introduction, reducing will/climate for investment? Government limiting capability of services?

Bottom Right: Sustainable Slowdown

Society is cautious towards new technologies, and government intervention drives change

"Local Life"

Traditional transport modes are increasingly optimised through modern and sustainable alternatives, enhancing their integration with urban landscapes. The development of polycentric cities and regions supports the "15-minute city" concept, significantly reducing car usage by promoting walking and accessible public transportation. This approach creates a more walkable environment, with ample space dedicated to active modes of transportation, as long-distance travel becomes less common. As a result, neighbourhoods begin to thrive, with a focus on producing food locally and fostering a sense of community. These changes not only improve the quality of life for residents but also contribute to a more sustainable and resilient urban future.

Dilemmas: What products can we produce and reuse locally? How can we innovate if we limit our world to a smaller scale, reducing exchange with other places and cultures?
Keywords: Sustainable Alternatives, 15-Minute City, Active Modes of Transport, Local Food Production, Community Focus

Bottom Left: Mobility Patchwork

Society is cautious towards new technologies, and market competition drives change

"Slow City"

In this scenario, the economy takes precedence, leaving public spaces as an afterthought. The city is filled with various vehicles, and while AI governs the systems, poor and unreliable services lead to frequent gridlocks. The cityscape becomes monotonous and fragmented, with no place standing out as exceptional. The pressure on public spaces increases, resulting in diminished social cohesion and a less vibrant community life.

The dominance of vehicles in the urban environment creates a chaotic and congested atmosphere. Streets are often clogged with traffic, making it difficult for pedestrians and cyclists to navigate safely. The lack of reliable public transportation options forces residents to rely heavily on private vehicles, exacerbating the problem. Public spaces, which should serve as communal areas for relaxation and social interaction, are instead overshadowed by the constant flow of traffic and the noise it generates.

Moreover, the absence of well-designed public spaces means there are fewer opportunities for community events and gatherings, leading to a sense of isolation among residents. The city's infrastructure, focused primarily on economic activities, neglects the importance of creating a liveable and enjoyable environment for its inhabitants. As a result, the overall quality of life declines, with residents feeling disconnected from their surroundings and each other. This imbalance between economic priorities and the need for vibrant public spaces ultimately undermines the city's potential for growth and prosperity.

Dilemmas: How to improve public space and keep a thriving city when Smart City Technology is neglected, and public transport is not invested in? Can enhancing green spaces prevent further negative impacts of this scenarios?

Questions for Future Research

Fast City

- Technological Innovation and AI Services: How can rapid technological advancements and AI services be managed to minimise urban sprawl and ensure equitable access to transport?
- Transport Modes and Public Space: What strategies can be implemented to balance the use of different transport modes while preserving high-quality public spaces for pedestrians and active mobility?
- Urban Landscape Dynamics: How do the rapid appearance and disappearance of centralities affect urban planning and the provision of public services?

City Life

- Intermodal Transport Hubs: What are the best practices for designing intermodal transport hubs that anchor thriving urban places?
- Active Modes and Public Space: How can cities promote active modes of transport while ensuring well-organised and accessible public spaces?

Local Life

- Sustainable Alternatives: What are the most effective sustainable alternatives for modern transportation methods in urban areas?
- 15-Minute City Concept: How can the 15-minute city concept be effectively implemented to reduce car usage and promote walking and public transportation?
- Community Focus: How can urban design foster a sense of community and improve the quality of life for residents?
- Innovation and Exchange: How can cities innovate while maintaining a smaller scale and reducing exchange with other places and cultures?

Slow City

- Public Space Improvement: What strategies can be employed to improve public spaces in cities where the economy takes precedence over public transport and smart city technology?
- Green Spaces: Can enhancing green spaces mitigate the negative impacts of poor public transport and fragmented cityscapes? If so, how?
- Social Cohesion: How does the pressure on public spaces affect social cohesion and community life in urban areas?
- Economic Prioritisation: How can cities balance economic growth with the need for vibrant and cohesive public spaces?

Data & AI

Bio

Dr. Sascha Hoogendoorn-Lanser, Director of the Mobility Innovation Centre Delft and part of TU Delft's Innovation & Impact Centre, leads strategic initiatives that shape the future of transportation. Her work focuses on advancing innovative technologies and policies to create a sustainable, safe, inclusive, and future-proof mobility system, encompassing optimised passenger transport and resilient freight infrastructure.

Sascha leads AIM-TT (AI Learning Initiative for Multimodal Traffic and Transportation), a collaborative effort with private and public stakeholders. This initiative explores the potential of AI in the MTL domain, emphasising practical learning from real-world applications. It focuses on co-developing knowledge through use cases, each tailored to different temporal and spatial scales, transportation modes, application contexts (e.g., regular operations and disruptions), data availability, and other critical factors.

Email address: S.Hoogendoorn-Lanser@tudelft.nl

Four Scenarios

The scenarios explore how data and AI may transform the mobility landscape by 2050, driven by two critical uncertainties: the degree of government intervention and societal openness to emerging technologies. These narratives are not predictions but frameworks to examine how varying governance models and technological adoption could shape the interplay between innovation, equity, and ethical considerations in mobility systems. Each scenario presents a distinct vision of the future, from market-driven ecosystems dominated by private companies to government-led frameworks prioritising societal goals. Central to all is the transformative potential of AI-powered systems, such as predictive analytics, automated decision-making, and real-time optimisation. At the same time, these advancements raise critical questions about privacy, human autonomy, and the societal impacts of algorithmic decision-making. The scenarios highlight both the opportunities and challenges of integrating data and AI into mobility, offering a lens to evaluate trade-offs between efficiency, inclusivity, and sustainability in an increasingly connected world.

Top Left: Innovation Fast Track
Society embraces new technologies, and market competition drives change

"Big Tech Mobility"

In this future, large technology companies have revolutionised the mobility ecosystem by leveraging vast amounts of user data and advanced AI systems. Data collection, ownership,

Sascha Hoogendoorn-Lanser

and usage enable real-time traffic optimisation, personalised route planning, and dynamic pricing mechanisms, delivering seamless and highly attractive mobility services. AI tools analyse patterns, predict user needs, and adapt services to create a truly user-centric experience, improving convenience, efficiency, and satisfaction. AI-powered platforms excel in addressing individual and often local preferences. Swarm-intelligence algorithms manage intersections, reducing congestion and saving time, while predictive analytics ensure personalised service delivery. Private companies continuously innovate, offering cutting-edge mobility solutions that attract investment and drive rapid technological progress. The competitive market fosters creativity, resulting in a diverse array of AI-enabled services tailored to users' varying needs.

However, this success comes with challenges. Data privacy remains a concern as users exchange personal information for access to these advanced services, often without a full understanding of how their data is handled. AI systems increasingly shape user decisions, raising questions about maintaining autonomy in a world where algorithms determine optimal routes and modes. Ethical considerations, such as mitigating bias in AI systems and ensuring inclusivity, require vigilance to prevent inequities. While interoperability across systems can be limited, ongoing collaboration efforts between companies hint at a growing recognition of the need for shared standards to unlock even greater efficiencies.

