TDM 2025

12TH INTERNATIONAL SYMPOSIUM ON TRAVEL DEMAND MANAGEMENT

Extended Abstracts Presented at the 12th International Symposium on Travel Demand Management (TDM 2025)

The University of Sydney Business School CBD Campus

133 Castlereagh Street, Sydney, Australia

9-11 December 2025

TDM 2025

12TH INTERNATIONAL SYMPOSIUM ON TRAVEL DEMAND MANAGEMENT

Content

1. About TDM Symposium Series

The International Symposium on Travel Demand Management (TDM) is a long-standing global forum dedicated to advancing research, policy, and practice in managing travel demand for more efficient, equitable, and sustainable transport systems. Since its inception in 1998, the TDM Symposium Series has brought together leading researchers, policymakers, practitioners, and industry experts to explore how societies can influence travel behaviour, reshape mobility choices, and manage the pressures on transport networks.

Over more than two decades, the TDM Symposia have become a cornerstone event for the global transport community—providing a platform for presenting cutting-edge research, discussing new policy approaches, showcasing innovative case studies, and fostering collaboration across countries and disciplines. The series has been instrumental in developing shared understandings of how behavioural, technological, economic, institutional, and spatial factors influence travel demand, and how these insights can be applied to deliver safer, cleaner, and more resilient mobility systems.

As urban environments evolve and transport challenges grow more complex—from congestion and emissions to equity, automation, digital disruption and post-pandemic behavioural shifts—the TDM Symposium Series continues to play a critical role in shaping the future of mobility. Each edition carries forward the mission of connecting global thought leaders to address emerging trends, evaluate new strategies, and support evidence-based decision-making in transport planning.

History of the TDM Symposium Series

The TDM Symposium Series has been hosted around the world, reflecting its international reach and the diverse transport challenges faced across different regions. Previous symposia include:

- TDM 2023 – 11th International Symposium
  18–20 September 2023 · Accra, Ghana
- TDM 2021 – 10th International Symposium
  17–19 November 2021 · Virtual (hosted from Dublin, Ireland)
- TDM 2019 – 9th International Symposium
  19–21 June 2019 · Edinburgh Napier University, Scotland
- TDM 2017 – 8th International Symposium
  26–29 September 2017 · Taipei, Taiwan
- TDM 2015 – 7th International Symposium
  Arizona, USA
- TDM 2013 – 6th International Symposium
  Dalian, China
- TDM 2010 – 5th International Symposium
  Aberdeen, Scotland
- TDM 2008 – 4th International Symposium
  Vienna, Austria
- TDM 2005 – 3rd International Symposium
  Edinburgh Napier University, Scotland
- TDM 2003 – 2nd International Symposium
  Imperial College London, UK
- TDM 1998 – 1st International Symposium
  Newcastle University, UK

2. Foreword by Co-Chairs of the Local Organising Committee

It is a pleasure to be hosting the 12th International Symposium on Travel Demand Management (TDM 2025). As a founder member of the series first held in Newcastle (1998) and later as an organiser (Aberdeen, 2010), it has been very satisfying to see the Symposium grow in stature and influence. This Symposium series began at a time when TDM was in its infancy. The benchmark definition of TDM remains that of Meyer (1999)[1], who described TDM as an 'action or set of actions aimed at influencing people's travel behaviour in such a way that alternative mobility options are presented and/or congestion is reduced' (p 576). This definition still holds true today, although the objectives evolve with time, now encompassing a wide range of overlapping issues like (in no particular order) equity, sustainability, accessibility, noise and emissions, public health, streetscape, last mile delivery, shared bikes and cars, affordability and quality of life.

Within ITLS, we have benefited greatly from our longstanding partnership with Transport for NSW, whom we are delighted to have as a Symposium sponsor and technical tours host. One example of our collaboration is the recent Promoting Sustainable University Travel project which explored changes in staff and students' travel behaviour at USYD in the light of pandemic-modified study and work modes. Subsequently, one of our Schools ran a pilot University Travel Choices programme. Outputs from the project have also been used by the Sustainability team to calculate USYD's scope-3 emissions (Social impacts of Climate Change and Travel Choices) with advice from ITLS. This is just one example of the impactful TDM-related research conducted at Sydney University.

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12TH INTERNATIONAL SYMPOSIUM ON TRAVEL DEMAND MANAGEMENT

In addition to enjoying the Symposium presentations, I hope that you have an opportunity to explore some of the transport innovations on the ground included in our technical tours or by venturing onto the new Metro, taking a trip on the Light Rail or a zero-emission bus, or enjoying one of our new intercity Mariyung trains.

Welcome to Sydney!

Prof. Michael G H Bell

Professor and Chair of Ports and Maritime Logistics

Institute of Transport and Logistics Studies (ITLS), University of Sydney Business School

Prof. John D Nelson

Transport for NSW Chair and Professor of Public Transport

Institute of Transport and Logistics Studies (ITLS), University of Sydney Business School

[1] Meyer, M. D. (1999). Demand management as an element of transportation policy: using carrots and sticks to influence travel behavior, *Transportation Research Part A: Policy and Practice*, *33 (7–8)*, 575-599.

3. TDM Scientific Advisory Committee

- **Prof. Wafaa Saleh** (Chair), Edinburgh Napier University, UK
- **Dr. Augustus Ababio-Donkor**, Kwame Nkrumah University of Science and Technology, Ghana
- **Prof. Gerd Sammer**, University of Natural Resources and Applied Life, Austria
- **Prof. Jason Chang**, National Taiwan University, Taiwan
- **Prof. Peter Jones**, University College London, UK
- **Prof. Yi-Chang Chio**, The University of Arizona, USA
- **Prof. Juan do Dios Ortúzar Salas**, Pontificia Universidad Católica de Chile, Chile
- **Prof. Manfred Neun**, Honorary ECF President
- **Prof. Stephen Ison**, De Montfort University, UK
- **Prof. Elisabetta Cherchi**, NYU, Abu Dhabi
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- **Prof. Chandra Bhat**, University of Texas, USA
- **Prof. Peter White**, University of Westminster, UK
- **Prof. Masao Kuwahara**, Tohoku University, Japan
- **Prof. Jan-Dirk Schmoecker**, Kyoto University, Japan
- **Dr. Maria Chiara Leva**, Technological University Dublin, IE
- **Prof. Milos Millenkovic**, University of Belgrade, Serbia

4. TDM 2025 Local Organising Committee

Co-Chairs

- **Prof. Michael Bell (**Chair of Ports and Maritime Logistics, Institute of Transport and Logistics Studies (ITLS) | University of Sydney Business School)
- **Prof. John Nelson** (Chair in Public Transport, Institute of Transport and Logistics Studies (ITLS) | University of Sydney Business School)

Secretary

- **Dr. Supun Perera** (Senior Research Fellow, Institute of Transport and Logistics Studies (ITLS) | University of Sydney Business School)

Committee Members

- **Professor Emerita Corinne Mulley** (Institute of Transport and Logistics Studies (ITLS) | University of Sydney Business School)
- **Prof. Stephen Greaves** (Professor in Transport Management, Institute of Transport and Logistics Studies (ITLS) | University of Sydney Business School)
- **Prof. David Levinson** (Professor of Transport in the School of Civil Engineering | University of Sydney)
- **Dr. Yuting Zhang** (Research Fellow, Institute of Transport and Logistics Studies (ITLS) | University of Sydney Business School)
- **Dr. Emily Moylan** (Senior Lecturer, School of Civil Engineering | University of Sydney)
- **Dr. Jennifer Kent** (Senior Research Fellow, School of Architecture, Design and Planning | University of Sydney)
- **Mr. David Surplice** (Senior Manager, Travel Demand Management | Transport for NSW)

5. Sponsors of TDM 2025

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6. TDM 2025 Program

Time		Tuesday 9th December			
8.30am	9am	Registrations			
9am	9.30am	Welcome to Country (including Didgeridoo performance) [Level 17, Lecture room 1]			
9.30am	10am	Welcome by Prof. David Hensher AM and Prof. Michael Bell (Chair of the Local Organising Committee) [Level 17, Lecture room 1]			
10am	10.30am	Keynote by Josh Murray (NSW Secretary of Transport) [Level 17, Lecture room 1]			
10.30am	**11am**	**Morning Tea**			
		Parallel Session 1 (Level 17, Lecture room 3)	**Parallel Session 2 (Level 16, Seminar room)**	**Parallel Session 3 (Level 16, Lecture room 5)**	**Parallel Session 4 (Level 17, Lecture room 2)**
		Theme: Public Transport Planning and Reform, Session Chair: Prof. John Nelson	**Theme: Simulation and Modelling Innovation, Session Chair: Prof. David Levinson**	**Theme: Emerging Mobility and Micromobility Integration, Session Chair: A/Prof. Chinh Ho**	**Theme: Equity and Inclusion in Transport Systems, Session Chair: Mr. David Surplice**
11am	11.25am	Time for a Reset of Bus Contracts? (by: David Hensher AM)	Estimating Desired Trip Demand for Discretionary Purposes under Mobility Constraints (by: Genichiro Nakagaki)	Stakeholder Perspectives on Mobility Hub Functions in Mediterranean Contexts: An Analytic Hierarchy Process Analysis (by: Maria Attard)	Walking Equity: Public Perceptions on the Distribution of Benefits and Burdens (by: Ashikur Rahman)
11.25am	11.30am	*Room Transition Break*			
11.30am	11.55am	The divisibility index: a theoretical device to support public transport design (by: Valentina Gomez)	Automated Conversion of Predicted Historic Road Maps to Graph Representations (by: Ethan Yin)	Public views on policies to promote cycling and micromobility: a Sydney case study (by: Stephen Greaves)	Smart Mobility or Smart Divide? Evaluating the Equity Impacts of TDM Measures in the UK (by: Wafaa Saleh)
11.55am	12pm	*Room Transition Break*			
12pm	12.30pm	Linking COVID-19 Ridership Changes with Tokyo Metro Centralities (by: Xi Lin)	Priority-Based Multi-Agent V*: A Simulation Framework for Non-Lane-Based Street Traffic (by: Abdullah Zareh Andaryan)	Promoting micromobility as a TDM tool in Australia: Opportunities and challenges (by: Geoff Rose)	Methodological Distortions in Agent-Based Models: Implications for Equity-Focused Travel Demand Management (by: Esta Qiu)
12.30pm	**1.30pm**	**Lunch**			
1.30pm	2pm	Keynote by Prof. Kay Axhausen [Level 17, Lecture room 1]			
		Parallel Session 1 (Level 17, Lecture room 3)	**Parallel Session 2 (Level 16, Seminar room)**	**Parallel Session 3 (Level 16, Lecture room 5)**	**Parallel Session 4 (Level 17, Lecture room 2)**
		Theme: Active Transport, Data Analytics, and Micro-Mobility Behaviour, Session Chair: Dr. Yuting Zhang	**Theme: Road Pricing and Demand Management, Session Chair: Mr. David Surplice**	**Theme: Household Decision-Making and Evolving Travel Behaviour, Session Chair: Prof. Michael Bell**	**Theme: Resilient and Data-Driven Public Transport Systems, Session Chair: Prof. Corinne Mulley**
2pm	2.25pm	Volume pricing discounts and shared e-scooter use (by: Geoff Rose)	Empirical Investigation on the Use of Road Pricing as a Road Safety Strategy: A Discrete Choice Experiment (by: Humberto Barrera-Jimenez)	Joint decision of household vehicle ownership, fuel type and ADAS feature choices (by: Shamsunnahar Yasmin)	Resilience of Public Transport Systems through Socio-ecological Perspective (by: Joshitha Tottala)
2.25pm	2.30pm	*Room Transition Break*			
2.30pm	2.55pm	CatBoost-Based Prediction of Daily Bicycle Counts at the Link Level in the Sydney CBD (by: Xueqing Shi)	The Impact of Reservation Order Ratio on the Efficiency of Ride-pooling Service (by: Zixuan Yang)	Enhancing Travel Behaviour Insights: The Transformative Power of GPS in Household Travel Surveys (by: Adri van der Mescht)	Identifying the Public Transport Service Gaps for Tourism: A Smart Card Data Analysis for International Tourists in Taiwan (by: Chia-Jung Yeh)
2.55pm	3pm	*Room Transition Break*			

3pm	3.30pm	Evaluating Electric Micro-Mobility Ownership Choice Stated Preferences for Car Owners: A Mixed Logit Model (by: Yikang Wu)	Road Pricing Unravelled: An Integrated Framework to Inform Research and Practice (by: Humberto Barrera-Jimenez)	Aggregate Travel Behaviour Changes Post-Pandemic: Insights from the Queensland Household Travel Survey (by: Siddhesh Patil Kulkarni)	Comparative Analysis of Charging Technologies in Modular Bus Systems (by: Haoran Zhao)
3.30pm	**4pm**	**Afternoon Tea**			
		Parallel Session 1 (Level 17, Lecture room 3)	**Parallel Session 2 (Level 16, Seminar room)**	**Parallel Session 3 (Level 16, Lecture room 5)**	**Parallel Session 4 (Level 17, Lecture room 2)**
		Theme: Travel Behaviour of Special Populations and Mode Adoption, Session Chair: Dr. Emily Moylan	**Theme: Emissions, Low-Carbon Policies, and Traffic Management, Session Chair: Prof. Michael Bell**	**Theme: Behavioural Insights, Equity, and Decision-Making in Travel Choices, Session Chair: Prof. Corinne Mulley**	**Theme: Active Mobility and Behavioural Insights, Session Chair: Prof. Stephen Greaves**
4pm	4.25pm	Modelling the effects of travel time use on mode choice and the value of travel time savings tackling self-selection and endogeneity bias (by: Ana Luiza de Sá)	Impacts of Internal Combustion Engine Vehicles (ICEVs) and Hybrid Electric Vehicles (HEVs) on Emission and Signal Timing at Isolated Intersections (by: Ponlathep Lertworawanich)	Behavioural-science approach to optimise the use of traveller information tools (by: Ronny Kutadinata)	Active Travel to School: Policy Insights from Distance, Environment, and Lifestyle Determinants (by: Laya Hossein Rashidi)
4.25pm	4.30pm	*Room Transition Break*			
4.30pm	4.55pm	Profiling Public Transit Use among Aging Populations: A Latent Clustering Approach (by: Meredith Alousi-Jones)	Investigating preferences for low-emission zone measures: do time and space matter? (by: Ching-Fu Chen)	Unpacking public transport fares and their implications for equity and sustainability: Insights from sub-Saharan Africa (by: Gift Dumedah)	Understanding Behavioural Needs for Active Travel in New South Wales (by: Sara Haider)
4.55pm	5pm	*Room Transition Break*			
5pm	5.30pm	Understanding the dynamics of market evolution and the intention-behaviour gap in the context of BRT adoption (by: Ahmed El-Geneidy)	The screen-line traffic counting location problem under observation uncertainly (by: Toshiki Arai)	Examining Intra-Household Dynamics in Daily Travel Time Allocation among Dual-Earner Couples (by: Shamsunnahar Yasmin)	Strategic Cost Assessment of Bike-Train Integration: What Should Cities Build? Infrastructure for Shared Bikes, Private Bike Parking, or On-Train Boarding (by: Regine Tejada)
6pm	**9pm**	**Networking Reception (at The Castlereagh, 199 Castlereagh Street)**			

Time		Wednesday 10th December		
8.30am	9am	Registrations		
9am	9.30am	Keynote by Simon Hunter (Chief Transport Planner, Transport for NSW) [Level 17, Lecture room 1]		
9.30am	10am	TRIPS Launch (Prof. David Hensher AM, Dr. Supun Perera, Mr. Ben Wood and Prof. Michael Bell) [Level 17, Lecture room 1]		
10am	10.30am			
10.30am	**11am**	**Morning Tea**		
		Parallel Session 1 (Level 17, Lecture room 3)	**Parallel Session 2 (Level 16, Seminar room)**	**Parallel Session 3 (Level 16, Lecture room 5)**
		Theme: Empirical Insights in Sustainable Transport Practice, Session Chair: Prof. David Levinson	**Theme: Pathways to Net Zero: Decarbonising Transport Systems, Session Chair: Dr. Emily Moylan**	**Theme: Urban Form, Density, and Mobility Interactions, Session Chair: Mr. Ben Wood**
11am	11.25am	Understanding satisfaction and travel behavior of nationwide Fare-Free Public Transport in Luxembourg (by: Francesco Viti)	Decarbonizing Land-Based Passenger Transport in Saudi Arabia (by: Yagyavalk Bhatt)	How Land Use and Infrastructure Location Shape Travel Behaviours (by: Ed Chan)
11.25am	11.30am	*Room Transition Break*		
11.30am	11.55am	Scaling Mobility as a Service through Multiservice Platforms: Evidence from Australia and Japan (by: Chinh Ho)	The Path to Net Zero: Travel Demand Management to support Decarbonising Australia’s Transport System (by: Eleanor Short)	Simplified Travel Demand Forecasting Using Low-Cost Data from the Australian Census (by: Graham McCabe)
11.55am	12pm	*Room Transition Break*		
12pm	12.30pm	Shared Bike Availability Service Gap Measurement: A Case Study in Taipei City (by: Robert B.C Liu)	The danger of incorrect objectives for TDM (by: Liz Ampt and Kate Mackay)	Integrating industrial land and urban freight - city level planning (by: Michael Stokoe)
12.30pm	**1.30pm**	**Lunch**		
		Plenary Workshop (Level 17, Lecture room 1)		
		Joint Australia-Japan Mobility Workshop, Workshop Moderator: A/Prof. Chinh Ho		
1.30pm	2.00pm	Social acceptance of automated bus services in Gifu (by: Prof. Fumitaka Kurauchi)		
2pm	2.30pm	MaaS, MaaF and Beyond: Do Integrated Modal Mobility Services have a Future? (by: Prof. David Hensher AM)		
2.30pm	3.00pm	“Smart Local Mobility” and Japan’s COI/SIP initiatives toward a society with no mobility divide (by: Takayuki Morikawa)		
3pm	3.30pm	Achieving desired sustainable travel behaviour change: Insights from practitioners (by: Prof. John Nelson)		
3.30pm	**4pm**	**Afternoon Tea**		

		Parallel Session 1 (Level 17, Lecture room 3)	Parallel Session 2 (Level 16, Seminar room)	Parallel Session 3 (Level 16, Lecture room 5)	Parallel Session 4 (Level 17, Lecture room 2)
		Theme: Innovations in Travel Demand Management, Session Chair: Dr. Yuting Zhang	**Theme: Understanding Traveller Behaviour and Mode Choice, Session Chair: Mr. David Surplice**	**Theme: Urban Freight, Electrification, and Emerging Logistics Systems, Session Chair: Prof. Michael Bell**	**Theme: Transport Equity, Behaviour, and Urban Change, Session Chair: Prof. Stephen Greaves**
4pm	4.25pm	The knife, the fork, and the spoon: 3 trip charges for the TDM toolbox (by: Harry Barber)	Integrating the Node-Place Model and Urban Resilience Based on Vitality Changes in Response to COVID-19: Classifying and Evaluating Station Areas in Aichi, Japan (by: Hyundo Kang)	Quantifying Bias and Fairness in Large Language Models for Electric Vehicle Charging Demand Management (by: Artur Grigorev)	Equitable for whom? Parking policy reform in Sydney's Inner West (by: Kendall Banfield)
4.25pm	4.30pm	*Room Transition Break*			
4.30pm	4.55pm	Health Impacts of Sydney's Bankstown Rail Line Closure: Implications for Travel Demand Management (by: Christopher Standen)	Exploring travel behaviour change through user-centric incentives (by: Corinne Mulley)	Comparison of charging behaviour for private and fleet company EV users using a data-driven approach (by: Tuo Mao)	From Car Seats to Walking School Bus (WSB) Stops: Understanding Parental Mode Choice Preferences Through a Stated Choice Experiment (by: Khatun E Zannat)
4.55pm	5pm	*Room Transition Break*			
5pm	5.30pm	Demographic-Based Correction Framework for Cross-Regional Transfer of Activity-Based Travel Demand Models (by: Yuanchen Ma)	Examining the Trade-off between Travel Time vs. Travel Opportunities in Choosing Multimodal Travel Options (by: Shamsunnahar Yasmin)	Micrologistics Challenges and Opportunities (by: Michael Stokoe)	Exploring aspects of transport-induced gentrification: the case of Sydney's CBD and South-East Light Rail Project (by: John Nelson)
5.30pm	**6pm**	**International Scientific Committee Meeting (Level 16, Executive Boardroom)**			
7pm	**10pm**	**Conference Dinner Cruise (meet at 6.45pm at King Street Wharf 4)**			

Time		Thursday 11th December		
		Parallel Session 1 (Level 17, Lecture room 3)	**Parallel Session 2 (Level 16, Seminar room)**	**Parallel Session 3 (Level 16, Lecture room 5)**
		Theme: Network Optimisation and Intelligent Traffic Systems, Session Chair: Prof. Michael Bell	**Theme: Transport Equity, Time Use, and Social Inclusion, Session Chair: Mr. David Surplice**	**Theme: Shared Mobility and Ride-Sourcing Innovations, Session Chair: Prof. Stephen Greaves**
9am	9.25am	Penalty decomposition methods for second-best congestion pricing problems on large-scale networks (by: Wenxin Zhou)	Evaluating Transport Equity for the Public Transport Seasonal Pass: A Case Study of TPASS in Taiwan (by: Barbara T.H. Yen)	Reducing Unreliability in Ridepooling Systems Through Shareability Shadow (by: Amir Elmi)
9.25am	9.30am	*Room Transition Break*		
9.30am	9.55am	Zone-cut based approach for path-independent OD trip matrix estimation (by: Ruri Sase)	Who Owns Time? Socioeconomic Inequalities in Time Wealth and Well-being in the UK (by: Wafaa Saleh)	Beyond functionality: Psychological and social drivers of car-sharing use among tourists (by: Ching-Fu Chen)
9.55am	10am	*Room Transition Break*		
10am	10.30am	Application of Gamification to Alleviate Traffic Congestion on Expressways ~ Game Development and Demonstration in Hiroshima area ~ (by: Yoshiro Azuma)	Shared Micromobility and Social Inclusion: A Tale of Two Countries (by: Yuting Zhang)	User-organized Pre-pooled Ride-hailing: Exploring a New Mode (by: David Levinson)
10.30am	**11am**	**Morning Tea**		
		Parallel Session 1 (Level 17, Lecture room 3)	**Parallel Session 2 (Level 16, Seminar room)**	**Parallel Session 3 (Level 16, Lecture room 5)**
		Theme: Passenger Behaviour and Innovation in Public Transport, Session Chair: Prof. Corinne Mulley	**Theme: Smart Freight and Urban Delivery Systems, Session Chair: Prof. Michael Bell**	**Theme: Walking, Accessibility, and Sustainable Mode Choice, Session Chair: Prof. John Nelson**
11am	11.25am	Passenger acceptance of personalized passenger information in public transport (by: Michelle van Ardenne)	Multi-period operations optimization for passenger-freight shared transport: A game-theoretic approach (by: Yuxin Zheng)	Pedestrian Destination Choice Set Generation: A Hybrid Graph-Theoretic Approach (by: Fatemeh Nourmohammad)
11.25am	11.30am	*Room Transition Break*		
11.30am	11.55am	Personalised Incentives for Demand Management in Public Transport: A reverse-engineering Approach (by: Xia Zhou)	How Fast Is Too Fast? A Multi-Objective Optimization Ensuring Courier Safety in an On-Demand Meal Delivery System (by: Simon Hu)	Optimizing Passenger Walking at Drop-off with Anticipatory Methods in Ridepooling Systems (by: Xinyu Wang)
11.55am	12pm	*Room Transition Break*		
12pm	12.25pm	Stakeholder expectations towards the testing of autonomous, on-demand e-buses in the Maltese Islands (by: Karyn Scerri)	Extreme Heat and Road Safety: Assessing the Risks Faced by Delivery Riders in Urban India (by: Kamal Achuthan)	At what break-even distance does people shift to sustainable modes? A generalised cost approach for mode choice in short trips (by: Shamsunnahar Yasmin)
12.25pm	12.30pm	*Room Transition Break*		
12.30pm	1pm	Redefining Success in Demand Responsive Transport: A Context-Dependent Performance Evaluation Based on Service Intentions (by: Chia-Jung Yeh)	Fleet Sizing and Pricing for a Hybrid AVs-HVs Ride-Hailing Platform under Fulfillment Requirements (by: Xiaonan Li)	Assessing the predictive power of open-access walkability indices for walking behaviour (by: Hisham Negm)
1pm	**1.15pm**	**Closing Remarks and Award Presentation by Prof. Michael Bell [Level 17, Lecture room 1]**		
1.15pm	**2pm**	**Lunch**		
2pm	**5pm**	**Technical Site Visits**		

7. Keynote Sessions

Josh Murray

Secretary of Transport, NSW

This keynote will provide high-level context on the current directions, priorities and system-wide challenges shaping transport in New South Wales. It will frame the broader environment in which travel demand management is evolving, including straegic considerations, long-term planning horizons and the changing expectations on modern transport networks.

Simon Hunter

Chief Transport Planner, Transport for NSW

This keynote will offer background on the planning frameworks and evidence bases used across NSW, including the role of state-level guidance, consistent assessment methods and data-led approaches. It will outline how these tools support a more integrated understanding of transport impacts and help guide decisions across projects and development contexts.

Professor Kay Axhausen
ETH Zurich

This keynote will situate current TDM research within broader international developments, highlighting global trends in travel behaviour, modelling approaches and the use of large-scale mobility data. It will provide context on how these research directions inform future transport policy, planning methodologies and the post-pandemic evolution of mobility.

8. TRIPS Public Launch

The TDM 2025 Symposium marks the public launch of TRIPS – the Trip Rate Integrated Planning System, Australia's first national database for land-use-based trip and parking generation surveys. Developed through a collaboration led by the University of Sydney's Institute of Transport and Logistics Studies (ITLS), TRIPS establishes a unified national framework for collecting, analysing and reporting trip generation data across diverse development types and urban contexts.

The platform addresses long-standing gaps in consistency and transparency by providing a central, accessible evidence base to support traffic impact assessments, strategic planning, development evaluation and multimodal transport modelling. With foundational support from state transport agencies, local councils and industry partners, TRIPS is designed as enduring research and planning infrastructure that will grow over time through continued data contributions. Its launch at TDM represents an important step toward more reliable, data-driven and nationally aligned approaches to transport planning and development assessment in Australia.

Dr. Supun Perera

TRIPS Project Director

Prof. Michael Bell

Academic Lead

Mr. Ben Wood

Implementation Lead

9. Joint Australia–Japan Workshop on Smart Mobility

This workshop brings together leading Australian and Japanese researchers to explore emerging issues in mobility, transport innovation and cross-national perspectives on travel behaviour, technology adoption and community impacts. The session will feature short presentations followed by a moderated discussion.

Professor Fumitaka Kurauchi

Social Acceptance of Automated Bus Services in Gifu
Gifu City has been operating an autonomous bus service in its city centre since 2023, with services planned to continue through 2028. Ongoing longitudinal surveys have been conducted to track changes in community acceptance of the service. Three rounds of surveys completed to date provide early insights into how public attitudes evolve over time as exposure to the technology increases.

Professor David Hensher

MaaS, MaaF and Beyond: Do Integrated Modal Mobility Services Have a Future?
This presentation will offer reflections on the opportunities and challenges surrounding Mobility as a Service (MaaS) and Mobility as a Feature (MaaF), including key lessons for future integrated mobility offerings.

Professor Takayuki Morikawa

“Smart Local Mobility” and Japan’s COI/SIP Initiatives toward a Society with No Mobility Divide

An overview of Japan’s national research and innovation programs aimed at addressing mobility gaps, promoting inclusive local transport solutions, and supporting community-level mobility resilience.

Professor John Nelson

Achieving Desired Sustainable Travel Behaviour Change: Insights from Practitioners

This talk will draw on practitioner experience to highlight strategies, challenges and opportunities for achieving meaningful and lasting behaviour change in contemporary transport systems.

Workshop Moderator

Dr Chinh Ho

10. Extended Abstracts

Tuesday 9th December: 11am-12.30pm
Parallel Session 1 (Level 17, Lecture room 3)
Theme: Public Transport Planning and Reform, Session Chair: Prof. John Nelson
Time for a Reset of Bus Contracts? (David Hensher)
The divisibility index: a theoretical device to support public transport design (Valentina Gomez, Andrés Fielbaum and Sergio Jara-Diaz)
Linking COVID-19 Ridership Changes with Tokyo Metro Centralities (Xi Lin, Claudio Feliciani, Daichi Yanagisawa and Katsuhiro Nishinari)

Time for a reset of bus contracts?

David A Hensher*

Institute of Transport and Logistics Studies (ITLS)
The University of Sydney Business School
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Introduction

In the last 40 years we have seen an accumulation of global experiences in delivering bus services under a range of contracts, including public ownership. Driven initially by an ideological position that competition in the market is highly desirable in delivering cost efficient services (linked mainly to competing bus services, in contrast to the broader multi-modal competitive element), it was not long before the natural monopoly argument was used, especially in urban contexts, in recognition of the risk and often evidence of inefficient competitive outcomes through economic deregulation. This led to a global preference for competition for the market (or competitive tendering) in settings where government wished to move away from publicly owned and provided bus services. In some contexts, it was decided to stay with an incumbent operator under a negotiated performance based contracting regime. We now have a significant amount of real-world experience with many versions of such contracts, with lessons learnt, positive and negative, giving a rich array of ideas that should be embedded in what we might do to improve on the delivery of bus services, given the set of primary objectives linked at least to customer service and value for (taxpayers) money. This paper sets out a contract reset strategy within which we propose a number of significant changes in the way the majority of bus contracts are currently delivered. The arguments and proposals are sufficiently generic to apply to any context in which all relevant stakeholders, notably the regulator and the operator, would want to venture in developing and implementing the next generation of bus contracts. Some key elements that need drastic reform include a move to more flexible (hence less rigid) contracts, identifying risk and ensuring it is shared across all who benefit, simplifying contracts at the *ex ante* bid stage with a recognition of an ability to review and revise during the tenure of the successful bidder, the opportunity to migrate to a collaborative contract (of great value in the decarbonisation transition), and to protect trust in the partnership between the principle and agents.

Things we have learnt over the last 40 years

Extracting the most important lessons in contract design and implementation over the last 40 years is a daunting task, not only because there is no such thing as an 'ideal contract' (as identified in Hensher et al. 2008), but that whatever themes are chosen, there will always be gaps in the views from regulators and operators. Despite this acknowledgment, there are some key themes that have survived numerous discussions and presentations that garner support from many stakeholders, who agree that resetting the elements of bus contracts is well overdue if there is a belief that what matters is value for money and customer satisfaction.

It was found that competitively tendered contracts have gradually become more complex, not least due to amendments introducing more incentives. Contracts have also evolved in terms of completeness, e.g., going from subjective to more objective measures of performance. These trends may be seen as forms of regulatory creep. External factors and difficulties in reinforcing the more complex contracts eventually resulted in premature termination. Later contracts have not been better at avoiding contract distress.

It was also observed that procuring authorities tend to design increasingly unbalanced contracts, i.e. contracts where they hold almost all sanction possibilities and contract termination powers. This leads to asymmetries that have also been used in unpredictable ways. Some bus operators have now decided not to participate in tenders under such conditions, an observation that applies to similar markets such as Great Britain. Those that still do may be guilty of contractual folly, a condition that could lead to the winner's curse. Public Transport Authorities can also be guilty of contractual folly, if they sign contracts for critical bus services with unproven operators or include tough requirements that may be impossible to enforce if the operator fails completely, increasing the risk of emergency contracts.

2.1 Flexibility

The dominant theme is the need for ***flexibility***, especially at the *ex ante* vs *ex post* the bid stages, with a recognition that the historical rigidity of contract bidding and content has undermined many opportunities to improve the delivery of services during the contract period as the market and other circumstances change. Specifically, there is a growing recognition that the contract set out at the bidding stage should ensure zero ambiguity (or at least sensible clarification), designed by experts in the industry (in contrast, too often, by lawyers with limited experience in the bus delivery space), and that it is made clear at the bid stage that the successful bidder will be able to sit down with the regulator and review the details in a way that ensures that both parties have a clear understanding on what will be agreed to, and a recognition that changes throughout a contract period may be required as the delivery of services starts to show appropriate new needs, aligned with a changing market environment. This is what is happening in Singapore and being planned in the Netherlands with a committed focus on flexibility.

In general, with exceptions to date such as Singapore, more emphasis should be placed on preparing for tender/negotiation and the pre-contractual phase, but also managing the relationship and contract on an on-going basis, not just one point in time.The rigidity of most contracts has resulted in an erosion of trust, and a far too often response that 'this is what you agreed to and that is all you are getting'. Fines linked to unfair abatement result (a dominant one being fines for violating on-time running), that are the antithesis to what should happen.

Some of the underlying themes linked to a move to greater flexibility in bus contracts include avoiding lock-ins (i.e., idea of adaptation, especially. in longer term contracts), the need for proper incentives to operators, a recognition that many current abatement conditions are a questionable tool to use in light of most issues outside of the operator's control (Hensher 2014), which is counter to a good recipe for trust in partnership (Stanley and Hensher 2008). Flexibility should recognise the need to utilise more steering mechanisms such as roll-over contracts as an incentive mechanism, as well as building in risk in contract transfer cost. Hensher et al. (2016) found that, on average, a 1% mark up on the Lowest Offer Price (LOP) to account for disruption costs associated with the change of provider are valued at a 1.5% mark up on the LOP ("Transaction Cost"), and this should be reflected in the bidding process in recognition of benefits potentially lost by replacing an incumbent. It aligns with the often stated views that CT Evaluation Committees do recognise the inherent risks in changing the service provider

Risk Sharing

A Thredbo conference recommendation on appropriate risk sharing between the authority and operator is that risks should be allocated to the party that can best manage the risk (Leong et al. 2020, Gwilliam and Toner 1998). This is often difficult to determine, and inadequate risk allocation in the past may have triggered a revolving re-allocation of (arguably unmanageable) risks. This is akin to the idea of regulatory cycles initially proposed in Gwilliam (2008). In general, but especially under a green transition, it is reasonable to assume that no one bus operator, let alone a regulator, can claim that they are the best agent to manage risk, or indeed the experts advising each operator and government. Whereas operators often have greater experience in running a bus business (the operations level in the STO framework of strategic, tactical and operations), the regulator has tactical responsibility which is currently unclear, suggesting that both the operator and the regulator are best to work together to share their skill sets and networks of advisors, and agree on appropriate risk sharing in order to achieve the strategic intent of government. This approach can be aligned with what is happening at present in many jurisdictions; namely the trend of de-risking on both sides of the operator in the value chain: on the manufacturer side with vehicles-as-a-service and the ever advancing (digital) capabilities of buses with many defects/maintenance requiring the expertise of the original equipment manufacturer (with links to new technologies like autonomous and electric); and on the government side with the government ownership of assets and management contracts. In some markets (e.g., Singapore, which modelled itself on Perth and London, Goh and Swee 2017), government takes ownership of the assets and sets the standard for training of bus captains (through the Singapore Bus Academy). In Darwin, the government even undertakes crew scheduling and development of rosters for their contracted bus operators. Bus operators can therefore become, or are becoming, nothing more than an organiser of labour to operate buses and are vulnerable to being squeezed out of the transport ecosystem (e.g., imagine a bus manufacturer putting drivers on their products and suddenly being able to take the role of a bus operator).

Contract Complexity

Real world contracts are almost always "incomplete" in the sense that there are inevitably some circumstances or contingencies that are left out of the contract, because they were either unforeseen or simply too complex and/or expensive to enumerate in sufficient detail. We argue that attempts to burden the contract with complexity, instead of recognising sensible boundaries for an incomplete contract that allow for incompleteness and negotiation, is not a preferred strategy (Hensher 2010). Incompleteness and negotiation give both parties the opportunity to suggest changes (or variations) that move towards efficient and effective delivery, in contrast to the often-seen evidence that overly complex contracts lead to ambiguity in translation and operator focus on such compliance with a diminished interest in exercising a commitment to continuous improvement in the service (through risk sharing outside of the contract). Such complexity may also result in a budget blow out as a consequence of high transaction costs in ensuring compliance (especially if it ends up in court) and, depending on the bargaining base of each party, a risk of high outlays with little gain in service. Negotiation under incomplete contracts is relatively more transparent in that the defined variation is clarified during negotiation; however, there may still remain an inability to fund any agreed shortfall without a budget contingency in place at the time that government establishes its forward estimates.

Roadmap set of recommendations

A reset of a local bus contract beyond 2025 should align with at least the following reforms:

1. Be a less specific contract that is flexible and contemplates change, and which needs to be drafted by all experts in the value chain as a commitment to trust.
2. A simplified contract at the bidding stage that is flexible in recognising clarity of input once won, by
    - recognizing the value of a ‘simple’ *ex ante* contract that is of sufficient detail to satisfy the primary objectives of a tender or negotiation (both having the exact same structure).
    - being prepared to announce *ex ante* that the winner of a tender or negotiation will have the opportunity *ex post* to work with the regulator to clarify current expectations and agree on a plan when change is reasonable and accepted as a result of circumstances not under the control of the operator or regulator, and including the possibility for innovative new ideas.

3. Have thoughtful contract terms (contract length) that overcome the fear of excessive profit or stall change.
4. Build in a contingency budget that protects government forward estimates from the inability to support genuine cases of change, and to ensure the process is transparent through engagement of an independent assessor.
5. Align with an asset ownership structure that avoids stranded asset risk, eases Government balance sheets, and avoids higher than government risk pricing and which recognizes that those who benefit should incur the appropriate level of risk.
6. Embrace new data sources to deliver key performance indicators (KPIs) (contrasted with key compliance indicators) that focus on customer outcomes and pave the way for growth and innovation, rather than focusing on simply not going backwards from an operator's perspective.
7. Allow for greater KPI flexibility in recognition that abatements can have significant commercial impacts and, increasingly in many geographical jurisdictions, do not deliver the strategic outcomes that we aspire to.
8. Re-introduce incentives that align with government objectives such as achieving sustainable mode shifts and growing patronage across the network, both achievable under gross and net contracts.
9. Think about a new collaborative contracting model as a supply chain partnership (SCP) which is designed to establish clear lines of risk and its allocation in line with who obtain the benefits.
10. Recognize that the transition to clean energy is a special long term case of reframing the nature and extent of risk, and how it might be shared until there is an agreed level of experience in identifying the full set of costs involved when they are eventually allocated to the appropriate party, and in particular if they will, in the long term, be the responsibility of the operator and any one they collaborate with in submitting a bid or entering a negotiation. That is, we must put decarbonisation into a context re contracts - who owns what and who manages what as experience builds.
11. Establishing and maintaining a smart trusting client partnership for contracting that:
    - Develops and builds in manageable steps.
    - Fixes minimum necessary scope and specification before design.
    - Understands the 'should cost' before tendering or negotiating.
    - Accepts risks the other party cannot manage.
    - Avoids premature commitment to contract completion date.
    - Keeps budget contingency under lock and key (for genuine requests)

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The Divisibility Index: A Theoretical Device To Support Public Transport Design

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Introduction

Consider a public transport system serving a corridor. There is a long history of analytical models to determine the optimal strategic decisions, such as frequencies, stops spacing, or subsidies (Mohring, 1972, Jara-Díaz & Gschwender, 2003, Fielbaum, 2024, Coulombel & Monchambert, 2023). However, not enough has been done to understand the network-related aspects. In particular, two usual networks found in different cities worldwide are either having a line covering the whole corridor, or two lines each serving one segment. The latter is typically observed with the two lines converging at the CBD, or in a feeder-trunk manner connected at a subcenter. In this research, we investigate theoretically under which conditions a divided line is better than a single one, minimizing the sum of users' and operators' costs. Understanding which is the optimal alternative is relevant for assessing the role of transfers, as well as the benefits and drawbacks of transfer-based line structures.

Methodology

We formulate the problem in a linear city model, where we focus on the supply aspects by considering a given demand pattern. We define the General Linear City as a path of k nodes $\{n_1, n_2, ..., n_k\}$, where all passengers travel in the same direction. We define a line by means of its sequence of stops (Eqs. 1 - 3). The first one is the complete line in the General Linear City (it stops in each node), and the other two are the result of dividing the line in the i-th node, which enables offering different frequencies and bus capacities at each segment. We define the line structure S_0 (Eq. 4) that contains the complete line, and the alternative line structure S_i (eq. 5) formed by the two divided lines divided at node i.

$$l_0 = [n_1, n_2, ..., n_k] \quad (1)$$

$$l_{(0,i)} = [n_1, n_2, ..., n_i] \quad (2)$$

$$l_{(i,k)} = [n_i, n_{i+1}, ..., n_k] \quad (3)$$

$$S_0 = \{l_0\} \quad (4)$$

$$S_i = \{l_{(0,i)}, l_{(i,k)}\} \quad (5)$$

The objective is to minimize the total value of the resources consumed (VRC), i.e. the sum of operators' and users' cost. The design variables are the line structure S (S_0 or one of the S_i), the frequencies f_l of all the lines l involved in S, and the vehicles' capacity of every line K_l. The VRC is given by:

$$VRC(S, f, K) = \sum_{l \in S} B_l(S, f)(c_0 + c_1 K_l(S, f)) + Y(p_{\text{iv}} \bar{t}_{\text{iv}}(S, f) + p_w \bar{t}_w(S, f)) + p_R R(S, f) \quad (6)$$

Where $B_l(S, f)$ is the fleet size. c_0 and c_1 are, respectively, the fixed cost per vehicle and the component that grows linearly with its size. $\bar{t}_{\text{iv}}(S, f)$ is the average in-vehicle travel time and p_{tr} is its value; $\bar{t}_{\text{w}}(S, f)$ is the average waiting time with value of waiting p_w, and $R\,(S, f)$

the total number of transfers, each with a penalty p_R. It is convenient to split a line at node i iff $\min_{f_0,K_0} VRC(S_0, f_0, K_0) > \min_{f,K} VRC(S_1, f, K)$.

Analysis

A careful analysis of Eq. (6) yields three conditions that favoring division: i) inducing few transfers, ii) a large difference in the maximum flows between the two segments, and iii) the segment with the lower maximum flow being long. We then synthesized these three conditions into a new Divisibility Index (DI) -Eq. (7)- to measure the suitability for division at a given node. The higher the index, the more advantageous it is to split the line at that node.

Definition 1: (Divisibility Index) Denote Y as the total passengers, $\zeta_l(n)$ as the number of passengers crossing the n-th node, and l_i the length of the section with the largest flow. Then, the divisibility index (DI) of node i is:

$$DI(i) := \left(1 - \frac{\tau_l(i)}{Y} d_1\right) \left| \max_{1 \leq n \leq i} \zeta_l(n) - \max_{i \leq n \leq k} \zeta_l(n) \right| \left(1 + \left(|l_i| + \frac{|l_i|}{|l|}\right) d_2\right) \qquad (7)$$

The DI can be used to develop simple rules to decide whether and where to split a line. First, we consider the best candidate for division as the node with the largest DI. The question then is whether splitting the line at that node does improve the system. Evidently, this question can be answered by calculating the VRC of both line structures: we call this the *formula procedure*. A faster alternative is determining if the DI is large enough, compared to a predetermined threshold appropriately chosen. If the DI of the best candidate is above the threshold, then split the line at the node, otherwise, don't: the *threshold procedure*. In both cases, it is natural to generalize the procedure to the possibility of admitting more than one division per line in an algorithm; it starts with a complete line and determines whether or not there is a split at its node with the greatest DI. If the decision is to split, then the process continues recursively on both obtained segments.

The approaches are tested numerically in a particular case of the General Linear City inspired by the parametric city model (PCM, Fielbaum *et al.* (2016)). We verified the impact of the three divisibility conditions on the shape of the optimal structure and the accuracy of the algorithms. The threshold procedure achieved an average error of 0.1%, while the formula procedure achieved an average error of 0.03%, demonstrating the success of both.

Discussion

We have analytically established the conditions determining whether a divided line is better than a single one. These three conditions are synthesized into a new divisibility index DI to measure the suitability for division at any a given node. Two algorithms that use the divisibility index are proposed to determine whether and where to split a line. An application of these algorithms has proven that they provide an excellent approximation of the true optimal network. Nevertheless, the DI concept could be applied indeed to any line forming a more complex public transport network and combined with additional procedures for the network design. This suggests the algorithms described and applied here could be extended to such general layouts, and constitutes the main direction we identify for future research.

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Linking COVID-19 Ridership Changes with Tokyo Metro Centralities

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Introduction

Complex Network Theory (CNT) enables the identification of critical nodes through centrality analysis and has been applied to aviation (Kong, 2023), railways (Liu et al., 2020), and multimodal transport systems (Zhou et al., 2021), as well as to metro systems (Vichiensan et al., 2023). However, studies on metro networks often overlook key factors such as passenger volume and travel time, focusing only on topological structure. This study addresses these gaps by incorporating both passenger volume and travel time into the Tokyo Metro network analysis. After redefining weighted centrality metrics, it further examines the relationships between COVID-19-induced ridership shifts and these weighted centrality measures.

Centralities

a) Strength Degree Centrality: Strength degree centrality quantifies the connectivity intensity of a station by summing the weights of all its connected edges. Unlike traditional methods that only consider edge-based weights, this approach incorporates both passenger volumes and comprehensive travel time, calculated as:

$$S(i) = \sum_{j \in \Gamma(i)} \frac{\frac{P_i}{d_i} + \frac{P_j}{d_j}}{2 \cdot T(i,j)},$$

where, P_i and P_j are total passenger volumes of stations i and j, d_i and d_j are the numbers of edges connected to stations i and j, $T(i,j)$ is comprehensive travel time between stations.

b) Betweenness Centrality: Betweenness centrality reflects a station's role in facilitating transfers, computed by the proportion of shortest paths passing through it. This method incorporates passenger volumes to emphasize high-flow routes:

$$B(i) = \sum_{s \neq t \neq i} P_s \cdot P_t \cdot \frac{\sigma_{st}(i)}{\sigma_{st}},$$

where, σ_{st} is the number of shortest paths between stations s and t, $\sigma_{st}(i)$ is the number of these shortest paths that pass through stations i.

c) Closeness Centrality: Closeness centrality evaluates how centrally located a station is. In this study, it incorporates both passenger volume and comprehensive travel time to reflect network accessibility more realistically:

$$C(i) = \frac{\sum_{j \neq i} P_j}{\sum_{j \neq i} P_j \cdot T(i,j)}.$$

Coupling of Pandemic Ridership Shifts and Weighted Centrality Metrics

Based on station-level passenger volumes before and after COVID-19, the Figure 1(a) visualizes the distribution of ridership from 2019 to 2023, expressed as a ratio relative to the 2019 baseline. Figure 1(b) illustrates the outlier stations identified each year, where "above-trend" means ridership recovery was significantly stronger than the yearly average, and "below-trend" means it lagged significantly behind the network-wide recovery pace.

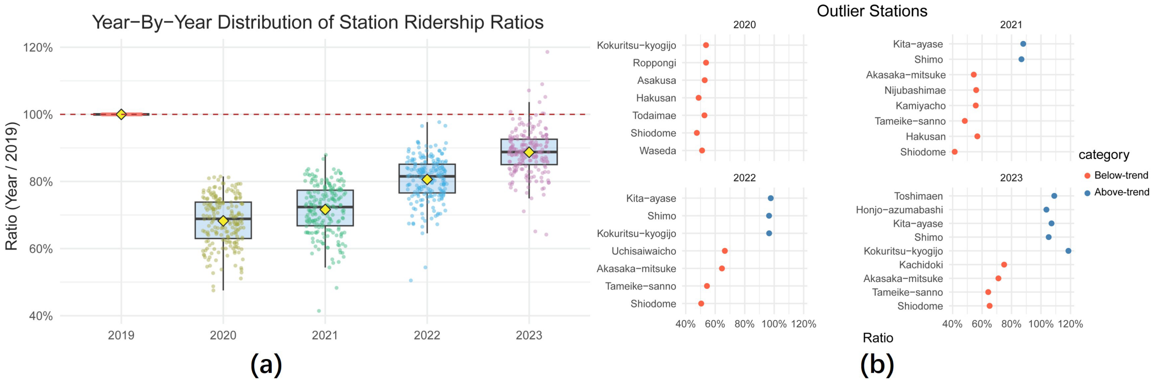

Figure 1. Yearly Ridership Distributions and Outlier Stations.

Figure 1 shows 17 identified outlier stations. To further investigate their relationship with three centralities mentioned above, centrality metrics were calculated using 2019 data, and stations were subsequently ranked according to the value of each centrality, as illustrated in Figure 2.

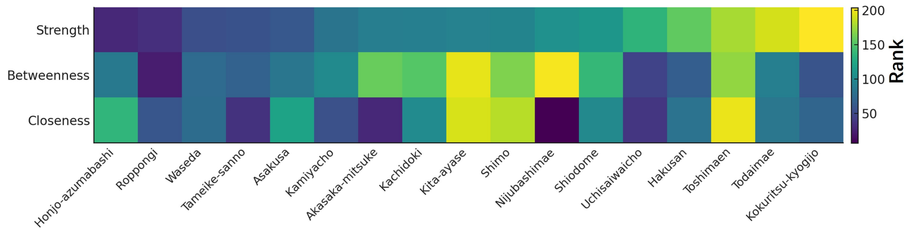

Figure 2. Centrality Rankings of Outlier Stations Across Three Metrics.

Based on their 2019 weighted centrality ranks, the outlier stations were grouped into eight types. Specifically, Table 1 shows these types and their outlier status.

Table 1 Passenger-count outliers for selected Tokyo Metro stations

Category	Station(s)	Outlier status
All/Most Indicators High	Roppongi / Kamiyachō / Waseda / Tameike-sannō / Uchisaiwaichō	Below-trend outlier
All/Most Indicators Low	Toshimaen / Shimo / Kita-ayase	Above-trend outlier
Typical High C/High B	Akasaka-mitsuke/ Nijūbashimae/ Hakusan	Below-trend outlier
Typical Low S	Todaimae	Below-trend outlier
Typical High S	Asakusa	Below-trend outlier
	Honjō-azumabashi	2023 Above-trend outlier
High B & Low S	Kokuritsu-kyōgijō	2020 Below-trend; 2022, 2023 Above-trend
Typical Low B	Kachidoki	Above-trend outlier
Balanced station	Shiodome	Below-trend outlier

As shown in the table, stations with high weighted centrality in 2019 typically reflect areas of intense pre-pandemic activity and experienced sharp ridership declines during both the pandemic and recovery phases. In contrast, stations with low centrality scores showed smaller ridership reductions, indicating greater resilience. Exceptions include Todaimae, likely affected by policies at the University of Tokyo, and Shiodome, which exhibited balanced centrality rankings but experienced a notable decline, possibly due to its office-dense surroundings. Kokuritsu-kyōgijō showed an unusual increase in 2023, potentially due to renewed development plans in the area. These cases suggest that ridership trends are not solely determined by network centrality. Overall, weighted centrality appears linked to pandemic ridership shifts, though further analysis is needed to clarify the relationship.

Acknowledgements

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Tuesday 9th December: 11am-12.30pm
Parallel Session 2 (Level 16, Seminar room)
Theme: Simulation and Modelling Innovation, Session Chair: Prof. David Levinson
Estimating Desired Trip Demand for Discretionary Purposes under Mobility Constraints (Genichiro Nakagaki and Tomio Miwa)
Automated Conversion of Predicted Historic Road Maps to Graph Representations (Ethan Yin and David Levinson)
Priority-Based Multi-Agent V*: A Simulation Framework for Non-Lane-Based Street Traffic (Abdullah Zareh Andaryan, Michael Bell, Mohsen Ramezani and Glenn Geers)

Estimating Desired Trip Demand for Discretionary Purposes under Mobility Constraints

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Introduction

In transport planning practices, public transportation systems are developed based on realized trip data. However, residents often fail to realize trips due to mobility constraints such as limited access to transportation services. These unrealized trips, particularly for discretionary purposes such as shopping and leisure, represent a latent portion of travel demand not captured in conventional models. This study aims to estimate desired trip demand, defined as the sum of realized and unrealized trips, by developing a statistical model that accounts for both components. We focus on shopping and leisure trips, which are more affected by transportation constraints than essential trips such as commuting or medical visits. We also compare two estimation approaches depending on the available data: the Full Demand-Constraint Model (FDCM), which utilizes the exact number of unrealized trips, and the Censored Demand-Constraint Model (CDCM), which only requires binary information on whether unrealized trips occurred.

Previous studies and Research Gaps

Previous studies have categorized latent travel demand into several levels (Clifton & Moura, 2017) and have explored its determinants from both personal (e.g., driving license) and contextual (e.g., service availability) perspectives. However, most research has focused on vulnerable groups such as the older adults and treated realized trips as a proxy for travel demand. Miwa *et al.* (2023) addressed this by proposing a demand-constraint model considering unrealized trips for older adults in rural Japan, but assumed Poisson distributions and lacked broader demographic representation. This study expands on their framework in two significant ways: (1) by incorporating negative binomial distributions to address overdispersion in trip count data, and (2) by applying the model to a broader dataset including all adult age groups and various municipal population sizes across seven prefectures of Japan.

Data Collection

We collected data from an online survey in September 2023. The survey targeted residents aged 18 and older across seven prefectures (Aichi, Gifu, Shizuoka, Mie, Niigata, Toyama, and Ishikawa), collecting 5,976 valid responses. The questionnaire included sections on individual and household attributes, transportation accessibility, and frequency of both realized and unrealized shopping and leisure trips. To focus on transportation-related constraints, unrealized trips were asked using the following phrasing: "In the past month, how often did you intend to go shopping (leisure) but couldn't do so due to lack of available transportation?"

Model Framework

Desired trip demand $Y_{i,n}$ for purpose i (shopping or leisure) and individual n is the sum of realized $Y_{i,n}^{+}$ and unrealized trips $Y_{i,n}^{-}$. Mobility constraint $\bar{Y}_{i,n}$ denotes the achievable trip frequency under current conditions. If the desired demand $Y_{i,n}$ exceeds the mobility constraint $\bar{Y}_{i,n}$, an unrealized trip is generated; if $Y_{i,n}$ doesn't exceed $\bar{Y}_{i,n}$, infinite series are computed from the number of realized trips to infinity to estimate $\bar{Y}_{i,n}$. We model both $Y_{i,n}$ and $\bar{Y}_{i,n}$ using negative binomial distributions to accommodate overdispersion. To capture correlation between shopping and leisure demands, a bivariate negative binomial distribution is adopted. The FDCM uses observed frequencies of both realized and unrealized trips, while the CDCM estimates desired demand based on whether unrealized trips occurred or not. Parameters are estimated using maximum likelihood estimation, taking into account the joint probability structure of demand and constraints.

Results and discussions

Two separate age groups were analyzed: younger adults (under 29) and older adults (over 65). As the model performance, parameters of CDCM were similar to those of FDCM, suggesting that even limited binary information on unrealized trips can be effectively used for demand estimation. About young adults, for leisure trips, males and single-person households showed higher desired demand, while residents with driver's licenses or those living in large cities exhibited lower demand. In addition, this generation is more likely than others to have unrealized trips. For older adults, in contrast to younger adults, leisure demand was higher among those with higher household income and those living in medium-sized municipalities. As mobility constraints model, across both age groups, longer distances to destination and fewer transit services were associated with stronger constraints. These findings confirm the need to consider both realized and unrealized trips when assessing true mobility needs, and highlight the demographic and contextual variability in demand and constraints.

Conclusion and Recommendations

This study proposes and validates an advanced modeling approach for estimating desired trip demand, incorporating both realized and unrealized trips. The application of a bivariate negative binomial model enables the analysis of interrelated trip purposes and accommodates overdispersed data. The CDCM prove especially valuable for large-scale surveys where respondents may be unable to provide exact counts of unrealized trips. Our results also suggest that younger and older populations exhibit distinct patterns of demand and constraint, which should be considered in transportation planning. Future research should explore further segmentation (e.g., income level, household structure), test the model in other regions or countries, analysis of the relationship with trip satisfaction, and incorporate temporal dynamics or qualitative factors affecting unrealized trips.

Acknowledgements

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Automated Conversion of Predicted Historic Road Maps to Graph Representations

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Introduction

Maps of historic streets provide details about transportation systems and urban development. Unfortunately, the properties of old cartographic resources make it difficult to extract this information. Through image segmentation, deep learning techniques—in particular, U-NET architectures—can extract road networks; nevertheless, there is still a gap in the conversion of pixel-based predictions into structured representations for network analysis.

According to Uhl et al. (2017), road networks can be recreated using convolutional neural networks and historical photos. Nevertheless, these methods yield segmentation masks based on pixels that are not organised enough for quantitative network analysis. Limited ground truth data, contemporary reference bias, and map deterioration artefacts are some of the difficulties associated with the conversion.

The method was trained and evaluated on a selection of maps from the John Sands' map series of Sydney obtained from the City of Sydney Archive, and street network maps from Open Street Maps. The propopsed method demonstrates an ability to accurately extract and maintain street network connectivity, intersection locations all while preserving the topological structure of the map.

Methodology

The conversion pipeline consists of four main stages designed to transform U-NET probability maps into topologically accurate graph structures whilst preserving essential network connectivity.

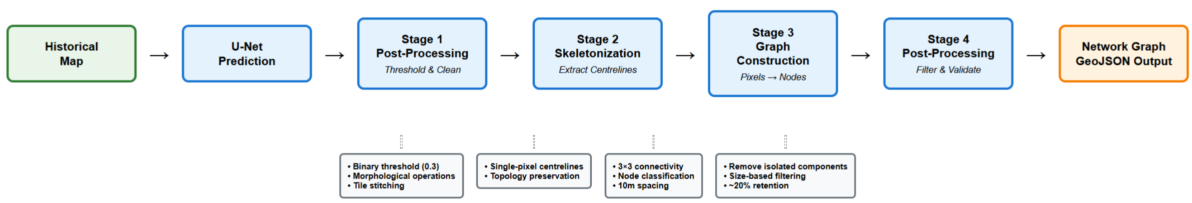

Figure 1. Proposed methodology pipeline showing the four-stage conversion process from historical maps to graph representations with technical details for each stage

Post-Processing and Binarisation: U-NET probability outputs undergo thresholding at 0.3 to generate binary road masks. Individual tiles are stitched into full representations with morphological cleaning using OpenCV operations including opening to remove noise artefacts and closing to fill gaps.

Centreline Extraction: Binary road maps are converted to skeletal representations using skimage morphology skeletonisation, reducing thick road segments to single-pixel-wide centre lines whilst preserving topological structure.

Graph Construction: Every road pixel becomes a graph node with 3×3 neighbourhood connectivity. Nodes are classified as intersection (>2 neighbours), endpoint (1 neighbour), or shape nodes (2 neighbours). Dense graphs are systematically simplified through iterative culling, removing alternate shape nodes whilst maintaining 10-metre spacing.

Graph Post-Processing: Two filtering mechanisms ensure validity: intersection-based component filtering removes components without intersection nodes, whilst size-based filtering eliminates components with $\leq$10 nodes, typically preserving 20% of components.

Results and Discussion

The methodology was evaluated using John Sands maps (1877-1903) from Sydney City Archive, with 1877 serving as training data (1,836 tiles) and 1903 for testing. Ground truth annotations were created through manual digitisation following Turner et al. (2023).

Table 1. Performance metrics for U-NET segmentation and graph construction

Metric	1877 Map	1903 Map	Intersection	Edge
Precision	0.961	0.922	0.778	0.967
Recall	0.776	0.664	0.773	0.826
F1 Score	0.966	0.951	0.776	0.891
Dice/IoU	0.851/0.754	0.773/0.644	–	–

U-NET segmentation achieved good performance across datasets. The 1877 training map showed high precision (0.961) and recall (0.966), whilst the 1903 test map demonstrated generalisation with precision (0.922) and recall (0.951). Matthews Correlation Coefficient values of 0.839 and 0.745 indicate robust performance despite class imbalance.

Graph construction successfully preserved network structure. Intersection detection achieved precision (0.778), recall (0.773), and F1 score (0.776), identifying 1,846 true intersection nodes. Edge connectivity preservation showed strong recall (0.826), indicating most road connections were maintained. High edge precision (0.967) reflects accurate road allocation with minimal false positives. These results indicate that the proposed methodology prioritises the minimisation of false positives, as this encourages the method to avoid fabricating new roads it is a reasonable priority for network extraction.

Conclusion

This research presents a pipeline converting U-NET predicted historical road maps into graph representations, maintaining network topology whilst demonstrating computational efficiency for large-scale processing. When analysed the resulting graphs present a high level of accuracy that will enable quantitative analyses of historical urban development, supporting research in urban planning history and transportation network evolution.

The methodology addresses a gap in historical cartographic research by enabling automated conversion from deep learning predictions to structured network data for transportation analysis. Edge connectivity preservation of (0.891 F1) the graph ensures that the majority of the streets documented in historical maps are extracted without creating false positive roads. Future work should focus on improving performance in dense urban regions, developing scale-adaptive algorithms, and extending the approach to automated geolocation applications. Further work should also be done to generalise this method to be applied on more maps outside the dataset established in this paper.

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Priority-Based Multi-Agent V*: A Simulation Framework for Non-Lane-Based Street Traffic

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Introduction

Urban mobility is undergoing a fundamental transformation as cities strive to create environments that prioritize safety, sustainability, and inclusivity (Moreno et al., 2021; Rui & Othengrafen, 2023). This has led to the adoption of shared spaces, pedestrian-prioritized zones, and low-speed residential streets, where traditional lane-based traffic models are inadequate (Moreno et al., 2021; Rui & Othengrafen, 2023). In these settings, diverse road users interact dynamically within the same space. Modeling such environments presents significant challenges for existing simulation platforms (Asaithambi et al., 2016; Papathanasopoulou & Antoniou, 2018).

Widely used tools like VISSIM and AIMSUN rely on car-following models and lane-based frameworks. VISSIM employs the Wiedemann psycho-physical car-following model (PTV Group, 2025), while AIMSUN uses the Gipps model (Aimsun, 2022). These approaches perform well in structured settings but are less effective in simulating non-lane-based scenarios, where lateral freedom and adaptive interactions dominate (Asaithambi et al., 2016; Kashyap et al., 2022).

To address this gap, we introduce a new priority-based multi-agent V* algorithm that extends our prior work on the velocity-aware A* method (Andaryan et al., 2025). V* incorporates velocity, acceleration, and vehicle dynamics into the path planning process, operating over a space-time-velocity lattice. The present work extends V* to support multi-agent navigation in unstructured 2D spaces with real-time prioritization.

Rather than seeking to replace commercial simulation tools, this project aims to complement these by providing a non-lane-based simulation platform—a capability not currently addressed by mainstream tools. This aligns with broader industry and government goals around safe and inclusive street design, particularly in shared space areas, smaller junctions, residential neighborhoods, and active transport corridors where vulnerable road users must be carefully modeled.

Through this combined V*-PBS (V*-priority based simulation) architecture, our framework generates collision-free, dynamically feasible, and time-optimal trajectories for heterogeneous agents in non-lane-based environments. Although the traffic is not channelled into lanes, the simulated agents (vehicles and pedestrians) do follow priorities relating to passing on the left (or right in countries which drive on the right) or giving way when in conflict. Crucially, by adjusting agent parameters such as wheelbase L, maximum speed, and acceleration profile, the system supports a wide spectrum of road users, from highly agile pedestrians to large vehicles with significant turning constraints. The methodology and some initial illustrative simulation results are set out in the Appendix.

Discussion

The proposed priority-based multi-agent V* framework enables the generation of collision-free, dynamically feasible trajectories for vehicles and pedestrians in non-lane-based environments. This capability addresses the need for accurate simulation of non-lane-based traffic behavior—an area not well served by current traffic simulation tools like AIMSUN and VISSIM.

By embedding vehicle kinematics in a space-time-velocity lattice and leveraging priority based simulation (PBS) for inter-agent coordination, the system enables design testing for street layouts, such as shared spaces or small junctions. The framework provides a two-dimensional, fully dynamic representation of agent (vehicle and pedestrian) motion, complementing existing lane-based models, which are more applicable to road networks.

Future work will focus on scaling the framework, incorporating policy-driven agent behaviors, and deploying the tool in practical street design and transport planning studies with industry and government partners.

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APPENDIX: Methodology and results

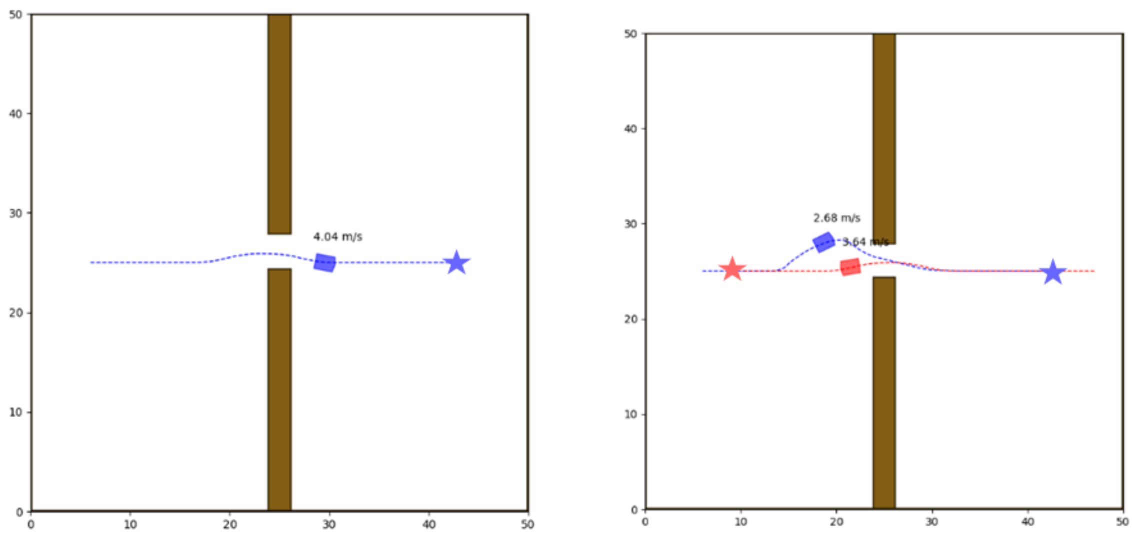
We address the problem of computing dynamically feasible, time-optimal trajectories for multiple AVs navigating through non-lane-based environments. Each agent must reach a goal region while respecting dynamic limits and avoiding collisions. The environment is modeled as a continuous 2D space with known static and dynamic obstacles.

The search space is discretized into a space-time-velocity lattice where each node $n = (x, y, \theta, v, t)$. Successor states are generated by applying admissible steering and acceleration inputs, integrated using the bicycle model. The lattice employs a hexagonal spatial discretization to ensure angular uniformity. V* uses a best-first search with an open list prioritized by $f(n) = g(n) + \hat{h}(n)$, where $g(n)$ accumulates travel time, and $\hat{h}(n)$ is an admissible heuristic estimating the time-to-go to the goal from node n. At each expansion, V* selects the node with minimum $f(n)$, growing a time-optimal search tree.

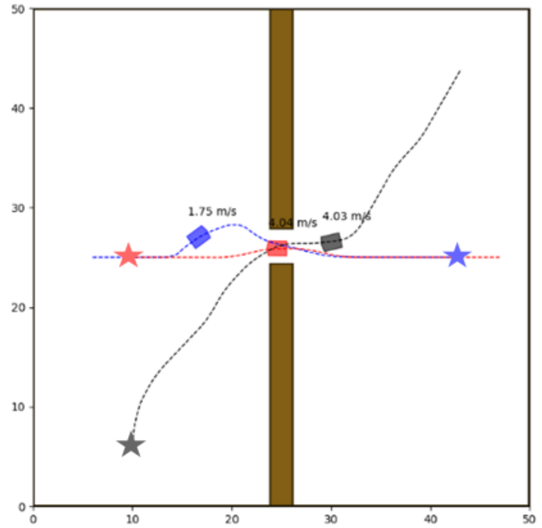
For multi-agent scenarios, we embed V* into a Priority-Based Search (PBS) framework (Ma et al., 2019), a well-established method for decoupling agent planning through dynamic priority assignment. In this framework, agents are assigned a priority ordering, and each agent sequentially plans its path using V*, treating the planned trajectories of higher-priority agents as dynamic obstacles. This ensures that each agent reasons over the spatiotemporal occupancy of the environment while respecting its own motion constraints. If a conflict is detected—i.e., if an agent cannot find a valid path given the current priority ordering—PBS adaptively resolves it by reordering agent priorities and replanning affected agents. This hierarchical coordination scheme allows the system to scale to larger multi-agent settings without incurring the computational burden of fully joint planning.

Results

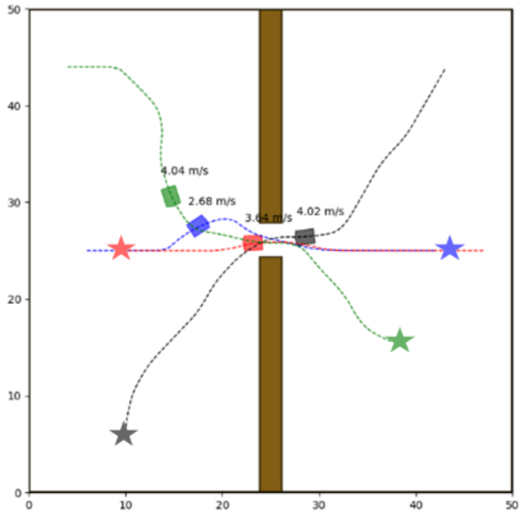
We tested the priority-based multi-agent V* framework on scenarios involving multiple AVs navigating through a constrained, non-lane-based environment. All vehicles share the same dynamic model and motion limits. To evaluate the effectiveness of the framework, we conducted a series of simulation experiments where groups of AVs negotiated a shared bottleneck under varying traffic configurations.



(a) (b)



(c)



(d)

Figure 2: Multi-agent navigation scenarios using priority-based V. Each subplot shows a scenario where agents must traverse a bottleneck. The agents are represented as pointed boxes, and the dashed lines and the stars indicate the trajectories and the goal of agents with matching colors, respectively. Obstacles are depicted as brown rectangles.*

Fig. 2 presents results from these scenarios, illustrating how the framework dynamically resolves conflicts to minimize the total travel time of all agents. In the single-agent case (Fig. 2a), an AV navigates the environment alone, computing a smooth, time-optimal trajectory while respecting vehicle dynamics and obstacle constraints. In the two-agent scenario (Fig. 2b), the blue agent receives lower priority and yields to its right, following traffic conventions. The three-agent scenario (Fig. 2c) shows that the red agent holds the highest priority as its progress is least disruptive, the black agent follows the red agent with second priority to maintain flow, and the blue agent is assigned the lowest priority to prevent blocking other agents. Finally, in the four-agent scenario (Fig. 2d), the red agent again holds highest priority, the black agent follows red with second priority, the blue agent yields with lower priority, and the green agent, positioned behind blue, also receives lower priority to ensure overall efficiency. These results highlight the framework's ability to generate collision-free, dynamically feasible trajectories that respect traffic conventions and optimize multi-agent flow in complex environments.

Tuesday 9th December: 11am-12.30pm
Parallel Session 3 (Level 16, Lecture room 5)
Theme: Emerging Mobility and Micromobility Integration, Session Chair: A/Prof. Chinh Ho
Stakeholder Perspectives on Mobility Hub Functions in Mediterranean Contexts: An Analytic Hierarchy Process Analysis (David Micallef, Maria Attard, Vasiliki Amprasi, Panagiotis Papantoniou, Dimosthenis Pavlou, Loukas Dimitriou and Christos Gkartzonikas)
Public views on policies to promote cycling and micromobility: a Sydney case study (Stephen Greaves and Matthew Beck)
Promoting micromobility as a TDM tool in Australia: Opportunities and challenges (Geoff Rose and Stephen Greaves)

Stakeholder Perspectives on Mobility Hub Functions in Mediterranean Contexts: An Analytic Hierarchy Process Analysis

David Micallef[1], Maria Attard[1*], Vasiliki Amprasi[2], Panagiotis Papantoniou[2], Dimosthenis Pavlou[2], Loukas Dimitiriou[3], Christos Gkartzonikas[3]

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Keywords Mobility Hubs, Mediterranean Region, stakeholder perspectives, AHP, sustainable mobility, Hub functions, multimodality

Introduction

The Mediterranean region faces unique transport challenges characterised by dispersed population distributions, rural peripheries, and significant variations in population density between urban centres and coastal areas. Mediterranean countries often exhibit highly centralised urban development with substantial rural populations lacking comprehensive, sustainable connectivity. Sustainability and mobility are therefore two key preoccupations in the Mediterranean region (Giannopoulos, 2020).

Primarily in Northern and Central Europe, mobility hubs have emerged as a response to issues of connectivity and multi-modality. The distinction between a regular public transport node and a shared mobility hub is sometimes difficult to identify. However, it can be seen as a unique facility because of the diversity and sustainability of the transport modes offered, the integration of shared mobility services, the inclusion of additional facilities at the hub, and the holistically integrated route decision support (Blad et al., 2022). Existing literature on mobility hubs primarily focuses on dense urban environments with established rail networks. However, Mediterranean transport infrastructure presents different challenges, with rail networks primarily serving major urban centres while leaving rural and coastal areas underserved.

This creates a significant research gap: can mobility hubs be adapted to the Mediterranean context? What are the general sentiments of stakeholders and the challenges they anticipate in their effective implementation?

This research was undertaken as part of the GREENMO project which aims to promote green and inclusive mobility hubs for Mediterranean areas by leveraging citizens' real needs (https://greenmo.interreg-euro-med.eu/). The results of the study aim to contribute to the development of a joint strategy for green and inclusive mobility hubs tailored for Mediterranean countries. The project investigates and compares both top-down (policymakers and other high-level stakeholders) and bottom-up (citizens, local communities) perspectives, thereby co-defining specific, tailor-made recommendations for mobility hubs for the Mediterranean region.

The paper addresses the methodology and results from the top-down approach utilized in this project, which aimed at identifying and analysing the perspective and priorities of high-level stakeholders, including how they perceive the relative importance of different hub functionalities. The objective is to provide evidence-based insights for developing context-appropriate mobility hub strategies that align with both policy aspirations and practical implementation realities across the Mediterranean.

Methods

This study employed semi-structured interviews with 59 high-level stakeholders – including public entities and transport operators – in Malta, Greece, Italy, Bosnia and Herzegovina, Cyprus, and Spain. The interview guide included seven main themes:

a. Stakeholder perspectives and decision-making processes
b. Core transport issues
c. Understanding of mobility hubs
d. Mobility patterns and data
e. Stakeholder engagement
f. Funding and resources

Stakeholder Perspectives and Decision-Making Processes: Given the various remits the various stakeholders may have in the broad transport ecosystem, a baseline understanding of the participants' roles in policy design and implementation aided in providing important context to the remainder of the interview (Whitmarsh et al., 2007).

Core Transport Issues: Informed by Antrop's (2004) seminal work on landscape and transport interaction. This thematic area aimed to establish baseline understanding of transport challenges within participants' jurisdictions.

Understanding of Mobility Hubs: This theme aimed to evaluate the level of knowledge or familiarity the high-level stakeholders have, as well as the initial or general sentiments towards mobility hubs. This question included sub-themes related to the anticipated challenges in implementing a mobility hub. This question was informed by Weustenenk and Mingardo (2023), Storme et al. (2021), Aydin et al. (2022) and Morimoto (2021).

Mobility Patterns and Data: As mobility hubs – or transport planning in general – cannot be effectively planned or located without understanding travel patterns, this question aimed at uncovering the knowledge, availability, and usage of mobility data in planning. The literature consistently demonstrates that transport infrastructure decisions made without robust mobility data frequently fail to meet user needs and achieve intended outcomes (Kitamura et al., 1997; Gonçalves et al., 2017; Litman, 2024; Semanjski et al., 2016). These questions were essential to determine whether stakeholders had access to the evidence base necessary for informed mobility hub planning decisions.

Stakeholder Engagement: Cartenì et al. (2020) emphasie the importance of participatory transport planning approaches. This theme was necessary to evaluate the level of communication and engagement high-level stakeholders have with other high-level stakeholders as well as their level of engagement with public stakeholders, including citizens.

Funding and Resources: Informed by the analysis of Whiteing et al. (2006) on transport project financing structures, this theme aimed to understand what financial or other resource-related hurdles there may be in the implementation and operation of a mobility hub.

Although the semi-structured interview guide had predefined general themes, additional themes emerged during the coding process. The translated interview transcripts were coded in NVivo to support thematic analysis.

Additionally, during the interview, participants were presented with a pairwise comparison matrix (AHP matrix) evaluating five core mobility hub functions adapted from Wicki et al., (2022): core transport system offering, public space provision, services (such as parcel lockers), commercial use (such as cafes), and multimodal integration. The results are analysed and compared at a regional level and by stakeholder categorisation. This allows for a better understanding of the differences or similarities in insights from stakeholders with varying levels of influence and operational remit, e.g. ministries, agencies, authorities, and operators.

The data from the Analytic Hierarchy Process (AHP) exercise was processed and analysed using Python, providing a quantitative representation of the stakeholders' priorities that served to complement the qualitative insights.

Initial findings

Preliminary analysis reveals variations and similarities in stakeholder priorities across the studied regions. Core transport system offerings consistently ranked highly across all contexts, reflecting the fundamental infrastructure gaps in Mediterranean rural areas. However, public space and commercial functions showed varying importance levels, with no meaningful difference between island and mainland contexts.

Multimodality, including the provision of connection to personal transport integration, emerged as particularly crucial in all areas with limited public transport coverage, where mobility hubs must accommodate various transport modes including private vehicles, cycling, and emerging micromobility solutions. A variance in the prioritisation of services and commercial use was observed amongst both stakeholder types and geographical contexts, providing insight into the general priorities of various stakeholders, particularly in tourist-dependent economies where commercial integration is considered more important.

Unanimously, stakeholders indicated significant implementation challenges related to land ownership laws, funding mechanisms, stakeholder engagement processes, and the lack of data integration. The analysis revealed gaps between policy-level aspirations for sustainable mobility and practical implementation constraints.

Acknowledgements

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Public views on policies to promote cycling and micromobility: a Sydney case study

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Introduction

Driven by sustainability and public health objectives, many cities are adopting policies to promote cycling and emerging forms of micromobility, like e-bikes and e-scooters. Experiences suggest that successful/accepted approaches must consider the local situation and public opinion (Rissel et al., 2018). Drawing on a survey of 1,500 Sydneysiders conducted in November 2024, the current paper describes the degree of public support - and factors associated with this support - for transport policy options that support micromobility and restrict motor use in Greater Sydney, a highly motorised city with a traditionally hostile attitude towards cyclists (Pucher et al., 2010) and e-scooters (Greaves et al., 2025).

Methods

Survey Data: This study was designed within a broader study of travel/health in Greater Sydney, the Sydney Travel and Health Study - STAHS (Greaves et al., 2024). The survey captured self-reported health, travel and neighbourhood perceptions, with additional questions soliciting levels of agreement with 13 policy statements supporting micromobility or restricting cars. Participants were recruited by a market research company using their online consumer panels. Eligible participants were aged 18+ residing in Greater Sydney. The aim was 1,500 participants with quotas for age, gender and location (inner, middle, outer Sydney to match the latest Australia (2021) census and different city areas. Participants received nominal compensation for completing the survey, which took 10–15 minutes and ran from November 11 to 30, 2024 (late spring to early summer in Sydney). The study was approved by the University of Sydney ethics committee (protocol 2019/217).

Analytical methods: Descriptive statistics were used to describe sample demographics and levels of agreement with the 13 policies. Multivariate logistic regression models were used to compare likelihood of support for each policy by demographics, frequency of transport mode use, and perceptions of the neighbourhood environment (*space precludes presentation here, but results will be presented at the conference*). Finally, a simple linear regression model was developed that summed the agreement scores across the 13 statements providing an indication of overall support for policies.

Results

Policies receiving the most support are building more separated bikepaths and providing more bike/e-scooter parking, while policies with the least support were focused around removing or increasing the cost of car parking (Figure 1). Evidently, there was support for moderating impacts of traffic (lower speed limits, traffic calming). People were divided over their support for e-bicyles/bicycles and e-scooters, with significant numbers neutral. People were generally more supportive of bicycles/e-bicycles than e-scooters, with more support for private vs shared e-scooters.

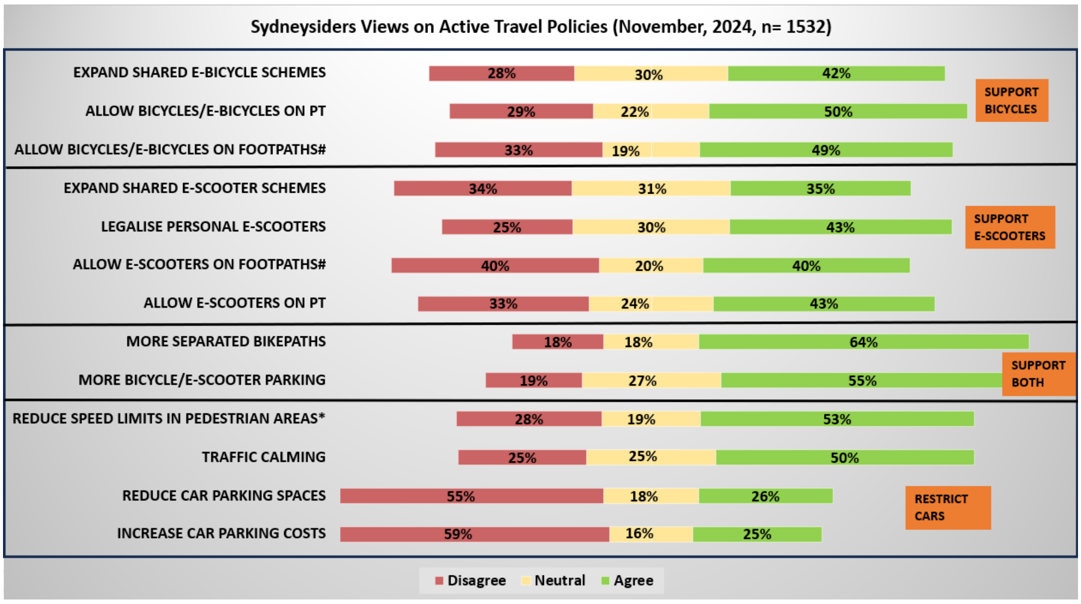

Figure 1: Sydneysiders Views on Cycling and Micromobility Policies

Overall support for policies declined with age and among frequent car users with a converse increase in support among regular cyclists and e-scooter riders (Table 1). Support was higher among those with convenient PT, pleasant and safe walking environments, little traffic, convenient cycling routes and little green space.

Table 1: Overall Support for Active Travel Policies

	Coefficients		t	Sig.
	B	Std. Error		
(Constant)	26.307	3.678	7.153	0.000
Age	-0.267	0.026	-10.32	0.000
Car/Motorbike (own , taxi, Uber)	-2.11	0.761	-2.773	0.006
Bicycle	2.629	1.298	2.025	0.043
E-Bicycle	3.21	1.542	2.081	0.038
It is pleasant to walk	1.957	0.508	3.853	0.000
There is convenient public transport	1.744	0.414	4.214	0.000
There is little green space	1.045	0.335	3.12	0.002
It is safe to walk after dark	1.153	0.379	3.045	0.002
There is little traffic	1.743	0.37	4.709	0.000
There are convenient routes for cycling	1.639	0.381	4.303	0.000
Model Summary				
Model	R	R Square	Adj. R Square	Std. Error
1	.558a	0.312	0.297	13.02682

Discussion/Conclusions

Unsurprisingly, people have a natural tendency to support policies of self-interest, with a strong link between their own modal usage and policies supporting that mode. Frequent bicycle and e-scooter users demonstrate some areas of mutual support, particularly around shared schemes, which are set to expand with forthcoming e-scooter legalisation (NSW Government, 2025). People are generally supportive of cycling and to a lesser extent e-scooter policies, with strongest support for providing more cycling infrastructure and parking. With micromobility volumes growing by roughly 20% per annum, this issue will grow in urgency (Greaves et al., 2025). Frequent users of cycling, micromobility and public transport generally favour car restrictions, while frequent car users oppose this. The continuing adoption by some councils of lower speeds in heavily pedestrianised areas along with traffic calming initiatives is a move in the right direction, but a more coordinated statewide approach is needed. While people appear generally supportive of tempering the impacts of the car (speed, calming), parking restrictions remain a deeply unpopular option. In a city where parking is already expensive and in short supply, this remains politically unpalpable.

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Promoting micromobility as a TDM tool in Australia: Opportunities and challenges

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Introduction

Providing and promoting alternatives to the private car is a key Travel Demand Management (TDM) strategy in Australia as it is in many parts of the world (Rissel et al., 2018). Particularly critical are sustainable and convenient alternatives to the millions of short trips made by cars. Cycling and walking are clearly integral here, but are not always an appealing option due to barriers such as distance, topography, heat, the physical limitations of travellers and in the case of cycling, not owning/having access to a bike (Vukalivich et al., 2025). Since the millennium, and given extra impetus during the COVID-19 pandemic, there has been an explosion in micromobility (MM) - small, light-weight personal vehicles using a combination of human and electric auxiliary power including e-bikes, e-scooters, e-skateboards (Rojas-Rueda, 2020) which are either owned privately or used as part of public hire schemes. MM has grown rapidly into an industry that was worth B$44 in 2020, projected to reach B$214 by 2030 (Yadav and Mutreja, 2019). The intrinsic appeal of these MM devices as a more sustainable and increasingly practical option for short trips means that MM aligns well as a potential element in a TDM strategy. They have been found to replace short to medium length motor vehicle trips (Wu et al 2024) and public shared use e-scooter and e-bike schemes have been found to reduce the carbon footprint of urban travel (Kraussa etr al, 2022, Li et al, 2023).

This paper considers the opportunities and challenges associated with promoting MM as an element of TDM strategy in Australia, where MM is growing by roughly 20%/annum (Greaves et al., 2025). It highlights the critical importance of further evolution of the regulatory framework to ensure not only that these devices offer a viable urban travel option for users but also that safety risks for users and non-users are adequately managed. The risk for the sector is that legislators will respond to high profile public safety events with bans that undermine the potential that MM holds as an element of a TDM strategy.

MM Devices in the Australian context

When Austroads published its TDM Guidelines (Austroads, 1994) there were few e-bikes on the road and other forms of light electric powered mobility did not exist. Fast-forward 30 years and the landscape has changed dramatically. Most states have approved or are trialling shared variants of e-bikes and e-scooters, although there have been several high-profile bans such as those in the City of Melbourne, largely in response to concerns around anti-social user behaviour[1]. Likewise, leased or outright ownership of e-bikes and e-scooters continues to grow with 150,000 e-bikes forecast to be sold this year[2]. An estimated 350,000 people across Australia owned an e-scooter one in 2024 - equating to about 1.3 % of the population. Even in NSW, a state where private scooters cannot legally be used on the road system, 2.6% of respondents purportedly owned one in 2024, with one in 10 anticipated purchasing one in the next 12 months (Greaves et al, 2025). Part of the growth in demand for e-bikes has come from the delivery industry, through their proven potential to provide a quick, efficient, and cheap method for first/last mile freight/food in urban centres (Conway et al 2017, Makik, et al, 2023). This has manifested in larger, more powerful bikes and trikes, which present infrastructure challenges given that new models emerging overseas, such as the semi-trailer e-cargo bike[3] have dimensions that exceed the current infrastructure design guidelines in Australia.

It is fair to say that the rules and regulations have struggled to keep pace with these technological and societal changes, which have been felt the world over. Within Australia, while there is federal policy on the dimensions of MM vehicles, it is up to each state and local council to set specific rules around the vehicles, where, how and by whom they can be operated (Greaves et al., 20205). This has resulted in confusing rules and regulations creating a patchwork quilt operating environment.

Pressing Issues – MM Safety

Two fundamental areas are emerging which require the attention of policy makers. First, operating non-compliant devices at high speed and secondly user behaviour particularly intoxicated riding of shared e-bikes and e-scooters (Berecki-Gisolf and Hayman, 2025). Recent, high-profile incidents involving an elderly pedestrian killed by a modified e-bike allegedly traveling at 80 kph in Victoria[4] and a middle-aged pedestrian killed by a shared e-scooter being ridden by an intoxicated driver riding with a pillion passenger[5], have brought this issue to the fore once again. A recently-published study found 176 e-scooter injuries in young people aged 5-15 at the Sunshine Coast University Hospital in 2023 and 2024 (Clanfield and Sharman, 2025). One in ten injuries were life threatening or potentially life threatening.

Even though e-bikes and e-scooters have many benefits, these examples highlight their associated risks. For these risks to be properly addressed, an overhaul of regulations covering e-bikes and e-scooters is urgently needed. The City of Perth has already responded to the recent e-scooter death by stopping the use of shared e-scooters in Perth, a move reminiscent of the City of Melbourne's decision last year to ban those same devices. Unless the regulations governing these devices are enhanced to ensure they are not only easily understandable to the public but also capable of being enforced there is a real risk that legislators may respond by extending bans, undermining the potential that MM can play in helping to manage travel demand. The problems are twofold: first, there is nothing to stop the importation of high-performance e-bikes and e-scooters from overseas, and second enforcement is difficult, and rarely occurs, because the police do not have the equipment to easily test motor power which is central to our current e-bike and e-scooter regulations. The Federal Government has a clear role to play in stemming the importation of e-bikes and e-scooters which manifestly exceed the legal limits for public use in Australia. States and Territories then need to evolve their regulations to place an emphasis on operating speed and enable enforcement using radar devices. These changes would bring the regulatory environment for MM in line with how motor vehicles are currently regulated.

Research Needs

A strong evidence base is needed to guide policy decisions relating to MM so it can contribute to TDM strategic outcomes. There is a major gap in understanding of the factors influencing the purchase and use of private MM devices, particularly e-scooters. Enhanced understanding of incentive mechanisms to encourage use of these devices to eliminate motor vehicle trips, and reduce motor vehicle ownership, would be valuable from a TDM policy perspective. Footpath riding is legal in some states and a contentious issue in others. Evidence is needed to guide policy makers on where and how it can safely be included as part of the infrastructure available to riders of MM devices. Research is also needed on both regulations and enforcement settings to ensure that the MM system is not only effective in helping to manage travel demand but also safe for users and non-users.

Footnotes

[1] https://www.abc.net.au/news/2024-08-15/share-hire-e-scooter-laws-australia-melbourne-ban/104224386
[2] https://www.statista.com/outlook/mmo/bicycles/electric-bicycles/australia
[3] https://bicyclenetwork.com.au/newsroom/2025/06/04/the-bike-semi-trailer-has-arrived/
[4] https://www.theage.com.au/national/victoria/screams-a-crumpled-bike-pedestrian-struck-by-illegally-modified-bike-fights-for-life-20250513-p5lyot.html
[5] https://www.abc.net.au/news/2025-06-05/city-of-perth-to-suspend-e-scooter-hire-after-pedestrian-death/103234938

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Tuesday 9th December: 11am-12.30pm
Parallel Session 4 (Level 17, Lecture room 2)
Theme: Equity and Inclusion in Transport Systems, Session Chair: Mr. David Surplice
Walking Equity: Public Perceptions on the Distribution of Benefits and Burdens (Ashikur Rahman, Stephen Greaves and Chinh Ho)
Smart Mobility or Smart Divide? Evaluating the Equity Impacts of TDM Measures in the UK (Wafaa Saleh and Augustus Ababio-Donkor)
Methodological Distortions in Agent-Based Models: Implications for Equity-Focused Travel Demand Management (Esta Qiu, Vahid Noroozi, Regine Gerike and Travis Waller)

Walking Equity: Public Perceptions on the Distribution of Benefits and Burdens.

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Introduction

Walking is often considered the most vulnerable mode of transport despite its positive impact on health and well-being. Pedestrians typically encounter the highest exposure to air and noise pollution, crash risks, harsh outdoor weather, and uneven topography. In addition, active travel initiatives or projects eventually create a divide in the population by facilitating the target group and depriving the non-target group. Walking equity, originally coined by Lee et al. (2017) as active transport equity, refers to the fair distribution of walking benefits, costs, opportunities, and risks across different population groups and places. Over the years, researchers have developed numerous indices, metrics, and frameworks to evaluate various aspects of walking, such as level of walkability, comfort and ease of walking, perceptions towards walking, built environment impact on walking and so on. Nonetheless, how the mismatches in the share of walking infrastructure or walking-friendly environment among different stakeholders could be inclusively assessed remains a debatable topic. This is not about the plethora of available measurement methods or models in the literature, but rather about achieving a major, if not unanimous, agreement among the target groups and decision makers on which distribution principle is most suited, given the local context and priorities.

In terms of the distribution principles of benefits and costs, Lewis et al. (2021) compiled 14 theories to attain transport equity rooted in Philosophy, Economics, and Planning. However, in a public transport equity research, Zhu et al. (2024) argued that out of all such distribution principles, utilitarian, egalitarian, and sufficientarian approaches address the three fundamental concerns in distributive justice: overall welfare, fairness, and basic minimums. *Utilitarianism* focuses on maximising overall well-being, such as increasing total health. *Egalitarianism* emphasises fair distribution of walking opportunities to individuals and communities. *Sufficientarianism* aims to meet everyone's basic minimum level of walkability, such as safe footpaths and access to key services.

These three distribution principles would be best explained using this pragmatic example. Suppose a local council plans to improve the footpath network within its jurisdiction. Given a limited budget, a utilitarian approach would select those footpaths that serve the highest number of pedestrians, such as walking routes around shopping malls, schools, transport hubs, etc. An egalitarian approach would target all sidewalks with special attention to those that serve the most vulnerable communities. A sufficientarian approach would ensure that every local road has at least a basic, functional footpath to walk on, although some footpaths' quality could be superior to others. Thus, these three concepts capture almost all practical equity concerns that may arise (Zhu et al. 2024). Facilitating target groups to choose among such approaches might be a new direction towards the participatory distribution principle in walking equity research.

Walking equity is a multi-faceted phenomenon. Rahman et al. (2025) conducted a systematic literature review and identified six critical dimensions of walking equity for a comprehensive assessment: accessibility, built environment, health, safety, affordability, and environmental exposure. However, the literature often assesses walking equity from a single perspective, typically accessibility and health, while ignoring other critical elements such as affordability, safety, and the built environment. This paper aims to bridge the knowledge gap by developing an inclusive measurement framework of walking equity and identifying the set of most preferred distribution principles using Greater Sydney as an empirical setting. Therefore, the research objective is to foster a comprehensive assessment of walking equity by minimising the current shortcomings, so that allocation of resources and constraints on the pedestrians becomes more human, justifiable, and fair.

Methods and Data

This research investigates public perceptions of these three distribution principles for achieving walking equity in Greater Sydney. The statements of Table 1 are designed to capture public opinions around six dimensions of walking equity. Perceptions will be gathered via a survey of about 1,500 Greater Sydney residents planned for October-November 2025. As people's perception is a subjective construct, this research will use a combined analytical approach of Latent Class Analysis (LCA) and Generalised Structural Equation Modelling (GSEM) as shown in Figure 1. Wang et al. (2025) demonstrated the enhanced capability of LCA-GSEM-based estimates of latent constructs and social factors in a multi-step analysis similar to this research.

The proposed data analysis can be divided into three steps (Figure 1). In the first step, the survey responses to the nominal, unordered, forced-choice-based statements (as illustrated in Table 1) across all six dimensions of walking equity will be analysed using LCA to derive the potential participant clusters. This will reflect the maximum support or strongest beliefs of the respondents regarding the distribution principles across six dimensions. The authors hypothesise that there might be mixed responses from the people across the dimensions. In the second step, partial walking equity from the perspective of each dimension will be estimated using GSEM based on the inputs from the latent classes in step 1, subjective primary survey data (additional Likert-scale questions), and objective secondary data. In the final step, overall walking equity will be assessed based on all the partial calculations in step 2 and the survey responses from the overall Likert-scale questions, as shown in Table 1.

Table 1: Sample primary survey design.