Dilemma: In a market-driven ecosystem dominated by big tech, the transformative potential of data and AI creates seamless, personalised mobility services, but it also raises critical concerns. Users gain convenience and efficiency by trading their personal data, yet this exchange often lacks transparency, leaving privacy at risk. AI systems, while optimising individual experiences, increasingly influence user decisions, challenging autonomy and informed consent. Additionally, without ethical oversight or shared standards, proprietary algorithms may perpetuate biases, exclude underserved populations, and limit interoperability. The core dilemma lies in balancing innovation and competitiveness with fairness, privacy, and inclusivity in a largely unregulated environment.

Top Right: Hyperconnected Systems

Society embraces new technologies and government intervention drives change

"Unified AI Networks"

In this government-led scenario, data and AI are harnessed to create a unified and equitable mobility system. Centralised data platforms are used to collect, standardise, and share information across public and private entities, enabling seamless integration of AI-powered services. From real-time traffic management to optimised logistics hubs, AI systems prioritise sustainability, accessibility, and societal goals. Standardisation ensures interoperability, allowing various modes of transport to work harmoniously, from urban transit to rural mobility solutions.

AI plays a central role in achieving societal objectives. Predictive algorithms optimise travel demand and reduce emissions, while dynamic routing systems balance congestion and efficiency. Transparent, data-driven governance builds public trust, with AI tools used to allocate resources equitably, such as prioritising underserved regions or supporting inclusive transport options. Privacy-by-design frameworks ensure that personal data is protected, fostering confidence in the system.

Dilemma: Centralised AI systems in government-led ecosystems offer unprecedented opportunities for achieving societal goals like sustainability and equity, yet they come with significant trade-offs. While transparent, data-driven governance builds public trust, the extensive use of data collection and AI raises concerns about surveillance, privacy, and cybersecurity. Additionally, as decision-making increasingly relies on AI, maintaining human autonomy and accountability becomes a pressing challenge. The dilemma lies in balancing efficiency and control with fairness, individual freedoms, and public confidence in a highly regulated environment.

Bottom Right: Sustainable Slowdown
Society is cautious towards new technologies, and government intervention drives change

"Cautious AI Innovation"

In this scenario, society takes a cautious approach to technological adoption, prioritising proven, low-risk AI applications and data usage that align with sustainability and equity goals. AI and data systems are employed primarily to enhance the efficiency of existing infrastructure and services rather than introducing disruptive innovations. For instance, predictive algorithms are used to optimise schedules and resource allocation in electrified rail networks and cooperative logistics hubs, reducing energy consumption and minimising waste.

Government policies enforce strict regulations on data collection and usage to address privacy concerns and build public trust. Shared, localised data platforms facilitate collaboration among transport providers, but they avoid invasive data collection practices. AI systems are designed to support rather than replace human decision-making, ensuring transparency and preserving autonomy for both operators and end-users. Ethical frameworks guide the development of AI tools, focusing on inclusivity and alignment with societal values such as accessibility and environmental stewardship. Dilemma: The cautious adoption of AI ensures strong privacy protections and ethical oversight, fostering trust and inclusivity. However, this deliberate approach may struggle to address emerging mobility challenges and dynamic demands. The dilemma lies in balancing the need for controlled, ethical progress with the agility required for smarter, adaptable mobility solutions.

Bottom Left: Mobility Patchwork
Society is cautious towards new technologies and market competition drives change

"Fragmented AI Solutions"

In this market-driven and fragmented future, private companies develop niche AI and data-driven solutions tailored to specific markets and user groups. These solutions often operate independently, creating a patchwork of disconnected mobility services with varying levels of sophistication and adoption. Data silos dominate the ecosystem, as companies prioritise protecting proprietary information over collaboration. AI tools are primarily designed to optimise individual services, such as personalised navigation or demand-responsive transport, rather than achieving broader societal goals like sustainability or equity.
Limited government oversight exacerbates inefficiencies, as there is little coordination or standardisation of data and systems. Privacy concerns remain unaddressed, with minimal transparency around how data is collected, shared, or monetised. Users in urban areas may benefit from advanced AI-powered services, but rural and underserved regions are often left with outdated or no solutions. Algorithmic biases further exacerbate social inequalities, as AI systems prioritise profitability over inclusivity.

Dilemma: This fragmented system highlights the tension between innovation and societal cohesion. While private companies drive AI-advancements in niche areas, the lack of interoperability, ethical oversight, and equitable access undermines the potential for system-wide benefits. The dilemma lies in addressing growing inequities and inefficiencies while preserving the competitive dynamics that spur technological innovation in this market-driven framework.

Questions for Future Research

- How can AI systems in mobility be designed to complement human decision-making, supporting autonomy and accountability rather than replacing human oversight?
- What ethical frameworks are required to mitigate biases in AI-driven mobility decisions and ensure inclusivity and equality for all user groups?
- How can public trust in AI-powered mobility systems be enhanced, addressing both the overestimation of AI capabilities and scepticism about its decisions?
- What strategies can address gaps and biases in mobility data, particularly for underrepresented scenarios such as incidents, extreme weather events, or infrastructure disruptions?
- How can AI decision-making in mobility systems be made more transparent, fostering accountability and equitable outcomes across stakeholders?
- How can AI tools effectively manage the complexity of mobility systems, characterised by multiple actors, interconnected decisions, and competing objectives?

Mobility Innovation Ecosystem

Bio

Deborah Nas is a Professor of Strategic Design for Technology-Based Innovation at the Faculty of Industrial Design Engineering and leading the Mobilisers vision team, responsible for the future scenarios outlined in this document. She plays a key role in various university-wide initiatives, having led vision teams on quantum technology, digital campus, and energy transition. Besides, she is a member of TU Delft's Dream Hall steering committee, where ambitious student teams push technical boundaries by developing innovations such as hydrogen boats, hyperloop systems, and exoskeletons.

Beyond her role at TU Delft, Deborah is the Innovation Lead at QDNL's Centre for Quantum & Society, a member of the supervisory board of Hardt Hyperloop, part of the investment committee of Innovation Quarter, and a keynote speaker. She is the author of *Design Things That Make Sense* (2021), a practical guide and toolkit for designing technology-enabled products. Known for bridging academic theory and practical application, Deborah is widely recognised for her insights into how technology shapes the future.

Four Scenarios

Innovation Fast Track
Society embraces new technologies and market competition drives change

"Competing for the Future"

The startup ecosystem thrives, with private investment and venture capital driving mobility innovations tailored to European needs. Capital-intensive technologies, such as automated cars, are dominated by global giants from the US and Asia. The automotive sector mirrors the computing industry, with distinct roles for hardware manufacturers and software developers.

Small, automated delivery robots crowd urban pavements, while larger automated delivery vans serve less dense areas. Remote operators in low-wage countries supervise these vehicles to optimise costs. Light electric vehicles dominate urban mobility, with startups emphasising sustainable, compact designs. However, high company turnover causes uncertainty about long-term service continuity.

Subscription-based models lower adoption barriers but make companies asset-heavy, leading to frequent bankruptcies and market volatility. The rapid pace of innovation and a focus on scaling quickly often result in security breaches and malfunctioning technologies, eroding consumer trust. Privacy becomes a luxury, with economic models prioritising data monetisation. Consumers are enticed to trade personal data for discounts, fuelling privacy concerns.