Dimensions *(Two dimensions out of all six are presented as examples).*	**Forced-choice statements based on three distribution principles.** Participants will be requested to choose one principle out of three across all walking equity dimensions.		
	Utilitarianism Aims to maximise the overall welfare of the majority of the population.	**Egalitarianism** Everyone should have an equal access to primary resources; however, the vulnerable groups may receive priorities.	**Sufficientarianism** People's primary resources must be ensured at least at a minimum/basic level.
Built-Environment	Most neighbourhoods should have walking-friendly infrastructure, and it's acceptable if some do not have that.	All neighbourhoods should have similar quality walking-friendly infrastructure.	All neighbourhoods should have a minimum standard of walking-friendly infrastructure.
Safety	Most streets should be safe for walking, and it's acceptable if some are less safe due to local contexts.	All streets should be equally safe for walking.	All streets should meet a minimum level of safety standard.

Overall Likert scale-based statements irrespective of the distribution principles.	
Walking Equity	- Overall, walking provision in my local area is fair. - The walking provision in my local area is also suitable for elders, children, and people in mobility scooters. - Overall, my local area allows walking for daily activities without major barriers.

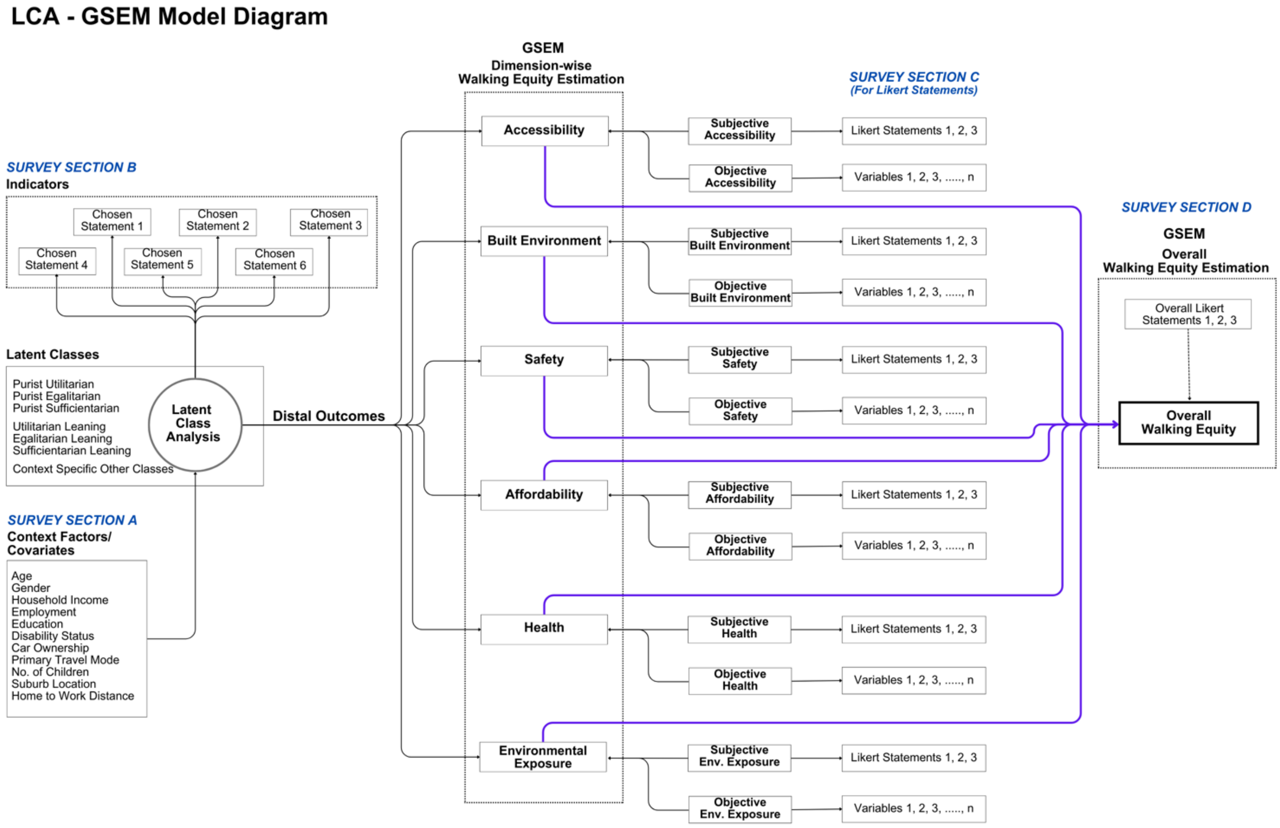

Figure 1: Proposed analytical plan for walking equity estimation.

Expected Results and Discussion

The primary data collection will use an online survey scheduled in October-November 2025. It is anticipated that people's support for the three distribution principles would vary across the six dimensions of walking equity. Hence, the research aims to propose two novel directions from the traditional evaluation of walking equity. Firstly, the best outcomes of walking equity might not follow a certain resource allocation principle; rather, a combination of prominent distribution principles, which emerged from the bottom-up public responses across different components or dimensions of walking equity, is a better solution. Secondly, in addition to dissecting walking equity research outcomes based on various demographic or socio-economic groups, it is also crucial to integrate the population groups based on their beliefs or desires towards how resources and constraints for walking should be shared in the community.

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Smart Mobility or Smart Divide? Evaluating the Equity Impacts of TDM Measures in the UK

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Extended Abstract for the 12th International Symposium on Travel Demand Management (TDM)

Keywords: TDM, Smart Mobility, Transport Equity, Mobility Inequality, Congestion Pricing, Low-Emission Zones

Background

In response to growing concerns about urban congestion, environmental degradation, and unsustainable travel behaviours, cities across the United Kingdom and globally have increasingly adopted Travel Demand Management (TDM) policies and smart mobility innovations. These measures aim to reduce car dependency, optimise transport networks, and promote more sustainable travel behaviours. Common TDM interventions include congestion charging, low-emission zones (LEZ), parking regulations, and incentives for alternative transport modes. Alongside these, smart mobility solutions—such as Mobility-as-a-Service (MaaS), shared mobility platforms, real-time travel information, and app-based micro-mobility—are rapidly transforming urban mobility systems by offering more flexible, data-driven alternatives to traditional modes. While these strategies are often praised for their ability to alleviate traffic congestion, improve air quality, and enhance urban efficiency, a growing body of research has raised concerns about their social impacts, particularly in relation to fairness and equity. For instance, congestion pricing may disproportionately burden lower-income commuters who cannot shift travel times or modes easily. Similarly, the digital infrastructure underpinning smart mobility platforms tends to favour users with access to smartphones, stable internet connections, and online payment methods—factors that exclude economically and digitally disadvantaged populations.

Previous studies (Lucas & Jones, 2012; Eliasson & Mattsson, 2006) have highlighted how one-size-fits-all TDM measures can amplify existing mobility inequalities. Despite the growing integration of Artificial Intelligence (AI), Large Language Models (LLMs), and real-time data in travel demand forecasting, these tools—without explicit fairness constraints—may also inadvertently perpetuate socio-spatial inequities. The emerging discourse on mobility justice argues that urban transport systems should not only be efficient and sustainable but also inclusive, just, and sensitive to the needs of marginalised groups.

Research Problem and Question

This research is grounded in a critical question: *If Travel Demand Management is designed to alleviate congestion and enhance system efficiency, why do many of its applications risk reinforcing existing socio-economic inequalities?* Specifically, the study interrogates whether smart mobility and TDM strategies in UK urban centres are mitigating or deepening transport inequities based on income, education, digital access, and geographical location.

Research Aim

The primary aim of this research is to investigate the equity implications of TDM and smart mobility strategies in selected UK cities, with a focus on differential access, usage patterns, and perceptions across diverse socio-economic groups. The study seeks to determine whether these innovations achieve their intended benefits—such as improved accessibility and reduced congestion—without compromising social equity. Ultimately, it aims to offer policy-relevant insights into how TDM can be designed to serve all citizens more fairly.

Methodology

To explore these issues, the study adopts a mixed-methods approach combining quantitative survey data with qualitative insights. Three urban centres were selected as case studies—Edinburgh, Manchester, and Birmingham—due to their demographic diversity, varied levels of smart mobility implementation, and active TDM policies. A structured online questionnaire was developed using Google Forms and disseminated via transport forums, community organisations, and social media. The survey remained open for three weeks and yielded 306 valid responses. The instrument included four sections:

1. Socio-demographic characteristics (age, gender, income, education, car access)
2. Travel behaviour (commuting frequency, distance, and mode)
3. Smart mobility use and perceptions (including services like ride-hailing, MaaS, and e-scooters)
4. Views on transport equity, accessibility, and affordability (measured via Likert-scale items)

A stratified purposive sampling method was used to ensure broad representation across gender, age, income brackets, residential locations (urban/suburban), and smart mobility usage status. This sampling strategy enabled comparisons between users and non-users and between high- and low-income respondents.

The data analysis proceeded in two stages:

- Descriptive analysis using frequencies, cross-tabulations, and visualisations to characterise respondent demographics, travel patterns, and smart mobility access.
- Ordered logistic regression to explore the relationship between socio-economic factors (e.g., income, education, car access) and respondents' perceptions of transport equity. The dependent variable was a 5-point Likert-scale measure of agreement with the statement: *“I feel that current smart mobility services meet the needs of people like me.”*

Initial descriptive results showed that access to smart mobility services—such as app-based ride-hailing and e-scooter schemes—was significantly higher among respondents aged 18–34, those with higher income levels, and individuals with university-level education. Respondents in lower-income brackets (<£20,000 annual income) reported lower awareness of and participation in these services, citing cost, digital barriers, and safety concerns as major deterrents. Moreover, a spatial disparity was observed: urban core residents had greater access to shared mobility services compared to those in suburban and peri-urban zones. This spatial concentration of services mirrors demand-driven business models but inadvertently excludes those in less densely populated or economically marginal areas.

The regression model revealed statistically significant associations between perceptions of transport equity and several key variables:

- Income ($p < 0.01$): Lower-income respondents were significantly more likely to disagree that smart mobility meets their needs.
- Car access ($p < 0.05$): Those without private vehicles were more sensitive to limitations in affordable and reliable alternatives.
- Digital access (inferred from age and smartphone use): Older respondents and those unfamiliar with app-based systems expressed concerns over exclusion from new mobility services.

Interestingly, smart mobility users—especially those in higher-income brackets—expressed high satisfaction and viewed TDM policies (such as congestion zones) positively, citing benefits like reduced commute times and better air quality. However, non-users often saw these same policies as restrictive, costly, or unfair.

Conclusion

The study confirms that while TDM and smart mobility strategies offer significant potential for improving transport efficiency and environmental outcomes, they currently fall short in addressing—or may even exacerbate—socio-economic inequities. Access to and benefits from these systems remain unevenly distributed across income, digital literacy, and geographic lines.

To ensure a more inclusive future for urban transport, policy interventions must incorporate equity audits, fairness-aware AI models, and targeted support mechanisms (e.g., subsidies, non-digital access points, and outreach in underserved areas). Additionally, open science and community co-design frameworks are essential for ensuring that mobility innovations serve the broadest possible spectrum of society.

This research contributes to the growing literature on mobility justice and calls for a paradigm shift from merely efficient to equitable transport systems—particularly as UK cities continue to digitise and decarbonise their transport infrastructures.

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Methodological Distortions in Agent-Based Models: Implications for Equity-Focused Travel Demand Management

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Introduction

Agent-based models (ABMs) have emerged as a powerful tool for ex-ante assessment of travel demand management (TDM) strategies, as their ability to capture heterogeneous behaviours and temporal dynamics at the individual level enable analysis of both effectiveness and distributive impacts. While widely applied to assess sustainable transport policies, their value for equity analysis is particularly critical in the post-pandemic era. Studies have demonstrated the disparate impacts of travel demand management and changed travel norm on the broader population (Baudains et al., 2024; Brough et al., 2021; Adey et al., 2021), echoing Hine's (2007) early call for equity-conscious travel demand management.

An ABM typically relies on synthetic population with activity chains derived from travel surveys. Following model calibration, simulations generate detailed agent-level outputs, although these are often aggregated when used for practical transport planning or policy decision-making. Equity-focused quantitative analysis requires disaggregated data to expose disparities in marginalised populations (Dorimé-Williams, 2023). If ABMs are to be promoted for quantifying the distributional impact of policies, ensuring its analytical clarity becomes both a methodological and moral imperative. Distortions introduced during population synthesis, model calibration and output aggregation risk compromising the very advantages that make ABMs powerful for non-aggregated analysis.

This study aims to systematically assess the potential methodological distortions in using ABMs for distributional analysis, using the MATSim scenario of Leipzig, Germany. **Figure 1** outlines the general application process of a MATSim scenario for policy analysis and highlights the two stages of potential distortions i.e. pre-model and post-model.

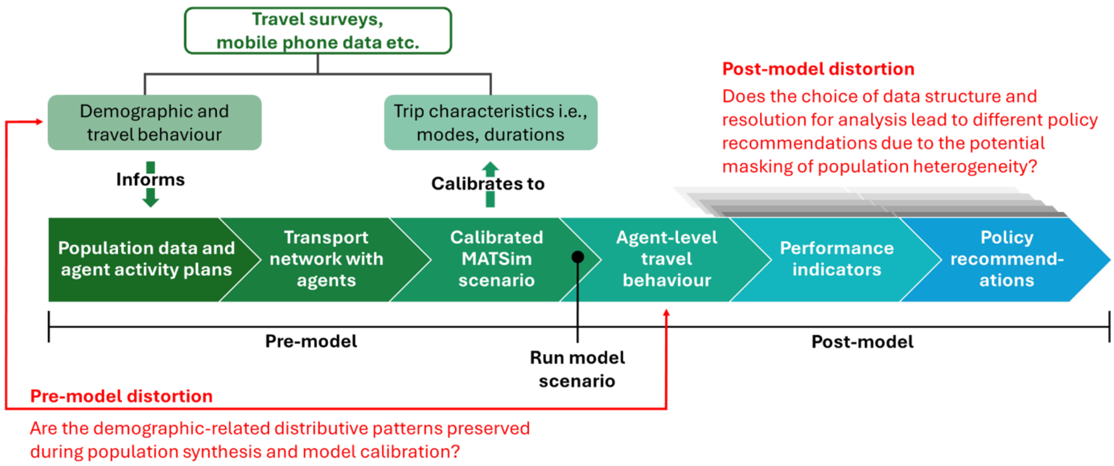

Figure 1 Potential methodological distortions during the pre-model and post-model stages

Pre-model distortion arises when equity-relevant population and behavioral distributions from survey data fail to be preserved during population synthesis and model calibration. Post-model distortion occurs when the segmentation of ABM outputs (spatial, temporal, or demographic) and their aggregation level misrepresent equity outcomes by masking population heterogeneity. This study's findings will provide actionable recommendations for leveraging ABMs' disaggregate capabilities to enhance transparency and representativeness in policy assessments.

Methodology

Pre-modal distortion

The Leipzig MATSim scenario is calibrated to the 2018 representative transport survey (SrV), which captures typical travel behaviour and demographic attributes of the population (Krombach et al., 2024). By comparing the distribution of travel behaviour indicators (e.g., linked trips, mode of longest leg, trip distance etc.) against demographic data in both the SrV and MATSim outputs, we assess whether the pre-model stage preserves or distorts these attributes.

During the pre-model stage, the Hamming-distance procedure ensures that synthesised activity chains are drawn from observed individuals with similar demographics. However, calibration to match aggregate trip characteristics (e.g., mode shares by distance) may introduce compensatory errors across demographic groups or spatial areas, potentially altering distributive properties. This analysis does not evaluate equity implications directly but examines whether the calibrated ABM scenario inherently maintains demographic-linked travel behaviour patterns.

Post-modal distortion

There is growing research that examines the socio-spatial and temporal aspects of transport provisions as mobility outcomes are shaped by the intersection of place, identity and time. While spatial, temporal and demographic-oriented analysis each offer useful lenses for equity analysis, examining them in isolation risks overlooking the complex ways in which transport disadvantage is structured. Error! Reference source not found. shows the interaction between the three dimensions, highlighting the need to incorporate all three segmentations to ensure equitable access for all transport users.

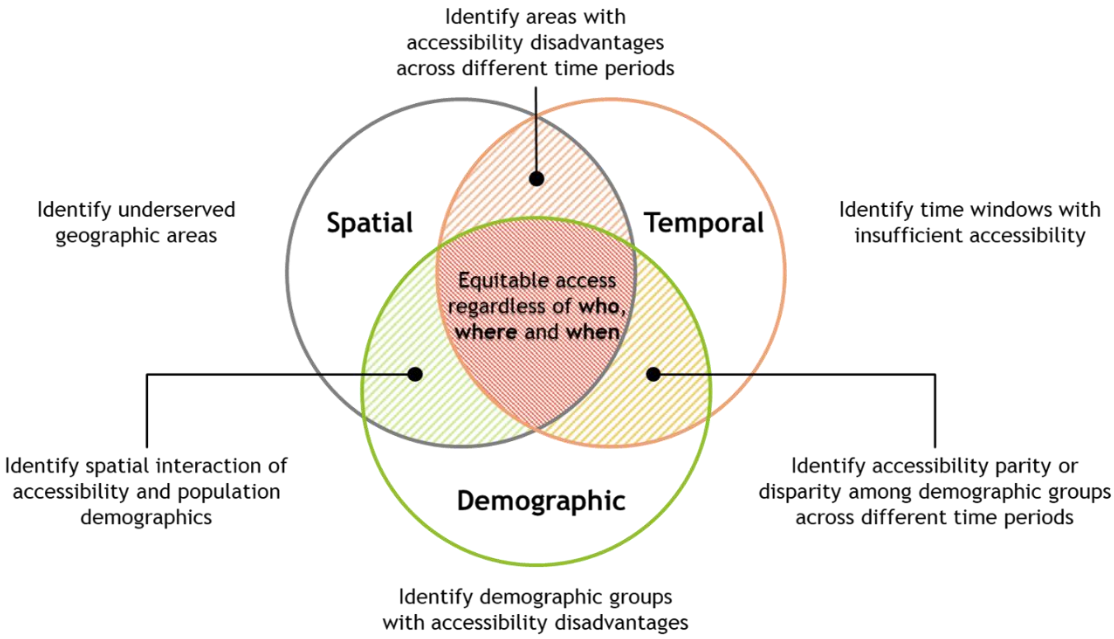

Figure 2 Segmentation dimensions for distributional analysis

In this analysis, we compute equity indicators across demographic characteristics, temporal periods and spatial resolutions. Each indicator consists of the three key components of justice frameworks (Page, 2007; Martens et al., 2019; Jafino, 2021): the *unit* (what is being distributed), the *scope* (to whom the unit is distributed), and the *shape* (the distributional ideal). In this study, we adopt three accessibility measures as *units*, which include travel time to work, utility-based accessibility (logsum) and cumulative opportunities (number of reachable opportunities within a given time threshold). The *scope* of each indicator is defined by the intersection of spatial, temporal and demographic dimensions. The *shapes* of the indicators are given by a suite of quantitative metrics ranging from traditional inequality indices (e.g. Gini index for overall disparity, Theil index for subgroup decomposition) to segregation measures such as the Concentration Index, as well as justice-theory based metrics discussed in Qiu et al., 2024. Through the multi-dimensional analysis, we observe how much heterogeneity is concealed both within each segmentation and by the absence of additional segmentation dimensions.

Expected results

We expect to observe discrepancies between the SrV and MATSim distributions of travel behaviour by demographics, which would suggest that equity-focused policy assessments require calibration targeting higher moments (e.g., variance by subgroup) rather than just aggregate metrics. Conversely, if the distributions align, it would indicate that the model preserves demographic-related travel behaviour through its calibration process, such that distinct behavioural patterns across groups are sufficiently captured by matching trip characteristics alone. This distinction indicates whether the model can reliably predict distributional policy impacts or needs refinement to the calibration criteria to avoid masking inequities.

We also expect the equity indicator values to be sensitive to the selection of segmentation dimensions and the chosen data resolution. Within each given dimension, segmentation (and subsequent aggregation) risks masking heterogeneity. For example, ecological fallacy and the modifiable area problem are well-recognised challenges in planning literature, where the former assumes (incorrectly) that relationships observed at the group level also hold at the individual level (Freedman, 1999), and the latter introduced arbitrariness to the analysis results due to the random definition of area boundaries (Openshaw, 1984). Studies have also shown that the travel needs and time differ for different demographics (Mattson, 2012; Steed and Bhat, 2000; De Palma et al., 1997). Higher variance in equity outcomes across segmentation levels indicates greater diversity in user needs, implying greater “risk” of disproportionately adverse impacts on vulnerable users when adopting a generalised aggregated approach.

This abstract outlines the research in progress; full results will be finalised and available for presentation at the symposium.

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Tuesday 9th December: 2pm-3.30pm
Parallel Session 1 (Level 17, Lecture room 3)
Theme: Active Transport, Data Analytics, and Micro-Mobility Behaviour, Session Chair: Dr. Yuting Zhang
Volume pricing discounts and shared e-scooter use (Michael Vincent and Geoff Rose)
CatBoost-Based Prediction of Daily Bicycle Counts at the Link Level in the Sydney CBD (Xueqing Shi, Maryam Bostanara and Christopher Pettit)
Evaluating Electric Micro-Mobility Ownership Choice Stated Preferences for Car Owners: A Mixed Logit Model (Yikang Wu, Mehmet Yildirimoglu and Zuduo Zheng)

Volume pricing discounts and shared e-scooter use

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Introduction

While the literature on shared e-scooters has expanded rapidly in recent years (Mitropoulos, 2023), the consideration of pricing and e-scooter use focuses on various pricing incentives, rider satisfaction and payment integration with public transit (Beale et al., 2023, Yan et al., 2023). Demand responses to price changes have been analysed but only using broad elasticity values assumed to apply to all e-scooter riders (Manout et al, 2024).

The literature does not explore of the implications of volume discounts (Bray, 2009) where riders are offered lower prices to buy more trips/riding time through single or multi-day passes. These passes may be offered to compete with rival operators who offer them or to lock in a customer to using that operator's e-scooters (Mohammad, 2013).

By comparing the usage patterns of different user groups depending on the pass they pre-purchased, this study aims to address the current knowledge gap by testing the hypothesis that "Segmenting e-scooter users according to their volume discount highlights significant differences in usage patterns". The study draws on data provided by one of the two operators (at the time) in Brisbane, Australia. We acknowledge that a weakness of this study is that it has drawn on shared e-scooter trip data from only one provider in one market.

Data and methods

Data was from Brisbane, Australia, covering the period from July 2022 to August of 2023, was provided by Beam Mobility. To ensure the privacy of users and protect commercial confidentiality, a unique ID was allocated to each trip, times were binned in 15 minute blocks with some results presented as proportions to mask magnitudes given their relationship to revenue. Data cleaning identified unrealistic measurements (e.g. speeds over the 25 kph the limit of the e-scooters) and resulted in the loss of less than 1% of the data, with 595,000 trips retained for analysis.

The payment class (PPU, Prepurchase Pass or Beam4All) of each trip was also provided. In the Brisbane market, Beam Mobility operate their transport equity program 'Beam4ALL', where eligible low-income users are granted a 50% discount. As well as payment class, a pass ID was included that links to all other trips conducted on the same pass by a specific user for prepurchase passes and Beam4All. This allowed for grouping by 1-day, 3-day, 7-day and 30-day passes as well as Beam4All which is issued on a 30-day basis. Over the period of analysis there was no fundamental changes in the nature or characteristics of the different pass types.

To test for statistically significant differences an analysis of variance (ANOVA) was first conducted on pass type (volume discount) to determine if any of them were different from the entire sample. T-tests and Wilcoxon tests were then used to identify statistically significant differences between pass types. Two sample T-tests were utilised where the two distributions being compared followed a relatively normal distribution and Wilcoxon rank sum tests for those that did not meet the assumption of normality (Ford, 2023).

Results

From 2022 to 2023 there was a 17% increase in the number of trips taken on Beam e-scooters in Brisbane (Figure 1). There was a substantial increase in the proportion of 7-day pass trips while Pay-Per-Use trips decreased as a proportion of all trips. Apart from growth in the overall market over time as users come to appreciate the benefits of using a shared e-scooter. Shortly we will consider potential reasons for the shifts in proportion of longer duration passes.

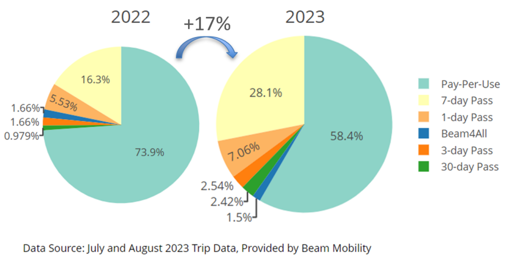

Figure 1: E-scooter trips by year and payment class

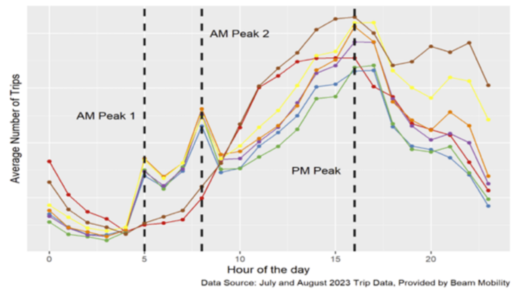

Figure 2: Average number of hourly trips by day of week (Y-axis is suppressed to conceal commercially sensitive information)

Monday to Friday exhibit similar use patterns each day (Figure 2), with Friday evening showing increased use, reflecting the beginning of the weekend. Saturday usage remains high beyond 5PM. Sunday usage reduces after 5PM. These temporal patterns of usage are quite typical of shared e-scooters (Mitropoulos et al., 2023). There is a clear AM bi-modal peak (5-6AM and 8-9AM) on every weekday. Beam Mobility indicated this is associated with building construction workers who typically start early. Public transport in Brisbane runs on a very limited frequency before 6 AM and this reinforces the role which shared e-scooters have in complementing public transport (Yan et al, 2023). Statistical analysis (ANOVA) confirmed that at least one payment group had a mean different from the population for both trip distance and trip duration when separating by payment group (p-value <2.2e-16). Subsequently, statistical tests performed on the transformed data (to achieve normality) indicates a difference in geometric means. We therefore fail to reject the hypothesis that segmenting e-scooter users according to their volume discount highlights significant differences in usage patterns. The 7 and 30-day passes show the most prominent AM/PM weekday peaks, characteristic of commuter use of the shared e-scooters. Ben-Akiva et al (1976) distinguished longer term ‘mobility decisions’ from shorter term ‘travel decisions’ made by travellers. Mode choice to work is a long term ‘mobility decision’ in their conceptual framework. Commuters may take time to have confidence in both the availability of shared e-scooters and their characteristics to ‘unlock’ there previous commuting choices and embrace the shared e-scooter alternative. On that basis it is not unreasonable to see growth over time in the passes which are associated with commuter use.

Each pass offers a maxiumum riding time across the days covered by the pass. Pass utilisation decreases as prepurchase pass length increase with pass utilisation of 1-day passes at 60% dropping to 15.7 % for 30 day passes. These results suggest that the riding allowances the operator offers on the different passes provide a generous allowance and the limits could be reduced without impacting the majority of riders.

Conclusions and implications

This research has implications for both operators of shared e-scooter systems and the policy makers who regulate their operation. For operators, the analysis of uptake and utilisation of different pass types has direct relevance to their revenue stream. For policy makers, it is clear that commuters have a preference for longer duration passes. Where policy makers are specifying the rules to govern the operation of e-scooters, attention needs to go beyond fleet size caps (Manout et al, 2024) to also include consideration of what pass types they require operators to offer to ensure that e-scooters are attractive to commuters rather than just recreational riders. In particular, policy makers should be ensuring that 7-day or longer passes are available in the market to attract commuter use. The findings of this research could be strengthened by analysing data from multiple operators in multiple markets.

Acknowledgements

Beam Mobility is acknowledged and thanked for their ongoing support of this project. Without the provision of data, research like this would not be possible.

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CatBoost-Based Prediction of Daily Bicycle Counts at the Link Level in the Sydney CBD

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Introduction

Promoting active transport is central to achieving the Sustainable Development Goals (United Nations, 2015). However, transport planners often lack reliable, fine-grained data on bicycle usage, making it difficult to plan and invest in cycling infrastructure (Bhowmick et al., 2022). Unlike motorized travel, cycling trips are typically shorter in time and distance, which adds complexity to volume prediction. This challenge is especially acute in dense areas such as Sydney's Central Business District (CBD), where space is limited, user profiles are diverse, and multiple urban factors interact in complex ways, making accurate and interpretable predictions essential for guiding investments.

Emerging crowdsourced data such as Strava offer new opportunities for bicycle volume prediction (Broach et al., 2024). However, several studies rely solely on Strava data to predict and analyse cycling volume, overlooking its inherent biases and limited representativeness (Boss et al., 2018; Fischer et al., 2022). Methodologically, some have employed Generalized Linear Models (Broach et al., 2024; Hochmair et al., 2019; Wang et al., 2021), which are sensitive to collinearity, show limited accuracy and struggle to handle complex interactions. On the other hand, Saberi and Lilasathapornkit have compared the performance of various machine learning methods (Saberi and Lilasathapornkit, 2024), but the models used lack interpretability, making it difficult to derive actionable insights for infrastructure planning.

This study addresses these gaps by integrating diverse data sources beyond Strava, employing a CatBoost model suited to structured urban data, and using SHAP analysis to interpret the role of each predictor in shaping cycling volumes.

The purpose of this work is twofold: (1) to accurately estimate bicycle volumes at the link level across the CBD, and (2) to identify the most influential factors driving these volumes to inform infrastructure planning.

Methods and data

Study area and input data

This study integrates diverse datasets to construct explanatory variables for predicting bicycle volumes at the link level in Sydney's CBD. The dependent variable is the observed daily count of cyclists from automated counters. Bicycle counter data are available for 71 locations across the area.

The modelling period covers six months from 1 June to 30 November 2024, during which daily bicycle count data and associated predictor variables were collected. All time-dependent features—including weather, calendar, and Strava usage data—are aligned to the same daily timeline.

Predictor variables fall into six major categories: Temporal variables, Strava data, Weather conditions, Land use composition, Population and demographics. Specific variables and relative data source are displayed in the **Table 1** of Supplementary Material. All predictors are spatially joined or aggregated to the road segment level on a daily basis.

Predictive model: CatBoost

To model cycling volumes, we apply CatBoost, a gradient boosting decision tree algorithm developed for high performance with structured data. CatBoost is particularly effective at handling categorical variables natively (without one-hot encoding), missing values, and nonlinear relationships and interaction effects between predictors (Prokhorenkova et al., 2018).

The model is trained using six months of link-level data, with observed cycling counts as labels. The dataset was randomly divided into a training set (80%) and a test set (20%). Model performance was evaluated using root mean squared error (RMSE), mean absolute error (MAE) and coefficient of determination (R^2) on the held-out test set.

Model interpretation: SHAP values

To understand how each predictor influences the model's outputs, we use SHAP (SHapley Additive exPlanations) analysis. SHAP values quantify the marginal contribution of each variable to individual predictions, offering both global feature importance and local interpretability (Lundberg and Lee, 2017). SHAP enables the translation of model results into actionable planning insights, supporting evidence-based decisions about where and when to invest in cycling infrastructure.

Results and discussion

Model performance

The CatBoost model demonstrated strong predictive performance in estimating daily bicycle volumes across road segments within Sydney's CBD. On the test set, the model achieved a Root Mean Squared Error (RMSE) of 193.52, a Mean Absolute Error (MAE) of 96.43, and a coefficient of determination (R^2) of 0.8521, demonstrating strong agreement between predicted and observed cycling volumes (**Figure 1**). The low MAE further suggests that the model makes accurate predictions even at the segment level, where counts can vary significantly across time and space.

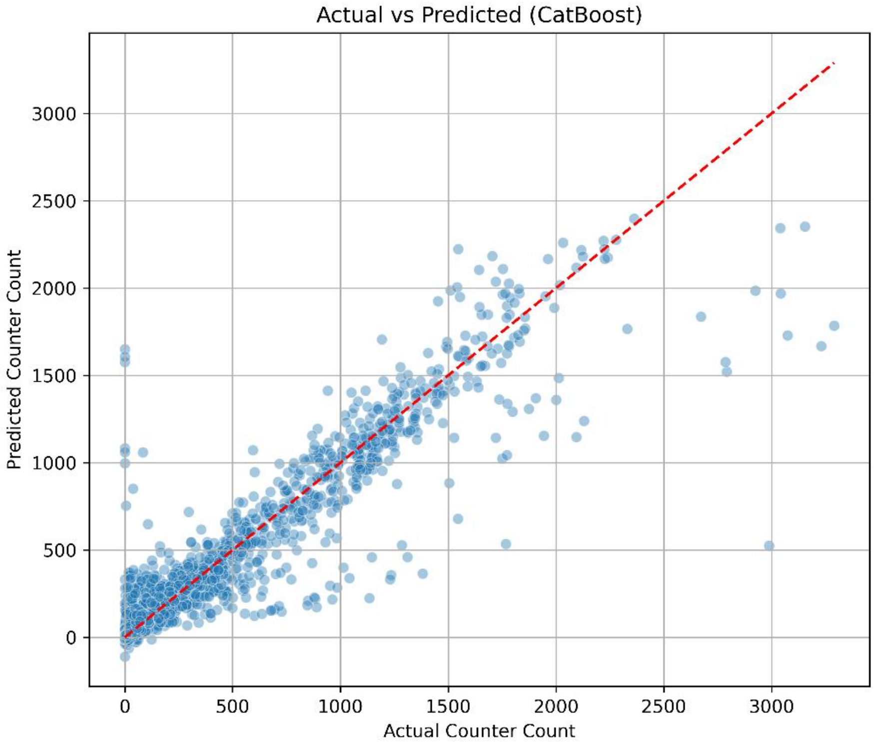

Figure 1. Predicted versus observed cycling volumes using CatBoost. Each dot represents a road segment on a specific day. The dashed red line indicates perfect prediction (y = x).

Correlation Between Strava and Observed Counts

To assess the relationship between crowdsourced Strava data and observed cycling counts, a Pearson correlation test was conducted. The analysis showed a statistically significant correlation ($r = 0.179$, $p < 0.001$), indicating a weak but non-random association between the two variables.

While the result suggests that Strava data reflect some aspects of actual cycling activity, the low correlation coefficient highlights its limitations as a sole predictor of true bicycle volumes. This may be attributed to factors such as nonlinear relationships, potential confounding variables such as land use, population density, or weather, as well as inherent sampling bias in Strava data, which primarily captures recreational or fitness-oriented cyclists.

These findings support the use of Strava data as a complementary feature within a broader predictive model that integrates socioeconomic, spatial, and temporal factors. This also justifies the use of a machine learning model like CatBoost, which can capture nonlinear effects and incorporate multiple data domains to improve prediction accuracy.

Variable importance (SHAP summary)

To interpret model behavior, SHAP values were computed and visualized in a summary plot (**Figure 2**). The most influential predictor was total population, suggesting that road segments surrounded by more residents are likely to have higher cycling volumes. Strava count ranked second, confirming that crowdsourced cycling data, despite its limitations, still contributes meaningful predictive information.

Demographic variables such as the proportion of female children (0–14), male seniors (65+), and female youth (15–24) also appeared among the top predictors. This may reflect underlying age-related patterns in cycling participation or neighbourhood characteristics.

Temporal features like non-working days and month were influential, consistent with weekly and seasonal variation in cycling activity. Several land use indicators, including Nature/Open space, Mixed/unknown land, and Residential land, also featured prominently, highlighting the role of the built environment.

Interestingly, weather variables such as precipitation, temperature, and UV index showed relatively lower global importance, suggesting that while weather conditions may influence day-to-day variation, their impact is less critical when compared to structural and spatial factors in the CBD context.

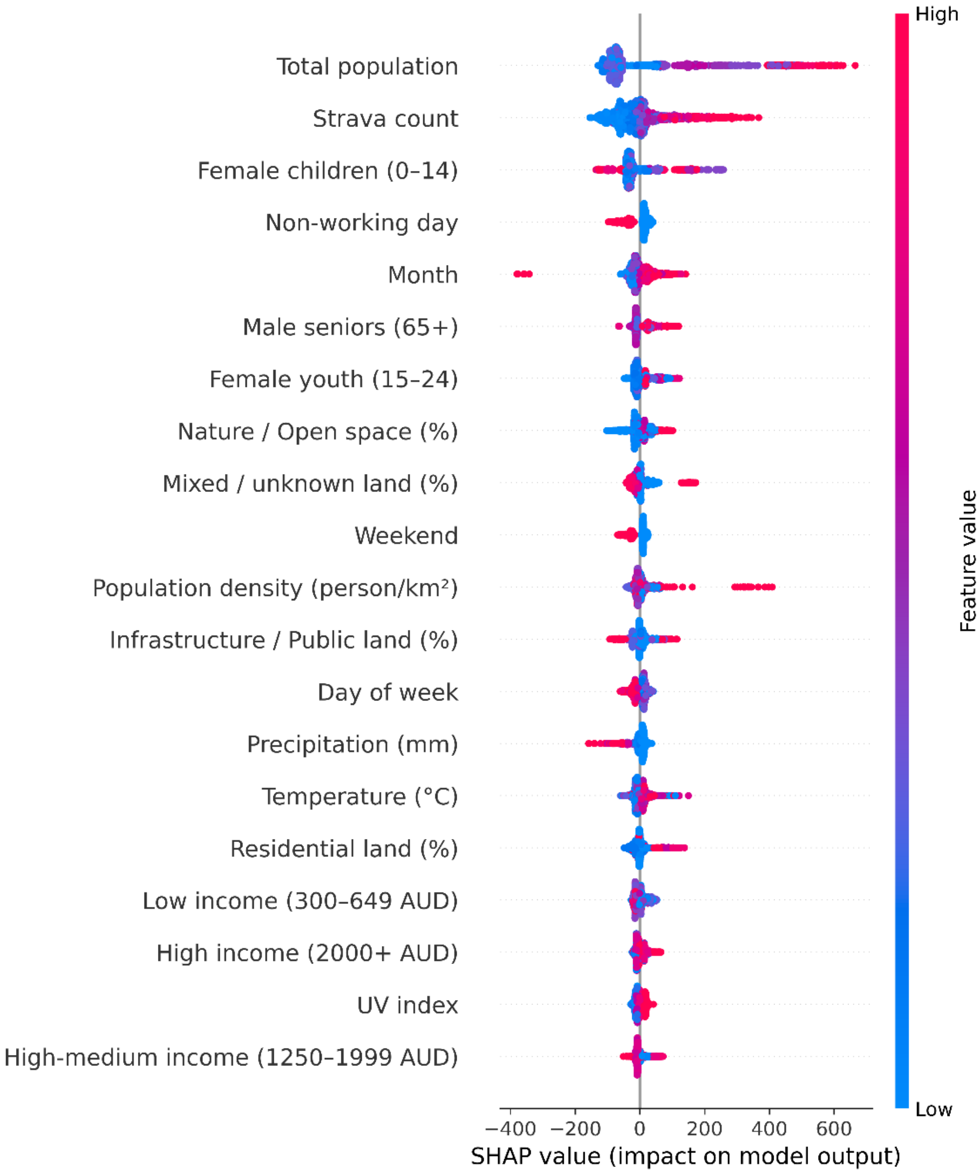

Figure 2. SHAP summary plot showing the global importance of each predictor in the CatBoost model. Each dot represents a single prediction; color indicates the original feature value (red = high, blue = low).

These findings reinforce the value of integrating multiple data domains—temporal, spatial, behavioural, and demographic—to support accurate and interpretable modelling for cycling infrastructure planning. Machine learning interpretability tools, such as SHAP, not only enhance prediction accuracy but also offer actionable insights to guide strategic and equitable investments in dense urban areas like Sydney’s CBD.

Future work

Future research will explore the development of more interpretable variables, improve spatial resolution of weather data, and extend the temporal scope to support forward-looking predictions. Scaling efforts will focus on expanding spatial coverage, either by creating localized models for different areas or designing a single scalable model applicable citywide.

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Supplementary Materials

Table 1 Summary of all variable and data sources considered in the study

Category	Variables	Spatial aggregation	Data source
Cycling	Observed cycling count data (response variable)	Point level	TfNSW
	Strava count data	Link level	Strava Metro
Population	Total population	SA1 level	ABS Census 2021
	Population density (person/sq.km)	SA1 level	ABS Census 2021
	Proportion of male children (0-14 yrs)	SA1 level	ABS Census 2021
	Proportion of female children (0-14 yrs)	SA1 level	ABS Census 2021
	Proportion of male youth (15-24 yrs)	SA1 level	ABS Census 2021
	Proportion of female youth (15-24 yrs)	SA1 level	ABS Census 2021
	Proportion of male middle-aged adults (25-64 yrs)	SA1 level	ABS Census 2021
	Proportion of female middle-aged adults (25-64 yrs)	SA1 level	ABS Census 2021
	Proportion of male seniors (65+ yrs)	SA1 level	ABS Census 2021
	Proportion of female seniors (65+ yrs)	SA1 level	ABS Census 2021
Income	Proportion of residents with very low income (0–299 AUD/week)	SA1 level	ABS Census 2021
	Proportion of residents with low income (300–649 AUD/week)	SA1 level	ABS Census 2021
	Proportion of residents with medium income (650–1249 AUD/week)	SA1 level	ABS Census 2021
	Proportion of residents with high-medium income (1250–1999 AUD/week)	SA1 level	ABS Census 2021
	Proportion of residents with high income (2000+ AUD/week)	SA1 level	ABS Census 2021
Land use	Proportion of surrounding land zoned as residential	Link buffer	EPI Dataset (NSW Spatial Services)
	Proportion of surrounding land zoned as commercial	Link buffer	EPI Dataset (NSW Spatial Services)
	Proportion of surrounding land zoned as industrial	Link buffer	EPI Dataset (NSW Spatial Services)
	Proportion of surrounding land zoned as infrastructure/public use	Link buffer	EPI Dataset (NSW Spatial Services)
	Proportion of surrounding land zoned as nature or open space	Link buffer	EPI Dataset (NSW Spatial Services)
	Proportion of surrounding land zoned as other / mixed / unknown	Link buffer	EPI Dataset (NSW Spatial Services)
Weather	Daily average temperature (°C)	City level	WeatherKit
	Daily total precipitation (mm)	City level	WeatherKit
	Daily average humidity (%)	City level	WeatherKit
	Daily average wind speed (km/h)	City level	WeatherKit
	Daily average visibility (km)	City level	WeatherKit
	Daily maximum UV index	City level	WeatherKit
	Rain condition type (binary)	City level	WeatherKit
Temporal	Indicator for non-working day	N/A	N/A

	Indicator for public holiday	N/A	N/A
	Indicator for weekend	N/A	N/A
	Day of the week (Monday–Sunday)	N/A	N/A
	Month of the year (January–December)	N/A	N/A

Evaluating Electric Micro-Mobility Ownership Choice Stated Preferences for Car Owners: A Mixed Logit Model

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Introduction

Electric micro-mobility (EMM) devices, such as e-bikes and e-scooters, are promoted as sustainable alternatives to private cars (Bretones et al., 2023). Encouraging private ownership can foster consistent usage, expanding EMM's societal benefits, and targeted incentives are increasingly recognized as essential policy tools for accelerating adoption. However, limited research has examined factors influencing EMM ownership decisions or the efficiency of incentives, especially among car owners—a key segment for mode shift (MacArthur et al., 2023; Zhou et al., 2023).

To address this gap, we conducted a stated preference (SP) experiment with 1,478 Brisbane car owners, generating 5,912 choice observations. Participants indicated their willingness to adopt EMM under scenarios featuring direct rebates or higher-value car replacement rebates, aimed specifically at trading in private vehicles. Using a mixed logit model to capture preference heterogeneity, we compare incentive effectiveness, particularly highlighting the understudied car replacement option. Results offer policymakers actionable insights for crafting efficient, context-specific EMM incentives for urban settings.

Survey Design and Mixed Logit Model

The online SP ownership experiment was conducted via SurveyEngine (SurveyEngine, 2024). Respondents faced three alternatives: purchase with a direct rebate (10%–20%), purchase with a higher-value car replacement rebate (50%–100%), or opt-out. Attributes included device type (e-bike/e-scooter), device price (AU$800–$2,500), riding rewards (1–4 cents/km), and annual maintenance coverage.

A D-efficient experimental design, created in Ngene, optimised attribute trade-offs to enhance statistical efficiency and scenario realism (ChoiceMetrics, 2012; Rose & Bliemer, 2009). The design was piloted with 145 respondents to generate Bayesian informative priors, improving overall reliability (Bliemer et al., 2008).

To capture preference heterogeneity, a mixed logit model (random parameters logit) was estimated using Apollo in R, employing 2,000 random draws (Train, 2009; Hess & Palma, 2019). Attributes expected to positively influence choice (rebate rate, riding rewards, maintenance) had positive lognormal distributions, while device price used a negative lognormal distribution. Device type had a normal distribution. Interaction terms included price-income and device-gender, along with error components addressing intra-respondent variability.

Results

The modelling began with a basic MNL, which performed poorly (McFadden's R^2 = 0.015, log-likelihood = -5,781). Switching to a mixed logit model significantly improved performance, increasing R^2 to 0.302, improving log-likelihood to -4,537, and substantially lowering the BIC from 11,802 to 9,221. These results highlight the importance of capturing unobserved preference heterogeneity, which the basic MNL overlooked.

As detailed in Table1, the estimates for each parameter are reported, with most parameters found to be statistically significant based on robust t-ratios. For each random coefficient, both the mean (μ) and standard deviation (σ) are presented. While most parameter estimates are statistically significant, it is important to note that the absolute values themselves are not directly interpretable; rather, the actual effect of each parameter is reflected through its specified distribution.

Parameter	Estimate	Robust t-ratio
asc_direct rebate	1.2417	5.6913
asc_car replacement rebate	0.5852	2.3775
asc_optout	0	NA
b_direct rebate rate		
μ	0.8929	1.7161
σ	0.1512	0.1440
b_car replacement rebate rate		
μ	-1.4776	-1.4679
σ	-0.8450	-2.2779
b_full price		
μ	-6.4949	-5.8064
σ	13.9737	7.1779
b_device type (e-bike compared to e-scooter)		
μ	1.4782	4.7145
σ	-1.6554	-4.8891
b_riding reward		
μ	-8.1203	-5.2873
σ	4.0166	6.0394
b_free annual maintenance		
μ	-2.9951	-5.0586
σ	2.3124	6.6393
sigma_panel	-1.8517	-18.6172
gamma_full price $\times$ income	-2.6106	-7.0481
gamma_device $\times$ female	-0.6729	-2.7187

Table 1: **Parameter estimates for the mixed logit model**

Elasticities were calculated by increasing each numerical attribute by 1% and observing the resulting change in choice probabilities for each alternative. The resulting elasticity values, which reflect the percentage change in choice probability in response to a 1% increase in the corresponding attribute, are presented in Table 2.

Attribute	Direct rebate	Car replacement rebate	Opt-out
Full price	-0.029	-0.029	0.064
Rebate rate (for direct rebate)	0.608	-0.623	-0.258
Riding reward	0.0018	0.0062	-0.0082

Table 2: **Choice probability elasticities (%) for key attributes by alternative**

As a key component of the ownership choice analysis, the scenario test estimates the direct market penetration rates under a range of potential policy configurations prior to real-world implementation. Seven scenarios were proposed, each with varying attribute levels and fiscal costs, progressing from low to high. The detailed scenario configurations are provided in Table 3, and the corresponding changes in choice probabilities for each alternative are illustrated in Figure 1.

Scenario	Annual maintenance (Yes/No)	Riding reward (cents/km)	Device type	Rebate rate (car replacement) (%)	Rebate rate (direct) (%)
1 (Low cost)	No	2	E-scooter	50	10
2	No	4	E-scooter	75	15
3	Yes	10	E-scooter	100	20
4	No	4	E-bike	60	10
5	No	10	E-bike	80	20
6	Yes	20	E-bike	100	30
7 (High cost)	Yes	40	E-bike	120	40

Table 3: **Attribute levels for the seven policy scenarios**

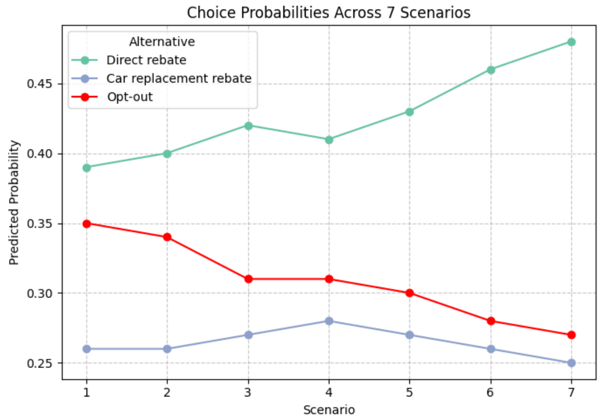

Figure 1: **Predicted choice probabilities for each alternative under seven policy scenarios.**

Discussion

Estimates from the mixed logit model indicate strong potential for EMM adoption under incentive policies. Among the numerical attributes, rebate rate is the most significant—especially for direct rebates—with increases for either alternative having the strongest positive effect on EMM purchase probability. E-bikes are generally preferred; higher income reduces price sensitivity, and females are less likely than males to purchase.

Our scenario analysis offers practical insights for policy design. As fiscal support moves from low- to high-cost scenarios, the predicted adoption probability via direct rebates increases from 39% to 48%, while opt-out rates decline. However, the car replacement rebate remains stable at a modest 25%–28%. This suggests direct rebates effectively encourage adoption, particularly when paired with riding rewards and free maintenance. Conversely, even substantial car replacement rebates have limited appeal, possibly due to behavioural barriers like personal attachment to cars or its suitability for only a small subset of car owners.

Further simulations indicate optimal fiscal efficiency at approximately 191 additional EMM devices per million AUD spent, aligning with findings from similar US studies. Effective incentive configurations typically yield about 31% opt-out rates and do not universally include free maintenance. Optimal scenarios usually feature higher riding rewards (10 cents/km), lower direct rebates (less than 10%), and moderate car replacement rebates (30%), resulting in roughly 30% of incentive spending on direct rebates and 70% on car replacement rebates.

These results highlight the need to carefully tailor incentive structures to maximise EMM adoption. While greater incentive generosity can increase uptake, there may be diminishing returns at the highest support levels. Policymakers must weigh the trade-off between fiscal cost and the targeted market penetration rate.

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Tuesday 9th December: 2pm-3.30pm
Parallel Session 2 (Level 16, Seminar room)
Theme: Road Pricing and Demand Management, Session Chair: Mr. David Surplice
Empirical Investigation on the Use of Road Pricing as a Road Safety Strategy: A Discrete Choice Experiment (Humberto Barrera-Jimenez, Mark Stevenson and Patricia S. Lavieri)
The Impact of Reservation Order Ratio on the Efficiency of Ride-pooling Service (Zixuan Yang and Xiaolei Wang)
Road Pricing Unravelled: An Integrated Framework to Inform Research and Practice (Humberto Barrera-Jimenez, Mark Stevenson and Patricia Lavieri)

Empirical Investigation on the Use of Road Pricing as a Road Safety Strategy: A Discrete Choice Experiment

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1. Introduction

Road pricing stands as one of the most comprehensive travel demand management policies. It operates as a push-pull mechanism by using prices to reduce the marginal social costs of driving and reallocating revenues to improve other transport modes. This way, drivers may opt for mode shifts or route and time of departure changes depending on the scheme specifics. Despite its documented effectiveness in managing congestion and pollution, the role of road pricing in improving road safety remains significantly under-explored.

While significant collision reductions have been observed in existing schemes, substantial gaps persist regarding this relationship and its importance. Compared to congestion and pollution, the road safety effects of road pricing are heavily underrepresented in literature. Empirical experimental investigations exploring its causal mechanisms are largely absent. The DCE investigates three key travel decisions: mode, route, and time of departure choices. The experiment's results reveal the utilities drivers associate with such a scheme, which are then used to calculate choice probabilities. These probabilities are subsequently translated into risk calculations as a measure of changed road safety.

2. Literature review

Empirical observational research findings are highly heterogeneous. While schemes such as Milan's present no change in fatalities over three years, London's showed substantial long-term improvements of 33% decrease in fatalities over two years. The specificity of studies and the multiple causal mechanisms of road pricing translate in high heterogeneity for the same case cities. For instance, mode-specific studies on car casualties in London found more modest reductions of 3.4% and 5.2% in the first-year post-implementation, while simulated studies highlight an increased likelihood of collisions immediately after implementation for vulnerable road users, due to increased exposure from mode shifts and altered traffic flow conditions (Singichetti et al., 2021). Significantly, any initial negative effects tend to reverse, with safety improving beyond baseline conditions within six months to three years post-implementation (Fecht et al., 2022; Singichetti et al., 2021). On computational simulations of diverse spatial arrangements, enforcement mechanisms, and price structures, 13% reductions in deaths primarily attributed to decreased Vehicle Kilometres Travelled (VKT) have been found to be determinant on the safety effects of existing schemes (Eenink et al., 2007). Importantly, all observed safety effects of existing mechanisms have been unplanned, emergent co-benefits of congestion-oriented policies. The literature review revealed no prior DCEs investigating this relationship.

3. Methodology

To evaluate the potential safety effects of a safety-oriented road pricing policy, this DCE is structured as a two-arm Randomised Control Trial (RCT). In this RCT the control arm is a subsample of drivers responding to a common congestion-oriented policy DCE (road price, policy description, discursive stimuli, attributes presentation, etc; as a function of congestion), and the intervention arm responding to the safety-oriented counterpart. To evaluate risk reductions as product of this differential policy approach, three distinct but connected stated decisions are explored, namely, mode, route and time of departure choices. To reduce the effects of the most behaviourally-bounded and road pricing-relevant unobserved variables, sampling is balanced across gender, income and driving patterns. Lastly, considering the focus on safety and the need to present policy design recommendations, this study also includes results from an adapted Driving Behaviour Questionnaire (DBQ) component and contingent valuation analyses.

4. Results

This experiment is work in progress. In the analysis phase, and as a parallel RCT, the models' results will be translated into choice probabilities and its correspondent reductions on exposure as a product of changed modal interactions, vehicle kilometres travelled and other metrics of risk. With the insights from utilities estimations recommendations for policy design will be provided, highlighting the relative relevance of each parameter.

5. Discussion

This experiment, first of its kind, is innovative in three fronts. First, being the first empirical experimental approach to unveil the potential behavioural responses of drivers to a safety-oriented road pricing scheme. Second, by merging the benefits of DCE and RCTs, not only absolute but comparative analysis are presented, thus, allowing for policy-making that is more aligned with the core principles of road pricing. Third, by translating the results of stated preferences to insights that can inform other modelling and simulation studies such as traffic models.

6. Conclusions and recommendations

Road pricing remains, despite its limited adoption, one of the most effective transport demand management strategies. Although limited real-world experience hinders the production of more observed empirical evidence, the existing schemes show a highly significant potential for its use as a road safety intervention. Highlighting such benefits from a causal perspective and through experimental findings such as those presented in this research, pose a significant opportunity to expand road pricing and reduce risk simultaneously. Both academia and governments could prioritise the research avenue this study opens, for more interdisciplinary approaches and opportunities around road pricing.

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The Impact of Reservation Order Ratio on the Efficiency of Ride-pooling Service

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1 Introduction

Rapid urbanization has strained transportation systems, worsening congestion and emissions. Ride-pooling improves resource efficiency (Shaheen and Cohen, 2018), yet demand uncertainty undermines its potential. The predictive models can mitigate this but still suffer from inherent inaccuracy. Reservation orders, in contrast, provide reliable future demand data which is a critical advantage. While reservations' benefits are established (e.g., Duan et al., 2020; Theodoridis et al., 2023), their systemic impact remains understudied. Low reservation ratios limit scheduling optimization, whereas excessive reservations may neglect real-time orders due to rigid priorities, increasing the waiting time. Besides, some current hybrid models predominantly adapt real-time matching algorithms with simplistic reservation adjustments, failing to dynamically reweight reservation/real-time priorities. To address these gaps, we propose a simulation model that: (i) introduces penalty-based dynamic prioritization to balance reservation guarantees and real-time order service, and (ii) evaluates multidimensional metrics to identify optimal reservation ratios. Our findings help platforms tailor reservation policies to local demand, balancing sustainability and user satisfaction.

2 Literature Review

Traditional matching algorithms prioritize anytime optimization (Alonso-Mora et al., 2017), but their myopic nature often leads to suboptimal solutions in global, as evidenced by the complex trade-offs required in mixed pooling/non-pooling markets (Wang et al., 2025). To mitigate this myopic nature, prediction-based approaches (e.g., Wang et al., 2021; Fielbaum et al., 2022; Yang et al., 2024) improve matching but remain limited by forecast uncertainty. Recent studies propose integrating reservation orders to enhance decision-making foresight. Duan et al. (2020) demonstrated that higher reservation ratios improve robustness to demand uncertainty and boost response rate and revenues, provided vehicles are sufficiently available. Further, Theodoridis et al. (2023)'s extension of Alonso-Mora's algorithm accommodated reservation orders (5–20 min ahead). By incentivizing users to disclose travel plans early, they achieved higher service rate, though computational complexity increased.

3 Methodology

In our model, the system adopts a discrete decision mechanism for matching and dispatching. For a given matching time point t_n $(n = 1,2,3 \dots)$ with time window size $\Delta\bar{t}$, the orders entering the current matching pool consist of: (i) real-time orders; (ii) reservation orders; (iii) any remaining orders from previous matching rounds. And we set a maximum capacity of two passengers per vehicle.

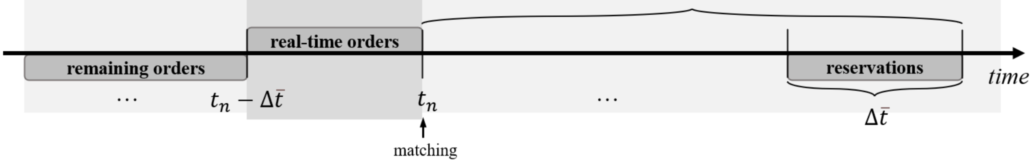

Figure 1 Example Diagram of Order Composition

For every matching stage, the system will solve an integer linear problem. $\boldsymbol{S}$ is the set of selected orders and $\boldsymbol{V}$ is the set of available vehicles in the matching pool. Specifically, $\boldsymbol{S}_r \subseteq \boldsymbol{S}$ is the set of reservation orders, and $\boldsymbol{V}_0, \boldsymbol{V}_1 \subseteq \boldsymbol{V}$ is the set of empty vehicles and partially occupied vehicles respectively. Denote $x_{s,v} \in \{0,1\}$ as the variable that if order $s \in \boldsymbol{S}$ can be assigned to vehicle $v \in \boldsymbol{V}$. Let $\overline{D_p}$ be the maximum pickup distance and $\overline{D_d}$ be the maximum detour distance. Noted that there already exists a matched order for a partially occupied vehicle $v \in \boldsymbol{V}_1$, we use s_v represent that order. Then $c(s,v)$ is the cost to match order $s \in \boldsymbol{S}$ and vehicle $v \in \boldsymbol{V}$, $p(v,s)$ calculates the pickup distance, and $d(s,s_v)$ calculates the detour distance if $v \in \boldsymbol{V}_1$. The problem is formulated as below:

$$\max_{x} \sum_{s\in \boldsymbol{S}} \sum_{v\in \boldsymbol{V}} c(s,v)\cdot x_{s,v} - \sum_{s\in \boldsymbol{S}_r} \sum_{v\in \boldsymbol{V}} (1-x_{s,v})\cdot M(t_n,t_s)$$

$$s.t. \qquad \sum_{v\in \boldsymbol{V}} x_{s,v} \le 1, \qquad \forall s \in \boldsymbol{S} \tag{1}$$

$$\sum_{s\in \boldsymbol{S}} x_{s,v} \le 1, \qquad \forall v \in \boldsymbol{V} \tag{2}$$

$$p(v,s)\cdot x_{s,v} \le \overline{D_p}, \qquad \forall s \in \boldsymbol{S},\ v \in \boldsymbol{V} \tag{3}$$

$$d(s,s_v)\cdot x_{s,v} \le \overline{D_d}, \qquad \forall s \in \boldsymbol{S},\ v \in \boldsymbol{V}_1 \tag{4}$$

$$x_{s,v} \in \{0,1\}, \qquad \forall s \in \boldsymbol{S},\ v \in \boldsymbol{V}. \tag{5}$$

Constraint (1) ensures that each order can be matched with at most one vehicle, while constraint (2) guarantees that each vehicle can be assigned to no more than one order. Constraints (3) and (4) further regulate the operational boundaries. And we solve the problem by KM method.

We use function $l(\cdot)$ to get the shortest distance of two locations. Notation o_s and d_s is the origin and destination of the order s respectively. $c(s,v)$ in the objective function can be calculated by equation (6):

$$c(s,v) = \begin{cases} -p(v,s) + W & if\ v \in \boldsymbol{V}_0 \\ -p(v,s) + l_s(s,s_v) + W & if\ v \in \boldsymbol{V}_1 \end{cases}, \qquad s \in \boldsymbol{S}. \tag{6}$$

W is a constant adding for maximization problem so we can get the minimum cost. $l_s(s,s_v)$ is the saved distance if order s and s_v can share a vehicle.

As for the penalty factor, it is just a constant M in our benchmark simulation. However, in our refined model, it will dynamically evolve over time (measured in seconds), enabling the system to incorporate reservation orders into the matching pool significantly earlier while maintaining balanced consideration of real-time demands. t_r is the reserved departure time for a reservation order $s \in \boldsymbol{S}_r$, the formula is:

$$M(t_n,t_r) = M\cdot \frac{300}{max\,\{t_r - t_n, 300\}}. \tag{7}$$

4 Results & Discussions

We construct the simulation environment using real-world road network data from Haikou City, sourced from OpenStreetMap. Order data derives from DiDi's anonymized historical records. Results reveal that longer $\Delta\overline{T}$ generally enhance operational efficiency, though with notable trade-offs. As reservation ratios increase, we observe an overall reduction in average waiting time accompanied by marginal increases for real-time orders and a gradual decline in system response rates. This occurs because higher reservation ratios dilute priority differentiation among reservations while vehicle pre-allocation reduces flexibility for real-time demand. Distance metrics show stable detour distances and pickup time slightly increases, indicating limited hidden costs of reservation prioritization. Interestingly, while the drive distance rises with reservation ratios for shorter entry times, the 15-minute scenario demonstrates a non-monotonic trend where distance peaks at 10-20% ratios before declining, suggesting prolonged entry times enable more effective demand clustering that ultimately reduces unnecessary vehicle movement.

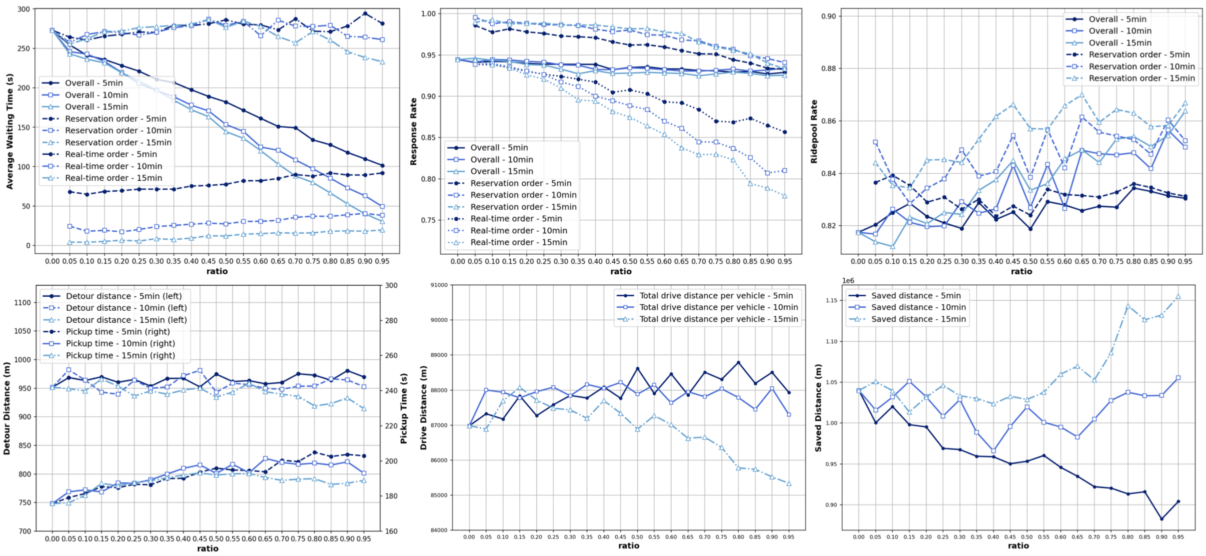

Figure 2 Key Metrics under Benchmark Scenario

Building on these insights, we implemented a time-varying penalty factor adjustment. This dynamic approach yields substantial improvements, increasing ride-pooling rates by 10-13% compared to static models while reducing waiting times, detour distances, and pickup times. However, these benefits come at the cost of over 15% lower response rates under high reservation ratios, as the extended planning horizon intensifies competition for limited vehicle resources.

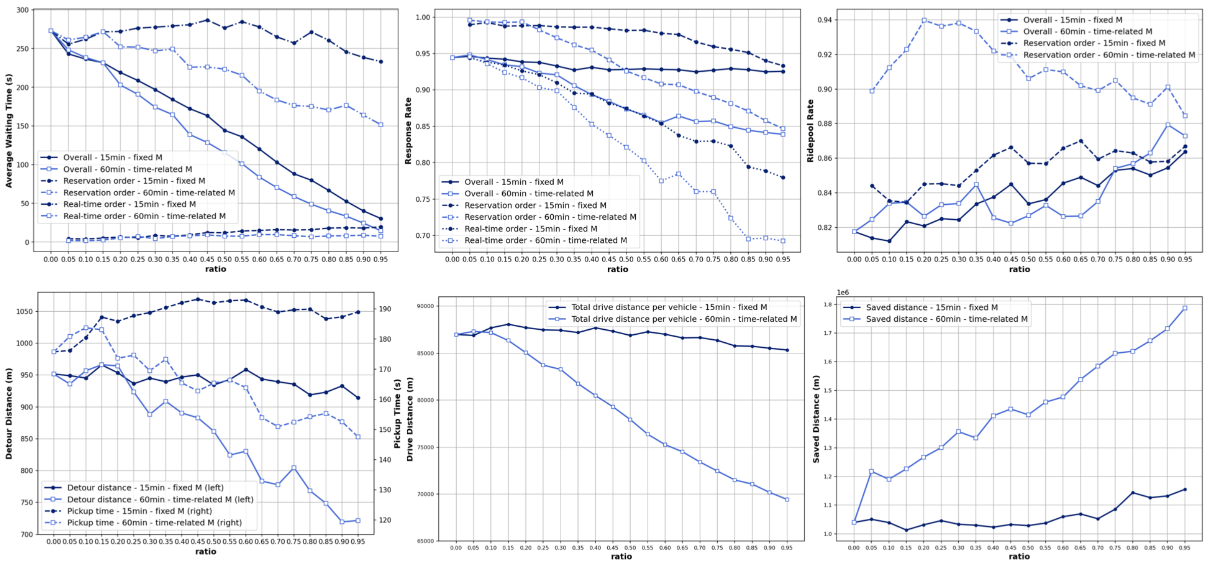

Figure 3 Key Metrics under Time-related Penalty Factor

5 Conclusion

This study develops a simulation system to evaluate how reservation ratios impact operational efficiency using Haikou's road network data. Our mixed-order simulations with dynamic penalty factors reveal that the system performs optimally within a reservation ratio range of 30-40%, where it successfully balances efficiency gains with service quality maintenance. Beyond this threshold, the focus on advanced scheduling begins to significantly compromise real-time responsiveness, making vehicle availability appear artificially scarce despite the theoretical advantages of longer planning horizons. These results provide platforms with actionable insights: implementing moderate reservation ratios with dynamic priority adjustments creates a robust operational framework, though successful deployment requires complementary fleet scaling to maintain system responsiveness.

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Road Pricing Unravelled: An Integrated Framework to Inform Research and Practice

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1. Introduction

Road pricing stands out as both an effective and efficient transport policy. By introducing charges for urban road use, it addresses negative externalities associated with car-based mobility and simultaneously facilitates improvements in intermodal transport systems. Cities worldwide grapple with persistent challenges such as stagnant progress in reducing crashes and congestion, as well as difficulties in increasing public transport ridership and securing its funding. Given these issues, the opportunity cost of neglecting to implement a strategy of this significance is substantial. The success of implemented cases, insights gained from failed attempts, and the cumulative knowledge exchange between academia and practice demonstrate that road pricing is not only a desirable solution but also a feasible one. This paper investigates the underlying forces, themes, and implications of road pricing as found in both academic and practical literature. It then proposes an integrated framework to guide future research and practical applications, with the goal of advancing the field.

2. Literature review

This paper draws on a vast body of road pricing literature, encompassing both scientific and applied research. A key challenge for road pricing in gaining traction among academics, government officials, and politicians is the disproportionate focus on its most contentious issues (Singichetti et al., 2022). These often include concerns about fostering inequality, privacy infringements, or impacts on individual liberties (Eliasson, 2016; Taylor & Kalauskas, 2010). However, this high-level thematic focus can overshadow the fact that many of these perceived problems stem from beliefs and attitudes highly dependent on specific local contexts and policy design (Vonk Noordegraaf et al., 2014). Despite these challenges, road pricing remains the most effective strategy for reducing car use (Kuss & Nicholas, 2022) and congestion (Federal Highway Administration, 2008).

3. Methodology

This paper presents a comprehensive analysis of road pricing policy by employing a review of reviews approach, building upon previous research to offer a compounded understanding. A mixed-methods approach was used, beginning with literature exploration and acquisition guided by PRISMA guidelines. An iterative combination of Force Field Analysis and Thematic Analysis identified driving and resisting forces in road pricing research and practice, allowing for the clustering and characterisation of themes related to these forces. Finally, the findings are contextualised within the PESTLE framework (Political, Economic, Social, Technical, Legal, Environmental). The results highlight promising avenues for future road pricing research and practical application.

4. Results

From 1057 initial records, 54 papers were selected for this study, evenly split between scientific and grey literature. Using a mixed-methods approach, 5 themes, 18 sub-themes, and 73 forces were identified and analysed. These are integrated into a new framework that offers a comprehensive, interdisciplinary view of road pricing through the lens of complexity, drawing from the humanities, social, technological, and engineering sciences. The PESTLE implications for each force are also outlined, and recommendations for advancing road pricing based on these findings are provided.

5. Discussion

Unravelling the complexity of the interaction of all inner and exogenous forces that either drive or hinder road pricing offers several advantages. First, viewing road pricing as a complex system helps scholars, practitioners, and communities make informed decisions. This approach allows them to accurately weigh both the potential benefits and drawbacks, ensuring that positive observations and potential are appropriately considered alongside negative beliefs. Second, by developing complexity-driven approaches to road pricing, its application to real-world issues like equity, accessibility, and transport externalities can be better aligned. This increases the likelihood of successful implementation. Finally, focusing research on causal exploration can open innovative avenues for both research and practical applications in road pricing.

6. Conclusions and recommendations

Road pricing, despite limited adoption, is a highly effective transport demand management strategy. Although real-world experience is scarce, existing schemes demonstrate its potential beyond congestion management, extending to urban governance. Analysing the causal benefits and costs of road pricing, as this research does, offers a significant opportunity to expand its use and reduce resistance. Both academia and governments should prioritise interdisciplinary research into road pricing, leveraging the avenues opened by this study.

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Tuesday 9th December: 2pm-3.30pm
Parallel Session 3 (Level 16, Lecture room 5)
Theme: Household Decision-Making and Evolving Travel Behaviour, Session Chair: Prof. Michael Bell
Joint decision of household vehicle ownership, fuel type and ADAS feature choices (Heshani Rupasinghe and Shamsunnahar Yasmin)
Enhancing Travel Behaviour Insights: The Transformative Power of GPS in Household Travel Surveys (Adri van der Mescht)
Aggregate Travel Behaviour Changes Post-Pandemic: Insights from the Queensland Household Travel Survey (Siddhesh Patil Kulkarni)

Joint decision of household vehicle ownership, fuel type and ADAS feature choices

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Introduction

Vehicle ownership is not only one of the cornerstones of travel demand modelling but also a key driver of energy usage, emissions and road-safety outcomes in modern transport systems. However, household vehicle ownership portfolios are rapidly evolving due to shift towards emerging vehicle technology, such as alternative fuel vehicles (AFVs) and Advanced Driver Assistance Systems (ADAS). Therefore, understanding the decision of household's vehicle ownership in the context of emerging vehicle technologies is crucial for developing sustainable transport policies and practices. The existing studies examined the adoption of these technology in isolation, overlooking potential interactions among vehicle ownership and the adoption of alternative fuel types and embedded safety features. This creates a crucial empirical and theoretical gap, with policy implications for both sustainable mobility and road safety. To address this gap, the study adopts a joint modelling approach to capture the interdependencies between household vehicle ownership, vehicle fuel type selection, and ADAS feature adoption, reflecting the increasingly interconnected nature of real-world household vehicle decisions. Leveraging the household travel survey data from Southeast Queensland through financial years 2019/20 to 2023/24 this study will inform policy interventions that account for key synergies and trade-offs inherent in household vehicle selection decisions.

Data and Methodology

This study utilises household travel survey data from Southeast Queensland (2019/20–2023/24), comprising 19,390 households and 29,896 vehicles, enriched with vehicle-level technology information. The dataset includes information on fuel type (petrol, diesel, hybrid, battery electric) as well as ADAS features information identified based on vehicle make, model, and manufacturing year information available in household travel survey. The ADAS information considered are Autonomous Emergency Braking (AEB), Forward Collion Warning (FCW), Lane Keep Assist (LKA), Lane Departure Warning (LDW) and Adaptive Cruise Control (ACC). Descriptive analysis reveals that the majority of households in the sample own either one vehicle (44.7%) or two vehicles (37.6%), while a smaller proportion report zero vehicle ownership (7.6%) or own three or more vehicles (10.1%). At the vehicle level, petrol vehicles account for the largest share (73.4%), followed by diesel (24.5%), with hybrid electric and battery electric vehicles 1.5% and 0.6% respectively, highlighting the early stage of electric vehicle diffusion. In terms of ADAS technology adoption, 36.1% of vehicles in the sample are equipped with at least one ADAS feature. Among the specific features, AEB is present in 31.3% of vehicles, FCW in 13.2%, LDW in 13.8%, LKA in just 5.5%, and ACC in 11.1% of the sample, reflecting the relatively recent introduction and limited market penetration of some ADAS features. The modelling framework applies a joint modelling framework, that simultaneously models household decisions regarding vehicle ownership, fuel type selection, and adoption of embedded ADAS features. Independent variables include socio demographic charcateristics such as household size, presence of children, age distribution, as well as land use characteristics including population density, accessibility and entropy, and transport infrastructure variables such as public transport network density, number of bus stops, and number of railway stations.

Findings and Discussion

In the study, the final model is specified based on exogenous variables which are statistically significant at 95% confidence level. Analysis results demonstrate significant heterogeneity in the uptake of AFVs and ADAS across household types. Households with two vehicles exhibit the highest adoption rates for both AFVs and ADAS-equipped vehicles, especially for hybrids and battery electrics, which are more likely to integrate advanced safety features than petrol or diesel vehicles. This is likely because multi-vehicle households can adopt new technologies while retaining a conventional vehicle, reducing perceived risks related to range and unfamiliar features. Market penetration of LKA remains limited, largely due to its recent introduction and association with premium models, making it less accessible to mainstream buyers. The slower uptake reflects both its recent market availability and its typical bundling with higher-cost vehicles. The integrated modelling approach reveals that younger households and those with greater public transport accessibility have lower vehicle ownership, likely due to more mobility options and a greater propensity for multimodal travel. In contrast, households with a higher proportion of males, part-time workers, or separate living arrangements tend to own multiple vehicles, reflecting lifestyle and employment needs for greater travel flexibility. Policy interventions, such as remote working guidelines, are shown to reduce vehicle ownership by decreasing the necessity for commuting, enabling households to function with fewer vehicles. Conversely, households in low-income areas during the COVID-19 period showed increased vehicle ownership, possibly due to economic disruptions leading to shared resources and increased reliance on private vehicles for safety. This underscores the interplay between urban form, public transport, and policy on car dependency. In terms of technology adoption, HEV and BEV uptake is positively associated with IT sector employment and residence in densely populated areas, reflecting greater environmental awareness, income, and early adopter tendencies, as well as better infrastructure and policy support. Queensland's green car loan program and zero-emission vehicle rebates have further boosted adoption, with financial incentives directly reducing cost barriers and accelerating transition to cleaner vehicles. For ADAS, white-collar employment status is associated with higher adoption of features like AEB and FCW, likely due to higher purchasing power and a greater emphasis on safety and technology in vehicle choice. In contrast, households in high-income areas are less likely to adopt LKA and LDW, possibly due to brand preferences, satisfaction with existing features, or delayed availability in luxury models. Regulatory changes, such as Australia's 2023 AEB mandate and ANCAP's LKA requirements for five-star safety ratings, have further driven adoption. Mandates and rating incentives encourage manufacturers to equip more vehicles with advanced features, increasing their prevalence across the fleet.

Conclusion and Recommendations

This research is among the first to empirically model the joint adoption of fuel and embedded safety technologies within household vehicle ownership. To accelerate sustainable fleet transitions, policies should consider the registration of second vehicle in household to be limited to technologically advanced vehicle, thereby restricting further adoption of conventional ICE vehicles. Evidence suggests that providing accessible green loan schemes is more effective than standalone rebates, and that rebate programs should be dynamically linked to the number of household vehicle registrations and subject to regular review, given the observed increase in EV adoption following rebate adjustments. Finally, equity-focused measures including targeted subsidies, scrappage incentives, and advanced vehicle car-sharing initiatives are essential to ensure low-income and marginalized households benefit from the transition to safer, low-emission vehicles.

Acknowledgment

The authors acknowledge the Queensland Department of Transport and Main Roads for providing access to household travel survey data, and QUT for scholarship support. The views expressed are solely those of the authors.

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Enhancing Travel Behaviour Insights: The Transformative Power of GPS in Household Travel Surveys

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Introduction:

Traditional Household Travel Surveys (HTS), primarily relying on self-reported travel diaries, face limitations in capturing the complexities of modern travel behaviour. These methods are susceptible to recall bias, underreporting of short trips, and inaccuracies in trip timing and location details. The integration of GPS technology in HTS offers a transformative potential to address these limitations and provide richer insights for transportation planning. This study explores the advantages of incorporating GPS data collection in HTS by examining a real-life example of the integration of GPS data with traditional paper diaries. It showcases the differences observed between the data from paper diaries only and the data from a combination of paper diaries and passive GPS data, demonstrating how the integration of GPS data has the potential to enhance data accuracy, increase completion rates, and unlock new dimensions of travel behaviour analysis.

Despite the growing interest in integrating GPS data with traditional paper diaries in HTS, limited studies have been conducted in this area.
This study aims to address these research gaps and provide insights into the effectiveness and implications of incorporating GPS data in HTS.

Main Body
Methodology

Data collection was conducted by delivering questionnaires and GPS devices to selected households. They were asked to fill in the questionnaires describing the travel they undertook on a specific day, their assigned travel day, and carry the GPS device for 3 days.
The data collected from households was data-entered, using processed traces from GPS devices as an additional source of information. Where the data in the paper diary and the trace did not match, respondents were called back to confirm if the additional data visible was indeed a valid trip or not.
A comparative approach was utilised to analyse data collected through both traditional paper diaries only and a combination of paper diaries and the processed traces from the GPS tracking devices.

Findings

The analysis of the integrated GPS and paper diary data from the Household Travel Survey (HTS) reveals several key findings that demonstrate the value of incorporating GPS technology in travel behaviour research.

1. **High GPS Opt-In Rates**

A consistent majority of households and eligible members aged 16+ opt-in for GPS, demonstrating steady engagement with the GPS component. This high opt-in rate indicates a willingness among participants to embrace GPS technology in travel surveys, laying a strong foundation for the collection of comprehensive travel data.

2. **Increased Travel Reporting Accuracy**

Respondents with GPS devices are consistently more likely to report travel on their pre-assigned travel day compared to those without GPS devices. This finding suggests that the presence of GPS devices encourages more accurate reporting of travel activities, potentially due to the awareness that their movements are being recorded.

3. **Enhanced Accuracy of Trip Details**

GPS data significantly improves the accuracy of reported trip times and location information compared to paper diaries. The precise timestamps and geographical coordinates provided by GPS devices enable the correction of errors and inconsistencies in self-reported data.

4. **More Stops Reported**

On average, respondents with GPS report more stops per person compared to those without GPS, indicating that GPS traces help verify stop information and capture additional stops missed in diaries. This highlights the role of GPS data in enhancing the completeness of travel data by identifying stops that may have been forgotten or overlooked by respondents.

5. **Value of Combined Methodology**

The number of stops picked up by each method of data capture illustrates the significant value of a combined GPS and Diary methodology improving the overall completeness and accuracy of the travel data.

6. **Forgotten Stops Captured by GPS**

GPS traces typically pick up 'forgotten' stops at various locations missed in diaries, such as accommodation, retail and transport features.

7. **Data Quality Benefits**

The integration of GPS traces enhances the overall accuracy and completeness of the travel data collected. By serving as a memory aid and validation tool, GPS data helps to correct inconsistencies, fill in missing information, and provide a more comprehensive picture of travel behaviour.

Challenges and Strategic Considerations:

While GPS technology offers numerous benefits for enhancing HTS, its integration presents certain challenges and requires thoughtful planning. One key consideration is balancing data quality and quantity within budget constraints. GPS technology provides rich data but comes at a higher cost, with an estimated 10% to 15% increase for ongoing studies, compared to surveys without GPS. Ensuring data privacy and effectively communicating security measures to respondents, especially those facing language barriers, is another challenge.

Determining the optimal number of carry days for GPS devices is crucial. Too few days may mean that respondents do not get into the habit of carrying the device and forget to take it on their travel day, while too many can lead to respondent fatigue and drop-out. Finding the right balance requires careful consideration of survey objectives and respondent burden. When deciding on the optimal number of carry days, it is important to consider the study's methodology and the respondent's existing commitments, as these factors can impact the feasibility of adding the GPS component.

GPS devices provide additional trace information and travel days, but the lack of a known methodology to effectively incorporate this data into existing transport models remains a challenge. While GPS data offers potential insights into route choices, inter-day and intraday variability, and traffic mix analysis, integrating this data into models is complex, as multiple days of data from different individuals do not equate to the insights gained from several days of data collected from a single individual.

Recommendations

This research recommends the wider adoption of GPS technology in HTS.
Integrating GPS data with traditional methods can significantly improve data quality and enable more sophisticated analysis of travel behaviour. However, it is essential to address data privacy concerns, ensure respondent confidentiality, and carefully consider the optimal number of carry days for GPS devices. Ongoing research and collaboration with partners and stakeholders are crucial for developing methodologies to effectively incorporate GPS data into existing transport models and unlocking its full potential for insights into route choices, inter-day and intraday variability, and traffic mix analysis.

Conclusion

The integration of GPS data in HTS represents a significant step forward in understanding travel behaviour and informing transportation planning decisions. By addressing the limitations of traditional paper-based methods and providing a more comprehensive and accurate representation of travel patterns, GPS technology has the potential to revolutionise travel behaviour research. However, its successful implementation requires careful consideration of challenges such as balancing data quality and quantity within budget constraints, ensuring data privacy, and determining the optimal number of carry days. As research progresses and methodologies for integrating GPS data into transport models are developed, the insights gained from this technology will become increasingly valuable for effective transportation planning decisions.

Aggregate Travel Behaviour Changes Post-Pandemic: Insights from the Queensland Household Travel Survey

Patil Kulkarni, S

Queensland Department of Transport and Main Roads (61 Mary St, Brisbane)

Introduction

The COVID-19 pandemic and an increasingly digital society has been a catalyst for a significant evolution in how people make their travel choices. This has resulted in lasting implications for urban mobility and transport planning. This study investigates changes in aggregate trip rates among key demographic segments and trip purposes in South East Queensland using data frm the Queensland Household Travel Survey. By comparing pre-pandemic (2017-2020) and post-pandemic (2022-2024) travel patterns, the study aims to uncover how different population segments have modified their travel habits. The findings provide critical insights into how key travel assumptions have changed and opportunities to further investigate these phenomena. The research is limited to the available survey data, which samples on average 1% of the mobile population per year.

Methodology

This study analysed travel behaviour from the QHTS comparing two periods: pre-pandemx (2017-2020) and post-pandemic (2022-2024). The focus was on aggregate trip rate changes across five life-stage personas:

- **0-17 Children:** Pre-school and school aged children
- **18-29 Young Adults:** Tertiary students, early careers and young parents
- **30-54 Primary Working Age:** Full-time workers with dependent children
- **55-74 Late Career:** Tapering work schedules, fewer dependents
- **75+ Retirement:** Limited working, increased social trips, diminishing activity

Trip rates were calculated as the average number of trips per person per day, segmented by persona and trip purpose (work, education, shopping, recreation, other). An additional dimension for the analysis was the proportion of individuals who did not travel at all on the survey day. This statistic provides additional context to trip making rates whether the changes are correlated with reduced trip making.

Statistical analysis of these trip rates has been conducted using python to demonstrate the statistical significance of the findings whether there is consistency or changes in the trip making behaviour

Findings and Discussion

Overall Trends

Aggregate trip rates have declined post-pandemic across all personas, with the majority of trip reductions in shopping trips and work related trips. Total trips showed a downward shift, indicating a broad shift in trip making behaviours. The overarching theme of shift suggests that non-mandatory travel has been highly susceptible to the pandemic-related disruptions, reflecting an increased reliance on online services, remote working and more cautious social interactions. Given the small data sample, it remains unclear if these findings are permanent or temporary.

Persona-Specific Insights

0-17 Children: Aggregate 10% decline in trip making, primarily from reduced shopping and recreational trips.

18-29 Young Adults: A 12% decline in trip rate, driven by reduced shopping trips with some decline in tertiary education and recreation

30-54 Primary Working Age: The largest by magnitude, with a 22% reduction constituted by significant reductions in all trip types and an increased immobility rate.

55-74 Late Career: The largest relative drop, a 27% reduction in trips, dominated by significant reductions in shopping trips and modest reductions in all other types.

75+ Retirement: A 18% reduction in trip rate, shopping and recreational trips are the primary reduction.

Trip Purpose Shifts

Commuting: Commuting trip rates have declined for white collar workers, with the largest declines for middle to late career workers. Blue collar workers see no significant decline except for workers aged 55+ who are more likely to be management or part time.

Education: School commutes are mandatory and have no observable change, however parents show a decline in trips to school or education. Tertiary commutes are insignificant and poorly sampled.

Shopping and Recreation: Shopping and recreation trips have shown significant declines post-pandemic with the decline in trip rate across all age groups, but most significant among older demographics. This decline does not appear to be correlated with employment status.

These findings suggest that while mandatory travel such as education has remained relatively consistent, work commutes have become less mandatory and other discretionary travel has declined significantly.

Non-Travellers

An important element of the analysis is the proportion of individuals who did not travel at all, acting as an indicator for the overall need to travel. The data suggests that this immobility rate has increased for people without mandatory travel, however the magnitude of this increase varies with the demographic group.

Further Investigations

There is significant opportunity to conduct a more focussed analysis on a particular demographic group, trip purpose or house trip dynamics. Investigations into the characteristics of trips made could unlock insight into what physical factors could be driving observed changes. As the Household Travel Survey is an annual rolling program, the 2024-25 data will be available for incorporation in this research.

Tuesday 9th December: 2pm-3.30pm
Parallel Session 4 (Level 17, Lecture room 2)
Theme: Resilient and Data-Driven Public Transport Systems, Session Chair: Prof. Corinne Mulley
Resilience of Public Transport Systems through Socio-ecological Perspective (Joshitha Tottala and Erik Jenelius)
Identifying the Public Transport Service Gaps for Tourism: A Smart Card Data Analysis for International Tourists in Taiwan (Barbara T.H. Yen and Chia-Jung Yeh)
Comparative Analysis of Charging Technologies in Modular Bus Systems (Haoran Zhao and Andrés Fielbaum)

Resilience of Public Transport Systems through Socio-ecological Systems Perspective

Joshitha Tottala[1], **Erik Jenelius**[1]
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Introduction

The need for resilient public transport (PT) systems is increasingly important in the face of both unanticipated disruptions, such as regional blackouts, the pandemic, and anticipated but transformative pressures such as climate change and electrification of the transport sector (Hayes et al., 2019; Sträuli et al., 2022). These events expose vulnerabilities in the PT system and in their mitigation strategies, which often prioritise short-term recovery within engineering frameworks (Chen et al., 2023; Chester et al., 2021; Sharifi, 2023). However, such approaches do not adequately acknowledge the interdependencies between PT and broader systems such as energy, land use, institutional arrangements, and social practices, which can produce cascading effects and non-linear feedback loops (Chan, 2025; Markolf et al., 2019; Schwanen, 2021).

To address these limitations, this study adopts a socio-ecological systems (SES) thinking of resilience. Originating from social and ecological sciences, SES thinking views human and natural systems as interconnected, co-evolving, and mutually dependent. In this framework, systems such as PT are not isolated technical infrastructures but are embedded within, and constantly interact with, wider social, ecological, economic and political environments (Wieland et al., 2023). The SES approach explores the resilience of PT beyond the engineering perspective and the physical infrastructure. It draws on emerging literature that frames resilience as dynamic and systemic, highlighting governance, behavioural responses, and institutional adaptability (Davoudi et al., 2013; Hayes et al., 2019; Huang & Wang, 2024). While SES-based resilience has been explored in various environmental and technological contexts and domains, its application to PT systems remains underdeveloped.

This study aims to fill that gap by defining resilience of PT in the socio-ecological context and developing a multi-layered PT system model. It introduces a disruption mapping framework that captures the impacts of both acute shocks (e.g., pandemics) and slow-onset disruptions (e.g., climate change, energy transitions, digitalisation) across time scales. By analysing both demand and supply-side responses, this work contributes to a more integrated understanding of PT resilience. It aims to inform practical strategies to enhance adaptability and preparedness in PT systems amidst growing complexity and uncertainty. Furthermore, it provides a theoretical foundation for future dynamic mappings and empirical simulations.

Methodology, Results and Discussion

In the face of an unpredictable future, a socio-ecologically resilient PT system evolves, adjusts, learns, and adapts itself, seeing disruptions as opportunities for renewal, innovation, and transformation. This definition is informed by insights from recent literature (Chan, 2025; Hayes et al., 2019; Schwanen, 2021). The SES perspective emphasises social and organisational dimensions, examining how PT systems adapt and evolve amid sudden shocks and long-term transitions.

The methodology integrates conceptual model building, disruption categorisation, mapping and scenario analysis. A core component of the methodology is a multilayered model for the

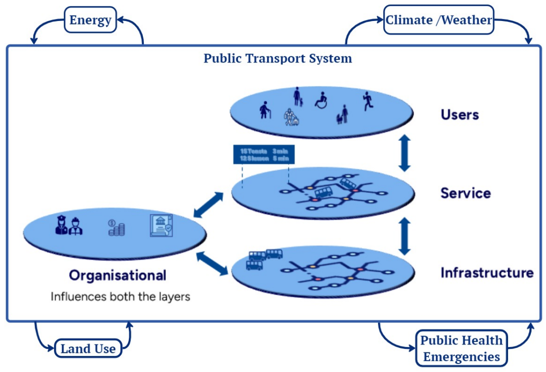

Figure 1: **Multilayered PT System**

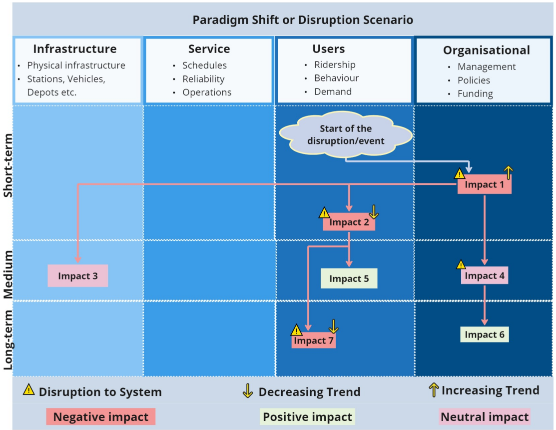

Figure 2: **Disruption Mapping Framework**

PT system, developed to capture PT systems' socio-ecological complexity and external interdependencies as shown in Figure 1. The model comprises four interconnected layers, namely Infrastructure, Service, Organisational, and Users, drawing from Jenelius (2022)'s model for the rail transport system. Disruptions initiated in one layer often propagate to others. Building on this, the study proposes a disruption mapping framework Figure 2 that uses temporal scales (short, medium and long-term) to map how disruptions unfold and propagate across the layers, enabling identification of cascading impacts and interactions between user behaviour, organisational practices, and infrastructure. The research draws on a combination of qualitative literature synthesis, case studies, and scenario framing to construct this framework (Markolf et al., 2019), laying the foundation for strategic preparedness planning.

The mapping framework in Figure 2 is applied to two cases, the COVID-19 pandemic and private electric vehicle (PEV) adoption. Both the case scenario mappings are presented in Figure 3 and Figure 4 . These two mappings are grounded in literature on the impacts of both disruptions on the PT system (Aloi et al., 2020; Asgarian et al., 2024; Kosmidis, 2025; Subbarao & Kadali, 2022), supplemented by contextual factors and inferred implications. Across both cases, users are the most impacted and a key driver of systemic change. Behavioural shifts such as remote work or private car use reshape travel patterns, influencing organisational decisions and infrastructure needs. The organisational layer plays a central role in enabling adaptation through coordination and responsive planning, while the slower-to-adapt infrastructure layer ultimately responds to these changes.

Both mappings show how a sustained decline in PT ridership can trigger self-reinforcing feedback loops such as reduced service, policy inertia, and delayed investment that constrain adaptation and risk locking the PT system into long-term decline. The COVID-19 case (see Figure 3) highlights how altered travel patterns can accelerate this process, while the PEV adoption case raises concerns about road space competition and underinvestment in PT infrastructure. Without intervention, the same feedback loops spanning revenue, ridership, fares, and accessibility could re-emerge, compounded by congestion pressures. Together, they underscore the need for organisational agility and proactive, user-centred planning that anticipates system-level change.

The disruption mapping framework offers a strategic preparedness tool for scenario planning and co-developing resilience strategies with PT stakeholders. It also highlights the key metrics that shape the resilience of the PT system that can be further quantified. Future work will focus on validation of the framework with PT authorities and a deeper analysis of how disruptions differentially affect diverse social groups, recognising their distinctive adaptive capacities.