Hyperconnected Systems

Society embraces new technologies; government intervention drives change

“A Shared Vision for Innovation”

Public-private partnerships flourish, with the government acting as a launching customer for startups and providing access to critical data resources. Open-source solutions ensure transparency, autonomy, and interoperability in platforms for data sharing, logistics coordination, and public space management. Innovations are evaluated against responsible innovation guidelines, aligning with societal and environmental goals.

Government AI and quantum computing centres co-develop digital solutions together with companies, fostering user trust and reducing business risks. However, the associated tender processes—designed to prevent favouritism—slow down innovation timelines. Also, the long-term contracts offered to winning parties incentivise innovation but slow market entry for new players. Living labs facilitate experimentation and societal co-creation, enhancing trust.

Public investments focus on technologies to produce carbon-neutral energy for decarbonising national mobility. However, international mobility—such as aviation and shipping—is governed by complex international frameworks, making progress slower. Besides, these sectors remain challenging to decarbonise, and traffic volumes continue to grow. The production of green hydrogen and e-fuels demands significantly more energy than direct green energy use, leading to persistent shortages despite increased energy generation. Consequently, green hydrogen is prioritised for hard-to-decarbonise Dutch industries like chemicals and steel. To mitigate the footprint of international mobility, Europe has prioritised the development of a hyperloop network. With low energy consumption, automated operations reducing the need for scarce skilled labour, and new, standardised regulations across Europe, the hyperloop emerges as a competitive alternative to international trains and planes.

> Did you know? Many of the Netherlands’ transport activities take place beyond the country’s borders, resulting in 75% of greenhouse gas emissions occurring abroad. For land transport, this accounts for 43%, and for inland shipping, 38%. In maritime transport, 93% of emissions occur outside Dutch territorial waters. Similarly, 93% of emissions from aviation take place outside the Dutch national borders (CBS, 2024)

Sustainable Slowdown

Society is cautious towards new technologies and government intervention drives change

“Deliberate Innovation for a Balanced Future”

The government prioritises community-driven initiatives and behaviour change, investing in proven technologies over untested ones. Bottom-up initiatives, such as neighbourhood vehicle-sharing schemes, are supported by government-provided digital platforms that streamline legal and administrative processes. These platforms encourage the shared use of cars, microcars, and light electric vehicles.

Although society remains cautious about adopting new technologies, digital platforms and AI tools introduced since the 2020s have become deeply integrated into daily life by 2050. These tools power travel budgets and remote work systems, effectively reducing mobility demand and aligning with CO_2 reduction goals. However, reliance on personal data tracking to operationalise these travel budgets raises significant privacy concerns, with citizens actively resisting surveillance creep.

Strict regulations ensure safety and environmental standards but slow advanced technology adoption. Public sector consultancy agencies flourish, guiding communities through behaviour-change initiatives. The Netherlands favours European suppliers to reduce privacy risks, while American and Asian automated vehicle providers show little interest in Europe’s fragmented markets and strong regulations.

Mobility Patchwork
Society is cautious towards new technologies; market competition drives change

"Surviving the Mobility Mosaic"

Local and international startups operate in the Netherlands but struggle to scale due to fragmented regulations and limited user uptake. Local governments issue short-term contracts focused on efficiency, discouraging investments with long return horizons. Private companies dominate urban markets, while large international players deprioritise the Netherlands due to its small market size and fragmented regulations.

Startups often replicate mobility concepts popular abroad to minimise risks. Many aim to be acquired by larger international firms after building local customer bases. People who can afford it purchase luxury, highly automated vehicles, which come with expensive subscription fees and insurance premiums due to costly repairs. Insurers differentiate premiums between sensor-rich and sensor-poor vehicles to attract diverse customers.
Innovation occurs in silos, with limited interoperability and public oversight. While competition drives localised innovation, companies focus on profitable routes and areas, exacerbating inequalities.

Questions for Future Research

- How can mobility innovation ecosystems balance rapid technological development with societal and ethical considerations?
- How can governments shape equitable and sustainable mobility innovation landscapes?
- What are promising cross-border innovation approaches to decarbonise international travel?
- Which factors determine societal willingness to adopt mobility innovations?
- How can stakeholders collaboratively address cybersecurity and privacy challenges in data-driven mobility innovation?
- How can policymakers anticipate and mitigate unintended consequences of fast-paced technological innovation in mobility?
- How can public-private partnerships maintain transparency and fairness in competitive mobility markets?

Appendix I: Broad Prosperity

Each scenario describes a possible future and links this to the broad prosperity goals as used by the Dutch Ministry of Infrastructure and Water Management in their Mobility Vision 2050: Accessibility, Living Environment and Sustainability, Safety, and Health (Ministerie van Infrastructuur en Waterstaat, 2023).

TNO defined these broad prosperity goals in a study commissioned by the Dutch Ministry of Infrastructure and Water Management (TNO, 2021). Its purpose was to explore how broader societal goals, encompassing well-being and sustainability, could be translated into mobility-related indicators to support integrated decision-making and policy evaluation.

Translated from this Dutch document and adapted to the wording used in Mobility Vision 2050 (Ministerie van Infrastructuur en Waterstaat, 2023), we use the following indicators in the scenarios:

Living Environment and Sustainability

- Climate:
  - Emissions
  - Energy usage
  - Climate resilience
- Environmental Impact:
  - Air quality
  - Soil quality
  - Raw material usage
- Noise Pollution
- Vibrations
- Spatial Use:
  - Infrastructure
  - Vehicles
  - Public space

Accessibility

- Access to Activities:
  - Jobs, facilities, and social connections.
- Availability of Mobility Options:
  - Modalities
  - Affordability
  - Attractiveness
- Ease of Use
- The TNO study explains that inclusivity is not a separate item because it can be part of all aspects. However, in the future scenarios in this scenario report, the impact of each scenario on inclusivity and equity is addressed explicitly in the accessibility section.
- Resilience, though not explicitly mentioned in the TNO study, is increasingly critical due to factors such as extreme weather events and geopolitical conflicts. Acknowledging its impact on accessibility, resilience is addressed within the accessibility section in each scenario.

Resilience is a measure of a system's ability to withstand and recover from external disturbances, expressed as Resilience = Probability of Disturbance × Impact of Disturbance × Speed of Recovery. Disturbances include climate-related shocks (e.g., extreme weather), geopolitical disruptions (e.g., war and conflict), economic crises, and health emergencies (e.g., pandemics). The design and structure of the mobility system are critical: decentralised, distributed systems tend to be more robust, as failures remain localised, whereas centralised, interconnected systems are efficient but more vulnerable to cascading failures. In the four scenarios, resilience is assessed based on the governance structure (market-driven vs. government-led), the technological and organisational capacity to adapt to shocks, and the distribution of resilience across regions and user groups, reflecting how the system anticipates, absorbs, and recovers from disruptions.

Safety and Security

- Traffic Safety:
  - Accidents
  - Casualties
  - Material damage
- Social Safety:
  - Individual perceived safety (on location)
  - Safety of groups
- External Safety:
  - Location-based risks
  - Group risks
- The TNO study does not explicitly mention cybersecurity. However, recognising that digital technologies introduce increasing vulnerabilities to the mobility system, potentially affecting safety, cybersecurity is incorporated into the safety section of the scenarios.

Health

- Physical Health:
  - Exposure to unsafe situations and negative environmental impact
  - Use of active modalities
- Mental Health:
  - Autonomy
  - Stress

Appendix II: Black Swans and Grey Rhinos

The future of mobility is inherently uncertain, shaped by a complex interplay of technological, societal, and environmental forces. While strategic foresight methods, such as scenario planning, allow us to explore plausible future trajectories, they cannot fully account for the disruptive potential of unexpected events—the so-called "Black Swans" (Taleb, 2007)—and the looming threats that are visible yet often ignored, referred to as "Grey Rhinos" (Wucker, 2016).

Black Swans are the shockwaves nobody expects: an overnight technological breakthrough, a sudden geopolitical stand-off, or an unforeseeable pandemic that disrupts society. While they may seem implausible, if they do occur, they can overturn established norms, unleashing chaos on supply chains and travel behaviour.

Grey Rhinos are the threats hiding in plain sight: creeping climate risks, festering urban congestion, or entrenched social divides that sabotage equitable access to mobility. They loom on the radar, but immediate pressures frequently push them to the back burner—until they grow into a crisis that can no longer be contained.

By recognising and addressing both Black Swans and Grey Rhinos, mobility planners and policymakers can build resilience and anti-fragility into the system. This involves creating adaptive strategies that not only mitigate known risks but also enhance the system's capacity to absorb, recover, or even grow stronger from unforeseen shocks. Understanding the interplay between these forces is crucial for navigating the uncertain terrain of mobility in 2050 and beyond.

In this appendix, we examine notable Black Swans and Grey Rhinos in the mobility domain, exploring their potential implications. Through this lens, we aim to illuminate the systemic vulnerabilities and opportunities that could shape the future of mobility in the Netherlands.

From full-blown military conflict to resource scarcities and floods, these scenarios may seem extreme. Yet, today's "unthinkable" can become tomorrow's reality with brutal swiftness. By daring to imagine the worst, mobility professionals can develop mitigation strategies for a more robust or resilient mobility system.

Black Swans and Grey Rhinos can emerge in all four scenarios, though how they are addressed and the outcomes they create can vary significantly. While they do not take centre stage in this report, they form a vital element of the Future Mobility Workshops, where academics and practitioners share insights, stress-test policies, and identify no-regret interventions. Over time, new Black Swans and Grey Rhinos will inevitably join the list, underscoring that no future scenario remains impervious to shocks and surprises.

This appendix discusses several examples as well as their impacts on the mobility system.

War

War can erupt with terrifying speed or simmer until it boils over, shattering the stability that economies like the Netherlands rely on. As a global trading nation, the Netherlands would be struck by ruptured supply lines and shortages of critical resources. Markets could convulse, public anxiety might skyrocket, and infrastructure—roads, rails, ports, and our digital infrastructure—could be sabotaged or commandeered.

Implication for the mobility system in The Netherlands

- *Fortress infrastructure:* When war becomes a genuine threat, national survival displaces all other priorities. Trains and trams would be refitted for minimal vulnerability, relying on decentralised signalling and less delicate energy sources. Diesel traction and mobile communication-based systems might dominate, as conventional power and digital grids could become prime targets.
- *Military first:* Forget about daily commuting convenience—those same tracks might be needed for troop and equipment movements. Bridges and tunnels would need massive reinforcement to bear the load of heavy armour. This could drain budgets meant for expanding or upgrading civilian capacity, while also igniting public debate over how to balance national security with everyday mobility.
- *Government in command:* In times of conflict, the state reclaims control. Private-sector innovation continues under strict orders, funnelling research and investment into resilience and defence requirements.

Key Questions for Discussion

- Which elements of the Dutch mobility system are most vulnerable to sabotage or blockade?
- How to ensure resilience against hostile actions?
- Are there feasible ways to reduce reliance on imported critical components or energy?
- How far should state authority extend during wartime to safeguard mobility?

Disintegration of Europe

A fractured Europe—imagine the EU unravelling or splintering alliances—could jeopardise the Netherlands' vital connections. Closed borders, conflicting regulations, and nationalist trade policies could blow up seamlessly integrated logistics systems, sabotage cross-border rail links, and stifle the flow of goods and people.

Implication for the mobility system in The Netherlands

- *Cross-border chaos:* Complex customs checks and disjointed standards could seize up just-in-time supply chains. Congestion at once-fluent transit corridors might bring trade to a grinding halt.
- *Economic hit:* As a linchpin of European logistics, the Netherlands stands to lose the most if free movement collapses. Ports, airports, and roads might be underused or stuck in administrative limbo.
- *Reduced cooperation:* EU-level funding for infrastructure and research could dry up, forcing the Netherlands to scramble for bilateral deals or domestic financing, complicating innovation and climate goals.

Key Questions for Discussion

- How could the Netherlands preserve essential transport networks in a splintered Europe?
- Are alternative treaties or alliances viable if EU frameworks dissolve?
- What strategies can prevent border slowdowns from paralysing the Dutch economy?

Sustainable Energy Shortage

Sweeping electrification of transport and the quest for greener energy may collide with grim realities if energy generation and storage cannot keep pace. Renewable adoption in the Netherlands is advancing, but scaling up too slowly or unevenly could plunge the country into a crippling energy shortage. Add volatile fossil fuel markets or political embargoes, and there's a perfect storm for economic disruption.

Implication for the mobility system in The Netherlands

- *Grid meltdown:* The surge in electricity demand for cars, buses, trains, and charging infrastructure could overwhelm an inadequately modernised grid. Blackouts or rationing would derail daily commutes and freight schedules, triggering a domino effect on supply chains and undermining public trust in clean mobility.
- *Inequitable energy access:* Big cities might hog the limited power available for their fleets, while rural areas languish, deepening the urban-rural divide. Rising energy costs could also make sustainable transport unaffordable for lower-income groups, sabotaging the goal of inclusive mobility.
- *Reliance on fossils lingers:* Until renewables can fully cover base load, the Netherlands may be forced to revert to coal or gas in emergencies—an uncomfortable trade-off that chips away at climate pledges.

Key Questions for Discussion

- How can the grid be reinforced quickly and effectively to accommodate skyrocketing electricity demand?
- Which policy levers will ensure fair energy distribution among regions and income groups?
- What measures align renewable energy expansion with robust mobility planning?
- Who or what should be prioritised if energy supplies become scarce?

Sustainable Energy Abundance

Imagine a future where renewable energy sources not only meet but surpass the growing energy demands. For instance, artificial intelligence and quantum computers could drive breakthroughs in green energy production technologies, such as optimising the design of ultra-efficient solar panels or advancing fusion energy technologies. They also hold the potential to refine energy storage systems, enabling more effective use of surplus renewable energy and the realisation of high energy density (solid-state) batteries, powering electric heavy-duty vehicles. Such innovations would transform society as a whole. The Dutch mobility landscape would be cleaner, more reliable, highly affordable, and inclusive. However, while abundant green energy offers immense promise, it also brings new challenges that require careful navigation to maximise its potential.