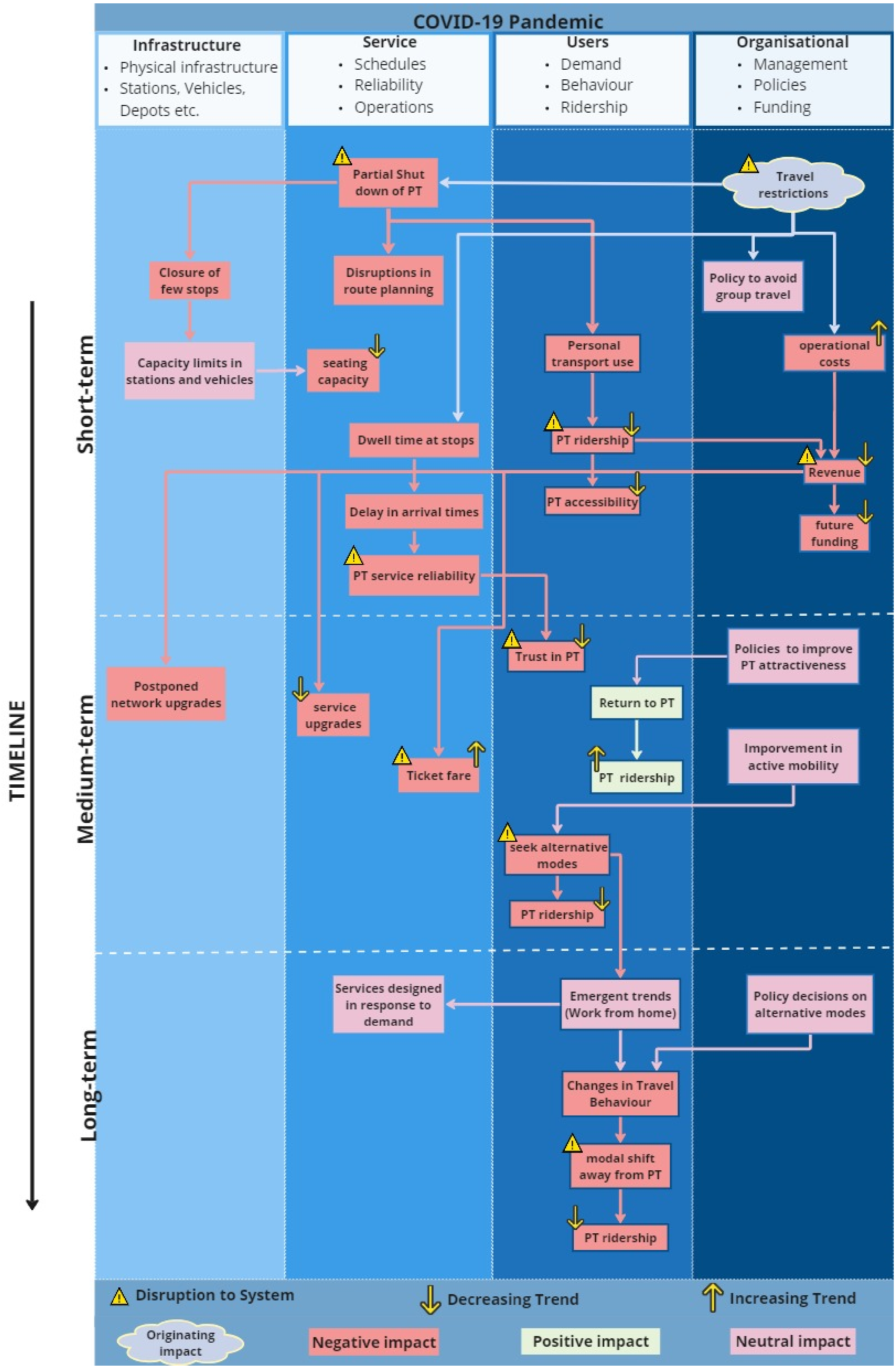

Figure 3: **Disruption Mapping for Covid-19**

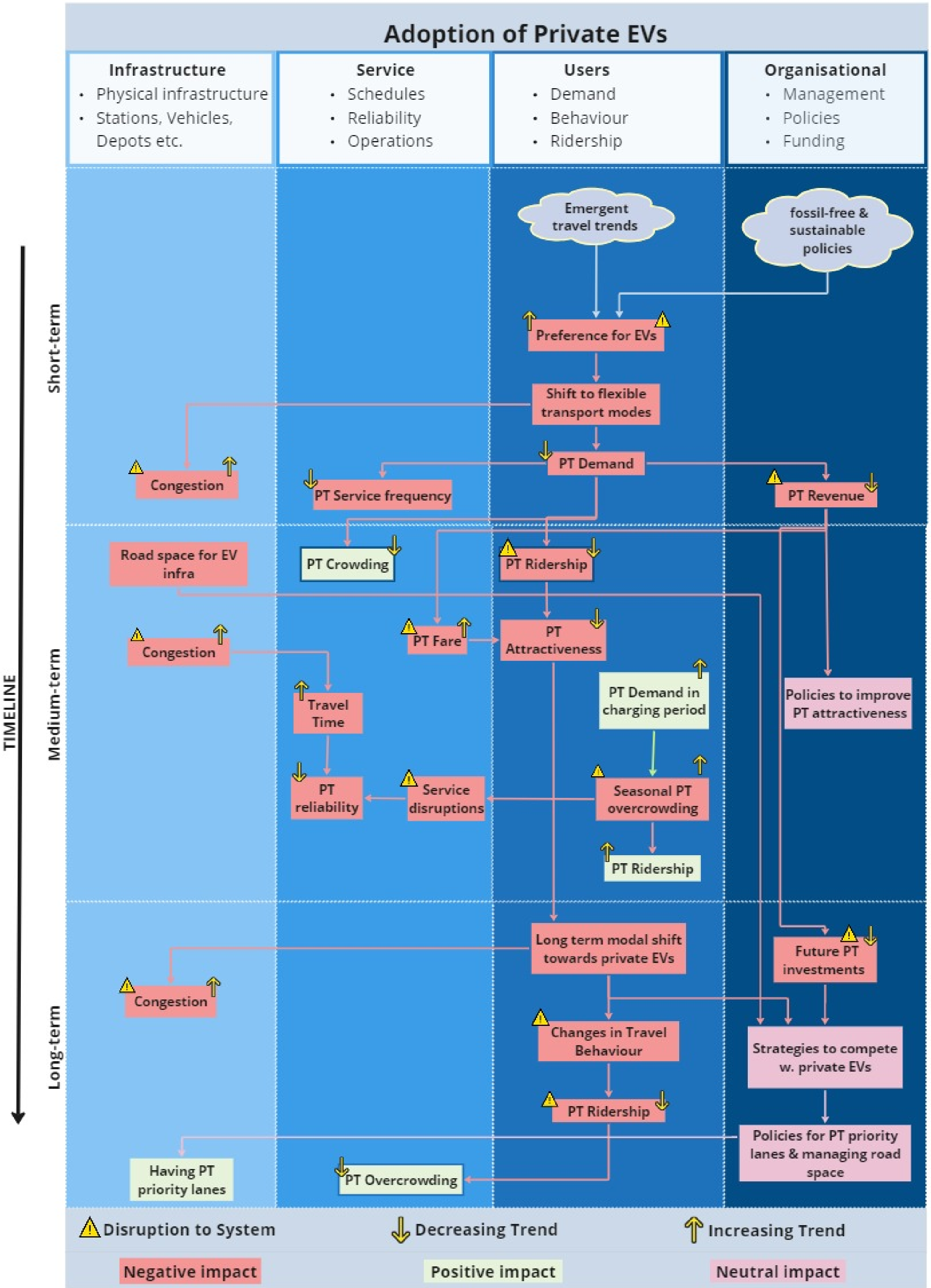

Figure 4: **Disruption Mapping for future adoption of PEVs**

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Identifying the Public Transport Service Gaps for Tourism: A Smart Card Data Analysis for International Tourists in Taiwan

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Introduction

Public transport plays a vital role in facilitating travel for international tourists. Better accessibility significantly contributes to tourists' overall satisfaction in terms of travel experience (Prideaux, 2000; Romão & Bi, 2021; Thompson & Schofield, 2007). For some highly attractive destinations (e.g., Tokyo in Japan, London in the UK), there might be some concerning negative externalities (e.g., traffic congestion) caused by the tourism industry. Promoting a modal shift toward public transport is therefore essential for achieving a more sustainable tourism industry (Barr & Prillwitz, 2012; Hall et al., 2017). The question is how to investigate tourist travel patterns to motivate them to use public transport as the main mode. Existing studies often rely on surveys (e.g., Ho & Mulley, 2013; Le-Klähn et al., 2014; Malhado & Rothfuss, 2013) or interviews (e.g., Edwards & Griffin, 2013; Lumsdon, 2006) to identify the factors influencing public transport use for tourism. However, these methods are limited in terms of identifying key participants and their familiarity with surveyed public transport services or local contexts. Therefore, this study addresses the gap via public transport smart card data analysis to explore travel patterns and identify critical influencing factors. In order to investigate the spatial features of tourist travel patterns, a multilevel zero-inflated Poisson (ZIP) regression model is employed, which can predict the expected number of trips for each place and identify areas with significant discrepancies between the actual and expected trips. The places with substantial gaps are then clustered into several groups to better understand the features of the associated attraction sites. This study can pinpoint critical factors influencing international tourists' use of public transport and offers specific spatial improvement strategies.

Literature Review

The factors influencing tourists' use of public transport have been widely discussed in the literature. Key motivations include the desire to avoid driving in unfamiliar environments, reduce traffic congestion, address environmental concerns, and prefer active travel modes such as cycling and walking (Guiver et al., 2008; Guiver et al., 2007; Kim et al., 2023; Le-Klähn et al., 2014; Lumsdon, 2006). In contrast, the primary barriers preventing tourists from using public transport include a lack of information (Edwards & Griffin, 2013; Malhado & Rothfuss, 2013), particularly for older tourists who may be less familiar with mobile devices (Gross & Grimm, 2018). In addition, the accessibility and comfort of public transport are also the main concerns for tourists (Le-Klähn et al., 2014; Malhado & Rothfuss, 2013). Therefore, transport authorities should provide accessible and comprehensive public transport information and guidance tailored specifically to tourists (Le-Klähn & Hall, 2015).

Methodology

This study utilises one-month public transport smart card data (i.e., June 2024) for all public transport systems in Taiwan. To focus on international tourists, the dataset is filtered by identifying travel patterns for each cardholder. Specifically, users whose trips both begin and end at the airport metro stations are classified as international tourists. The trips made by these selected users are then aggregated within spatial grids, which serve as the dependent variable. Other than tourist travel patterns, another key aspect is tourist attraction distribution (e.g., hotels, attraction sites). Besides, public transport service quality (e.g., frequency) is also included in the analysis. A multilevel zero-inflated Poisson regression model is developed to identify the critical factors of public transport use. By applying the model, this study predicts the expected number of trips in each spatial unit and identifies the discrepancies. Hierarchical clustering using the Ward linkage method is then employed to classify the underperforming areas based on their characteristics. This enables the provision of specific suggestions tailored to each cluster.

Findings and Discussions

Multilevel Modelling Result

Several critical factors are identified by the fixed estimates of the multilevel ZIP model shown in Table 1. The incidence rate ratio (IRR) shown in Table 1 represents the percentage change for each one-unit increase in the corresponding variable in the count model. The daily public transport service frequency is expected to have a positive impact on international tourists' trips, with an estimated 2.64% increase for every additional 100 service runs provided. This finding underscores the importance of public transport provision in enhancing the accessibility of attraction sites and appealing to tourists. In terms of the tourism supply aspect, the average Google Map reviews of attraction sites have a moderate impact on trips, with an estimated 2.08% increase for every additional 1,000 comments. This suggests perceived popularity increases tourist visits. Enhancing the total number of comments, alongside improving service quality and the overall tourism experience, can increase the visibility of attractions to international tourists.

Table 1. Multilevel zero-inflated model fixed effect estimates.

	Estimate	p-value	IRR[2]
Count Model			
Intercept	3.472***	0.000	-
Daily public transport service frequency	0.026***	0.000	2.641
Number of metro stations	1.509***	0.000	352.352
Average reviews of attractions	0.021***	0.000	2.079
Hotel capacity	0.148***	0.000	15.945
Distance to the airport	-0.085***	0.000	-8.128
Zero-inflated Model			
Intercept	-0.600***	0.000	-
Distance to the city centre	0.401***	0.000	-
Distance to the airport	0.015***	0.009	-

[1] Significance level: *: p<0.1; **: p<0.05; ***: p<0.01

[2] The incidence rate ratio (IRR) is obtained by exponentiating the coefficient and represents the percentage change for each one-unit increase in the corresponding variable.

Proximity to the airport and the district centre is a natural factor of tourist trips, as most international tourists tend to travel within areas with higher accessibility. Even though destinations located farther from the airport or district centre may offer high-quality tourism services, the distance-decay effect diminishes the willingness to visit. To alleviate the negative impact of distance, both public transport supply and targeted promotion are critical.

International tourists often face accessibility challenges due to language barriers and unclear public transport information. To address this, a comprehensive, multilingual guide to using public transport across the entire country should be provided, including instructions for intercity travel and services beyond major urban areas.

In addition to the fixed effect estimates, the multilevel model accounts for the random variation of variables across the country, enabling more nuanced and district-specific interpretation. The random effect estimate of each county is shown in Figure 1. The random intercept (Figure 1(a)) shows that the capital city (i.e., Taipei City) and its peripheral counties have a higher coefficient, implying that those areas are naturally appealing to international tourists due to their popularity and accessibility. In contrast, counties located in eastern Taiwan generally exhibit lower intercept values, indicating that tourism in those areas is inherently less recognised and less attractive. This highlights the heterogeneous nature of tourism resources across regions.

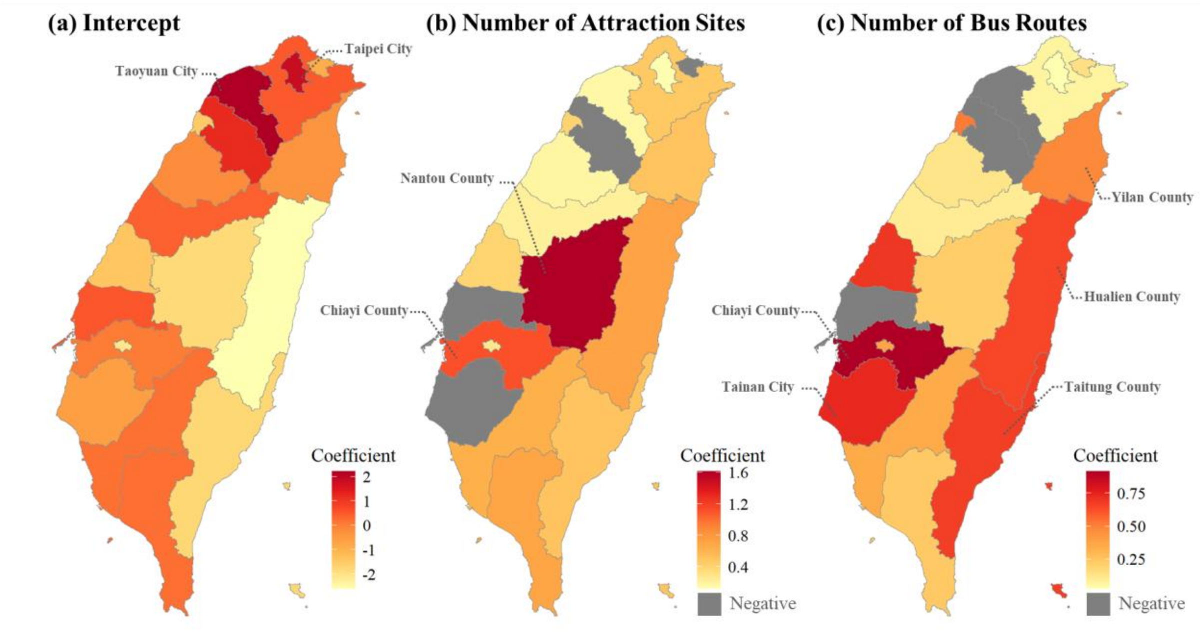

Figure 1. Random effect estimates of each county.

The effect of the number of attraction sites (Figure 1(b)) varies across Taiwan. Most counties exhibit positive effects of the number of attraction sites, with Nantou County and Chiayi County showing the strongest impact. This implies that international tourist trips could increase substantially with the development of an additional attraction. Therefore, expanding and investing in attraction sites, particularly in Nantou County and Chiayi County, would be beneficial to diversify tourism offerings and enhance their appeal to tourists. In contrast, the negative effect can be found in four counties marked dark grey in Figure 1(b). This counterintuitive result implies that, regardless of the adequacy of attraction sites in these counties, the primary barrier to tourism development is a lack of effective promotion. To address this, local authorities should clarify their tourism positioning and actively leverage social media to market attractions to international audiences. The number of bus routes (Figure 1(c)) generally has a positive effect on international tourist trips, with the impact particularly pronounced in suburban and rural areas. In these regions, accessing attraction sites via public transport can be challenging. Although most bus routes connect to main transport hubs, attraction sites are often dispersed, resulting in time-consuming transfers. Therefore, introducing additional bus routes could address this issue by improving network linkage and accessibility to key attractions. The variation of effects further highlights the need to improve the bus service coverage in areas where tourism is not well-recognised by international tourists.

Policy Implications

The multilevel zero-inflated regression model applied in this analysis can be further used to predict the expected number of trips for each spatial unit. The discrepancy between actual and expected trips can be interpreted as an indicator of tourism performance. Spatial units where actual trips fall short of expected trips by more than 50% are identified as underperforming areas. These areas are then clustered based on the categories of attraction sites and public transport provision. The clustering result is shown in Figure 2.

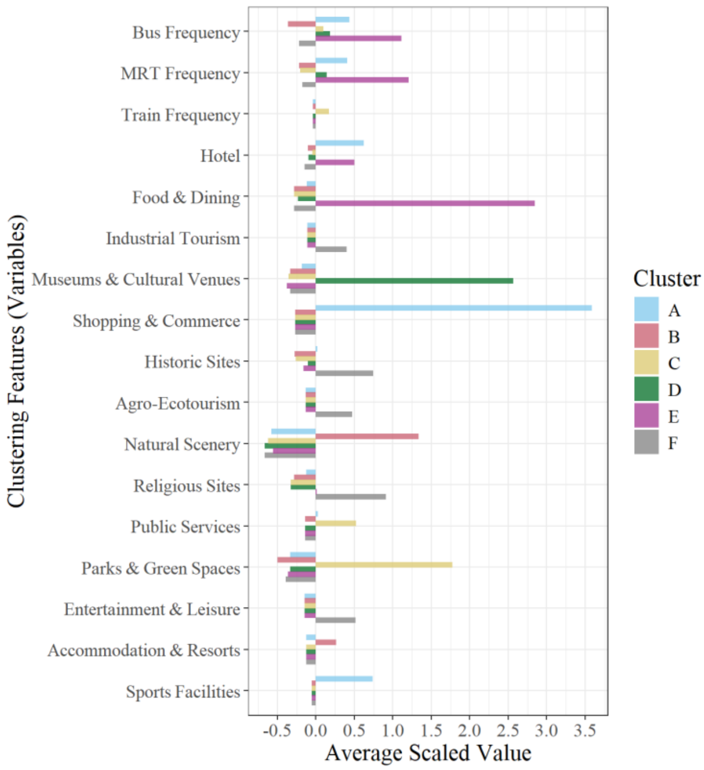

Figure 2. Cluster profiles of underperforming areas.

The labelling of three selected clusters is presented as follows: ***Cluster A*** exhibits relatively high accessibility to public transport and shares significant commonalities in features related to the shopping category. This cluster can therefore be labelled as “Urban Shopping.” ***Cluster B*** shows the lowest accessibility to public transport, but is rich in tourism resources, particularly natural scenery and resort areas. This cluster can be defined as “Countryside Sightseeing.” ***Cluster C*** presents features in both green spaces (e.g., parks, trails) and public services (e.g., university campus) and with moderate public transport accessibility.

Combining all the results from the multilevel zero-inflated Poisson regression model and hierarchical clustering analysis, this study derives policy implications from two perspectives: county-based and attraction category-based. In terms of county-based implications, the bus routes should be expanded in areas with low public transport accessibility, particularly in eastern and southern Taiwan. Promotion and marketing are essential for areas in central and southern Taiwan, where they typically offer a rich tourism experience but with fewer international tourists. Based on the clustering analysis of underperforming areas, the “Countryside Sightseeing” should be prioritised for improvement by offering adequate public transport services. All other detailed policy implications will be shown at the conference.

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Comparative Analysis of Charging Technologies in Modular Bus Systems

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Introduction

Public transport serves as the backbone of metropolitan areas, with buses being one of its most essential components. Conventional buses services lack of flexibility and accessibility to accommodate fluctuating the demand. This inconvenience has prompted the development of modular bus services to improve the performance (Tian et al., 2025; H. Lin et al., 2025; Li et al., 2025). Moreover, conventional fossil fuel buses contribute to the transportation sector's greenhouse gas emissions, which negatively impact climate change and ecosystems (Manzolli et al., 2022). In response to the demand for alternative energy sources, bus services have adopted electrification. The primary barrier to the widespread adoption of battery electric buses is their limited driving range, which highlights the critical role of charging technology (Zhou et al., 2024; Hendriks and Sturmberg, 2024; Zeng and Qu, 2023). We analyze the application of depot and mobile vehicle-to-vehicle charge technologies within the modular bus service.

Model Formulation

We formulate a discrete model of modular bus services following the framework proposed by (Khan and Menéndez, 2025). We consider a cyclical bus line serving bus stops $\{1, \cdots, S\}$, indexed by s. Passengers arrive at bus stops following a Poisson process with arrival rate λ_s. We assume that passengers have the same alighting probability p_s at stop s. An assembled bus comprises P pods with a capacity of K. The total fleet size of pods in the system is F. Assembled buses operate bus runs indexed by r. The travel time from bus stop s to $s+1$ is c_s. The arrival time $t_{r,s}$ of bus run r at stop s is

$$t_{r,s} = \max\{d_{r,s-1} + c_{r,s-1}, d_{r-1,s}\} \quad (1)$$

where $d_{r,s-1}$ represents the departure time of bus run r at stop $s-1$, $c_{r,s-1}$ is the travel time from stop $s-1$ to stop s in bus run r and $d_{r-1,s}$ is the departure time of the last bus run at stop s. Here we assume that there is no overtaking between buses. Before introducing the departure time, let us explain the dwelling time at bus stops. Assembled buses visit stops in one of two modes: non-stop, fully stop. Full stops occurs in two cases: Case 1 - when the stop has a high volume of passengers, Case 2 - when the alighting ridership exceeding the capacity of a pod or when the non-alighting ridership exceeds the capacity of non-swapping pods. Otherwise, non-stop operations emerge. The assembled bus detaches a pod and the pod at the bus stop attaches to the assembled bus. The dwelling time $w_{r,s}$ depends on the visit mode and the the actual boarding and alighting demand. The departure time is calculated as $d_{r,s} = t_{r,s} + w_{r,s}$.

With *depot charge*, the assembled bus is charged at the terminal station. The charging process increases the cycle time. If the remaining battery level is insufficient to support the next cycle, the assembled bus will be fully charged. The increased time T_C in depot charge is

$$T_C = \max\{B - B_i | B_i \in B_r\} \frac{B}{B_R} \quad (2)$$

where $\max\{B - B_i | B_i \in B_r\}$ is the maximal battery needed to be charged, B_r is the set of batteries of pods taking bus run r, B is the travel time supported by the full battery, B_R represents the charging time from empty to full. In the case of the *mobile charge*, the assembled bus is charged using in-motion vehicle-to-vehicle technology using *charge pods*. They are the pods that attaches to the assembled bus. This charge pod is charged at a stop where it detaches from the assembled bus. As the charging occurs dynamically during operation, no additional cycle time is incurred. However, this requires large battery capacity of charge pods and the charging rate of mobile charge.

Experiments and Conclusion

We build a discrete event simulation to analyze the impact of two charging technologies on passengers' waiting time. The simulation runs for 3 hours.The values of the constants in the model are set following Khan and Menéndez (2025). We set the battery capacity low to capture the extreme case. The charging rate is set according to Wang et al. (2024) as 6 km/min. Stops 1 and 5 are scheduled for a full stop.

Figure 1 shows the bus trajectory under depot charge. The first three runs initialize the system, and the headway between them is set to be the same. Buses run out of battery after nearly 19 runs, which is the gap around 6,000 seconds. The extra depot charging delay expands the headway between bus 1 and bus 3. Such no-service time window increases the waiting time for all passengers. The average waiting time for passengers is 212 (s/pax). Figure 2 shows the bus trajectory under mobile charge. As the bus swaps a pod in most cases, dwell time is almost eliminated. Further, buses run sequentially with no charge delay at the terminal station. Compared to depot charge, buses cycle without the time window for charging, which reduces the waiting time. The average waiting time is 193 (s/pax), which is about 19 seconds shorter than that in depot charge. For the entire 3-hour simulation, this reduction amounts to a total passenger time saving of approximately 16 hours.

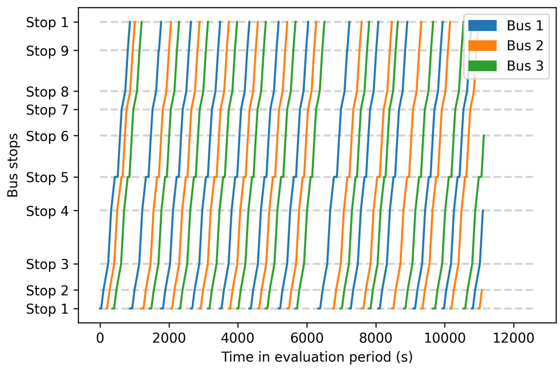

Figure 1: Bus trajectories during the evaluation period of the depot charge

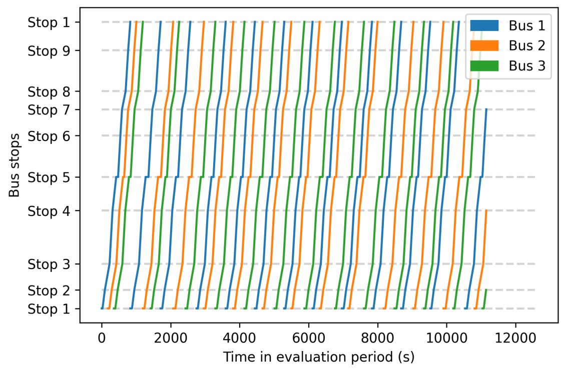

Figure 2: Bus trajectories during the evaluation period of the mobile charge

The conventional bus system suffers from two key limitations: operational inflexibility, stemming from rigid routes and schedules, and environmental unfriendliness, caused by dependence on fossil fuels. In response, electric modular buses present a promising alternative. The effectiveness of such services depends significantly on the choice of charging technology. To analyze this interaction, we build a discrete event simulation and analyze the application of depot and mobile vehicle-to-vehicle charge technologies within the modular bus service. We find that (1) the modular bus service substantially reduces dwell time; and (2) compared to depot charging, mobile charging further decreases passenger waiting time.

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Tuesday 9th December: 4pm-5.30pm
Parallel Session 1 (Level 17, Lecture room 3)
Theme: Travel Behaviour of Special Populations and Mode Adoption, Session Chair: Dr. Emily Moylan
Modelling the effects of travel time use on mode choice and the value of travel time savings tackling self-selection and endogeneity bias (Ana Luiza de Sá, Patricia Lavieri, Jacek Pawlak and Charisma Choudhury)
Profiling Public Transit Use among Aging Populations: A Latent Clustering Approach (Meredith Alousi-Jones and Ahmed El-Geneidy)
Understanding the dynamics of market evolution and the intention-behaviour gap in the context of BRT adoption (Thiago Carvalho and Ahmed El-Geneidy)

Modelling the effects of travel time use on mode choice and the value of travel time savings tackling self-selection and endogeneity bias

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1. Introduction

Travel time use (i.e., conducting activities while travelling) can significantly influence travel behaviour, with implications for key travel demand dimensions, such as mode choice and the value of travel time savings (VTTS) (de Sá et al., 2025a). Preferences for travel time use may lead individuals to choose "passengerised" modes (Mokhtarian, 2018) that could provide the best conditions to accommodate activities, such as public transport (PT) and automated vehicles (AVs). Linked to mode choice, the potential to use the in-vehicle travel time may decrease the VTTS, associated with lower resistance to travel longer journeys. Although both topics have been investigated, empirical evidence has often been impacted by methodological challenges (de Sá et al., 2025a), including: (i) mode choice self-selection associated with travel time use, and (ii) endogeneity bias in VTTS estimates. Both issues arise from including actual travel-based activity behaviour as explanatory variables of mode choice and VTTS changes. First, since travel time use and mode choice hold a bi-directional relationship, this approach does not allow for disentangling the causality between them. Second, it may solely account for VTTS differences between those who engage in activities *versus* those who do not.. Given these gaps, **this study investigates the effects of travel time use on mode choice and VTTS, while tackling self-selection and endogeneity bias.**

2. Methods

2.1. Conceptual framework

Figure 1 illustrates the analytic framework. **To investigate the role of travel time use for mode choice while controlling for mode choice self-selection**, we implement an attitude-based approach, similar to residential self-selection research (e.g., Cao et al., 2009). We introduce the psycho-social factor **"perception of the influence of travel time use on mode choice",** which explicitly capture the causal effect of travel time use on mode choice and will be included with direct effects on the utility function of different travel mode.

To address the effects of travel time use on VTTS while controlling for endogeneity bias, we consider traveller characteristics and travel context variables that both influence travel time use engagement and may account for value of time heterogeneity. According to de Sá et al. (2025b), these include psycho-social characteristics capturing motivations for travel time use and travel context variables revealing conditions that may facilitate travel-based activities. To reveal endogeneity bias, first, we calibrate a model considering travel time use (with and without activity transfer, capturing whether activities release time outside the journey or not, respectively) as the sole explanatory variable interacted with travel time. Then, we calibrate a model incorporating explanatory variables in Figure 1, interacted with travel time, to assess changes in the sign and statistical significance of travel-based activities' estimates. Finally, we estimate a model with statistically significant explanatory variables.

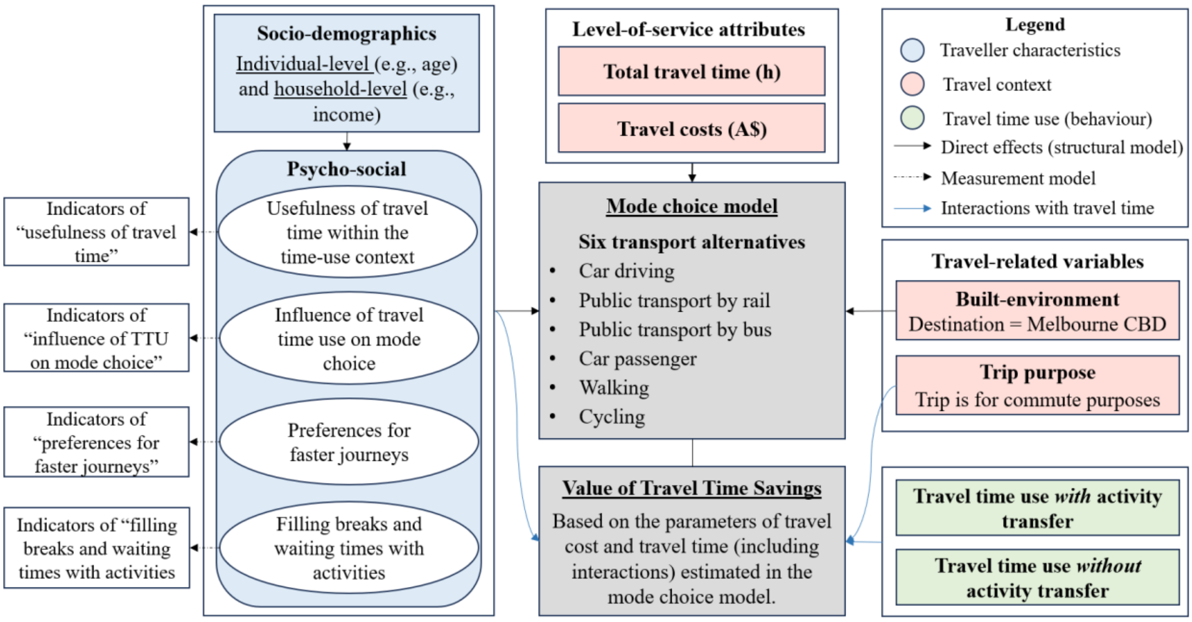

Figure 1. Analytic framework

2.2. Modelling methodology

We implement an Integrated Choice Latent Variable model, which is adequate given the consideration of endogenous psycho-social variables and a discrete outcome with six transport options. We estimated the model with the R package *Apollo* (Hess & Palma, 2019).

2.3. Data

We utilise revealed preference data collected via an online survey, conducted between June and September 2023, which targeted a representative sample (age, gender, and household income) of the adult population living in Greater Melbourne and Geelong (Australia). The final sample size is of 1508 participants, above the minimum required size of 897. Furthermore, we utilised the Google API "Directions" to obtain travel times and distances for chosen and unchosen travel modes, ensuring consistency and that all values originate from the same data generation source (Tsoleridis et al., 2022). For more information about the data, we refer to de Sá et al. (2025b).

3. Results and discussion

We tested different model specifications to underscore the endogeneity bias in VTTS estimates. "**Model 1**" includes interactions of self-reported travel-based activities with travel times: the interaction between "travel time use with activity transfer" and travel time is positive and statistically significant, while the estimate of "travel time use without transfer" is positive but non-significant. In "**Model 2**", which introduce variables from the analytic framework, the estimates of travel-based activities become non-significant. We argue that the inclusion of the relevant explanatory variables may have aided in controlling for endogeneity bias. "**Model 3**" excludes travel-based activities from the specification and consider only statistically significant estimates at a 90% confidence level. Considering "Model 3", we discuss travel-time-use-related effects on mode choice and the VTTS.

3.1. Mode choice

The construct "**perception of the influence of travel time use on mode choice**" (more likely to be stronger among Millennials, students, those who can perform travel-based mandatory activities, and less likely to be women or people who have a graduate) had statistically significant positive effects on the choice of **PT by rail** in journeys longer than 5 km, increasing the probability of selecting this mode in 7 percentage points (p.p.). This result partially supports the “passengerisation of travel” hypothesis (Mokhtarian, 2018). **This a reassuring result suggesting that travel time use can be an ally in driving a sustainability agenda toward greener modes.**

The construct also had significant positive effects on **car driving choice** in journeys shorter than 5 km - increasing the probability of car driving in 6 p.p. in this travel distance scenario. This interesting result resonates with Abeille et al. (2022), who observed that knowledge workers reported preferences for car driving to undertake privacy-sensitive activities. **Car driving choice among people who may wish to engage in cognitively demanding tasks raises concerns from a road safety perspective.**

3.2. Value of travel time savings

The VTTS results are presented in **Table 1**. These estimates were achieved by comparing scenarios where each explanatory variable is fixed to their maximum and minimum values, all else remaining equal - similarly to average treatment effects.

Table 1. VTTS estimates

Category	Car driver		PT by bus		PT by rail		Car passenger	
	VTTS (A$/h)	diff. (%)	VTTS (A$/h)	VTTS diff. (%).	VTTS (A$/h)	VTTS diff. (%)	VTTS (A$/h)	VTTS diff. (%)
Average VTTS	17.89	--	8.00	--	10.17	--	8.70	--
Perception of the usefulness of travel time (max)	15.96	-6.61 (-29%)	6.31	-3.40 (-35%)	8.27	-4.04 (-33%)	6.35	-3.54 (-36%)
Perception of the usefulness of travel time (min)	22.57		9.71		12.31		9.89	
Preferences for faster journeys (max)	21.42	4.07 (24%)	8.98	2.07 (30%)	11.31	2.48 (28%)	9.52	2.18 (30%)
Preferences for faster journeys (min)	17.35		6.89		8.83		7.34	
Filling breaks and waiting times w/ activities (max)	21.76	3.81 (21%)	9.04	1.81 (25%)	11.30	2.16 (24%)	9.87	1.89 (24%)
Filling breaks and waiting times w/ activities (min)	17.95		7.23		9.14		7.98	
Ability to conduct mandatory activities (max = 1)	16.18	-5.42 (-25%)	6.41	-2.79 (-30%)	8.56	-3.31 (-28%)	7.05	2.89 (-29%)
Ability to conduct mandatory activities (min = 0)	21.60		9.20		11.87		9.94	

The average VTTS estimate of motorised modes is A$14.69/h. In Australia, transport economic appraisal guidelines recommend estimating VTTS based on the marginal productivity of working time (Legaspi & Douglas, 2015) considering that the VTTS for private travel is valued at 40% of average hourly earnings. Given the median weekly earnings of A$1,341 in Melbourne in August 2023 (Australian Bureau of Statistics, 2023) and that a full-time employee works 37.5 hours weekly, the VTTS would be of A$14.30/h in Melbourne – only 2.7% lower than our estimate, suggesting representativeness based on the national guideline.

The ability to conduct mandatory activities and the “perceptions of the usefulness of travel time” account for significant VTTS decreases (-25% to -35%). This suggests that such characteristics may be linked to lower resistance to travel longer journeys, which has implications for residential and job relocations and potential activity-travel behaviour changes in an AV future. People with such characteristics might accept relocating to farther locations given their ability to perform activities. These dynamics might be exacerbated with AVs, especially if in-vehicle design is tailored to meet activity needs. We suggest that future research control for the referred variables to assess behavioural changes in an AV future.

“Preference for faster journeys” and “filling breaks and waiting times with activities” are linked to VTTS increases (+20% to +30%). The first construct has been associated with travel-based activities to “pass the time”, likely to decrease travel time disutility (de Sá et al., 2025c). Given their higher VTTS and the role of travel-based activities for them, people with such a preference may benefit more from policies aimed at decreasing travel time.

4. Conclusions

This study investigated the influence of travel time use on mode choice and VTTS. It is one of the first to address mode choice self-selection in regard to travel time use. By applying an attitude-based framework, we identified a statistically significant causal effect of travel time use on mode choice. Our findings also highlight the importance of controlling for traveller characteristics to control endogeneity bias in VTTS estimates — an advance over approaches focused solely on travel-based activities as explanatory variables. Overall, this study underscores the need for accounting for the effects of travel time use for a more realistic representation of travel behaviour to improve the accuracy of travel demand forecasting.

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Profiling Public Transit Use among Aging Populations: A Latent Clustering Approach

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Introduction

Market segmentation has long been used in both research and practice to identify distinct types of transit users based on their characteristics, needs, and travel behaviours (Anable, 2005; Beimborn et al., 2003; Krizek & El-Geneidy, 2007; Zhao et al., 2014). This approach allows for the tailoring of travel demand strategies and policies to different user and non-user groups with the goal of increasing satisfaction and use of public transit systems (Soto et al., 2021). Market segmentation is also highly adaptable. For example, when conducted over time, it enables the exploration of changes in travel behaviour, as well as shifts in sociodemographic and contextual realities (Carvalho & El-Geneidy, 2024; van Lierop & El-Geneidy, 2017).

As the number of older adults increases around the world, market segmentation can contribute to our understanding of their diverse travel needs and tailor strategies to support their sustainable travel and independence. However, older adults are often treated as a homogeneous group, segmented primarily by age, which overlooks the diversity in their travel behaviours and realities. In turn, policymakers and transit agencies often implement broad initiatives such as reduced fares for older transit users without adequately evaluating whether these measures truly address the varied preferences, needs, and travel patterns of older adults.

Based on the results of a Canadian multi-city survey, this study addresses these gaps by segmenting older adults (65+) into transit user profiles using a latent clustering approach. We examine how different groups of older adults interact with and perceive transit systems in their region and identify strategies to increase their transit use and travel satisfaction.

Though this study is limited to the public transit experiences and attitudes of older adults in a Canadian context, it can offer important and transferable insights, contributing to a more nuanced understanding of older adults as a diverse group of transit users and informing planning and service provision that better reflects their needs and travel behaviours.

Methods

This study draws from the Aging in Place Survey, an online survey conducted by the Transportation Research at McGill (TRAM) group. The survey focuses on the travel needs and experiences of older adults (65+) across six metropolitan regions in Canada, namely Toronto, Montréal, Vancouver, Halifax, Victoria, and Saskatoon. For this study, we selected respondents from the full sample who (i) have used public transit within the past year (n = 2,498), and (ii) suitably gave their opinion on the quality of public transit service and shared sociodemographic information (n = 1,912).

Using the *poLCA* package in R, we performed a Latent Clustering Analysis (LCA) to explore older adults' perceptions (i.e., reliability, convenience, comfort, and safety) and behavioural intentions towards transit (willingness to keep using and to recommend transit services), travel behaviour (use of public transit and driving), and income (Lezhnina & Kismihók, 2022; Weller et al., 2020). We evaluated models with two to six classes, inclusive. From four classes onwards, the reduction in AIC and BIC fell below 1%, indicating effective data separation, and four classes were therefore retained (de Oña et al., 2013).

Findings and discussion

We find four distinct groups of older transit users, including cautious supporters, car-reliant critics, transit enthusiasts, and pragmatic users, as shown in Figure 1. The cautious supporters (n=559) and car-reliant critics (n=248) tend be higher income when compared to their transit enthusiasts (n=575) and pragmatic users (n=530) counterparts.

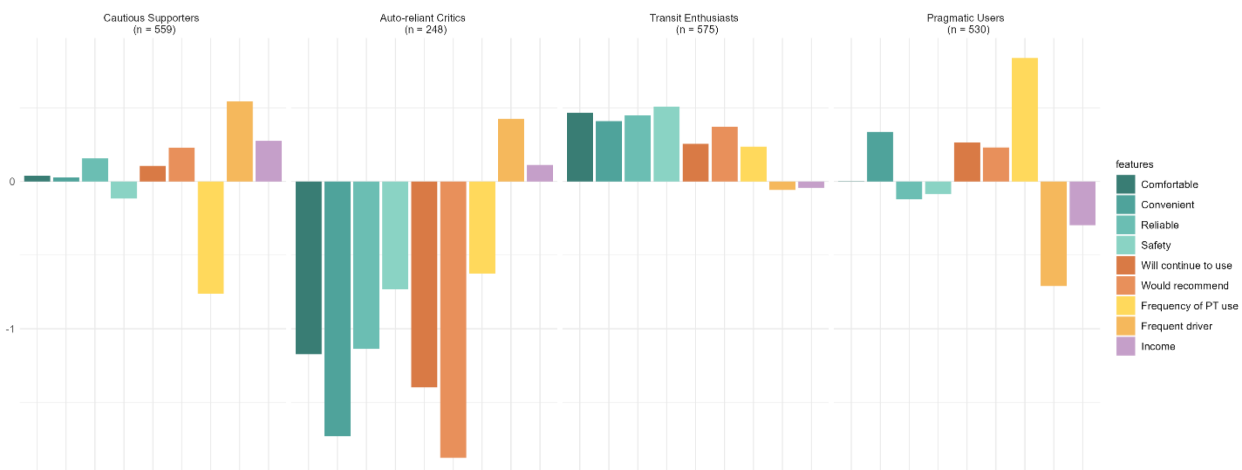

Figure 1 Cluster analysis for the sample of older adults who take transit

Though they use transit the least, cautious supporters have somewhat positive attitudes towards transit in terms of its comfort, convenience, and reliability, and would recommend it to friends and family. However, they are concerned about their personal safety when using the system. Auto-reliant critics have highly negative opinions of transit in their region, and neither plan to continue to use it nor would recommend it to others. Oppositely, transit enthusiasts' attitudes towards transit are highly positive, and they drive less than cautious supporters and auto-reliant critics. More than two-thirds of the pragmatic users do not have access to a private vehicle, suggesting a strong reliance of public transit to get around. This can be observed in their travel behaviour, as they are the most frequent users among the four classes. They also benefit from the highest level of accessibility by public transit, which is reflected in their positive opinion of its convenience.

Strategies that aim both to increase older adults' frequency of transit use and satisfaction with transit in their region can promote rider loyalty and cement public transit as an effectual and attractive mode of transport in older age. Segmentation highlights the heterogeneity of this age group and helps guide the improvements needed to ensure their public transit needs are better met. As represented in Figure 2, transit enthusiasts, already very satisfied with the transit in their region, would benefit from an increase in accessibility by public transit, providing them the opportunity to reach more destinations from their homes, and could therefore further increase their public transit use. Pragmatic users would conversely profit from improvements to transit service, directly improving their satisfaction given their highly frequent public transit usage. For the two less frequent user classes, improvements to the service and accessibility (most especially for auto-reliant critics) would be beneficial, with a particular emphasis on increasing their feeling of personal safety on public transit. For further study, we observed differences in Walk Score® and transit accessibility across the four classes, suggesting spatial analyses within and between regions could highlight local issues and offer direction for agencies to address older adults' needs.

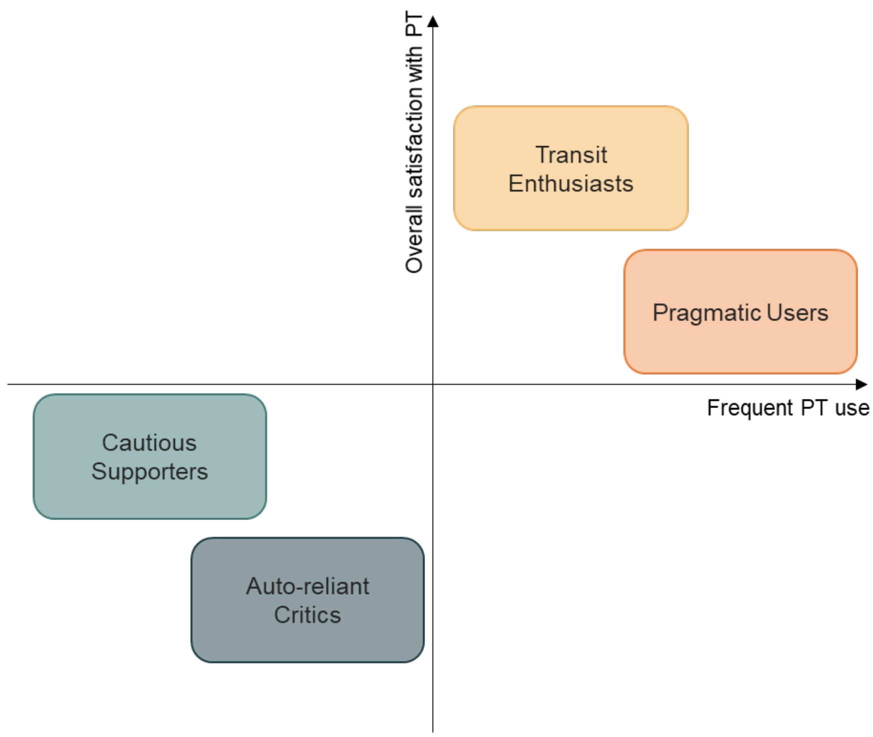

Figure 2 Frequency of PT use vs. Overall satisfaction with PT for the four classes of older riders

Acknowledgements

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Understanding the dynamics of market evolution and the intention-behaviour gap in the context of BRT adoption

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Introduction

Designed to deliver high-capacity, rail-like service at a lower cost, Bus Rapid Transit (BRT) systems have been associated with travel time savings, reliability gains, and, in many cases, increased ridership (Currie & Delbosc, 2014; Deng & Nelson, 2011; Levinson et al., 2003). However, the extent to which these systems successfully attract and retain users depends not only on their technical and operational performance but also on users' perceptions, attitudes, and willingness to adopt the service (Cain & Flynn, 2013). While much of the research on BRT implementation has focused on operational outcomes and ridership forecasts (Oort & MennoYap, 2021), fewer studies have examined the evolution of the transit market in response to a new BRT infrastructure. Even when individuals express positive attitudes or intentions towards a new service, actual adoption is not guaranteed (Chen & Chao, 2011; Sheppard et al., 2002; Thøgersen, 2006). This disconnect is well documented in the behavioural literature, which is known as the intention-behaviour gap. This study applies the intention-behaviour gap concept to examine how the market evolved in response to the implementation of a new BRT system in Montreal, Canada.

Data & Methods

This study draws on the Montréal Mobility Survey (MMS), a multi-wave, bilingual, online longitudinal survey administered by the Transportation Research at McGill (TRAM) group across the Greater Montréal region. To analyse changes in the market profiles and explore the relationship between intention and behaviour, both cross-sectional and panel survey data are employed. The 2021 wave of the MMS, conducted one year prior to the BRT's implementation, is used to segment the market and assess usage intentions across distinct user profiles (N = 552). Follow-up surveys in 2023 and 2024 (N = 2,194), conducted one and two years after the BRT opened, capture post-implementation shifts in user characteristics and travel behaviour. A subset of 209 individuals participated in at least one wave before and after the BRT opened comprising the longitudinal panel sample used to track individual-level market transitions. The study focuses on respondents residing within 2.5 kilometres of the BRT corridor, a catchment area that reflects reasonable access to the line by walking, cycling, or connecting via nearby public transit services.

To do so, we identify distinct transit market profiles through factor and cluster analysis using the cross-sectional samples, which are weighted to reflect the census distribution along the corridor. We repeat the analysis with the panel sample to ensure its comparability to the cross-sectional findings. The panel sample, which is weighted to reflect the weighted cross-sectional distributions, is employed to model behaviour stability and the intention-behaviour gap. Market profile stability over time is modelled through a binary logistic regression model, where the dependent variable is a binary indicator reflecting whether the respondent remained in the same cluster between the pre- and post-BRT waves or transitioned to a different cluster. Finally, we examine whether individuals who intended to use the BRT followed through with their intention using a multinomial logistic regression model. The dependent variable captures four mutually exclusive intention–behaviour categories: (1) intended and used the BRT, (2) intended but did not use, (3) did not intend but used, and (4) did not intend and did not use.