Implications for the Mobility System in the Netherlands

- *Unleashing Electrification:* With a surplus of renewable energy, the electrification of transport could reach unprecedented levels. Electric vehicles (EVs), buses, trains, and even freight trucks could operate seamlessly without the constraints of energy scarcity. High-capacity charging stations could proliferate, ensuring rapid and ubiquitous access to power, while urban areas could explore electrified micro-mobility solutions for last-mile connectivity.
- *Redefining Infrastructure Needs:* The availability of abundant green energy would likely drive innovation in energy storage and distribution infrastructure. Smart grids, decentralised energy systems, and vehicle-to-grid (V2G) technologies would become critical, enabling two-way energy flows that enhance grid stability and resilience.
- *Challenges of Managing Abundance:* While a surplus of green energy is desirable, it also requires sophisticated management. Excess energy generation could strain grid infrastructure or lead to inefficiencies if not adequately stored or utilised. Moreover, coordinating between energy producers, transport providers, and government agencies would demand new regulatory frameworks and innovative market mechanisms.
- *Affordability Driving Increased Travel:* The widespread use of renewable energy could significantly reduce energy costs, making transport more affordable for all. Lower operational costs for electric vehicles (EVs) and automated public transport systems would encourage increased travel, enabling people to commute more frequently and access opportunities further afield. This affordability could boost tourism, expand job markets, and foster greater social connectivity, transforming mobility patterns across the Netherlands, but also leading to more busy roads, congestion and increased non-exhaust emissions (e.g., fine particulate matter from various sources, including vehicle tires and brakes).
- *E-fuels for aviation and shipping:* With an abundance of renewable electricity, it becomes commercially attractive to produce green hydrogen and synthetic kerosene based on carbon capturing. While the production of these fuels is relatively inefficient, the low or even negative price of electricity results in an attractive business case for oil companies to divert their business towards producing e-fuels for aviation and shipping. Therefore, radical innovations in the design of airplanes, ships, and their respective propulsion systems would no longer be required to enable sustainable long-haul travel of people and goods.

Key Questions for Discussion

- How can the Netherlands ensure that abundant green energy directly benefits mobility while avoiding systemic inefficiencies?
- What role should the government play in incentivising the adoption of smart grids and V2G technologies?
- How can energy abundance drive innovation in mobility without exacerbating resource consumption or environmental degradation?
- What strategies can address the challenges of increased travel, such as congestion and non-exhaust emissions, while maintaining the benefits of affordability?

Shortage of Critical Materials

From rare earth metals for electric motors to essential components for batteries and solar panels, the global race to secure materials can leave the Netherlands scrambling. A sudden geopolitical embargo or a leap in global demand could choke off access to the very building blocks of a green transport system.

Implication for the mobility system in The Netherlands

- *Investment stalls:* Transport authorities might be forced to slam the brakes on major projects, from new rail lines to EV charging networks, as material costs soar or supplies dry up.
- *Compromised sustainability goals:* If the path to cleaner transport gets blocked by a lack of components, Europe might prioritise shoring up domestic auto manufacturing and fallback energy solutions. This detour could lock the continent into extended fossil fuel use, significantly undermining climate targets.
- *Knock-on effects:* Gaps in supply can ripple through every sector—freight, passenger transport, infrastructure—potentially leading to price spikes and national-level trade-offs on resource allocation.

Key Questions for Discussion

- How can circular economy principles drastically cut our dependence on finite materials?
- What regulatory frameworks or trade agreements might secure stable material flows?
- Can the Netherlands cope with prolonged shortfalls without sliding backwards on sustainability?
- Where is the tipping point between keeping fossil fuels on life support and propelling renewables forward?

Extreme Weather Events

Rising sea levels, punishing heatwaves, violent storms, and widespread flooding—climate change is spawning a host of extreme weather conditions that can disrupt travel, damage infrastructure, and paralyse entire regions of the Netherlands. Much of the country sits below sea level, leaving it especially vulnerable to catastrophic floods, but other threats—scorching summers that buckle rails, or ferocious winds that tear down power lines—can cause similarly dire consequences.

Implication for the Mobility System in The Netherlands

- *Infrastructure at Breaking Point:* Rail lines may buckle in extreme heat or be submerged by flash floods; airports could face ground stoppages or runway damage from storms; roads might be rendered impassable by fallen trees or collapsed embankments. Regions that lack robust protective measures could be cut off for extended periods, challenging evacuation plans and crippling daily commutes.
- *Erosion of Confidence:* Chronic disruptions caused by recurring extreme weather can degrade public trust in the reliability of transport networks. Businesses might relocate; families could rethink long-term housing plans, leading to demographic shifts within and beyond vulnerable areas.
- *Unequal Preparedness:* Wealthier regions can afford sophisticated adaptation measures—stronger dykes, covered stations, enhanced drainage—while poorer municipalities risk being left behind. This disparity could deepen existing inequalities in accessibility and economic opportunity.
- *Reactive vs. Proactive Measures:* If extreme events ramp up more quickly than anticipated, emergency funds intended for new infrastructure may be funnelled into damage repairs. This short-term “firefighting” approach delays progress on sustainable mobility upgrades and drains resources that could otherwise bolster long-term resilience.

Key Questions for Discussion

- What adaptive measures can strengthen Dutch infrastructure against floods, storms, and extreme heat?
- How can resilience planning be woven into broader mobility strategies to protect vulnerable regions and populations?
- Which funding models—public, private, or a mix—are best suited to finance large-scale protective investments?
- How can we ensure that all regions, regardless of wealth or political clout, benefit from effective mitigation efforts?

Poverty

Economic meltdowns—triggered by unsustainable healthcare spending, climate disasters, an energy crisis, or global trade strife—could catapult large swathes of the Dutch population into financial distress. When budgets shrink, so do mobility options for vulnerable groups. A rapid surge in living costs, coupled with rising transport prices, can trap people in jobless or underpaid areas, locking them into cycles of hardship. Meanwhile, breakthroughs in biotechnology might extend lifespans, stretching pension systems to breaking point, leaving many seniors isolated and unable to afford accessible transport.

Implication for the mobility system in The Netherlands

- *Growing mobility gap:* Public transport could become prohibitively expensive for those on the edge, forcing the poorest to rely on outdated, polluting modes of travel—if they can travel at all.
- *Social discord:* Anger could mount among those who feel betrayed by a system that was supposed to level the playing field. Political upheaval and protests might pressure governments into emergency interventions or even dismantling certain infrastructure projects in favour of direct subsidies.
- *Strain on inclusivity:* Rising poverty undermines the push for sustainable, seamless transport—green solutions often come at a premium.

Key Questions for Discussion

- What immediate steps can ensure affordable mobility for low-income communities?
- How can subsidies or targeted investments avert a two-tier transport system?
- Can mobility strategies address poverty's root causes, or will they merely treat the symptoms?

Pandemic

A global pandemic can disrupt society and the mobility system in profound and unexpected ways. As seen during COVID-19, restrictions on movement, shifts in work and travel patterns, and increased reliance on digital infrastructure can dramatically alter mobility demands. Health concerns, government-imposed lockdowns, and social distancing measures can lead to significant declines in public transport use and the rise of alternative modes of transport, such as cycling, walking, and private vehicles. At the same time, value chains are disrupted, and the increased demand for goods to be delivered can push the limits of the logistics system.

Implications for the mobility system in the Netherlands

- *Collapse of Public Transport Demand:* Fear of crowded spaces and government restrictions can drastically reduce the use of buses, trains, and trams, leading to financial strain on public transport operators and reduced service levels in the long term.
- *Shift to Active Modes and Private Vehicles:* With fewer people using public transport, walking, cycling, and private car use can increase. This shift may temporarily reduce emissions but exacerbate road congestion in urban areas.
- *Digital Transformation:* Remote work, telemedicine, and online shopping become dominant, reducing commuting trips but increasing the demand for efficient last-mile delivery and logistics services.
- *Health and Safety Investments:* Public transport operators and infrastructure managers may need to implement permanent health measures, such as improved ventilation, sanitation protocols, and contactless payment systems, adding operational costs.
- *Economic and Social Disparities:* Vulnerable populations without access to private vehicles may face isolation, as reduced public transport services limit mobility options. This could deepen existing inequalities in access to jobs, healthcare, and education.

Key Questions for Discussion

- How can public transport systems recover and adapt to changing demand after a pandemic?
- What measures can ensure mobility equity for populations reliant on public transport during and after a pandemic?
- How can the mobility system balance resilience and financial sustainability in the face of pandemics?
- How can cities maintain the gains in active mobility and reduced emissions seen during pandemic restrictions while avoiding a long-term increase in car dependency?

Appendix III: Methodology and Process

Theoretical and Methodological Background

The mobility system poses us with a "wicked design problem"; it is interconnected with many other challenges, addressing one issue often creates new problems, and the system is in constant flux, with evolving requirements and unforeseen challenges. The mobility system, and all the challenges it is interconnected with, are shaped by a dynamic interplay of social, technological, economic, environmental, and political factors. Anticipating uncertain shifts beyond the present is crucial for navigating this complex field.

Engaging with uncertainty requires systematic exploration of multiple alternative futures. "Futures Studies" (Bell, 2009) examines these possibilities using theoretical and methodological tools. While forecasting provides useful insights in certain cases, strategic foresight, a qualitative and non-predictive approach, facilitates the creation of shared visions to inform present-day decisions (Poli, 2017). Scenarios—internally consistent narratives of potential futures—are a key tool within strategic foresight. They are particularly effective for addressing deep uncertainty (Bohensky et al., 2006), encouraging proactive thinking (van Dorsser et al., 2020), and enabling experimentation with future outcomes (Mallard & Lakoff, 2011). Scenarios may be normative, reflecting preferred futures, or exploratory, examining how events might unfold.

The Mobilisers developed exploratory scenarios building on the Intuitive Logics school of thought, which originated from Pierre Wack's work at Royal Dutch Shell (Postma & Liebl, 2005), using a combination of analytical thinking and informed intuition to explore possible future scenarios. The Intuitive Logics approach differs from more quantitative forecasting methods by focusing on creating coherent and plausible stories about potential futures. This method encourages participants to think creatively about various possibilities, helping organisations prepare for a range of potential outcomes rather than relying on a single prediction. The resulting scenarios are intended to help stakeholders anticipate potential futures, prepare for unexpected changes in the environment, and improve decision-making by challenging existing mental models and assumptions.

Scenario Development Process

The approach combined brainstorming, research, and expert input to create scenario logics. The work consisted of co-creation workshops held in late 2023 and throughout 2024, including workshops with other mobility experts. Over 150 participants, including TU Delft researchers and external stakeholders, contributed to developing exploratory scenarios for the Dutch mobility system in 2050.

Key steps included:

Setting a focal point: All components of the mobility system for people, encompassing access to essential facilities, travel for work, education, and leisure, as well as the transport of goods within supply chains and e-commerce, are in scope for developing the scenarios. Military use cases were excluded from the project scope. The focus was placed on the Netherlands to address its most direct area of impact while also considering the country's European and global roles as an international hub for the movement of people and goods. The year 2050 was chosen as the time horizon to represent the long-term future, providing a framework for exploring transformative possibilities and envisioning profound societal and technological changes. This time horizon strikes a balance between being distant enough to allow meaningful change to unfold and being close enough to logically connect with actions initiated today.

Horizon Scanning: Systematic identification of signals—perceived indicators of small or local phenomena that have the potential to grow in scale and reach (Profitiliotis, 2022). Through extensive research across societal, technological, economic, environmental, and political domains, 219 carefully selected signals were synthesised into 28 thematic clusters called "signals of change". Two examples are “Europe becoming less appealing for businesses, startups and industry due to increased regulations on labour, tax, sustainability, applications of new technologies, etc., as well as the lack of venture capital, potentially making Europe a technology-follower“ and “The rise of new modes of transport like hyperloop and vertical take-off and landing air transport leading to revolutionary changes in travel/ logistics efficiency and patterns, significant impacts on existing transportation infrastructure, and new opportunities and challenges in urban and regional planning”.

Ranking Signals of Change: Signals of change were assessed for their importance and uncertainty. Key uncertainties (low certainty, high impact), trends (high certainty, medium or high impact), and weak signals (low or medium certainty, medium impact) were distinguished. This created a short list of 11 key uncertainties.

Selecting Key Uncertainties: Each possible combination of pairs of the shortlisted key uncertainties was evaluated against specific criteria: the dimensions needed to be independent and uncorrelated; both dimensions could plausibly evolve into their extreme opposite states within the time horizon; the resulting four combinations should be rich, distinct, and structurally different. This resulted in 10 possible scenario canvasses, which were further assessed on their strategic value for exploring the future mobility system in The Netherlands. This resulted in one preferred combination of key uncertainties.

Creating a canvas: Through an iterative design process, the selected key uncertainties were finetuned and improved to form the final scenario canvas:

- Level of government intervention (government-driven vs market-driven change).
- Societal openness to technological change (cautious vs embracing new technologies).

Scenario Construction: The scenario descriptions were initially developed by exploring each scenario in a utopian and dystopian version, imagining the best- and worst-case outcomes for the mobility system by 2050. These versions were then synthesised into intermediate, balanced descriptions incorporating elements from both extremes, ensuring a comprehensive exploration of potential futures. The final four scenarios were finetuned for diversity, plausibility, and strategic relevance.

Aligning with Complementary Frameworks: During the scenario construction, intermediate results revealed that Jim Dator’s archetypes (Dator, 2009) and Cultural Theory (Thompson, 1990) provided complementary lenses for understanding societal change. While Dator focuses on envisioning long-term futures, Cultural Theory grounds its analysis in present-day cultural dynamics. They are rooted in distinct disciplinary traditions but overlap conceptually in several ways, enriching the scenario development process. For example:

- Innovation Fast Track aligns with Growth (Dator) and Individualism (Cultural Theory), reflecting an optimistic belief in innovation and market-driven solutions.
- Hyperconnected Systems resonates with Transformation (Dator) and Egalitarianism (Cultural Theory), sharing a focus on radical systemic change, albeit for different reasons (spiritual or technological in Dator, justice-oriented in Cultural Theory).
- Sustainable Slowdown parallels Discipline (Dator) and Hierarchy (Cultural Theory), emphasising regulation, tradition, and stability.
- Mobility Patchwork echoes Collapse (Dator) and Fatalism (Cultural Theory), anticipating systemic failure and focusing on survival or detachment, although it describes a less negative future.