Results

A cluster solution of four profiles was found to provide the best qualitative description of the market at both points in time. The selection of clusters was based on its prevalent or most defining characteristics. In the pre-implementation sample, the identified clusters were labelled as potential low-income rider, potential choice rider, active travel–inclined, and car-oriented individual. Following implementation, a similar set of clusters emerged. The post-BRT market was composed of low-income BRT riders, BRT telecommuter riders, active travel–inclined individuals, and car-oriented individuals. While some labels were adjusted to reflect actual BRT usage, the overall structure of the profiles remained consistent. The stability of the clustering solution over time suggests that the underlying segmentation of the transit market along the Pie-IX corridor persisted through the implementation of the BRT system.

However, while aggregate market profiles remained stable over time, behavioural consistency at the individual level varied across user types (Figure 1). In particular, low-income riders (61.4%), active travel–inclined individuals (68.4%), and car-oriented individuals (76.1%) displayed high profile stability, while choice riders (35.2%) were significantly more fluid in their travel patterns. The binary logistic regression model revealed that other pre-BRT characteristics beyond the initial market profile also significantly influenced profile stability, such as reported disabilities, telecommuting frequency, and proximity to the corridor. Across all market profiles, transit usage increased and driving rates decreased after the corridor implementation, indicating a potential travel demand management role of new rapid transit service.

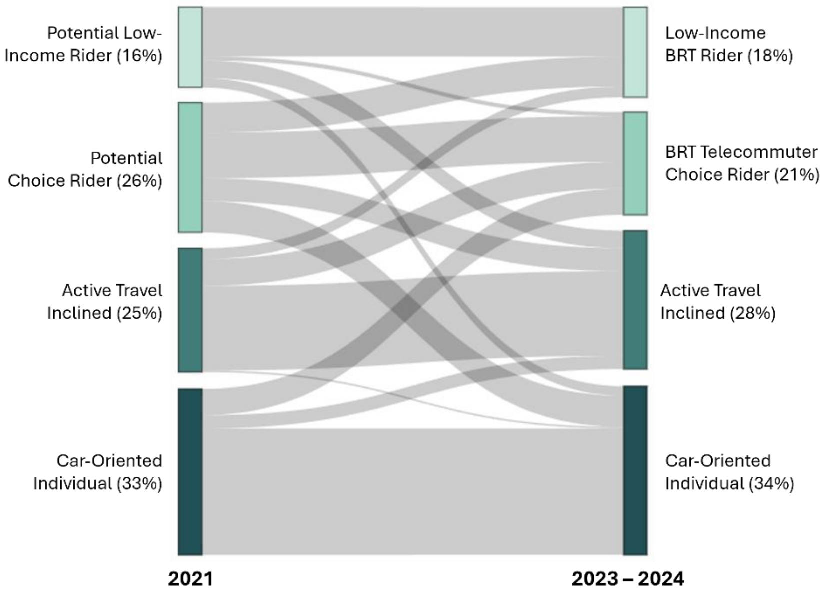

Figure 1. Stability of the market segments over time at the individual level

Moreover, we provide evidence of an intention-behaviour gap regarding the analysed infrastructure. Nearly one-third of the panel either failed to follow through on their intention to use the BRT or adopted it despite having no initial plans to do so (Figure 2). Regression models revealed that follow-through was most likely among low-income users, who reported strong intentions and structural conditions conducive to BRT use (e.g., proximity, car inaccessibility). Conversely, car-oriented individuals were the least likely to follow through, reaffirming the behavioural inertia often associated with automobile dependence. Underlying constraints such as distance from the BRT and telecommuting frequency consistently influenced both market stability and adoption patterns, underscoring the interplay between attitudes and contextual limitations.

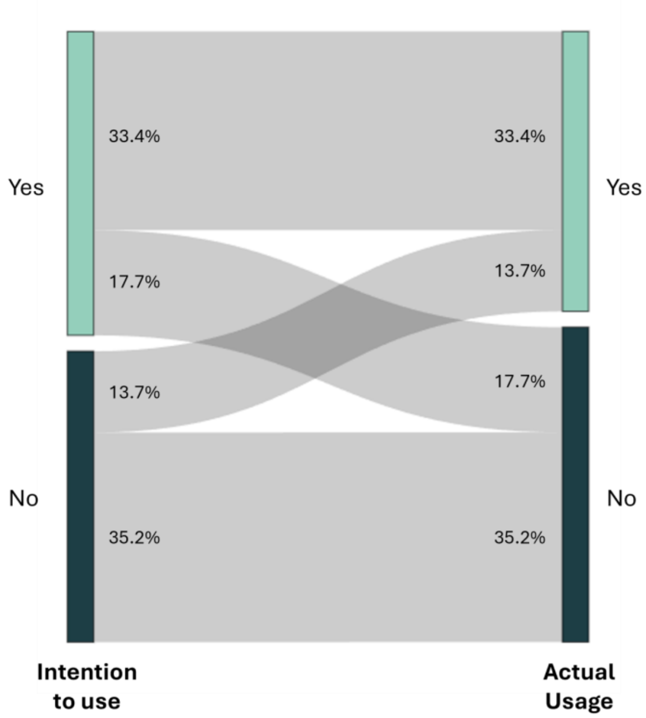

Figure 2. Intention-behaviour gap regarding the Pie-IX BRT

Conclusion

Overall, this study demonstrates the value of integrating behavioural theory with market segmentation in the evaluation of new transit systems. By highlighting where and for whom intention aligns with behaviour (and where it does not), it offers a framework for targeted transit planning. While the analysis offers valuable insights into behaviour change, it is not without limitations. For instance, the observation window may have been too short to capture deeper behavioural transitions. As cities continue to invest in sustainable mobility infrastructure, understanding the behavioural dynamics underlying ridership is essential not only for predicting demand but also for designing policies that support long-term adoption.

Acknowledgements

This research was funded by Natural Sciences and Engineering Research Council of Canada grant Towards a better understanding of the determinants and satisfaction of travel among different groups in major Canadian Cities (NSERC RGPIN-2023-03852), Fonds de Recherche du Québec Société et Culture (https://doi.org/10.69777/370079) and the Social Sciences and Humanities Research Council's partnership grant Mobilizing justice (SSHRC 895-2021-1009).

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Tuesday 9th December: 4pm-5.30pm
Parallel Session 2 (Level 16, Seminar room)
Theme: Emissions, Low-Carbon Policies, and Traffic Management, Session Chair: Prof. Michael Bell
Impacts of Internal Combustion Engine Vehicles (ICEVs) and Hybrid Electric Vehicles (HEVs) on Emission and Signal Timing at Isolated Intersections (Ponlathep Lertworawanich)
Investigating preferences for low-emission zone measures: do time and space matter? (Ching-Fu Chen and Chin-Hsiang Lin)
The screen-line traffic counting location problem under observation uncertainly (Toshiki Arai, Ruri Sase, Satoshi Sugiura and Hiroaki Nishiuchi)

Impacts of Internal Combustion Engine Vehicles (ICEVs) and Hybrid Electric Vehicles (HEVs) on Emission and Signal Timing at Isolated Intersections

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Introduction

According to Lee et al. (1019), the transport sector is responsible for 25 percent of global carbon dioxide emissions, with 75 percent of these emissions arising from road transport. Road transport not only produces greenhouse gases but also contributes to traffic congestion, noise pollution, and road accidents. In the Asia-Pacific region, economic growth has led to increased motor vehicle ownership, particularly in urban areas. Traffic signals in cities play a crucial role in managing traffic and ensuring safe crossings for both vehicles and pedestrians. However, congestion at intersections significantly increases emissions, especially with frequent stops and starts. As traffic demand grows, the need for effective signal operations becomes more critical. Properly managed signals can alleviate congestion and reduce emissions, whereas poor signal management can exacerbate congestion and elevate emissions. Since Webster introduced his signal timing method in 1958, traffic researchers have developed numerous signal control algorithms, primarily focusing on minimizing total delays. Some research, however, aims at minimizing emissions. Lv and Zhang (2012) showed that higher platoon ratios reduced stops, which correlated more strongly with emissions than delays. Lv et al. (2013) used genetic algorithms to balance delay and emissions, noting that longer cycle lengths increased delays but lowered emissions. Tu et al. (2022) and Wang et al. (2022) showed Hybrid Electric Vehicles (HEVs) reduce emissions under low power demand but produce high CO during acceleration. Karjalainen et al. (2024) found Plug-in Hybrid Electric Vehicle (PHEVs) emit less particulate mass and black carbon, though cold starts boost emissions on short trips. With the advent of Hybrid Electric Vehicles (HEVs), which typically have lower emissions than Internal Combustion Engine Vehicles (ICEVs), the potential for emission reduction seems evident. Nevertheless, to fully harness the emission reduction benefits of HEVs at signalized intersections, traffic signal controls should be tailored to the emission performance of HEVs, which differs from that of ICEVs in various operating modes (accelerating, decelerating, idling, and cruising). Therefore; the main objective of this research is to study effects of ICEVs and HEVs on signal timing to achieve the minimum emission at isolated intersections.

Methodology

This study proposes a new emission-based signal timing method to minimize emissions at isolated intersections. The relationship between delay, number of stops, and cycle length is examined. The cumulative diagrams of arrival and departure curves exhibit that longer cycle lengths increase delay per unit time as shown in Figure 1. However, the number of stops per unit time decreases with increasing cycle length as shown in Figure 2. The delay-minimizing signal control strategy therefore differs from the emission-based signal control strategy. To minimize emission, one must balance between delay and stop. Emissions are estimated as the product of the time vehicles spend in different operating modes (cruising, idling, decelerating, accelerating) and the corresponding emission rates. The net emission impact of traffic signal control is the difference in estimated emissions with and without traffic lights. The emission-based signal timing optimization is formulated as a non-linear mathematical program to minimize emissions per unit time. The objective function includes uniform delay, random arrival delay, and a number of stops per cycle. Constraints include proportion, capacity, boundary for splits, and cycle length limits.

Case Study

A case study is conducted to investigate signal timing at a single intersection formed by two one-way streets. The study compares traffic signal timing and performance measures (emissions per hour, average delay per vehicle, average stops per vehicle) using the Webster (1958) Method and the proposed emission-based method. Three demand scenarios with different ICEVs and HEVs compositions are analyzed. The results show that the Webster (1958) method always produces the same signal timings for identical demand scenarios because it is a delay-based method that does not account for the impact of different vehicle operating modes on emissions. The proposed emission-based method, however, provides different signal timings based on the percentage of HEVs in the traffic stream. With emission-based timing plans, a higher percentage of HEVs results in better performance measures than the Webster (1958) method in terms of emissions per hour and average number of stops per vehicle, although not necessarily for average delay per vehicle. As the percentage of HEVs increases, the cycle length tends to decrease due to lower overall emission rates. Another interesting aspect of the results is the effect of directional differences in traffic demand. Even though the total sum of demand is the same in all scenarios (from both EB and NB directions), different directional demands lead to different signal timing plans and performance measures. The larger the directional difference in traffic demand, the more pronounced the proposed emission-based method is at reducing emission and average number of stops. Longer cycle lengths are more suitable for larger directional differences in traffic demand. When the directional difference is smaller and the percentage of HEVs is higher, the proposed emission-based timings tend to align with the Webster (1958) timings. These findings indicate that intersections with significant directional differences are ideal candidates for emission improvements.

Conclusions

The main purpose of traffic signals at intersections is to regulate the flow of intersecting traffic, ensuring safe and convenient passage. However, if the traffic signal timings are not well-calibrated, it can cause significant travel delays or prolonged passage through intersections. Traffic congestion is currently a major issue and a significant cause of air pollution. The severity of pollution escalates when traffic is heavily congested, with frequent stop-and-go movements at intersections. This study examined various literature on traffic signal timing design. Key findings from the reviewed literature indicated that: 1) Different vehicle operating modes (idling, decelerating, accelerating, cruising) impact vehicle emission rates differently, 2) Improved traffic signal control can reduce vehicle emissions, 3) The optimal signal timing to minimize delays differs from the timing that minimizes emissions, and 4) HEVs typically produce smaller emissions than ICEVs in all operating modes.

This study proposes a new method for calculating traffic signal timing to reduce air pollution emissions at isolated intersections for undersaturated conditions, and analyzing case studies with different traffic volumes in three scenarios with different ICEVs and HEVs compositions. The results show that while longer cycle lengths reduce the frequency of vehicle stops per unit time but they also increase the average delay per unit time. Hence, the optimal traffic signal timings must balance delays and the number of stops, as vehicle emission rates are influenced by the different vehicle operating modes. Upon the completion of this research, the conclusions are as follows:

- Minimizing Delay vs. Minimizing Emission: The method for calculating traffic signal timing aimed at minimizing delay differs from the method focused on minimizing emission rates.
- Impact of Traffic Volume Differences: The larger the disparity in traffic volumes between different directions, the more pronounced the differences in outcomes between the two methods. Therefore, intersections with significantly varying traffic volumes should be given special consideration when designing signal timings that prioritize minimizing emission.
- Impact of HEVs: With emission-based timing plans, higher percentage of HEVs yields better performance metrics compared to Webster (1958) timing plans in terms of emissions per hour and average number of stops per vehicle, but not average delay per vehicle. As the percentage of HEVs in the traffic mix increases, the cycle length shortens. This reduction is attributed to the lower overall emission rates that come with a higher proportion of HEVs in the traffic composition.

Figures

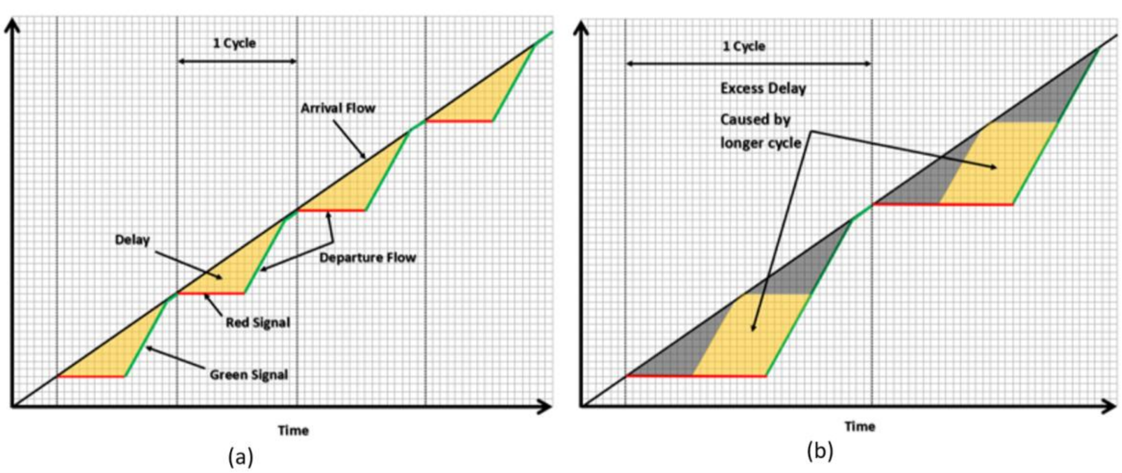

Figure 1: Cumulative diagram of arrival and departure curves at a signalized intersection

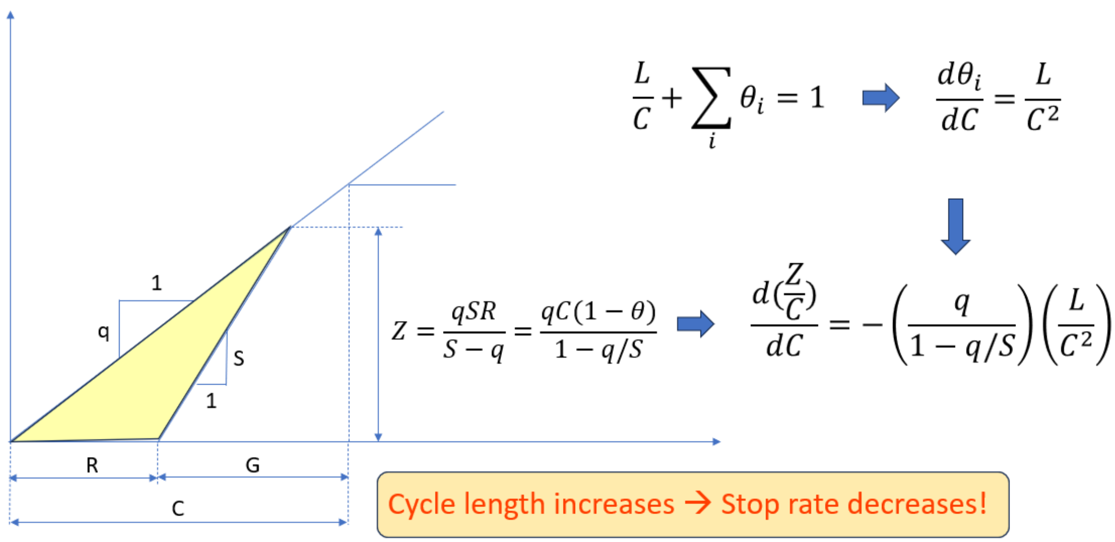

Figure 2: Number of stops at signalized intersection

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Investigating preferences for low-emission zone measures: do time and location matter?

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Introduction

Low Emission Zones (LEZs) have been widely adopted in cities around the world as a primary strategy for reducing urban traffic emissions and improving air quality. To alleviate the inconvenience experienced by affected residents and commuters, local authorities have introduced a range of supporting measures. Although these interventions help balance environmental objectives with mobility needs, their design and implementation entail varying administrative costs and may differentially influence public acceptability (Rejeb et al., 2025). Understanding individuals' acceptance and preferences for LEZs is a prerequisite for the success of LEZs policies. Previous studies have investigated the affecting factors, including individuals' characteristics and psychological variables, on preferences for LEZs measures. According to the Construal Level Theory (Trope & Liberman, 2003), individuals' attitudes toward a policy would be affected by its perceived psychological distance. However, few studies have systematically compared the relative appeal of LEZ measures across different contexts in terms of time and location. To address this gap, this study develops a hybrid choice model that elicits preference rankings for hypothetical interventions under varying scenarios regarding time and location of implementation using a survey sample collected in Taiwan.

Method and Data

We propose a Hybrid Choice Model (Ben-Akiva et al.,2002), which simultaneously accommodates socioeconomic variables, latent constructs, and choice behavior. The structural model includes socioeconomic and travel-related variables and latent variables reflecting environmental perceptions (environmental attitude and problem awareness) and policy-related perceptions (perceived fairness and freedom infringement). In the choice model, respondents are presented with four LEZ schemes, i.e., Park&Ride, temporary access permits, resident exemption, and subsidies for eco-friendly vehicle purchases, and are asked to rank these options under four contextual scenarios. The contextual scenarios are designed by two psychological distance dimensions (see Table 1): time of implementation (short-term: within one year; long-term: five years later) and location of implementation (within or outside living area).

A rank-ordered logit (ROL) model (see Figure 1) was employed to handle the ranking data, thus forming a rank-ordered logit kernel-based hybrid choice model for estimation. The ROL approach "explodes" each ranking into a sequence of discrete choices, which can be equivalently estimated as a series of conditional-probability multinomial logit models. An online survey from March to May 2025 yielded 4,028 valid responses after excluding incomplete responses.

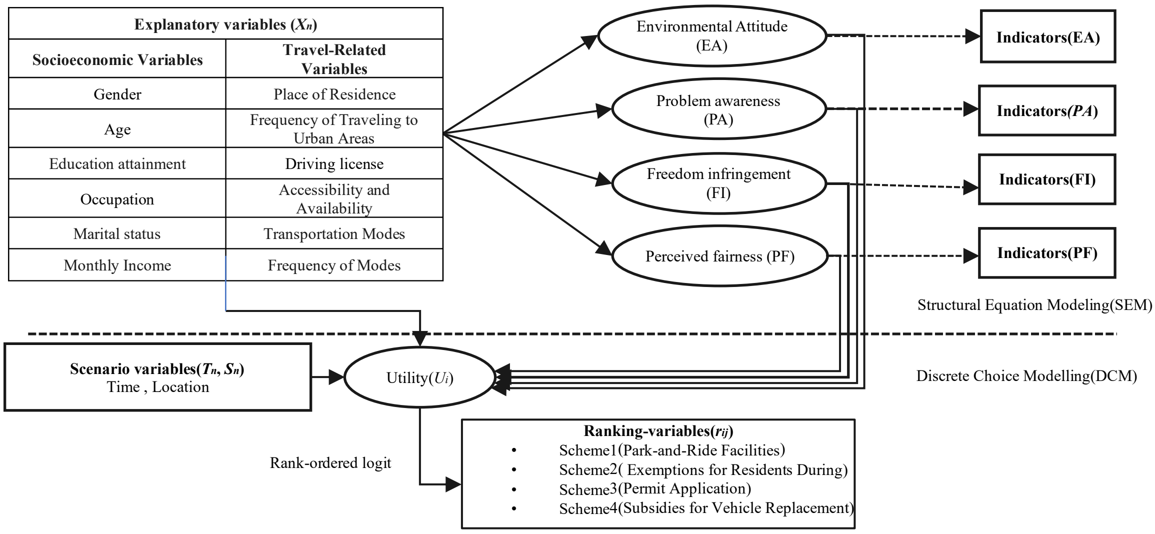

Figure 1: Conceptual framework

Table 1: The latent variables and measurement items

Latent Variable		Measurement items	Resources
Environment attidude (EA)	EA1	It is important for me to adopt a lifestyle that doesn't harm the environment.	Shin et al. (2017)
	EA2	I consider the potential environmental impact of my transportation choices when making travel decisions.	
	EA3	I am concerned about the destruction of our planet's environment.	
	EA4	I am willing to accept some inconvenience in transportation in order to take environmentally sustainable actions.	
Problem awareness (PA)	PA1	I have perceived traffic congestion in my surroundings..	Sun et al. (2016)
	PA2	I have perceived air pollution from motor vehicles in my surroundings..	
	PA3	I have perceived traffic noise in my surroundings..	
Freedom infringement (FI)	FI1	I believe that low-emission zones will infringe on my right to move freely.	Hsieh (2022)
	FI2	I believe that low-emission zones will infringe on my freedom.	
Perceived fairness (PF)	PF1	I believe that low-emission zones will be a fair measure for me.	Hsieh (2022)
	PF2	I believe that low-emission zones will be a fair measure for local residents.	
	PF3	I believe that low-emission zones can promote the interests of the whole people in the district.	
	PF4	I believe that the types of cars restricted by a low-emission zones would be selected carefully by the government.	
	PF5	I believe that the government will follow legal procedures during the formulation process.	

Findings

Results of the latent variable model (Table 2) indicate that male respondents and petrol car users tend to hold lower levels of environmental awareness and perceive that LEZ is unfair and a freedom infringement. Respondents who work in the transport-related industry have higher levels of perceived freedom infringement of LEZ. Those who do not live in the urban area have higher levels of perceived unfairness for the LEZ policy.

The preferences for LEZ measures vary for different time-location contextual scenarios. When LEZ measures were scheduled to be implemented within one year and within living areas, the Exemptions measure was ranked first, indicating the preference for minimal disruption by the LEZmeasure. Even for the scenario of implementation after five years within living areas, the Exemptions measure remains the top-ranked. However, when the LEZ measures apply to outside living areas irrespective of the time dimension, the Park&Ride facilities measure becomes the most preferred, indicating the respondents' concern for alternative mobility solutions to prevent the inconvenience derived from the LEZ policy.

While both Park & Ride facilities and Subsidies measures might be perceived as indirectly incentivizing private vehicle use and less environmentally friendly, they are yet relatively equitable for the public. In addition, for those living within the zone, the Access Permit measure might be deemed an ineffective solution for reducing emissions despite its free access to the zone. For those living outside the zone, however, the Park & Ride facilities measure cannot fundamentally resolve traffic issues within the restricted zone; all three measures(Park & Ride, Subsidies, and Access Permits) turn out to be preferred over the Exemptions measure because they are less likely to affect the residents in the zone. The perceptions of freedom infringement of mobility make them opt for the other three measures apart from "exemptions'.

Through comparative analysis of time and location scenarios, this study finds that both dimensions significantly influence the preferences for LEZ measures. Temporally, when implementation is imminent (within one year), respondents clearly favor options that minimize disruption to daily life, whereas with ample preparation time (after five years), they are more willing to evaluate and adopt alternative measures. Spatially, resistance to lifestyle changes is evident when measures fall within respondents' usual activity zones. However, when restrictions extend beyond their daily environments, acceptance of various measures increases markedly. The primary contribution of this study lies not only in demonstrating that the public exhibits distinct preferences among different LEZ measures but also in validating the context-dependent preference shifts based on psychological distance. When considering various LEZ interventions, policymakers should carefully assess their acceptability and thoughtfully tailor implementation to target populations.

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Table 2: The estimated results

	Alternative (Base: resident exemption)	Coefficients (T value)			
		Implementation within 1 year	Implementation within 1 year	Implementation within living area	Implementation outside living area
Intercept	Park & Ride facilities	**-0.469*** (-16.381)**	**-0.365*** (-12.847)**	**-0.511*** (-17.917)**	**0.715*** (24.63)**
	Access permits	**-0.708*** (-25.391)**	**-0.572 (-20.757)*** **	**-0.748 (-26.85)*** **	**0.317*** (11.41)**
	Subsidies	**-0.412*** (-14.564)**	**-0.217*** (-7.685)**	**-0.454*** (-16.073)**	-0.019 (-0.679)
Dummy_location (Base=within living area)	Park & Ride facilities	**1.143***(32.048)**	**1.063***(30.012)**		
	Access permits	**0.996***(28.905)**	**0.802***(23.474)**		
	Subsidies	**0.387***(11.034)**	**0.31***(8.85)**		
Dummy_time (Base=within 1year)	Park & Ride facilities			**0.106***(3.012)**	0.026(0.73)
	Access permits			**0.149***(4.328)**	-0.046(-1.34)
	Subsidies			**0.23***(6.564)**	**0.153***(4.372)**
EA	Park & Ride facilities	-0.054 (-1.332)	-0.047 (-1.167)	**0.084** (2.09)**	**-0.194*** (-4.711)**
	Access permits	**-0.087** (-2.254)**	-0.055 (-1.417)	0.045 (1.168)	**-0.192*** (-4.938)**
	Subsidies	**-0.157*** (-3.989)**	**-0.082** (-2.076)**	-0.043 (-1.088)	**-0.199*** (-5.019)**
PA	Park & Ride facilities	0.003(0.056)	0.051(1.12)	**-0.18***(-3.998)**	**0.245***(5.348)**
	Access permits	0.049(1.118)	0.033(0.761)	**-0.13***(-2.969)**	**0.221***(5.03)**
	Subsidies	**0.086*(1.921)**	**0.143***(3.2)**	0.001(0.027)	**0.232***(5.139)**
FI	Park & Ride facilities	**-0.065*** (-3.569)**	**-0.049*** (-2.68)**	**-0.058*** (-3.209)**	**-0.058*** (-3.141)**
	Access permits	-0.009(-0.527)	-0.011(-0.645)	-0.005(-0.3)	-0.016(-0.917)
	Subsidies	**-0.045** (-2.503)**	**-0.058*** (-3.207)**	**-0.05*** (-2.773)**	**-0.055*** (-3.034)**
PF	Park & Ride facilities	**0.076(2.381)****	**0.069(2.198)****	**0.114(3.624)*****	0.029(0.908)
	Access permits	0.009(0.302)	0.005(0.161)	0.042(1.366)	-0.03(-0.989)
	Subsidies	0.041(1.327)	-0.018(-0.572)	0.039(1.255)	-0.017(-0.546)

The screen-line traffic counting location problem under observation uncertainty

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Introduction

The screen-line traffic counting location problem (SLTCLP) plays a vital role in travel demand management (TDM) by identifying optimal sensor locations to monitor traffic flow across screen lines in a road network. The SLTCLP aims to determine the optimal location of screen lines that intercept all paths for specific origin-destination (OD) pairs. Traditional approaches rely on enumerating all possible paths, which is computationally intensive and difficult to implement for large-scale networks.

To overcome this computational challenge, recently Sase et al. (2025) proposed a novel solution method without path enumeration. Their approach is based on the concept of graph cuts providing an exact and efficient solution method.

However, the assumption of perfect sensors does not always hold in real-world applications. This study addresses the critical issue of observation uncertainty by extending the problem setting of the SLTCLP. We propose a new mathematical model that incorporates the concept of a sensor observation rate, defined as the proportion of time a sensor accurately measures traffic volumes. Based on this concept, we formulate an optimization problem to determine sensor locations that guarantee a prescribed observation rate.

Methodology

Let $G(V, E)$ be the directed graph, and consider $(i, j) \in E$, where a traffic sensor with an observation rate r_{ij} can be installed. The relationship between the unobserved rate P_j after passing through link (i, j) and the unobserved rate P_i before entering the link can be expressed using the binary decision variable z_{ij}, which indicates whether a sensor is installed as illustrated in Fig.1:

$$
\begin{aligned}
&P_j = P_i \cdot (1 - r_{ij})^{z_{ij}} \quad \forall (i,j) \in E \\
&\text{where} \quad z_{ij} = \begin{cases} 1 & \text{if a sensor is installed on link } (i,j) \\ 0 & \text{otherwise} \end{cases}
\end{aligned}
\tag{1}
$$

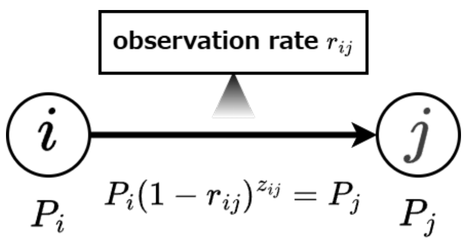


Figure 1: Installation of a traffic sensor with observation rate r_{ij} on link (i, j)

When there is a unique path from an OD pair $(s,t)|s,t \in V$ without any branching, the unobserved rate from s to t is equal to P_t, and can be written as follows:

$$P_t = P_s \cdot \prod_{ij \in E} (1 - r_{ij})^{z_{ij}} \tag{2}$$

Suppose the road administrator has set a target value for the unobserved rate between OD pair (s,t). By formulating a mathematical optimization problem that constrains the unobserved rate to remain below this target η, we obtain the following equations.

$$\min_{\mathbf{z}} \sum_{(i,j) \in E} z_{ij} \tag{3}$$

subject to

$$P_j - P_i \cdot (1 - r_{ij})^{z_{ij}} = 0 \quad \forall (i,j) \in E \tag{4}$$

$$P_t \leq \eta \tag{5}$$

$$P_s = 1 \tag{6}$$

$$0 \leq P_i \leq 1 \quad \forall i \in V \tag{7}$$

$$z_{ij} = \{0, 1\} \quad \forall (i,j) \in E \tag{8}$$

Since constraint (4) is nonlinear, the problem cannot be solved as a linear programming program. To address this, the natural logarithm is applied to the variables. Let $\rho_i = \ln P_i$ and $\delta_{ij} = \ln(1 - r_{ij})$, then constraint (4) becomes:

$$\rho_j - (\rho_i + \delta_{ij} z_{ij}) = 0 \tag{4'}$$

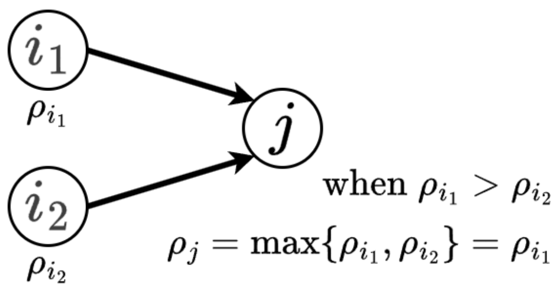


Figure 2: A node j with multiple incoming links

Next, consider the case where multiple paths exist between multiple OD pairs $(s,t) \in S \times T^s$. As the number of paths increases exponentially with the network size, it is computationally very challenging to compute observation rates for each individual path. As illustrated in Fig.2, at a node j with multiple incoming links, the unobserved rate is taken as the maximum among all incoming paths. The following equation (9) represents the worst-case unobserved rate at node j:

$$\rho_j = \max_{\mathbf{z}} \{\rho_i + \delta_{ij} z_{ij} \ \forall (i,j) \in E\} \tag{9}$$

By combining this with the inequality $\rho_t \leq \ln \eta$, which is the natural logarithm of inequality (5), we obtain:

$$\rho_i + \delta_{ij} z_{ij} \leq \rho_j \leq \rho_t \leq \ln \eta \quad \forall (i,j) \in E, t \in T^s, s \in S \tag{10}$$

Using inequality (10), the maximum function (9) can be replaced by the following linear inequality, which subsumes (4'):

$$\rho_j - (\rho_i + \delta_{ij} z_{ij}) \geq 0 \quad \forall (i,j) \in E \tag{11}$$

Under the constraint that the unobserved rate for the OD pair (s,t) is less than or equal to η, the sensor location problem can be reformulated as the following mixed-integer linear programming (MILP) problem:

$$\min_{\mathbf{z}} \sum_{(i,j)\in E} z_{ij} \tag{3}$$

subject to

$$\rho_j^s - (\rho_i^s + \delta_{ij} z_{ij}) \geq 0 \quad \forall (i,j) \in E, s \in S \tag{11}$$

$$\rho_t^s \leq \ln \eta \quad \forall t \in T^s, s \in S \tag{5'}$$

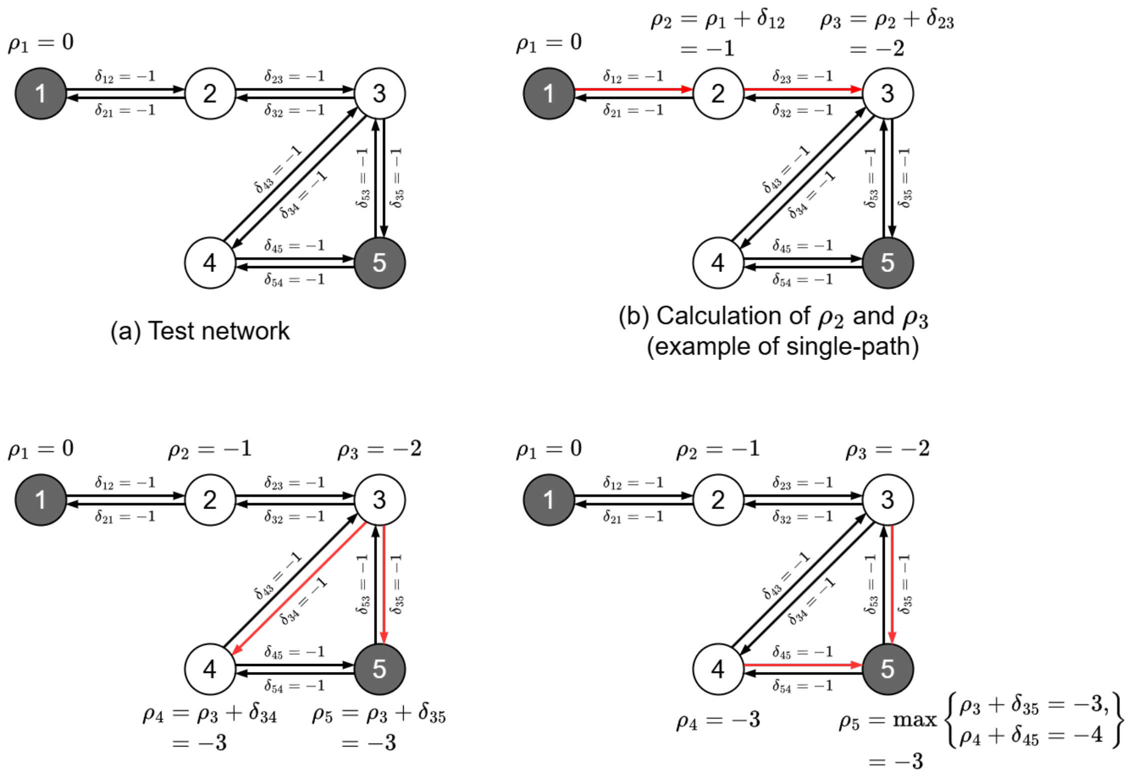
$$\rho_s^s = 0 \quad \forall s \in S \tag{6'}$$

$$\rho_i^s \leq 0 \quad \forall i \in V - s - T^s, s \in S \tag{7'}$$

$$z_{ij} = \{0, 1\} \quad \forall (i,j) \in E \tag{8}$$

Illustrative example using a small network

We demonstrate the proposed method using a small network shown in Fig.3. Consider a case where the unobserved rate for $(s,t) = (1,5)$ is evaluated, and the natural logarithm of the sensor observation rate for each link is $\delta_{ij} = -1$ (i.e., $r_{ij} = 1 - e^{-1}$).



(a) Test network

(b) Calculation of ρ_2 and ρ_3 (example of single-path)

(c) Calculation of ρ_4 and ρ_5 (example of divergence)

(d) Calculation of ρ_5 (example of merge)

Figure 3: Example calculation of the unobserved rate in a network with single-path, divergence, and merge scenarios

Fig.3(b) illustrates a case of single-path, where the unobserved rates can be calculated sequentially starting from the constraint $\rho_1 = 0$. Fig.3(c) illustrates a case with a divergence. The unobserved rate for each outgoing link is calculated using the unobserved rate at the node where the divergence occurs. Fig.3(d) illustrates a case with a merge. For a merging node, the unobserved rate is the maximum value of the unobserved rates from each of the incoming links.

In the network of Fig.3(a), when minimizing the number of installed sensors under the constraint $\rho_5 \leq -2$, the minimum number of sensors required is 2. This is achieved when $z_{12} = z_{23} = 1$. Furthermore, when minimizing the number of sensors under the constraint $\rho_5 \leq -3$, the minimum number of sensors required is 4. This is achieved when either $z_{12} = z_{23} = z_{34} = z_{35} = 1$ or $z_{12} = z_{23} = z_{35} = z_{45} = 1$.

While this example illustrates the concept using a single OD pair, the proposed model addresses the sensor location problem for guaranteeing the required observation rate for multiple OD pairs. A detailed discussion will be presented during the conference presentation.

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Tuesday 9th December: 4pm-5.30pm
Parallel Session 3 (Level 16, Lecture room 5)
Theme: Behavioural Insights, Equity, and Decision-Making in Travel Choices, Session Chair: Prof. Corinne Mulley
Behavioural-science approach to optimise the use of traveller information tools (Ronny Kutadinata, Hendrik Zurlinden, Inez Rojas, Annet Hoek and Simone Pettigrew)
Unpacking public transport fares and their implications for equity and sustainability: Insights from sub-Saharan Africa (Gift Dumedah, Patrick Azong, Precious Adwoa Okyere, Hannibal Bwire and Steven Jones)
Examining Intra-Household Dynamics in Daily Travel Time Allocation among Dual-Earner Couples (Namrata Ghosh and Shamsunnahar Yasmin)

Behavioural-science approach to optimise the use of traveller information tools

Ronny Kutadinata*[1], Hendrik Zurlinden[1], Inez Rojas[2], Annet Hoek[2], Simone Pettigrew[2]

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Introduction

This project aims to identify the optimal use of traveller information tools to influence customer's behaviour in line with the 4R's principles: *Reduce*, *Remode*, *Reroute*, and *Retime*. If successful, this will improve the overall customer journey and lead to long-term, positive behaviour change. Working collaboratively with Transport for NSW (TfNSW), key project aims include: (i) identify and understand current global best practice on network optimisation, demand management, and behavioural science interventions; (ii) analyse TfNSW's existing control centre traveller information tools including mobile or web based travel apps and identify opportunities and challenges in optimising their use to influence behaviour; (iii) and ultimately provide TfNSW with options and recommendations on improving customer journey outcomes, harnessing travel demand management and behaviour change techniques.

Best Practice Review

The best practice review involves literature review and consultations with global experts and international road agencies. The review was focused on the following realms of inquiry: capturing customer voice, transport management tools, organisational/stakeholder frameworks, and communications and messaging. The review found many studies that discussed these aspects, and the findings can be summarised into the following 3 points:

- The effectiveness of any behavioural intervention is to ensure that the effort is personalised to address individual barriers to change, targeted towards those that are more susceptible to change, and interventions are delivered in the appropriate contextual settings.
- The development of digital technologies and solutions has seen the rise of use of digital tools, such as mobile apps, to implement behavioural interventions.
- The fundamental requirement of any travel demand management initiative is a traveller information system with appropriate types of information and accurate data to help inform the customer's decision making.

Methodology

The three main stages of the proposed methodology are gap analysis of existing practice, public surveys, and synthesis of recommendations for optimal use of travel information tools for influencing behaviours.

1. Firstly, a stocktake of existing travel information tools is undertaken through consultations targeted to various departments within TfNSW. Based on this stocktake, a comparison is performed with the best practices found during the review to identify opportunities for improvements.

2. Two public surveys will be undertaken as part of this project. Survey 1 will collect data on the various factors that impact travel decisions and travel information needs, the results of which will inform the development of a series of experimental scenarios to be included in Survey 2. Note that, at the time of the symposium, only Survey 1 would have been completed.
3. The responses from the surveys will be analysed using appropriate statistical and modelling techniques to discover the relationships between the various factors impacting the travel decision (i.e. independent variables, such as demography and trip attributes), the various types of traveller information and its delivery, and the eventual travel decision being made. The results of the analysis will inform the development of guidance documents on how to use of various traveller information tools to increase the likeliehood of inciting behavioural change.

Preliminary Results

At this stage, the project team has completed the first stage of the project, namely the stocktake and gap analysis. It was found that TfNSW has utilised and supported many channels to provide information to customers. This includes real-time information, service alerts, and trip planning tools. Additionally, TfNSW has also been continuously running TDM programs targeting major trip generators. However, there are some key gaps in TfNSW's practice that needs to be addressed, as follows.

- TfNSW is unsure about the efficiency of the various information channels to incite the desired behavioural change. Additionally, there are still some issues with the accuracy and timeliness of the real-time information provided to these various channels.
- TfNSW is unsure on the most cost effective method of scaling up their TDM program.

The project team has identified some early indications of possible improvements that can be made to existing TfNSW suite of tools. It is worth noting that, at this stage of the project, these suggestions are preliminary and will be updated at later stages of the project.

- It is important to target the effort to "nudgeable" customers by analysing their second-best travel option.
- Information delivery methods can be improved by targeting the right context, provision time, and place, and with the right message content.
- The provision of tools/apps to help customers plan and undertake their journeys can be utilised to also provide personalised interventions.
- However, the use of apps needs to be carefully considered to ensure appropriate level of engagement from the wider public, which can be achived through, e.g., incentives.

Expected Outcome

The final outcome of the project will be guidance documents on the optimal use of TfNSW traveller information tools that, based on the behavioural science analysis, are expected to most likely lead to behavioural change. At the time of the symposium, the project would have completed Survey 1, from which the project team will create a preliminary output as a "prototype" of the final output, based on suggestions for the improved use of one TfNSW traveller information tool. The presentation will share the results of this preliminary analysis.

Acknowledgements

This project is a collaboration and funded by Transport of New South Wales, the National Transport Research Organisation, and iMOVE CRC (supported by the Cooperative Research Centres program, an Australian Government initiative).

Unpacking public transport fares and their ımplications for equity and sustainability: Insights from sub-Saharan Africa

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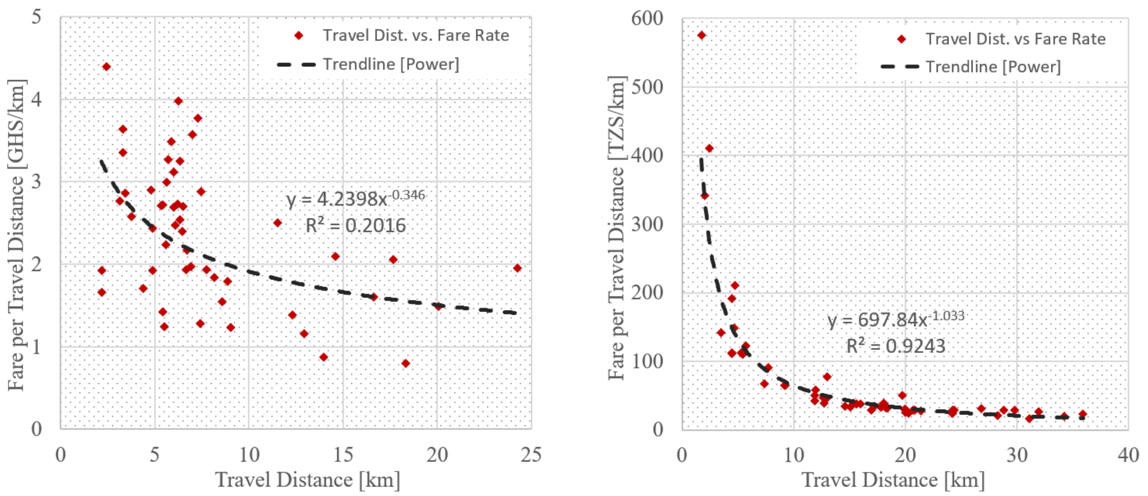
Introduction

Travel fares represent a cornerstone of revenue generation for public transport systems globally, serving as a critical factor in ensuring operational sustainability and accessibility (Brown, 2018; El-Geneidy et al., 2016; Hörcher & Tirachini, 2021). In Sub-Saharan Africa (SSA), where paratransit dominates the public transport landscape, limited investment, subsidies, and funding exacerbate the reliance on fares, which directly impact mobility and access to opportunities. Despite the availability of transport infrastructure in these regions, high service costs often hinder regular usage by vulnerable populations, thereby widening socioeconomic inequities. Furthermore, inconsistent and spatially dissimilar fare structures undermine the affordability and reliability of transport systems, placing additional strain on service providers and risking operational collapse. This study investigated travel fares across paratransit modes in Accra-Ghana, and Dar es Salaam (DAR)-Tanzania, aiming to quantify spatial disparities in fare structures based on route, travel distance, and travel time. Using comprehensive data analysis, the study highlighted significant variations in fare structures within and across modes, reflecting broader challenges in ensuring equitable accessibility. The findings revealed critical implications for policy development, including the need for standardized fare policies that balance affordability for passengers with revenue sustainability for operators. The study provides actionable insights for fostering fair and efficient transport systems that support the well-being of residents and promote social equity in SSA cities.

Body

Public transport fares were collected through on-site data gathering at terminals and stops along selected paratransit routes in Accra-Ghana, and DAR-Tanzania. Routes were chosen to include all originating from each study area, regardless of their destinations. A GPS device with 1-2 meter accuracy was used to map stop locations via a combination of riding paratransit vehicles and walking the routes. Data was collected using semi-structured questionnaires addressing vehicle characteristics and route details, administered through in-person interviews with drivers and station patrons. In Accra, surveys covered 550 vehicles (420 minibuses, 130 taxis) across 52 routes (38 minibus and 14 taxi routes). In DAR, 650 vehicles (386 minibuses, 249 three-wheelers) were surveyed across 57 routes (41 minibus and 16 three-wheeler routes). Sample sizes were proportional to vehicle distributions at terminals, ensuring representation of all routes in each study area. Surveys were conducted on both weekdays and weekends to capture diverse operators and vehicles.

The scatter plot analysis (Figure 1) reveals an inverse relationship between fare rate (fare per distance) and travel distance, indicating diminishing returns. As travel distance increases, fare rates decrease at progressively smaller increments. This trend underscores the concept of economies of scale: shorter trips have higher per-kilometer fare rates due to fixed operational costs, whereas longer trips benefit from reduced fare rates. City-specific patterns show a consistent distance-based fare structure in Dar es Salaam, Tanzania (R^2 = 0.9243), compared to Accra, Ghana (R^2 = 0.2016), where fare variability by distance is more pronounced. Longer travel distances are associated with lower fare rates in both cities, but shorter distances remain disproportionately expensive. Addressing the higher costs of short trips could enhance affordability for vulnerable populations relying on them, while lower fares for long distances might improve access to services. These findings, aligned with prior research Brown (2018) that highlights that low-income transit riders disproportionately pay higher per-mile fares for shorter distances. Future studies could integrate additional variables like passenger demand or trip purpose to refine the model's predictive accuracy and provide deeper insights into fare structures.