These frameworks validated the diversity of the scenarios and brought a deeper understanding of societal dynamics and their potential trajectories, offering theory to further enrich the scenarios.

Continuing Scenario Development: Further scenario refinements were made based on the initial scenario construction and sourcing from complementary frameworks. This process followed an iterative process of workshops, expert input, peer reviews, consultations, and presentations at academic and non-academic events to enhance the scenarios' robustness and ensure their alignment with practical considerations and stakeholder insights.

Refining Scenario Outputs: To balance detail and readability, the scenarios were summarised into concise descriptions highlighting key elements and trade-offs. Expert perspectives provided insights into specific areas of mobility. Each perspective underwent peer review, and further contributions will be added to the scenario website www.tudelft.nl/mobility-futures.

This iterative and participatory process enabled the formation of scenarios that are robust, relevant, and actionable for exploring the future of mobility in the Netherlands.

Limitations

The scenario development process is qualitative and long-term in focus, with 2050 serving as a symbolic horizon. As such, it does not accommodate short- or mid-term quantitative forecasts for specific markets, industries, or sectors. Consequently, the process does not include detailed technology roadmapping or predictive analytics.

The focal topic of this effort was the mobility of people and goods, shaping the scenarios to prioritise relevance and utility within this context. As a result, these scenarios may not directly apply to actors with significantly different focal topics. Furthermore, the scenarios reflect collective mental models of the multifaceted mobility system as perceived and represented by the Mobilisers team and participants. Involving a different team or additional experts might yield alternative outcomes.

It is also important to note that the Mobilisers all work at a technical university and share a belief that technology is a vital component in addressing societal challenges and achieving Europe's 2050 sustainability goals, particularly if we aim to maintain comfortable lifestyles and freedom of choice.

Despite these limitations, the scenarios provide a robust foundation for exploring transformative possibilities and fostering strategic discussions about the future of mobility in the Netherlands.

Many experts have contributed to this process in various capacities and stages. We extend our deep appreciation to the more than one hundred TU Delft researchers who participated in our workshops, as well as to the mobility experts from external organisations, including the Ministry of Infrastructure and Water Management, MRDH, Vervoerregio Amsterdam, the municipalities of Amsterdam, Rotterdam, Utrecht, and The Hague, CROW, EIT Urban Mobility, Connekt, and many others who supported this effort in one way or another.

Appendix IV: References

- Asif Ahmed & Peter Stopher (2014) Seventy Minutes Plus or Minus 10 — A Review of Travel Time Budget Studies, Transport Reviews, 34:5, 607-625, DOI: 10.1080/01441647.2014.946460

- AUTO2X. (2024). Auto2xtech. Retrieved January 28, 2024, from https://auto2xtech.com/level-3-automation-in-1-in-5-cars-in-europe-by-2025/

- Bell, W. (2009). Methods and Exemplars in Futures Research. In W. Bell (Ed.), Foundations of Futures Studies: History, Purposes, and Knowledge (pp. 239-317). Piscataway: Transaction Publishers.

- Bohensky, E. L., Reyers, B., & Van Jaarsveld, A. S. (2006). Future ecosystem services in a Southern African river basin: a scenario planning approach to uncertainty. Conservation Biology, 20(4), 1051-1061.

- Braess, D., Nagurney, A., & Wakolbinger, T. (2005). On a paradox of traffic planning. Transportation Science, 39(4), 446-450.

- Bureau Spoorbouwmeester - BSbm (2023, Juni 1) Klimaatadaptieve stations. Ontwerponderzoek Klimaatadapatieve stations Flux. https://www.spoorbeeld.nl/beleid/station-stationsomgeving/klimaatadaptieve-stations

- Bureau Spoorbouwmeester - BSbm (2024) Paris-Proof stations. Ontwerpend onderzoek naar materiaalgebonden CO_2-emissies in de ontwerpfase. https://www.spoorbeeld.nl/beleid/station-stationsomgeving/paris-proof-stations-bouwen-met-een-co2-budget

- Centraal Bureau voor de Statistiek. (2024). Motor vehicles admitted; type, age class, 1 January. Statistics Netherlands. https://www.cbs.nl/en-gb/figures/detail/85243ENG

- Centraal Bureau voor de Statistiek. (2024). Hoeveel personenauto's zijn er in Nederland? https://www.cbs.nl/nl-nl/visualisaties/verkeer-en-vervoer/vervoermiddelen-en-infrastructuur/personenautos

- Centraal Bureau voor de Statistiek. (2024, April 9). 684 verkeersdoden in 2023. Centraal Bureau Voor De Statistiek. https://www.cbs.nl/nl-nl/nieuws/2024/15/684-verkeersdoden-in-2023

- Centraal Bureau voor de Statistiek. (2024). Welke sectoren stoten broeikasgassen uit? Centraal Bureau Voor De Statistiek. https://www.cbs.nl/nl-nl/dossier/dossier-broeikasgassen/welke-sectoren-stoten-broeikasgassen-uit-

- Centraal Bureau voor de Statistiek. (2024, November 7). Verkeersprestaties personenauto's; kilometers, brandstofsoort, grondgebied. Centraal Bureau Voor De Statistiek. https://www.cbs.nl/nl-nl/cijfers/detail/85404NED?q=hoe%20oud%20zijn%20autos

- Cervero, R., & Sullivan, C. (2011). Green TODs: marrying transit-oriented development and green urbanism. International Journal of Sustainable Development & World Ecology, 18(3), 210–218. https://doi.org/10.1080/13504509.2011.570801

- College van Rijksadviseurs (CRa) en Bureau Spoorbouwmeester (BSbm) (2023, December 5). Advies Knooppunten - Verstandig verdichten. https://www.spoorbeeld.nl/nieuws/niet-alles-kan-kies-voor-echt-duurzame-gebiedsontwikkeling-van-stationsomgevingen

- Compare the Market. (2023). The most expensive public transport. https://www.comparethemarket.com.au/travel-insurance/features/most-expensive-public-transport/

- Dator, J. (2009). Alternative Futures at the Manoa School. Journal of Futures Studies, 14(2), 1-18

- de Haas, M. C. (2022). Longitudinal Studies in Travel Behaviour Research. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:85e7e4f5-77dd-40b1-bb87-084d12641630

- Durand, A., & Zijlstra, T. (2020). The impact of digitalisation on the access to transport services: A literature review. KiM Netherlands Institute for Transport Policy Analysis. https://www.kimnet.nl/binaries/kimnet/documenten/rapporten/2020/06/29/de-impact-van-digitalisering-op-de-toegang-tot-vervoersdiensten-een-literatuurreview/The+impact+of+digitalisation+on+the+access+to+transport+services_a+literature+review_PDFa.pdf

- European Commission (2024). Study on the need for harmonised rules to support the rise of micro-mobility and increased road safety for personal mobility devices. https://urban-mobility-observatory.transport.ec.europa.eu/news-events/news/european-commission-releases-report-harmonised-rules-personal-mobility-devices-2024-11-20_en

- European Environment Agency. (2024). From the daily office commute to flexible working patterns — teleworking and sustainability. https://www.eea.europa.eu/publications/from-the-daily-office-commute

- European Environmental Agency (2024) Average age of road vehicles per country. https://www.eea.europa.eu/data-and-maps/daviz/average-age-of-road-vehicles-6/embed-chart?chart=chart_1&chartWidth=817&chartHeight=676&padding=fixed&customStyle=.googlechart_view%7Bmargin-left:0px%3B%7D

- European Research Area Forum (2024). Living guidelines on the responsible use of generative AI in research. European Commission. https://research-and-innovation.ec.europa.eu/document/2b6cf7e5-36ac-41cb-aab5-0d32050143dc_en

- General Motors. (2024). https://news.gm.com/home.detail.html/Pages/news/us/en/2024/dec/1210-gm.html. Retrieved December 10, 2024.

- Hoogendoorn, S. (2011). Sturen op verkeersstromen: Waarom we niet zonder verkeersmanagement kunnen. NM Magazine. https://www.nm-magazine.nl/pdf/Sturen_op_verkeersstromen.pdf

- Kennisinstituut voor Mobiliteitsbeleid (KiM). (n.d.). De relatie tussen gezondheid en het gebruik van actieve vervoerwijzen. Den Haag: Ministerie van Infrastructuur en Waterstaat.

- Kennisinstituut voor Mobiliteitsbeleid (KiM) (2019). Mobiliteit en bereikbaarheid in stedelijk en ruraal Nederland [Mobility and accessibility in urban and rural Netherlands]. Ministerie van Infrastructuur en Waterstaat.

- Landgeist. (2021, November 9). Efficiency of train services in Europe. https://landgeist.com/2021/11/09/efficiency-of-train-services-in-europe/

- Knoope, M., Hoen, M., Hilbers, H., & Snellen, D. (2024). Transport poverty in the Netherlands: Risks and policy options in the transition to sustainable mobility. TNO. https://publications.tno.nl/publication/34642067/rD5lQO/TNO-2024-P12018.pdf

- Mallard, G., & Lakoff, A. (2011). How Claims to Know the Future are Used to Understand the Present. In C. Camic, N. Gross, & M. Lamont (Eds.), Social Knowledge in the Making (pp. 339-379). Chicago: The University of Chicago Press.

- Ministerie van Infrastructuur en Waterstaat. (2023). Mobiliteitsvisie 2050: Hoofdlijnennotitie. Ministerie van Infrastructuur en Waterstaat. https://www.rijksoverheid.nl/documenten/rapporten/2023/03/17/bijlage-hoofdlijnennotitie-mobiliteitsvisie-2050

- Nationaal Dataportaal Wegverkeer. (2020, December 14). Effecten maatregelen op wegverkeer. https://www.ndw.nu/actueel/nieuws/2020/12/14/effecten-maatregelen-op-wegverkeer

- NS. (2025, January 7). OV-fiets recordaantal keer gebruikt. NS Nieuws. https://nieuws.ns.nl/ov-fiets-recordaantal-keer-gebruikt/

- Postma, T. J., & Liebl, F. (2005). How to improve scenario analysis as a strategic management tool?. Technological Forecasting and Social Change, 72(2), 161-173.

- Profitiliotis, G. (2022). UNESCO HLCP Futures Masterclass on Horizon Scanning. Available at: www.youtube.com/watch?v=rN6I4dGHkb8
- RAI Vereniging. (2024). Elektrificatie Nederlandse wagenpark zet door. https://www.raivereniging.nl/actueel/nieuws/elektrificatie-nederlandse-wagenpark-zet-door-2658/
- RAI Vereniging & BOVAG. (2024). Mobiliteit in Cijfers Tweewielers 2024 - 2025. https://www.raivereniging.nl/actueel/nieuws/mobiliteit-in-cijfers-tweewielers-2024-2025/
- Kennisinstituut voor Mobiliteitsbeleid. (2023). Mobiliteitsbeeld 2023. https://www.kimnet.nl/publicaties/publicaties/2023/11/14/mobiliteitsbeeld-2023
- SAE International. (2021). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, from https://www.sae.org/standards/content/j3016_202104/
- Severengiz, S., Schelte, N., & Bracke, S. (2021). Analysis of the environmental impact of e-scooter sharing services considering product reliability characteristics and durability. Procedia CIRP, 96, 181–188. https://doi.org/10.1016/j.procir.2021.01.072
- Snelder, M., de Clercq, G.K., G. Homem de Almeida Correia, G., 't Hoen, M., Madadi, B., Martinez, I., Sharif Azadeh, S. & van Arem, B. (2025). Scenarios of automated driving based on a switchboard for driving forces - an application to the Netherlands. European Journal of Transport and Infrastructure Research, 25(1), 1-21.
- Taleb, N. N. (2007). The black swan: The impact of the highly improbable. Random House.
- The Guardian. (2023). https://www.theguardian.com/. Retrieved December 28, 2023, from https://www.theguardian.com/
- Thompson, M., Ellis, R., & Wildavsky, A. (1990). Cultural theory. Westview Press.
- TNO (2021). Indicatoren voor brede welvaart in het mobiliteitsdomein – een vertrekpunt voor discussie gebaseerd op een quickscan (TNO 2021 R12422). Commissioned by the Ministry of Infrastructure and Water Management. https://www.rijksoverheid.nl/documenten/rapporten/2022/01/10/indicatoren-voor-brede-welvaart-in-het-mobiliteitsdomein---een-vertrekpunt-voor-discussie-gebaseerd-op-een-quickscan
- van Dorsser, C., Taneja, P., Walker, W., & Marchau, V. (2020). An integrated framework for anticipating the future and dealing with uncertainty in policymaking. Futures, 124, 102594.
- van Oort, N., et al. (n.d.). Inclusive mobility. TU Delft. https://nielsvanoort.weblog.tudelft.nl/inclusive-mobility/
- van Oort, N., et al. (n.d.). What is the value of integrating bike sharing systems and public transport? TU Delft. https://nielsvanoort.weblog.tudelft.nl/what-is-the-value-of-the-bike-share-and-public-transport-combination/
- Wardrop, J. G. (1952). Some theoretical aspects of road traffic research. Proceedings of the Institution of Civil Engineers, 1(3), 325-378. https://doi.org/10.1680/ipeds.1952.11259
- World Bank. (2015). Moving Toward Climate-Resilient Transport. https://thedocs.worldbank.org/en/doc/326861449253395299-0190022015/render/WorldBankPublicationResilientTransport.pdf
- Wucker, M. (2016). The grey rhino: How to recognise and act on the obvious dangers we ignore. St. Martin's Press.

The following generative AI tools were used throughout the process:

- ChatGPT 4o was used to shorten texts, polish texts, and align writing styles across texts written by different team members.
- ChatGPT o1 was used to point out inconsistencies across the different perspectives.
- NotebookLM was used to discover where the written scenarios aligned with–and where they contradicted–frameworks and future scenarios from other authors.
- Perplexity was used as an advanced search engine.
- Grammarly was used for spelling and grammar corrections.
- The application of generative AI aligns with the principles of responsible AI use in academic research, as outlined by the European Research Area Forum (2024).