(a) Accra-Ghana (b) Dar es Salaam-Tanzania

Figure 1. Scatter plots show the diminishing returns of fare rates against travel distance

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Examining Intra-Household Dynamics in Daily Travel Time Allocation among Dual-Earner Couples

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Introduction

Rising female labour force participation, hybrid work arrangements and evolving family structures have reshaped household travel dynamics. Dual-earner households now dominate in many developed and emerging economies (OECD, 2023), accounting for more than two-thirds of total household labour hours (Broomhill & Sharp, 2005). In these households, travel behaviour emerges from interdependent role negotiations balancing work, care, and daily activities within finite temporal and spatial constraints (Almås et al., 2023; Zhang et al., 2005). While traditional gender roles are gradually evolving, empirical studies suggest that women continue to perform the majority of unpaid care work, even in dual-earner households (Craig & Powell, 2018; Samtleben & Müller, 2022). However, reforms such as expanded paternity leave policies and rising work-from-home (WfH) arrangements have led to temporary or partial reversals in caregiving–breadwinning roles and altered how couples divide time and travel responsibilities (Beck & Hess, 2016; Kaufman & Bernhardt, 2015; Kaufman & Taniguchi, 2019; Motte-Baumvol et al., 2017). Though uneven across contexts, these shifts introduce new complexities for Travel Demand Management (TDM), which still mostly focuses on modelling individuals as autonomous, and role-stable agents. Without recognising intra-household interdependencies, TDM strategies may misidentify both the drivers and the targets of demand-side interventions. Evidence shows that dual-earner couples allocate significantly more total daily travel time than single-earner or single-adult households, even after controlling for income and built environment factors (Kwon & Akar, 2022). However, most research has focused narrowly on commute or trip-purpose-specific patterns, overlooking how travel time is negotiated and divided within households.

This study addresses the abovementioned gaps by analysing how total daily travel time is allocated between partners within dual-earner households. The findings offer insight into household-level constraints, asymmetries, and behavioural interdependencies that underpin contemporary travel demand. To interpret these dynamics, this study draws on two theoretical frameworks. The Household Responsibility Hypothesis (HRH) attributes gendered travel inequalities to the unequal division of unpaid domestic labour (Johnston-Anumonwo, 1992; Turner & Niemeier, 1997). Complementing this, Sen's Capability Approach (Sen, 1990) frames travel time as an indicator of well-being, and freedom to convert available resources into valued activities. Together, these frameworks allow this study to conceptualise household travel capability as a dynamic, co-produced outcome emerging from the interaction between individual characteristics, partner roles, shared household resources, and structural opportunity conditions. While dual-earner couples share income and vehicles and reside in the same built environment, the total travel time spent by male and female partners often differs significantly. As a result, shared context does not guarantee equal travel time burdens.

Most transport studies overlook these recursive dynamics. This study contributes by modelling total daily travel time as a joint, negotiated outcome capturing how one partner's travel decisions influence the others. This approach offers a more realistic foundation for TDM strategies that reduce time-related burdens and promote equitable, role-sensitive interventions.

Data Sample

This study uses data from the Southeast Queensland Household Travel Survey (SEQHTS, 2017–2024) to model total daily travel time (all trip purposes) of male and female partners in cohabiting, heterosexual dual-earner households. The analysis uses binary gender (self-reported sex) and includes only couples with both partners employed (full or part-time). The modelling framework is partner-disaggregated and recursive, allowing for mutual travel-time influence, partner-specific attributes, and shared household factors.

Data Acquisition and Processing

The estimation sample includes 2,130 male and 2,130 female partners from eight Local Government Areas. Trip, person, and household-level data are merged at the SA2 level. Dual-earner households are identified using relationship and employment variables, excluding single adult households, non-partner co-residents, or those not in the labour force. The dataset is integrated with the Land Use and Public Transport Accessibility Index (LUPTAI) to capture multimodal accessibility, and spatial features derived using ArcGIS and entropy indices.

Empirical Context

The dependent variable is the natural logarithm of each partner's total daily travel time (minutes) across all trip purposes. Descriptive statistics reveal that male partners have slightly higher mean logged travel time (4.296) than female partners (4.159). Independent variables were grouped into five domains: partner-specific travel traits, demographics/employment, household capabilities, macro-spatial context, and built environment/service accessibility.

Econometric Modelling Framework

A partner-disaggregated, recursive copula modelling is used to capture mutual influence and non-linear interdependence in travel time between cohabiting partners. Each partner's logged travel time is modelled as a function of their own attributes and their partner's travel time. The general functional form of the model is specified as follows:

$$\log(y_i) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + \gamma \log(y_j)\, \varepsilon_i \qquad \text{Equation 1}$$

Where $\log(y_i)$ is the natural logarithm of total daily travel time for partner i ; $\log(y_j)$ log of the co-residing partner's travel time,γ measures partner's influence; $X_{1i}, X_{2i} \dots X_{ki}$, i are covariates; β_0 is the intercept; β_1, β_2, …,β_k are the coefficients, and ϵi is the normally distributed error term. The model jointly estimates residuals to account for unobserved correlation between partners. The model is estimated via Maximum Likelihood Estimation (MLE) in GAUSS.

Preliminary Results and Discussion

Preliminary results confirm statistically significant mutual influences between partners' travel times (γ), supporting the idea of negotiated travel decisions within households. Male partners tend to spend more time travelling overall, especially when departing early in the morning or during PM peaks. Female partners aged 30–39 employed in male-dominated sectors also report increased travel time, while older women (60–69) travel less. Households with children aged 13–17 experience higher travel burdens for both partners. Built environment effects vary.

Residence in Redland increases female travel time, whereas higher land-use mix decreases travel time for both partners. Proximity to bus stops and public transport access decreases travel time for male partners. Walkable environments are associated with increased travel time for females, whereas higher bikeway density and cycling accessibility decrease it. Importantly, WfH status moderates travel time distribution within couples, often shifting the burden to the commuting partner. These findings suggest that role asymmetries, not just gender per se, drive differentiated travel experiences, with important implications for demand management.

Recommendations for Further Study

This study reframes travel time allocation as an interdependent, household-level process shaped by evolving role configurations. Future research should disaggregate travel time by trip purpose and include same-sex households and qualitative insights on household negotiation. These insights are vital for designing equity-focused transport policies that are household-aware and responsive to real-world complexities like flexible work, gender role evolution, and caregiving burdens. Full model estimates will be presented during the conference session.

Acknowledgements

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Tuesday 9th December: 4pm-5.30pm
Parallel Session 4 (Level 17, Lecture room 2)
Theme: Active Mobility and Behavioural Insights, Session Chair: Prof. Stephen Greaves
Active Travel to School: Policy Insights from Distance, Environment, and Lifestyle Determinants (Laya Hossein Rashidi, Jennifer Kent, Akshay Vij and Emily Moylan)
Understanding Behavioural Needs for Active Travel in New South Wales (Sara Haider, John Nelson, Jennifer Kent and Sotiris Vardoulakis)
Strategic Cost Assessment of Bike-Train Integration: What Should Cities Build? Infrastructure for Shared Bikes, Private Bike Parking, or On-Train Boarding (Regine Tejada and Andres Fielbaum)

Active Travel to School: Policy Insights from Distance, Environment, and Lifestyle Determinants

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Abstract

Active travel to school (ATS) supports child health and sustainability, yet isolated interventions often underperform. Using data from 7,555 students in New South Wales and three modelling approaches, this study identifies key barriers to effective ATS promotion: (1) distance sensitivity varies, with the 2–3 km range being most critical; (2) omitting built environment factors can bias policy insights; and (3) a latent "permissive lifestyle" factor influences ATS behaviour. Together, these findings show that successful ATS policies require integrated strategies addressing spatial, behavioural, and structural dimensions.

Keywords: Active travel to school, distance, built environment, permissive parenting.

Introduction

Active travel to school (ATS), walking, cycling, or scooting, is a key policy goal for improving child health (Barros et al., 2024), reducing congestion (McDonald et al., 2016), and supporting sustainable communities (van Wee & Ettema, 2016). Effective policies require a clear understanding of active travel behaviour, including individual traits, travel distance, the built environment, and family context.

Distance is the strongest predictor of school travel mode and a key metric for evaluating active travel programs (Rodríguez-López et al., 2017). However, the effects of distance vary across students. Moreover, Built-environment (BE) factors, framed by the '6Ds' (Density, Diversity, Design, Destination accessibility, Distance to transit, and Demand management) (Cervero & Kockelman, 1997; Kent et al., 2023) influence mode choice and are often correlated with distance and each other. Given this interdependence, assessing the risk of omitted variable bias (OVB) in mode choice models is essential to ensure reliable policy insights. In addition to observable features, unobservable factors such as family attitudes and lifestyle may influence active travel to school and how barriers like distance are perceived.

This research asks: Why do isolated interventions often fail to increase active travel to school, and what broader reforms are needed? We examine (1) variation in distance sensitivity across student groups, (2) bias from omitted key built environment variables, and (3) the role of permissive family lifestyles in shaping and moderating ATS. Together, the findings suggest that piecemeal strategies are unlikely to succeed without broader reforms that address structural and behavioural barriers.

Data

Data come from the 2015 Schools Physical Activity and Nutrition Survey in New South Wales, covering 7,555 students (ages 4–17) from 86 schools (Hardy et al., 2017). It includes socio-economic, demographics, school type, and travel time by mode. In the current study, travel distance was estimated from travel time and average speeds.

Family lifestyle indicators (e.g., screen time rules, snack access, and sedentary time) were used for latent variable analysis. Built environment features were assessed within 1.5 km school buffers using data from the Australian Bureau of Statistics (ABS, 2016), Transport for NSW Open Data Hub (2023), Geofabrik (2018), and the General Transit Feed Specification (GTFS, 2022).

Method

The proposed policy-relevant insights are built on past results from a combination of modelling approaches. This research integrates findings from three complementary studies using a comparative, multi-method approach. Each study uses a different modelling strategy—binary logistic regression, multinomial logit modelling, and a sequential Integrated Choice and Latent Variable (ICLV) model—to isolate specific mechanisms affecting ATS: heterogeneous distance sensitivity, omitted variable bias from built environment factors, and the moderating role of permissive family lifestyles. While each method is tailored to its respective question, the results are brought together through elasticity comparisons and scenario analyses to examine how policy effectiveness varies depending on model completeness and behavioural assumptions. This comparative approach highlights the limits of cross-sectional inference and underscores the need for holistic policy solutions that account for spatial, behavioural, and structural complexity.

Findings

This research identifies three interconnected reasons why simple, isolated interventions to promote Active Travel to School (ATS) often fall short. First, while distance is the strongest deterrent to ATS, sensitivity to distance varies—students travelling 2–3 km show the greatest sensitivity, yet policies often reduce distances outside this critical range or for groups less likely to switch. Second, omitting key built environment variables introduces substantial bias in mode choice models; scenario analysis showed that predicted ATS outcomes can differ by up to 55% depending on model completeness, suggesting that cross-sectional correlations may mislead policy design. Third, a latent "permissive lifestyle" factor—linked to relaxed household rules—moderates the impact of distance, especially for short trips, implying that family self-selection may shape both residential choice and ATS behaviour. Taken together, these findings suggest that ATS outcomes are shaped by overlapping behavioural, spatial, and structural dynamics—and that piecemeal fixes (e.g., sidewalk improvements or minor zoning changes) may be insufficient. More comprehensive reforms—such as changes to school enrolment policies, or family-focused behaviour programs—are likely needed to produce lasting, equitable increases in ATS.

Conclusions

These studies offer critical evidence for policymakers aiming to boost active school travel (ATS). The research confirms the importance of established determinants like distance and the built environment (e.g., Density, Diversity, Design), while identifying the 2–3 km range as a key threshold where students are most sensitive to distance. This finding supports targeted infrastructure and safety investments within this zone and informs strategic catchment planning.

The research warns that omitting key built-environment variables can lead to substantial omitted variable bias, weakening policy reliability and equity outcomes. It also introduces a latent “permissive family lifestyle” factor, showing that behavioural norms influence ATS and should be addressed alongside infrastructure improvements.

Overall, these findings point to the need for more ambitious, system-wide ATS policies that go beyond isolated fixes and address structural, behavioural, and spatial factors through well-specified, evidence-based approaches. While limitations exist—such as a focus on the school-end environment and lack of direct parental data—the research sets a strong foundation for more targeted future work.

Acknowledgements

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Understanding Behavioural Needs for Active Travel in New South Wales

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Introduction

Active transport can promote healthier, more sustainable, and equitable societies. Despite clearly articulated visions in plans and policies, uptake of active transport remains low, particularly in traditionally car-dependent contexts. A key challenge for those seeking to increase active transport mode share is the need to accommodate the diverse structural and psycho-social contexts proven to shape transport behaviour. Infrastructure sufficient to support one person's active transport journey, for example, may not be sufficient for others, with differences likely shaped by a series of practical and psycho-social nuances. This paper reports data from a pilot survey assessing the active travel context, behaviour and preferences of 2000 participants from New South Wales, Australia. Its key contribution is a better understanding of the translation of psycho-social and behavioural characteristics to infrastructural preferences.

Literature context

Active travel uptake is influenced by the interplay of utilitarian, psychological and social factors (Kent, 2022). *Utilitarian factors*, such as travel time, distance to key destinations, and basic connectivity of walking and cycling infrastructure, are the fundamental conditions that determine whether active travel is considered efficient or practical (De Vos et al., 2021). However, *psychological factors*, including perceived safety from traffic appearance of walking and cycling can have a strong influence on enabling or inhibiting willingness to engage in active travel, with differing impacts for particular demographics (Dill et al, 2014). *Social factors,* such as community norms shaping not only attitudes to transport but to the aspects of life facilitated by transport, also shape travel behaviour, including active transport (Aldred et al, 2020). Recognising this interplay, transport scholars and professionals are coming to understand that effective active transport infrastructure needs to not only facilitate efficient access but also respond to the diversity of psycho-social contexts shaping cities.

Method

To better understand the complexity of the interplay described above, a survey instrument was designed to collect data on participants' context, behaviour and infrastructure preferences, as shown in Figure 1. Questions on context provide understandings of each participants' built environment and socio-economic/demographic background. Questions on behaviour are used to gather data on a series of utilitarian (eg. travel times, trip types), psychological (eg. perceived safety and self-efficacy for travelling by active modes) and social factors (eg. norms governing presentation at work and accepted ways of travelling) which are hypothesised to influence active travel. Questions on infrastructure preferences, such as stated preference where participants respond to various infrastructure scenarios, understand infrastructure related barriers and active travel comfort in different infrastructure settings. This is combined with quasi-revealed preferences where participants are asked about the modes of transport and infrastructure used. These insights are used to enable analyses of how preferences translate to behaviour and are shaped by context.

The survey was peer-reviewed, approved by the Human Research Ethics Committee of the University of Sydney (2015/HE000307) and distributed through a panel company, with data collection ongoing.

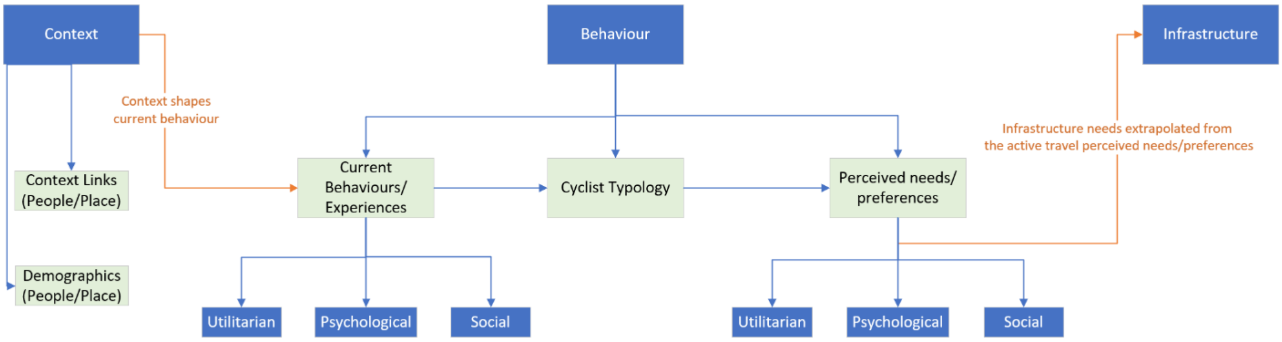

Figure 1. Survey Structure including context, behaviour and infrastructure

Results

Data collection is ongoing with final data anticipated to be available in July 2025.

The analysis will involve:

- Regression models to identify the factors that influence mode choice and travel frequency, disaggregated across utilitarian, psychological, and social behaviour themes. Then a combined regression model will be undertaken to assess the relative strength of all behavioural dimensions together.
- Factor analysis will be conducted on the travel attitude indicators to identify latent behavioural factors which will be compared with actual mode choices and local infrastructure availability to assess whether travel behaviour is constrained more by infrastructure gaps or attitude gaps, or both.
- Structural equation modelling (SEM) will then be applied to assess the interrelationships between latent behavioural factors from the utilitarian, psychological, and social questions and mode choice. The predicted mode choice from the SEM model will then be compared to the self-reported mode by respondents regarding their travel activity in the past week, across different geographical contexts to determine whether infrastructure or attitudinal gaps are limiting active travel uptake.

All findings will be geospatially analysed through ArcGIS across contextual categories to identify which infrastructure features are most effective at influencing active travel in specific types of areas/demographics. This staged approach will provide insights into behavioural drivers of active travel which will help assess the infrastructure that is most effective in various contexts.

Conclusion

The study will provide novel insight into the interaction between utilitarian, psychological, and social behavioural factors in relation to active travel, and how these influence infrastructure preferences across contexts. This is a critical contribution to active transport infrastructure that supports optimal uptake of active travel by responding to the complex needs of the people targeted for increased participation.

Acknowledgements

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Strategic Cost Assessment of Bike-Train Integration: What Should Cities Build? Infrastructure for Shared Bikes, Private Bike Parking, or On-Train Boarding

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Introduction

Integrating cycling and train systems promotes sustainable transport. This can be done by different strategies, such as (1) using shared bikes, (2) parking private bikes and then riding the train or (3) boarding bikes on train (Van Mil et al., 2021; Krizek and Stonebraker, 2011). However, implementing these strategies often requires a high investment cost, and poorly designed facilities fail to attract users. This results in underutilization and low returns, indicating that the chosen strategy is not suitable for the city's characteristics.

Previous studies address this problem by conducting site-specific cost analyses (e.g., Krizek and Stonebraker, 2011) or using optimization models to design a specific strategy (e.g., Jara-Díaz et al., 2022; Veillette et al., 2018). However, these approaches only focus on one strategy or use case-specific parameters that cannot be applied to other contexts. There is a lack of a general framework that can compare the different strategies.

This study aims to fill this gap by developing a cost-based model for decision-makers to compare the bike-train strategies across the city characteristics. This analysis specifically focuses on comparing the user and operator costs of the bike-train integration strategies, using a case study based on Sydney.

Methods

Continuous approximation, a strategic-level planning approach, is used to model the total costs for each strategy. It provides key insights and shows the trade-offs through the variables' relationships (Soriguera and Jiménez-Meroño, 2020). Figure 1 shows the typical user journey patterns for each strategy.

For Strategy 1 (Using shared bikes), the user cost includes the cost of time walking from the origin to the nearest bike station, cost of time biking from the bike parking to the train station, cost of time walking from the bike parking to the train, and the cost of time walking from the train to the destination. The operator cost for this strategy involves the cost of making the bike parking slots and the shared bike station, the cost of land, the cost of bikes, and the cost of rebalancing these shared bikes. Closed-form expressions can be derived to approximate these costs.

For Strategy 2 (Parking private bikes), there are key differences from Strategy 1 in user and operator costs. Instead of walking from the origin, the user rides the bike directly from the origin to the bike parking near the train station. Since this strategy uses private bikes, the purchase cost, incorporating the useful life of the bike, is included in the user cost. The operator cost involves the costs for station construction, land, and security personnel or equipment to ensure

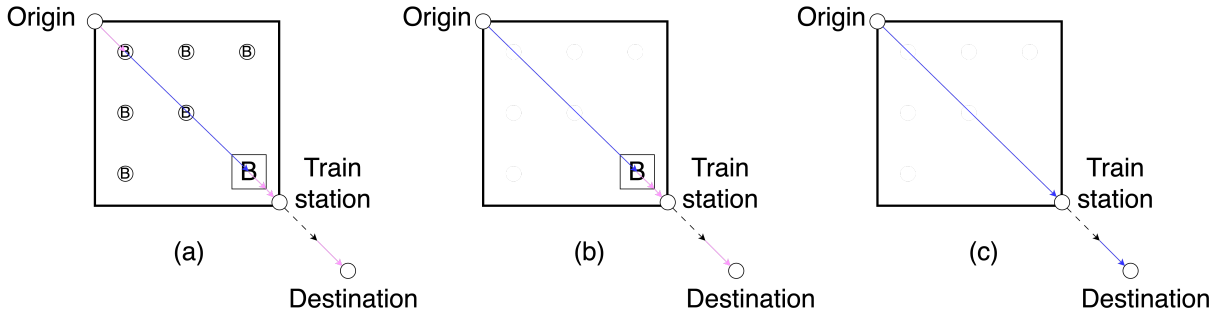

Figure 1: User journey when (a) using a shared bike, (b) parking a private bike, and (c) boarding bike on train

the safety of the parked bicycles. Unlike Strategy 1, there are no rebalancing costs in this strategy.

For Strategy 3 (Boarding bikes on train), the user cost involves the bike purchase cost, the cost of time biking to and from the train station, the cost of effort to load and unload the bikes from the train, and the cost of waiting for passengers due to longer dwell times. The operator cost includes the extra cost of operating the train with the bikes, and this involves the longer dwell times and the larger space occupied by the passengers with bikes. There is no decision variable used in Strategy 3 because train capacities and other operational constraints are fixed. There is also a hard constraint on capacity. This strategy becomes infeasible if the total number of passengers, including cyclists, exceeds train capacity, which is determined by platform lengths and space allocation standards for passengers.

Parameters were approximated based on prior literature, particularly the walking and biking distance estimates from Soriguera and Jiménez-Meroño (2020). Additional parameter values are specific to the Sydney context, especially in scenarios where cyclists travel from one Central Business District (CBD) station to another (e.g., Parramatta to Town Hall). These values were derived from existing studies, Sydney transport datasets, news reports, and relevant statistics reported by Statista. Closed-form expressions are found for Strategy 2 (Parking private bikes), while numerical analysis is done for the first strategy. The cost per user is compared across strategies using varying levels of demand.

Results and Discussion

Results show that in the context of Sydney, Strategy 3 (allowing bikes on trains) is the most cost-efficient option when demand is very low. In Sydney, if the number of bikers is less than or equal to 17 per hour, this strategy is optimal, as it just averages about one biker per train with a train frequency of 12 trains per hour. However, when demand exceeds around 47 bikers per hour, Strategy 3 becomes infeasible because the demand will be greater than the train's maximum capacity.

For demand levels between 17 to 8000 bikers per hour, Strategy 2 (parking private bikes) offers the lowest cost per user. This is because constructing a small parking space for a few users is more economical than building and operating the infrastructure required for a shared bike system. Additionally, the cost of rebalancing is high in a shared bike system, and if there are only a few users to share these costs, the cost per user becomes expensive. Additionally, allowing bikes to be boarded onto trains at moderate to high demand significantly increases train operator costs due to increased dwell times and space limitations.

As demand increases further, Strategy 1 (Using shared bikes) becomes the most cost-efficient option for both users and operators. Unlike private bikes, the shared bikes can be used multiple times throughout the period. One user takes the shared bike, rides on it, returns it as the trip ends, and another user can immediately take the same bike. When bikes are continuously used, a smaller number of bikes is required; thus, a smaller area of land is used for the parking. In the shared bike system, costs are distributed across a greater number of users, resulting in a lower cost per user. In contrast, the private bike will remain unused in the parking area for the whole period until the user returns. Accommodating all private bike users under high demand requires larger land for the parking area. This will lead to higher operator costs and eventually, a higher cost per user. Using the shared bikes in high-demand scenarios is more beneficial than parking private bikes.

This model can also be used for sensitivity analysis to help policymakers evaluate the impact of various operational conditions aside from the hourly demand. For example, the model can assess the effects of increased bike costs, limited train capacities, and expensive land costs. These insights help policymakers strategically prioritize infrastructure investments according to the different scenarios. Additionally, this model can be applied to other contexts, providing a general framework to compare the different bike-train strategies.

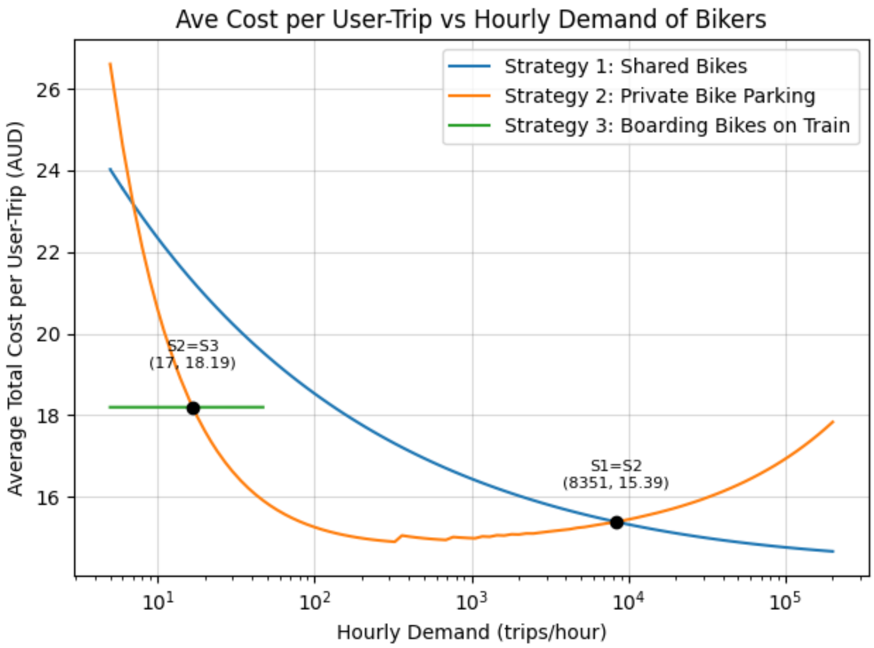

Figure 2: Cost (AUD) per user vs. Hourly Demand

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Wednesday 10th December: 11am-12.30pm
Parallel Session 1 (Level 17, Lecture room 3)
Theme: Empirical Insights in Sustainable Transport Practice, Session Chair: Prof. David Levinson
Understanding satisfaction and travel behavior of nationwide Fare-Free Public Transport in Luxembourg (Antonella Falanga, Francesco Viti, Armando Cartenì and Ilaria Henke)
Scaling Mobility as a Service through Multiservice Platforms: Evidence from Australia and Japan (Chinh Ho, Aitan Militão, Yuto Sasaki, Hitomi Sato and Toshiyuki Yamamoto)
Shared Bike Availability Service Gap Measurement: A Case Study in Taipei City (Barbara T.H. Yen, Corinne Mulley and Robert B.C Liu)

Understanding satisfaction and travel behavior of nationwide Fare-Free Public Transport in Luxembourg

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Introduction

Public transport (PT) is a key component of sustainable mobility, playing a fundamental role in mitigating congestion, reducing greenhouse gas emissions, and promoting social inclusion (e.g., Porru et al., 2021; Ceder, 2021). The quality of PT systems, as perceived by users, influences not only satisfaction but also future behavioral intentions. Attributes such as travel time, frequency, cleanliness, comfort, safety, and aesthetics significantly shape passenger experience and can either encourage or deter regular use (e.g., Eboli and Mazzulla, 2007; Tyrinopoulos and Antoniou, 2008; dell'Olio et al., 2011; de Oña et al., 2013).
In recent years, various governments and local authorities have introduced free or affordable fares through heavily subsidized PT policies to promote modal shift from private cars to collective transport, with the dual aim of addressing environmental challenges and improving equity in access to mobility (Cats et al., 2017; Hess, 2017; Van Goeverden et al., 2006; Loder et al. 2023; Inturri et al., 2020; Guzman and Cantillo-Garcia, 2024). In this context, Luxembourg represents a unique case. In March 2020, the country became the first in the world to introduce nationwide fare-free public transport (FFPT), granting all users free access to buses, trams and second-class train services (Ministry of Mobility and Public Works, 2020). The policy was implemented as part of a broader strategy to improve sustainability, reduce car dependency, and enhance social equity. Despite widespread international attention, there is still little evidence in literature about its long-term impact, especially when it comes to how satisfied people are with their trips and whether they actually change their travel behavior. Some studies have found that simply removing fares might not be enough to get people to switch to public transport, unless service quality and infrastructure also improve. Starting from these considerations, the aim of the study is to investigate how FFPT influences passengers' satisfaction and changes in their travel behavior. This study purposes to fill that gap by analyzing the impact of FFPT in Luxembourg through the comparison of two large-scale surveys: a survey conducted in 2020 before the introduction of the policy and a ex-post survey carried out from December 2024 onward. The research explores two key questions: (1) How does FFPT affect passengers' satisfaction with public transport services? (2) To what extent does satisfaction influence the intention to continue using and recommending public transport?.

Body

The research compares two surveys: an ex-ante survey conducted in 2020 by Institute of Socio-Economic Research (LISER) and University of Luxembourg (uni.lu), with 1,964 respondents (Luxembourg residents and cross-border workers from Belgium, France, and Germany) (Maciejewska et al., 2023) and an ex-post survey, launched in December 2024 and still ongoing, designed and disseminated by University of Luxembourg and University of Campania "Luigi Vanvitelli".

The latter was structured as a national online questionnaire, distributed through social media, institutional newsletters and flyers. It targeted adults (>16 years) who regularly travel to Luxembourg for work/study. The survey includes four main sections aiming at collecting information of socio-demographics, travel habits, satisfaction and service quality perceptions (e.g., cleanliness, comfort, punctuality, safety, cost), behavioral intention. Respondents answered satisfaction and intention questions on a 5-point Likert scale from “very dissatisfied”/”strongly disagree” to “very satisfied”/”strongly agree”. As of June 2025, 503 valid responses were collected in the ex-post survey. An initial descriptive analysis compared satisfaction scores and behavioral motivations between the two surveys. To explore latent relationships, an Exploratory Factor Analysis (EFA) was conducted, identifying consistent underlying constructs (e.g., comfort, safety, cleanliness). Subsequently, a PLS-SEM was calibrated with SmartPLS software to test the following hypothesis: H^{1+}: Satisfaction with PT service quality has a positive effect on behavioral intention (future use and recommendation).

The socio-demographic composition remained stable between surveys, with a majority of respondents residing in Luxembourg (76% in 2020; 78.1% in 2025). The age distribution shifted slightly toward younger users (18–34), who represent 69.4% of the ex-post sample (see Table 1).

A notable change occurred in the motivations for using public transport. Before FFPT, the top reasons included: “I don’t own a car” (20.0%); “environmental benefits” (18.7%); “less stressful than driving” (15.8%). In contrast, free access emerged as the top reason in the post-FFPT survey (21.4%), followed by environmental benefits (15.6%) and the ability to multitask (12.0%). Among cross-border commuters, free access also gained importance (13.8%), after environmental and practical considerations. These findings confirm that FFPT served as a strong incentive, particularly for new or previously discouraged users.

Both surveys assessed satisfaction with key PT attributes. The 2020 results already showed relatively high satisfaction with price, due to previously low fares. However, punctuality and frequency were recurring weaknesses, especially on bus lines. The ex-post survey confirmed that cleanliness and comfort remain the most appreciated attributes; punctuality and frequency, while slightly improved, continue to be the lowest-rated factors; the perception of value for money improved significantly due to free access (see Figure 1 and Figure 2).

The PLS-SEM model confirms H^{1+}, suggesting that satisfaction significantly enhances the intention to continue using PT and to recommend it to others. Moreover, free access shows both a direct and indirect effect (via satisfaction) on behavioral intention.

Luxembourg’s nationwide FFPT policy has positively impacted travel behavior and user perception. Free access has become a primary driver of PT use, especially for younger and lower-income populations. The improved perceived value of services has contributed to increased satisfaction, while operational weaknesses (e.g., frequency and punctuality) remain areas for attention.

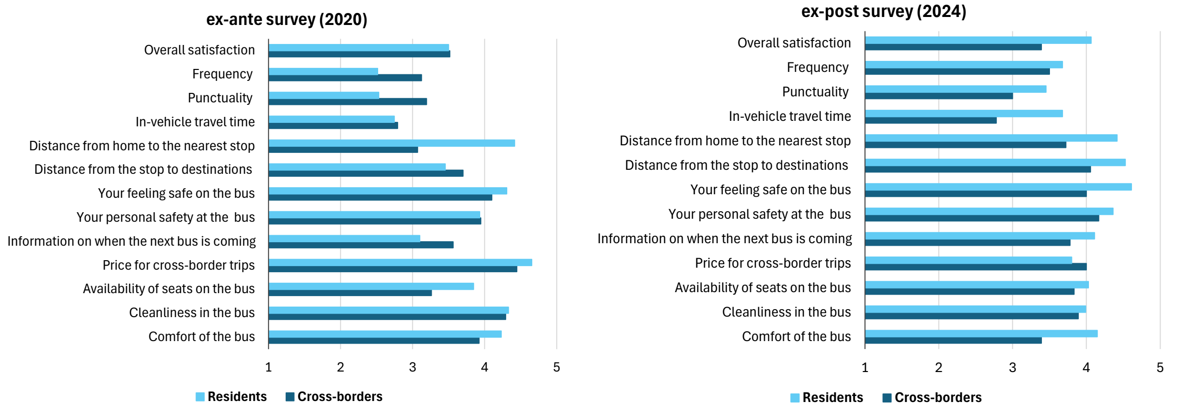
This research provides empirical evidence supporting the role of FFPT as a behavioral lever for modal shift. However, fare abolition alone is not sufficient: it must be complemented by service improvements to ensure long-term success. Recommendations for further study include the collection of new data to achieve greater sample representativeness, longitudinal tracking to assess whether behavioral changes are sustained over time, segment analysis by age, income, and residence to identify differential impacts. Furthermore it is planned to extend the SEM model to Luxembourg’s case offers valuable insights for other cities and countries considering FFPT, illustrating both its potential and its limitations within broader sustainable mobility policies.

Table 1 : Socio-economic characteristics

	2020	2024
Residence		
Resident of Luxembourg	76.0%	78.1%
Cross-border commuter (BE, FR and DE)	24.0%	21.9%
Gender		
Female	48.5%	47.9%
Male	51.5%	49.3%
Non-binary		1.4%
Prefer not to say		1.4%
Age		
18-24	7.7%	31.2%
25-34	31.9%	38.2%
35-49	39.5%	18.8%
50-64	17.4%	11.8%

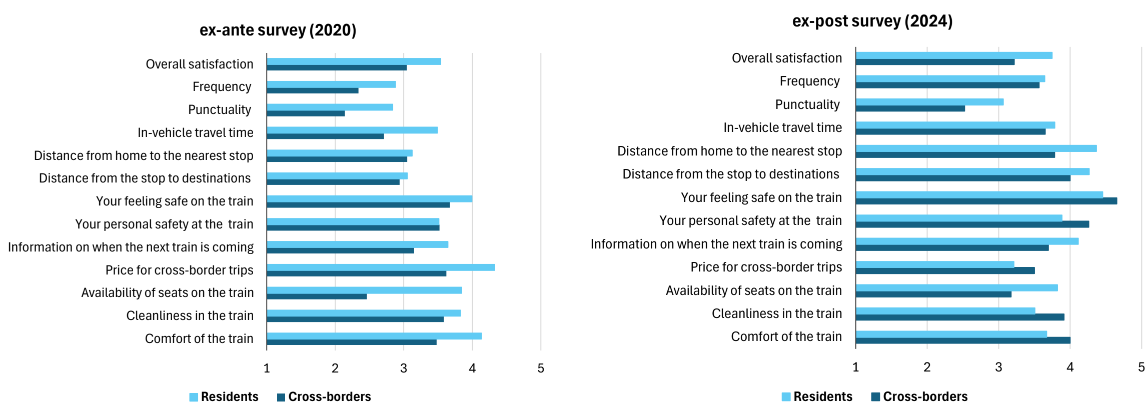
*Due to missing values, most variables have less than 1,964 responses.
** The age percentages for 2020 do not sum to 100% because only age groups shared with the 2024 survey were included.

Figure 1 : Level of satisfaction with different attributes of bus services in Luxembourg



(a) (b)

Figure 2 : Level of satisfaction with different attributes of train services in Luxembourg



(c) (d)

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Scaling Mobility as a Service through Multiservice Platforms: Evidence from Australia and Japan

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Introduction

Mobility as a Service (MaaS) has been promoted as a digital tool in travel demand management, with potential to reduce reliance on private cars and encourage sustainable mobility behaviours. Its conceptual roots lie in the development of intermodal digital platforms integrating public transport (PT), shared modes, and on-demand services into seamless packages (Ho et al., 2018). More recently, MaaS has evolved into Mobility as a Feature (MaaF), where mobility is bundled with non-mobility services such as entertainment, delivery, and subscription-based digital products, creating broader multiservice offers (Hensher and Hietanen, 2023).

This paradigm shift opens opportunities to address two enduring challenges for MaaS to become a mainstream product: (i) encouraging mode shift away from private cars, particularly the second household vehicle, and (ii) achieving commercial scalability by leveraging cross-subsidisation between mobility and non-mobility services. As such, multiservice platforms may better align individual consumer appeal with sustainable transport policy objectives.

The present study contributes to this agenda by empirically testing preferences for multiservice bundles in Australia and Japan. By conducting parallel Stated Preference (SP) experiments in two culturally and institutionally distinct contexts, we assess Willingness To Pay (WTP) for various mobility and non-mobility attributes, compare demand patterns, and discuss the implications for scaling MaaS across diverse urban settings.

Methods

The study employed online SP surveys administered in Australia and Japan, obtaining a valid sample of more than 1,000 parptipants in each country. The Australian survey design was informed by semi-structured interviews with industry stakeholders and the general public to identify relevant non-mobility services (Militao, 2025). The survey incorporated mobility attributes (i.e., unlimited days of public transport, car-sharing hours, micromobility minutes, and taxi/ride-hailing discounts), alongside non-mobility features including delivery entitlements, media subscriptions, entertainment discounts, and a reward points system. The design followed a Bayesian D-efficient framework with best–worst choice tasks. The Japanese survey retained the experimental structure but adapted non-mobility services to local consumption contexts: entertainment tickets (concerts, festivals), book/manga subscriptions instead of gaming, and capped discounts suitable to domestic price levels. Both surveys used screening questions and classified respondents by driving licence status and frequency of public transport use, ensuring balanced representation across market segments.

To compare across countries, a joint nested logit model (Ben-Akiva and Morikawa, 1990) was estimated using the "two-branch" trick that treats Australian and Japanese datasets as parallel nests with distinct parameters but shared error structures. Using generic cost parameters across two datasets, this approach allows for scale heterogeneity and facilitate formal testing of statistical differences across contexts. WTP estimates were derived and compared.

Results

The joint model results reveal both commonalities and divergences between the two contexts. In both countries, flexible Pay-As-You-Go (PAYG) offers were most preferred, reflecting market demand for flexibility. However, subscription bundles with PT and car-sharing entitlements attracted positive valuation in both contexts. Table 1 summarises the estimated WTP for selected service attributes. The results highlight several findings. With respect to mobility services, car-sharing is positively valued in both countries, with higher WTP in Australia. Public transport WTP in Australia is close to prevailing daily fare caps in Sydney, but in Japan is substantially below market price, reflecting employer coverage of commuting costs. In both countries, micromobility is consistently undervalued. As for non-mobility services, entertainment is negatively valued in Australia but attractive in Japan when offered as unlimited tickets. Reward points systems are positively valued in both contexts, particularly in Australia. Japanese appear to strongly object the inclusion of book/manga subscriptions in multiservice offers. Among different user groups, younger Australians favour bundle plans, while younger Japanese lean towards status quo options. Households with children show higher uptake in both datasets, albeit with country-specific differences in preferred bundles

Table 1. Willingness-to-pay for multiservice attributes in Australia and Japan.

Attribute	**Australia**	**Japan**
Unlimited PT days (AUD/day)	15.62	1.77
Car-sharing (AUD/hour)	7.79	5.62
Micromobility (AUD/min)	−1.43	−0.63
Taxi/Uber (AUD/1% discount)	1.26	NA
Points system (AUD)	43.95 (PAYG only)	29.25
Entertainment (AUD/1% discount)	−4.13	2.31 (PAYG only)
Entertainment unlimited times (AUD)	n/a	24.18
Entertainment 2 times (AUD)	n/a	−51.46

Notes: All values in AUD; negative values denote disutility; n/a = not applicable.

Discussion and Recommendations

The comparative evidence illustrates how contextual factors, including legislation, cultural norms and labour markets, shape the appeal of multiservice. In Australia, where commuters bear the cost of PT and car ownership is relatively accessible (licence-based), bundles that subsidise PT and car-sharing present tangible benefits. In contrast, in Japan, where employers cover commuting costs and car ownership requires proof of parking, multiservice bundles appeal more as substitutes for second-car ownership in dense metropolitan areas. Notably, WTP for PT is markedly lower in Japan than in Australia, consistent with institutional differences in cost-bearing. Conversely, entertainment and points-based gamification have stronger appeal in Japan, suggesting multiservice MaaS may thrive when positioned as lifestyle packages rather than purely mobility products.

The findings have important implications for policy and practice. First, market segmentation and context-sensitive bundle design are central to scaling MaaS. Providers should target groups with high potential uptake such as households with frequent delivery needs, younger adults motivated by gamification, and metropolitan households with limited car access.

Second, bundle design must reflect local contexts: in Japan, integrating unlimited entertainment and reward schemes can strengthen appeal through cross-subsidies, while in Australia, packages focusing on public transport discounts and car-sharing are more effective in reducing car dependence. Third, cross-subsidies from non-mobility services are essential to achieve commercial viability, as positive WTP for these services can offset the lower valuation of PT. Finally, governments play a key enabling role by establishing regulatory frameworks and fostering partnerships that allow providers to integrate both mobility and non-mobility services, while safeguarding public goals of sustainability, emissions reduction, and equitable access.

Conclusion

This study provides the first comparative empirical analysis of multiservice MaaS offers in Australia and Japan. The results confirm that while MaaS retains its sustainability promise, scaling it commercially requires broadening its value proposition beyond mobility. Multiservice platforms, framed as lifestyle solutions with mobility as a feature, can help reduce car dependence and deliver demand management benefits if tailored to local institutional and cultural settings.

Acknowledgements

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Shared Bike Availability Service Gap Measurement considering travel demand: A Case Study in Taipei City

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Introduction

Enhancing the accessibility to serve diverse users is one of the aims of public transport in urban areas (Eldeeb et al., 2024). However, there is a trade-off between accessibility and operating efficiency when planning the public transport network (Murray & Wu, 2003). In particular, the first- and last-mile problem becomes an obstacle for users accessing public transport services and increases reliance on privately owned cars and motorcycles. To deal with this issue, active transport in the form of shared modes, especially a public shared bike scheme, is often treated as a solution due to its low cost, faster speed than walking, and sustainability features (Farber & Fu, 2017; Liu et al., 2012; Yen et al., 2023). Thus, such shared modes can bridge the service gap between public transport nodes and users' origins and destinations, servicing the first- and last-mile problem. Shared modes in this way can also enlarge the catchment area of the public transport system through providing greater accessibility (Zuo et al., 2018). In Taipei City, Taiwan, for example, there are two main public transport modes, MRT and bus, each with high service quality. Taipei City introduced the dock- based public shared bike scheme branded as YouBike in 2012 to address the first- and last- mile problem in the urban area. However, the shared bike system might not guarantee service provision as shared bikes tend to float between stations in urban areas. The service quality (i.e., bike and dock availability) is not easy to measure since there are infrastructure limitations (e.g., dock availability) and operation strategies (e.g., shared bike relocation frequency). How to maintain the availability of both shared bikes and docks in each shared bike station is the most critical problem for the operator and authority. This study investigates the spatial distribution of bike and dock availability via hot spot methods to identify station features between shared bike supply and demand.

Case study area and data

The case study area of this research is Taipei City, the capital city and central business districts (CBDs) in Taiwan. Public transport modes in Taipei City include the main modes of MRT and city buses as well as heavy rail and highspeed rail. YouBike is the public shared bike scheme in Taipei City that started operating in 2012. The system is designed as a station-based docked system. There are currently 1,439 YouBike stations and 22,000 bikes in Taipei City with about 170,000 daily passengers as of September 2024. In order to maintain the performance of YouBike system, two operational indicators of hourly shared bike available rate and hourly dock available rates are used. In the remainder of the abstract, these are referred to operational variables. The hourly shared bike available rate indicates the proportion of time that the station is available for the bike within one hour, and the hourly dock available rate indicates the proportion of time that the bike station is available for users to return the bike within one hour. To carry out the hot spot analysis, the data was collected directly from the Taipei City Government between 7:00 and 9:00 am on each weekday in October 2024 and averaged.

The study uses the active population (i.e., active travellers) for each area in Taipei City as the proxy of demand for YouBike service. The data is recorded between 7:00 and 9:00 am on March 22, 2023, as provided by the central government. The data of the active population is strictly regulated and could only be provided for this time period and so is unmatched directly to the bike and dock data but is considered to be closely related. The active population is used to cross compare with the hourly shared bike available rate and hourly dock available rates.

Method

This study conducted hotspot analysis using Getis-Ord Gi* to explore the spatial distribution of the operational variables relating to bike and dock availability. Getis-Ord Gi* is a widely used statistical method for identifying the spatial distribution of high and low attribute values (Blazquez et al., 2015; Khosravi et al., 2022). Getis-Ord Gi* identifies the hot and cold spots from a spatial perspective. The Gi* statistic follows a Z-score distribution and allows the undertaking of significant tests. A high positive Gi* value indicates that the feature is in the cluster of high values and can be identified as a ‘hot spot’. In contrast, a high negative value indicates the feature is in the cluster of low values (i.e., cold spot).

Result and discussion

In order to specify the demand of each area in the morning peak, the active population is converted into a net population flow, which is the difference between the active population in the morning peak hour and the population in the preceding hour in each area. The net population flow in the morning peak hour (i.e., 7:00 to 9:00 am) is shown in Figure 1. If an area has positive population net flow (i.e., areas with red cells in Figure 1), then this indicates an inflow of people in the morning peak hour (e.g., business area, industrial park, school), while a negative net flow (i.e., areas with blue cells in Figure 1) indicates an outflow area (e.g., residential areas).

A cross-comparison between the results of hot spots analysis for both operational variables and the net population flow in Taipei City was conducted to provide an overview of YouBike's current balance situation. Figure 2 shows the hotspot analysis result of hourly shared bike available rate, and Figure 3 shows the result of hourly dock available rate. The operational variables are classified into hot (i.e., red stations in Figure 2 and Figure 3) and cold spots (i.e., blue stations in Figure 2 and Figure 3), while the net population flow is classified into positive and negative flow. For an area with negative net population flows, it is more likely to be lacking shared bikes (i.e., the cold spot of shared bike available rate) since the residents might ride the bike as their first mile mode for commuting, while the area with positive net flows, the lack of docks for users to return their shared bike (i.e., the cold spot of dock available rate) is more likely to occur. However, the results show that this does not appear to be the case. This might be attributed to effective shared bike distribution by the operator. Only a few residential areas have a low shared bike available rate, showing a service gap (i.e., insufficient supply in specific spatial and temporal patterns) of the YouBike system. In the CBD area, which is an area with positive net flow, the lack of shared bikes occurs during morning peak hours. It indicates that the demand inside the city is also strong, and more shared bikes might be placed in the CBD area to address the demand.

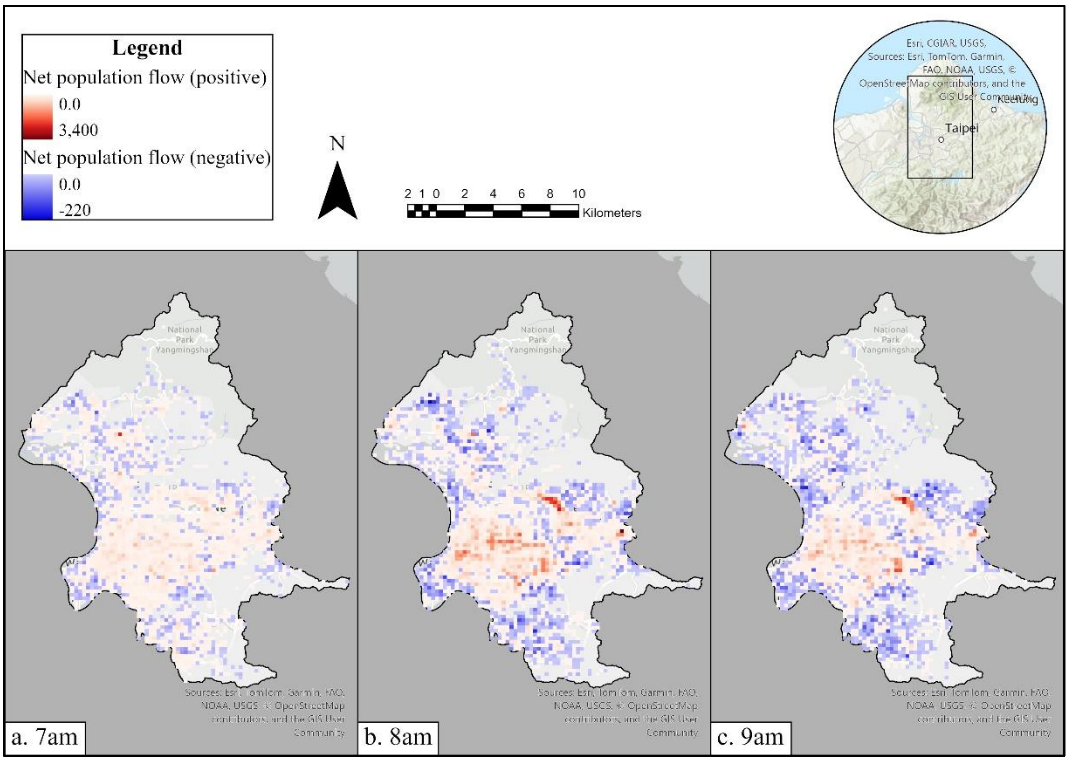

Figure 1 Net population flow in the peak hour

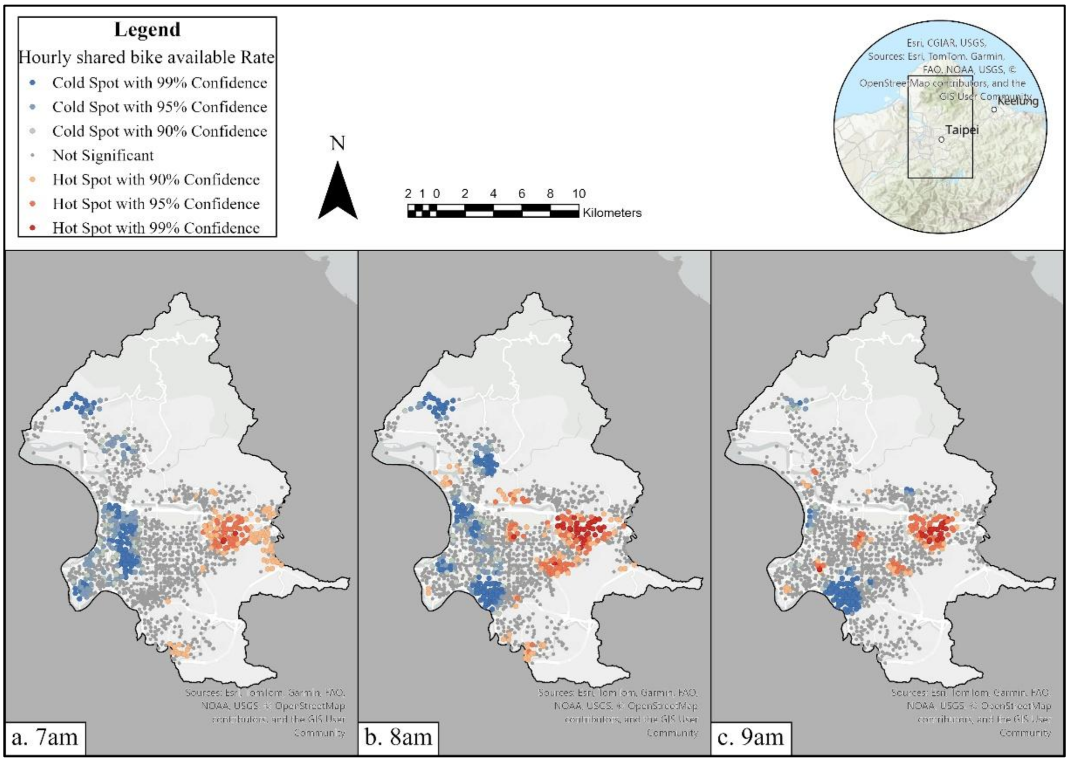

Figure 2 Hourly shared bike available rate in the peak hour

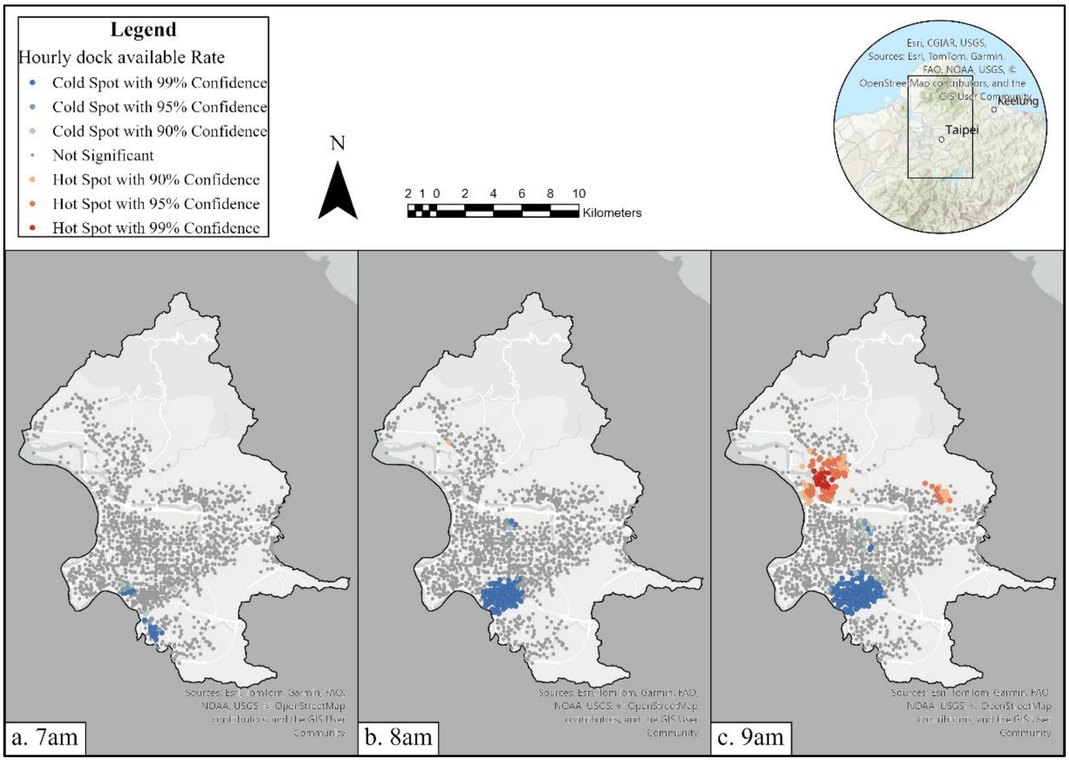

Figure 3 Hourly dock available rate in the peak hour

Recommendations for future study

This study provides an overview of the availability of the public shared bike scheme in the urban area. Several areas do have mismatches between the operational variables and demand, which can be improved to enhance the efficiency of resource allocation. In order to capture the factors that influence the operational variables and provide a more general and comprehensive analysis, a regression model considering spatial effects (e.g., geographically weighted regression, GWR) might be introduced in future studies.

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Wednesday 10th December: 11am-12.30pm
Parallel Session 2 (Level 16, Seminar room)
Theme: Pathways to Net Zero: Decarbonising Transport Systems, Session Chair: Dr. Emily Moylan
Decarbonizing Land-Based Passenger Transport in Saudi Arabia (Yagyavalk Bhatt)
The Path to Net Zero: Travel Demand Management to support Decarbonising Australia's Transport System (Eleanor Short)
The danger of incorrect objectives for TDM (Elizabeth Ampt and Kate Mackay)

Extended Abstract

Decarbonizing Land-Based Passenger Transport: Achieving Economy-Wide Net-Zero Emissions by 2060

Authors
Yagyavalk Bhatt, King Abdullah Petroleum Studies and Research Center
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Introduction

Saudi Arabia has laid out an ambitious decarbonization roadmap, targeting net-zero greenhouse gas (GHG) emissions by 2060. This study applies Integrated Assessment Modeling (IAM), specifically GCAM-KSA (KAPSARC 2025), to evaluate the long-term impacts of this commitment, focusing on the road passenger transport sector. The research identifies key pathways such as transitioning to electric vehicles and expanding public transportation—including rail and buses—to reduce emissions. Despite ranking 41st in global population, Saudi Arabia is the 10th-largest consumer of gasoline, with one of the highest per capita usage rates worldwide. Population growth, urbanization, and increased car ownership have significantly raised transport fuel demand and GHG emissions. In 2021, the transport sector contributed 18% to the nation's total GHG emissions of 743.39 $MtCO_2e$. Rising vehicle registrations and bus ridership reflect both the growing mobility demand and emerging shifts toward public transport, with a 233.9% year-over-year increase in bus passengers noted in 2022. To curb emissions, Saudi Arabia has initiated fuel economy standards, energy price reforms, and major strategic plans like Vision 2030 and the Saudi Green Initiative (SGI). These emphasize sustainability through energy diversification, electric and hydrogen vehicle adoption, and carbon capture technologies. The SGI targets include 50% electricity from renewables by 2030, planting 10 billion trees, and electrifying 30% of Riyadh's vehicles by 2030. Investments in Lucid Motors and plans to install 5,000+ fast EV chargers further underscore this commitment. City-level initiatives like the King Abdulaziz Project in Riyadh and the Jeddah Public Transportation Program aim to establish sustainable urban mobility systems. These projects integrate metro lines and Bus Rapid Transit (BRT) to offer efficient, low-carbon alternatives. Achieving Net-Zero by 2060 will require sustained focus on clean vehicle deployment, infrastructure investment, and comprehensive transport sector transformation. This study outlines viable decarbonization pathways to support Saudi Arabia's climate goals.

Research goals

This study employs a modified version of the Global Change Analysis Model (GCAM v7.0), an Integrated Assessment Model (IAM) that captures the interactions among energy systems, water, agriculture and land use, the economy, and the climate. It aims to assess the evolution of Saudi Arabia's road passenger transport sector within the broader context of achieving economy-wide Net Zero greenhouse gas emissions by 2060. The key objectives include analyzing current decarbonization ambitions, evaluating the additional efforts needed to meet Net Zero goals, estimating potential emissions reductions through public transport initiatives (bus and rail), and assessing the deployment of clean energy vehicle technologies such as electric vehicles (EVs). The study also seeks to provide empirical insights to policymakers, industry stakeholders, and consumers to support a sustainable transition in the transport sector. It is structured as follows: a description of the modeling framework, scenario design, and key assumptions; followed by a presentation and discussion of results under various scenarios; and concluding with a summary of findings and recommendations for guiding sustainable mobility in Saudi Arabia.

Methodology

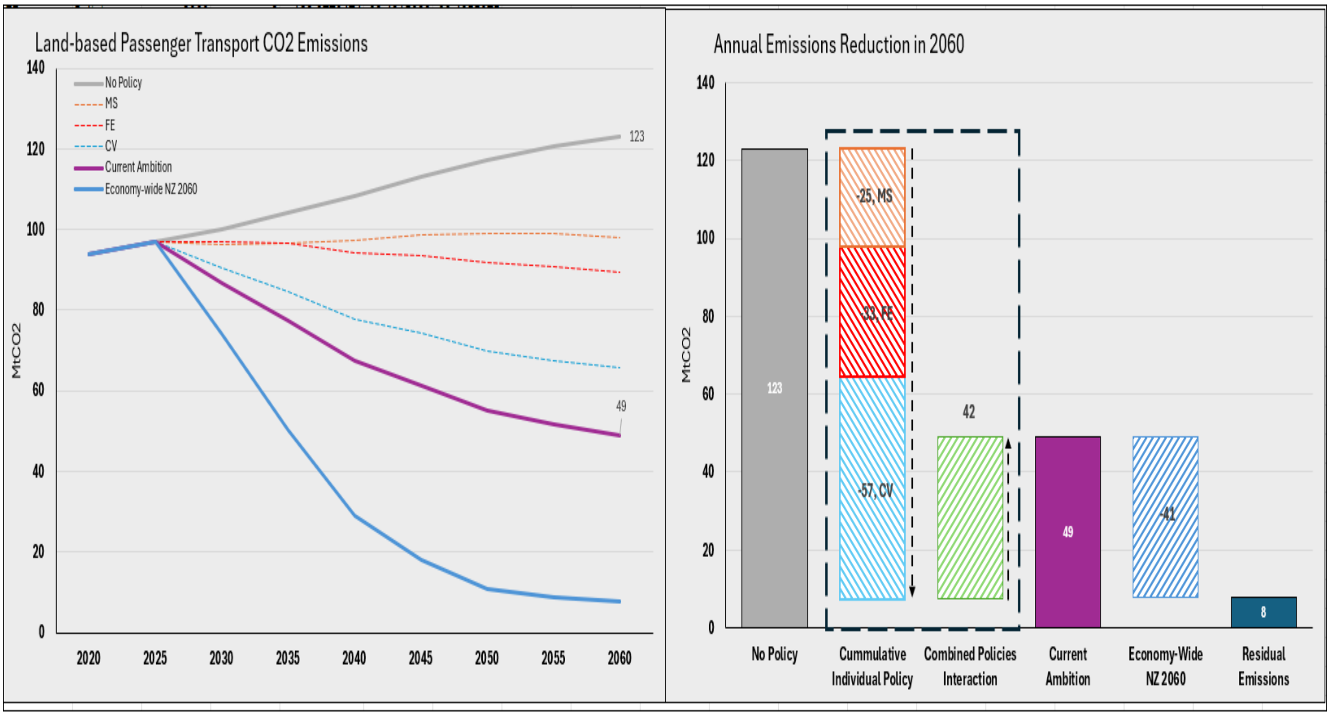
This study considers four scenarios out to 2060 using GCAM-KSA. These scenarios aim to evaluate the long-term impact of various policies and mitigation efforts on Saudi Arabia's energy system. For all the scenarios, we assume a growing economy and an increasing population, with per capita income reaching USD 37000 (2020 prices) in 2060 and a population of 60 million. We incorporate the impact of COVID-19 on the GDP growth rate in 2020 and its subsequent recovery in 2025, as projected by the International Monetary Fund (IMF) (IMF, 2023). The population and GDP growth rates thereafter align with the Shared Socioeconomic Pathways – Middle of the Road (SSP2) assumptions for the growth rate from the SSP database (Oliver Fricko, 2017). Saudi Arabia-specific critical policies and mitigation targets that are used to characterize the scenarios in this study are listed below.

Under the **No-Policy baseline**, Saudi Arabia retains pre-2015 conditions: no post-2015 Corporate Average Fuel Economy (CAFE) standards or other fuel-efficiency measures, no expansion of public transport infrastructure, no incentives for zero-emission vehicles, and no economy-wide net-zero (NZ) target. The **Current Ambition scenario** layers in today's commitments: the existing CAFE standards deliver incremental fuel-efficiency gains for light-duty vehicles; mode-shift policies aim for buses and rail to capture 20 % of domestic passenger travel by 2060; Riyadh's pledge for 30 % clean-vehicle sales by 2030 is applied nationwide but does not deepen thereafter; and, critically, there is still no binding economy-wide NZ goal. The most stringent pathway, **Economy-Wide NZ 2060**, preserves the fuel-efficiency and public-transport initiatives already underway, extends the 30 % clean-vehicle share nationally by 2030 (again without post-2030 escalation), and overlays a mandatory linear decline of greenhouse-gas emissions to zero across all sectors by 2060, effectively transforming the transport measures from aspirational to compulsory contributors within an integrated national decarbonization strategy.

Results

Saudi Arabia's net-zero pathway hinges on decarbonizing land-based passenger transport. Yet, simply adding the impacts of individual measures—like mode shifts, fuel efficiency improvements, and clean vehicle adoption—can overestimate total benefits due to trade-offs. For instance, improved fuel efficiency can diminish the incentive to adopt BEVs, while expanded public transportation reduces the need for private vehicle usage. Figure 4a illustrates these interactions: by 2060, the Current Ambition scenario saves about 207 million BOE compared to No Policy, whereas the Economy-Wide NZ scenario saves 340 million BOE, 133 million more than Current Ambition.

Figure 1. (a) Fuel consumption from the land-based passenger transport sector in Saudi Arabia across all scenarios; (b) CO_2 emissions from the land transport sector in Saudi Arabia; and (c) The interaction effect of policies.



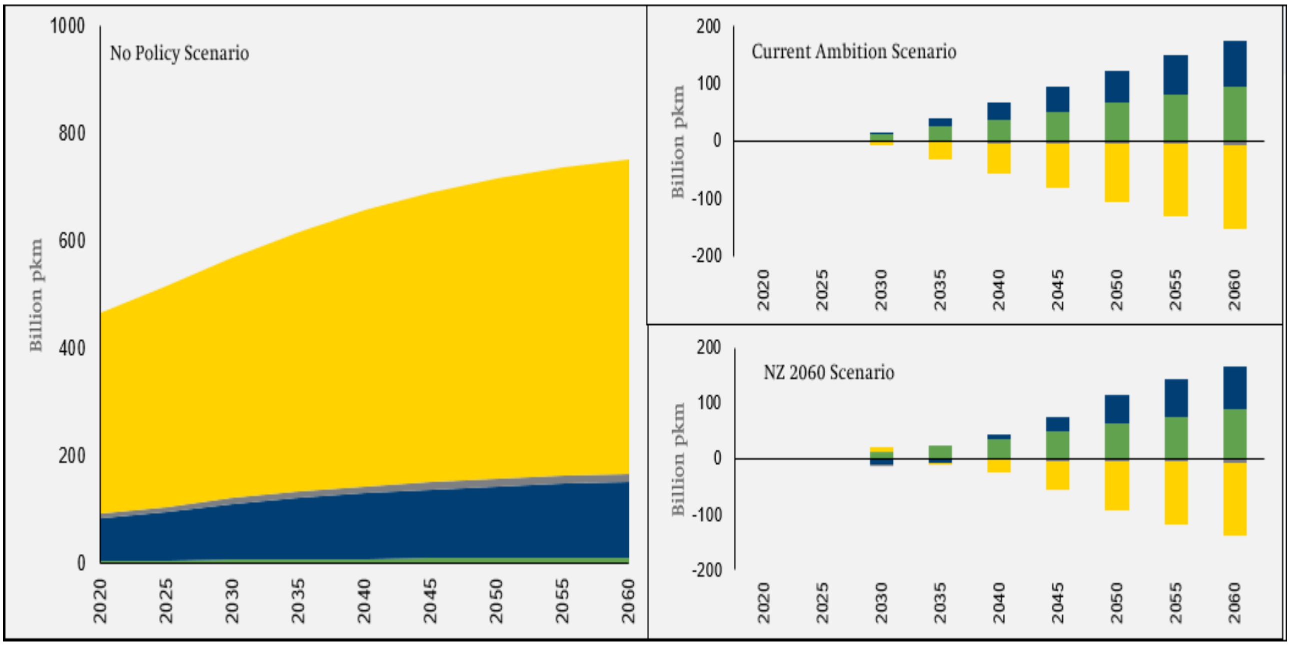
Source: Authors' analysis based on GCAM-KSA v2.0.

Note: MS = Modal Shift scenario; FE = Fuel Efficiency scenario; CV = Clean Vehicle scenario; MtCO2 = million tons of CO2.

Under the current ambition scenario, land-based passenger transportation emissions decline gradually but will not fully decarbonize by 2060. The right panel shows that combining multiple policies (fuel efficiency, clean vehicles, and modal shift) achieves a more substantial emissions reduction of around 74 $MtCO_2$, compared to the individual policy impacts of 33, 57, and 25 $MtCO_2$, respectively. This underscores the importance of a holistic approach—combining electrification, fuel efficiency, and alternative modes—to address emissions from multiple angles and remain adaptive to technological and market changes. In contrast, the Economy-Wide NZ 2060 scenario dramatically reduces emissions from land-based passenger transport to near-zero levels, driven by the widespread adoption of battery-electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs). BEVs become the primary mode for private vehicles and buses, while FCEVs also scale up, particularly in buses.

Shift to Clean Energy Vehicles and Public Transport

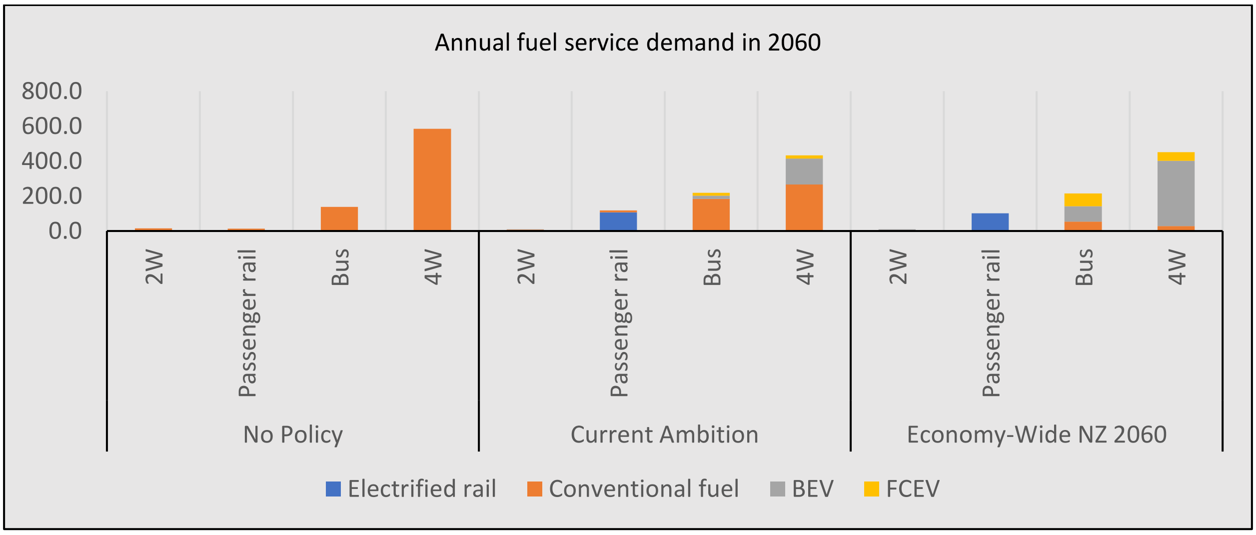
Figure 2. The potential for a modal shift in land passenger transport to public transport in the No Policy, Current Ambition, and Economy-Wide NZ 2060 scenarios.



Source: Authors' analysis based on GCAM-KSA v2.0.

Figures 2 and 3 illustrate projected modal and fuel shifts in Saudi Arabia's land passenger transport across three scenarios—No Policy, Current Ambition, and Economy-Wide NZ 2060. Total passenger demand grows from 466 to 752 billion passenger-kilometers (pkm) by 2060. In the No Policy scenario, four-wheelers dominate (78%), with buses at 18% (mainly private), and negligible rail usage. By contrast, under Current Ambition, 4W share declines to 57%, buses rise to 28%, and rail grows to 14%, reflecting public transit investments like city buses and Riyadh's metro. Similar patterns emerge in the NZ 2060 scenario. Fuel use also diversifies: while conventional fuels dominate under No Policy, the Current Ambition scenario reduces their share to 60%, with BEVs at 22% and FCEVs at 5%. Rail electrification contributes 14% to demand. In the NZ 2060 scenario, conventional fuel drops to 11%, BEVs surge to 60% (48% from 4Ws, 12% from buses), and FCEVs reach 16% (9.5% from buses, 6.5% from 4Ws), signaling near-total decarbonization.

Figure 3. The fuel service demand shifts in the No Policy, Current Ambition, and Economy-Wide NZ 2060 scenarios.



Source: Authors' analysis based on GCAM-KSA v2.0.

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Extended Abstract

The Path to Net Zero: Travel Demand Management to support Decarbonising Australia's Transport System

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Addressing the urgent need for decarbonisation in the transport sector, which accounts for nearly 20% of Australia's greenhouse gas emissions, the Australian Institute of Traffic Planning & Management (AITPM) has published its inaugural Policy Issues Paper, "The Path to Net Zero: Decarbonising Australia's Transport System." This transformative paper introduces the "Avoid–Shift–Improve" framework, a strategic approach designed to reduce travel demand, foster sustainable transport modes, and integrate low and zero-carbon technologies into Australia's transport ecosystem.

The transport sector is the second-largest contributor to Australia's national emissions after energy. Despite advancements in internal combustion engine technologies, emissions continue to rise, compounded by an aging vehicle fleet and the growing popularity of larger vehicles such as SUVs. Tackling these challenges requires bold and transformative measures, which are central to the recommendations outlined in the Policy Issues Paper.

The "Avoid" component of the framework addresses the root causes of excessive travel demand by advocating for smarter land use and transport planning. Strategies include promoting compact, mixed-use urban development, constructing high-quality walking and cycling networks, and ensuring frequent and reliable public transport services. Furthermore, digital systems that facilitate remote working, online learning, and virtual access to services are highlighted as key tools to reduce reliance on physical travel. The paper also underscores the importance of addressing urban sprawl and car-dependent communities by reforming planning rules and subsidies to encourage sustainable development.

The "Shift" component focuses on transforming travel choices and encouraging behaviour change. Key initiatives include investing in active transport infrastructure, extending the reach and appeal of public transport services, and promoting shared mobility programs such as car-sharing and demand-responsive transport. Pricing mechanisms—such as road user charges and differential parking fees—are recommended to disincentivize driving while incentivizing lower-carbon alternatives. Additionally, the introduction of Low Emission Zones is proposed as a progressive rollout strategy to reduce emissions while improving air quality. Behaviour change campaigns, including e-bike subsidies and targeted public information efforts, are identified as effective methods to encourage more sustainable travel habits.

The "Improve" component outlines the transition to zero-emission vehicles and the decarbonization of transport infrastructure. Recommendations include accelerating the adoption of electric vehicles (EVs) through incentives and the development of publicly accessible charging networks. For heavy vehicles such as trucks and buses, providing financial incentives and regulatory support for battery-electric and hydrogen-powered models is deemed essential. Rail transport offers significant opportunities for decarbonization, with electrification and battery-electric locomotives positioned as key areas of focus. While maritime and aviation sectors pose greater challenges for electrification, the development and use of low-carbon liquid fuels and sustainable aviation fuel are underscored as vital next steps. Furthermore, the paper highlights the importance of using low-carbon materials in infrastructure projects and critically evaluating the need for new construction to reduce embodied carbon.

Achieving rapid decarbonization in Australia's transport sector will require bold leadership and systemic reforms. The paper calls for establishing carbon budgets to guide emissions reduction efforts with accountability and transparency. Policy alignment across jurisdictions will be critical to maximizing the impact of decarbonization strategies. Decision-making and funding should be delegated to the most effective level, with local governments empowered to implement active transport infrastructure. The Australian Government's financial capacity must be leveraged to realign transport investment priorities, shifting focus from road projects to public and active transport initiatives.

AITPM is committed to fostering collaboration among governments, industries, and communities to achieve a Net Zero transport future. Its commitments include advocating for integrated urban policy and planning, promoting access to active and public transport, and providing resources and training to tackle decarbonization challenges. By bringing together stakeholders, AITPM aims to demonstrate leadership and drive the transition to a fully sustainable and decarbonized transport system.

This presentation will delve into the insights and findings of the Policy Issues Paper, focusing on the application of the "Avoid–Shift–Improve" framework to travel demand management. Join us to explore how governments, industries, and communities can collaborate to meet one of the most pressing challenges of our time—building a cleaner, greener, and more sustainable transport future.

Acknowledgements

We acknowledge the contribution of the AITPM Decarbonisation working group in the preparation of the Policy Issues Paper:

- Sebastian Davies-Slate
- Roger Green
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- Dr Eleanor Short
- Sara Stace
- Tim Sullivan
- Dr Shamsunnahar Yasmin
- Matt Faber
- Hannah Hartnett
- Kirsty Kelly

Extended Abstract

The danger of incorrect objectives for TDM

Elizabeth Ampt*[1] and Kate Mackay[2]

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Travel Demand Management[1] (TDM) programs across the world are carried out for different purposes. Most often this is to decrease private motor vehicle use (e.g. Eriksson et al., 2010; Cleland et al., 2023; Ampt, 2025). The purposes can range from reducing congestion, to improving road safety, to reducing climate impacts, to reducing local pollution, to changing the shape of cities and towns to foster more personal interactions, to creating health benefits of more active alternatives, to stimulating community interactions as part of the change, to saving money, to reducing road trauma and mental stress associated with driving, to creating independence without the need for a car – and probably others.

While the definition is widely agreed on, as researchers, transport planners, decision makers and modellers, we seem to expect people to behave in certain ways (to achieve this objective) without paying enough attention to the motivations behind the behaviour we want to change. Despite strong advances in behavioural science (starting as early as 1988 [Thaler, 1988] which showed that people do not behave 'rationally'), most TDM measures continue to assume that they will.

Examples come from all types of TDM approaches.

- Build some infrastructure. More (and safer) trains, buses, and bike paths will encourage more people to use alternatives. (Department of Infrastructure and Transport, 2022)
- Make some rules. Such as increase the price of car travel so that alternatives seem cheaper, decrease the price of alternatives so they become more attractive, regulate – no parking zones in the CBD will surely encourage alternative behaviours, banning or pricing diesel and petrol fuels will certainly encourage more people to change the way they travel, or making cheaper parking for those who share rides will definitely reduce the vehicles that come to our workplace. (e.g. Veitch and Rhodes, 2024; Rose et al, 2025)
- Listen to people. Find the motivations for their behaviour and get them to think about ways they could avoid one or two car trips that annoy them most – using their own solutions. This one is the least used, but has surprisingly been shown to be the most successful in many cases (e.g. Ampt and Mackay 2024).

Using the first two methods alone leads to frustrations for implementers and modellers alike – for example leading to some modellers to criticise 'over optimistic' assumptions of toll road forecasts (Bain and Sullivan, 2024) or studies to assess what would make it more likely for cyclists to use bike paths (e.g. Transport for NSW 2021).

[1] Often known as mobility management.

In other words, from the perspective of the transport planner, modeller and decision maker, people's travel behaviour is 'messy'. It is not 'rational' – people drive when it would be cheaper to walk, they walk when it would be quicker to drive. Hence we need to 'manage the demand' of these messy people to get them to behave in 'the way that is best of society'.

But we continue to create models and forecasts as if people will react 'logically' and change in the way expected. And, while these attempts often work at the outset, if they are changed, those messy people will go back to their messy behaviour. Or worse still, they will work out a way around it. 'I'll park my car in a quiet suburban street and walk the last bit of the way to my destination'.

When people's behaviours are considered from the perspective of the individual or household, they are totally logical – albeit based on subjective rationality (Brög, 1982) 'I take my children to school by car because it is too dangerous for them to walk'. If it is too dangerous to walk, and car is seen as safer, it is perfectly logical to take the children to school by car. Brög argued that the options which an individual has to choose from are determined by:

- The material supply of the transport infrastructure
- The constraints and options of the individual and their household and
- The social values, norms and opinions relevant to transport behaviour.

This means that each individual experiences situations uniquely. They are, in fact, behaving very rationally in response to their perception of reality. Early economists also recognised this as a reality, but considered it a type of weakness - bounded rationality (Simon, H, 1955).

This paper argues that once people's understanding of the situation and their motivations are considered, it becomes possible to change behaviour in a much more significant way. In particular, approaches to TDM need to be household based and we need to use extended ways of understanding motivations and marketing to different types of people. Furthermore, in order to ensure that change actually happens, we need to come up with imaginative ways to measure before and after behaviours.

The abstract, and the accompanying presentation, is designed as a thinkpiece, to present and comment on evidence from around the world which suggests that to achieve sustainable behaviour change there needs to be a much broader articulation consideration of the factors impacting on how people choose to undertake activities.

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Wednesday 10th December: 11am-12.30pm
Parallel Session 3 (Level 16, Lecture room 5)
Theme: Urban Form, Density, and Mobility Interactions, Session Chair: Mr. Ben Wood
How Land Use and Infrastructure Location Shape Travel Behaviours (Kevin Xu, Ben Wood, Ed Chan and Hadron Group)
Simplified Travel Demand Forecasting Using Low-Cost Data from the ABS Census (Graham McCabe)
Integrating industrial land and urban freight - city level planning (Michael Stokoe)

How Land Use and Infrastructure Location Shape Travel Behaviours

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Introduction

Travel demand is often treated as a behavioural outcome, managed through downstream tools such as pricing or infrastructure upgrades. This overlooks a critical gap in planning practice: the role of land use and infrastructure location in shaping demand itself. While prior studies have explored accessibility and urban form, few have positioned these as core demand management levers.

This study addresses that gap by reframing travel demand as a spatial outcome of long-term planning decisions. It builds on, but departs from, conventional travel demand management literature by focusing on how urban structure constrains or enables mobility choices from the outset. The purpose is to promote a more integrated, accessibility-led planning framework suited to current challenges including hybrid work patterns, limited infrastructure budgets, and net zero targets.

The study focuses on Australian metropolitan regions and is conceptual in scope, synthesising existing evidence rather than generating new models. While not exhaustive, it aims to provoke a shift in how planning decisions are framed, assessed, and operationalised.

Methodology

This study will apply a conceptual and applied methodology to explore how spatial structure shapes travel demand. The approach will synthesise planning literature, review infrastructure appraisal practices, and use scenario-based reasoning supported by observed data from Australian cities. The method will comprise four key phases:

References

Phase 1: Policy and Framework Review

The study will begin with a review of transport modelling and infrastructure appraisal frameworks used in Australian jurisdictions. This review will focus on how these frameworks treat travel demand, particularly whether demand is considered exogenous or shaped by spatial variables such as land use and infrastructure investment.

Phase 2: Empirical Comparison of Urban Forms

Case studies from selected metropolitan areas will be used to compare travel behaviours across different land use types. Key indicators will include residential density, proximity to public transport, and trip generation rates by mode. This will enable a comparative analysis of how spatial conditions influence travel demand, independent of behavioural interventions.

Phase 3: Scenario-Based Reasoning

The study will apply scenario analysis to explore the impact of different land use and infrastructure configurations on travel demand profiles. Scenarios will range from compact, mixed-use developments with high accessibility to dispersed, car-dependent suburban forms. The aim will be to test how different spatial structures could generate or suppress demand.

Phase 4: Policy Logic Synthesis

Insights from the above phases will be synthesised to critically assess prevailing demand management approaches. A new planning logic will be developed, positioning spatial structure as a primary lever for shaping demand, rather than a passive condition. This analysis will inform a shift from reactive to generative planning.

Preliminary Findings and Discussion

The study is expected to find that urban form and infrastructure location significantly influence the volume, timing, and mode of travel. Specifically:

Land use will act as a baseline determinant of demand. In mixed-use, walkable, and transit-served areas, car travel is likely to be substantially lower even without pricing or awareness-based interventions. This aligns with findings from Botte (2015), who demonstrated that residents in transit-oriented developments in Perth generated fewer car trips due to better proximity to services and transport.

Low-density development will constrain transport choice. Dispersed residential patterns with limited access to services and transit are expected to result in high car dependence and be costly to serve with sustainable transport modes. Kamruzzaman et al. (2016) found that in Brisbane, walkability and transit proximity were key predictors of non-car travel, reinforcing the need for well-connected urban form.

Infrastructure location will send long-term signals. Major investments will not only enable movement but shape land values, development patterns, and mobility expectations. However, most transport models are likely to treat infrastructure as responsive to demand rather than a demand-shaping input.

Increased access may not always be beneficial. In some contexts, high-speed or high-capacity infrastructure may enable longer, less sustainable commutes. The study will pose a question for further exploration: should access be constrained in some cases, particularly for high-carbon or low-efficiency modes, to support broader liveability and emissions objectives?

These findings will support a reframing of travel demand as a consequence of spatial planning, not merely a behavioural or operational challenge.

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Simplified travel demand forecasting using low-cost data from the Australian Census

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Introduction

Transportation models in Australia rely on data accumulated from surveys of travel behaviour and census information, with populations synthesised using various approximations to develop region-wide algorithms for trip generation. However, these algorithms do not actively factor in how changes in land-use density (both population and employment) result in behavioural changes with transport models consistently overestimating the demand for driving and underestimating the demand for other modes. Through analysis of the Australian Census data from 2016, we demonstrate how land use density and other metrics affect the travel modes used for the journey to work and hypothesise forecast mode share algorithms for the 2026 census.

Body

Transportation models in Australia, such as the NSW Sydney Strategic Travel Model (STM), Victorian Integrated Transport Model (VITM), Victorian Land Use and Transport Integration (VLUTI) model and Brisbane Strategic Transport Model (BSTM), rely on generalised trip generation formulae that are determined based on demographic profiles rather than population or employment density. For example, the STM (Fox et al, 2012) uses car availability, Work status and personal income for the home-work-mode-destination segmentation model.

This approach towards trip generation modelling is applied across the range of trip purposes as shown in the following extract (Fox et al, 2012) from the RAND report on the STM.

Table 14: Home–business mode–destination model segments

	STM (2001 base)	STM (2006 base)
Segment	**Car availability**	**Car availability**
a1	No car in HH	Unchanged
a2	No licence but at least one car	
a3	Competition for car; no company car	
a4	Free car use; one non-company car	
a5	Free car use; several licences in HH; no company car	
a6	Competition for car; one plus company car	
a7	Free car use; one company car	
a8	Free car use; several licences; one plus company car	
Segment	**Personal income**	**Personal income**
b1	<$15,599	<$31,199
b2	$15,600–25,999	$31,200–51,199
b3	>$26,000	>$51,199
Segment	**Activity duration**	**Activity duration**
c1	0–2 hours	NA
c2	2–6 hours	
c3	6+ hours	

Figure 1 Home–business mode–destination model segments (Fox et al, 2012)

When car ownership is considered to be a driver of behaviour, it would be expected that areas of low resident worker car (as driver) mode share would own fewer cars. However, when this is normalised on a dwelling basis (as shown in **Figure 2**),the rate of car ownership does not significantly change as density increases.

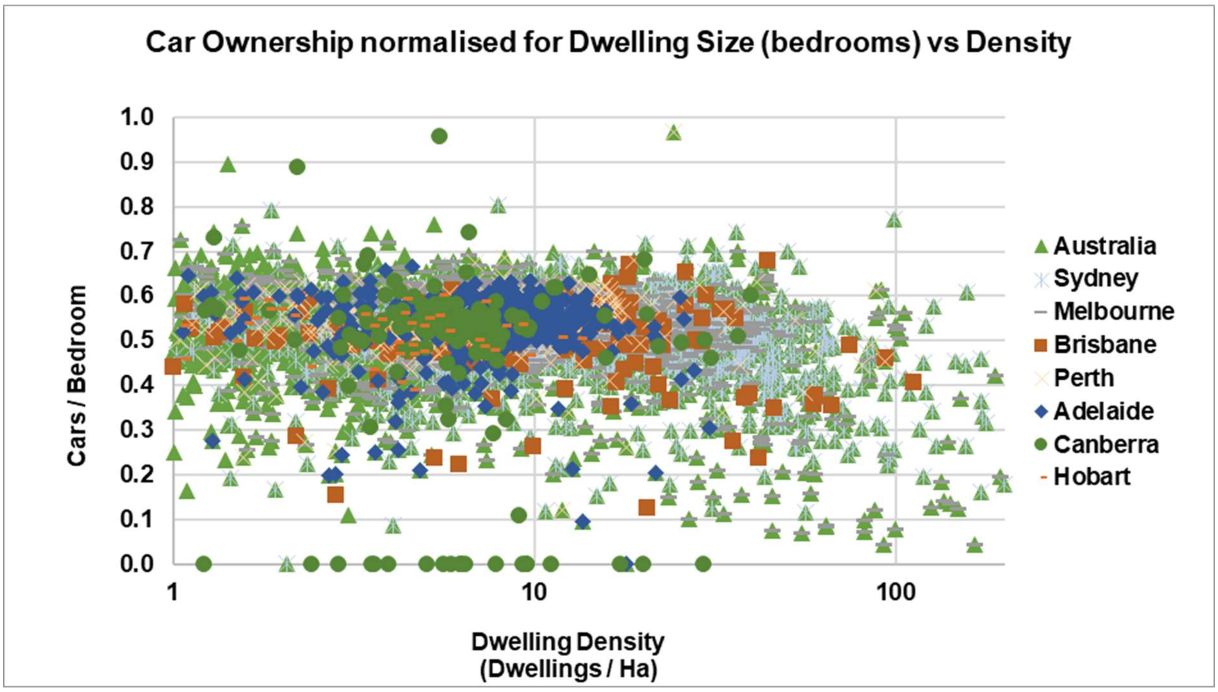

Figure 2 Car Ownership relative to Dwelling Density (ABS, 2016)

However, as suggested by others (Chatman, 2003, Zamir et al, 2014, Lewis and Sherman, 2012), density has a clear effect on mode share and this work seeks to establish to what extent that holds true for the Australian context.

By using the Australian Census of Housing and Population (ABS 2016) data for 2016 for 56,249 SA01 areas and 8,517 Destination Zones (DZNs) levels across a range of criteria, clear patterns were identified, demonstrating clear relationships between population and employment density and mode share, allowing the development of algorithms to forecast mode share with population density changes.

A range of analyses showed clear correlations between population and employment density and mode share for cars / private vehicles, public transport and active transport choices, with there being a high correlation between whether a resident worker in a zone used a mode and whether an employee who travelled to that zone also used the same mode.

For example, the following graph shows the relationship between residential density (population per hectare) and the decision to travel to work by car as a driver. This shows a clear relationship, where at approximately 30 people per hectare, travel to work by car (as the driver) starts to decline rapidly.

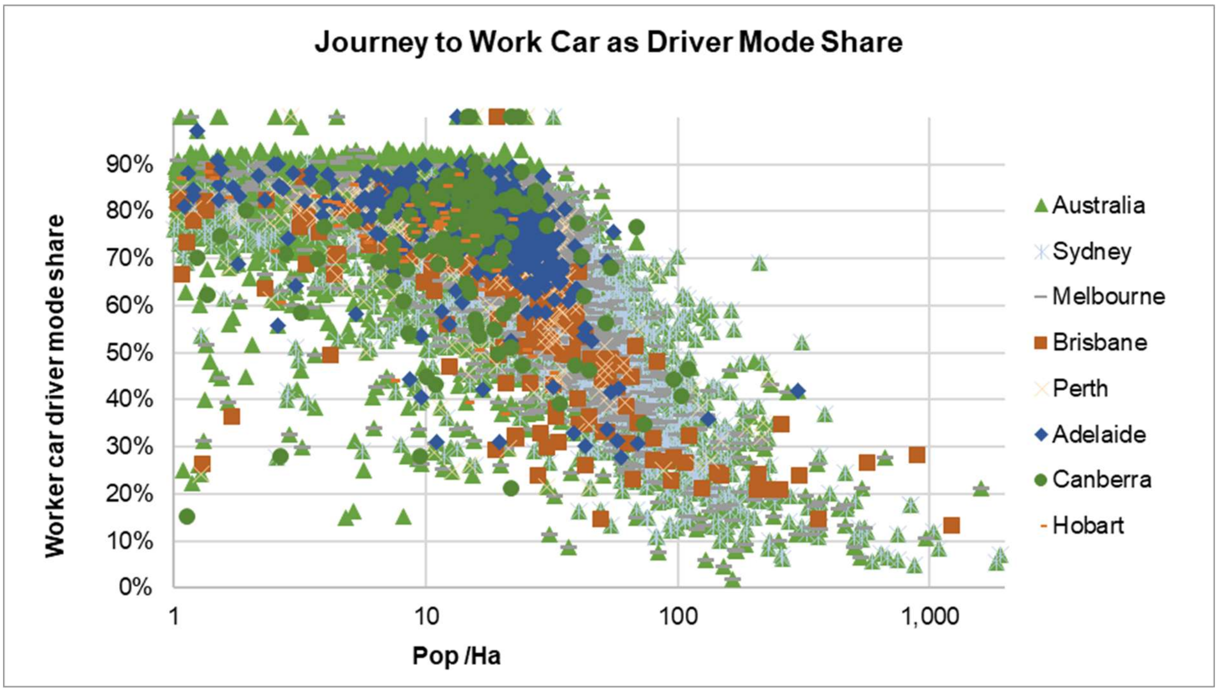

Figure 3 Journey to Work Car as Driver Mode Share (ABS, 2016)

From these results, an approach to modelling mode share for journey to work by car (as driver) was developed as shown in the following equation and graph.

$$Share_{Car} = a \times e^{bD} + cD + \text{e} \quad (1)$$

Where $Share_{Car}$ = Mode share for car as drive
D is the population density (people per hectare)
a = LB: 0.6086 UB: 0.8705
b = -0.131
c = -.00001
e = LB: 0.1234 UB: 0.1765

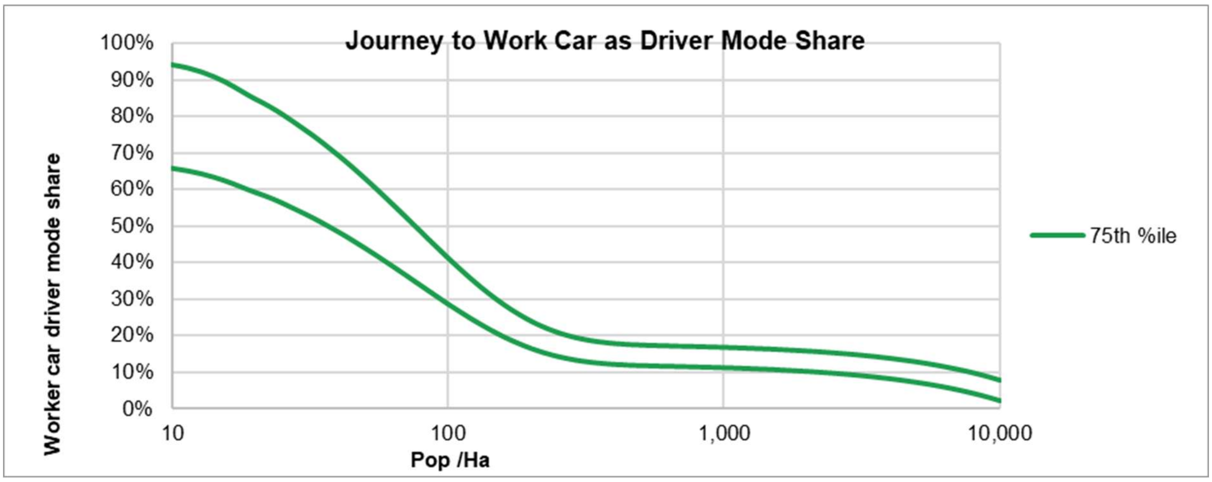

Figure 4 75th percentile mode share for car as driver

From this and other formulae developed, it is possible to forecast the effects of increasing population and employment density on an area, with the resultant reduced car usage.

Using the example of North Wollongong, NSW, Australia (shown in **Figure 5**), increasing population density in SA01 10704154801 from the current 205 dwellings (15 people/ha) to 705 dwellings (48 people/ha) could reduce the car as driver mode share from 65 % (ABS 2016) to 43 %, a reduction in 122 resident worker car trips leaving the area (in comparison to traditional modelling).

Figure 5 North Wollongong Area

Discussion

One of the outcomes of the current approach to mode share modelling is that there is a tendency to over-forecast demand for car usage in urban renewal areas, resulting in too much space being allocated to traffic and insufficient public transport services being provided.

The analysis outlined in this work suggests that there is an opportunity to improve transport mode share modelling as part of strategic and detailed modelling exercises, allowing governments and developers to better plan for non-car modes of travel when considering rezoning and development.

The next stage of this work will be to incorporate the 2011 and 2021 census data into the model and examine the outlier locations (e.g., lower density and lower car usage) to identify any significant causal effects.

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Extended Abstract

Integrating industrial land and urban freight - city level planning

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Introduction

This paper presents a proof-of-concept model for Integrated Land Use and Urban Freight Spatial Planning (ILUF), designed to address the growing challenges of metropolitan freight systems. The model integrates freight transport and industrial land use, mapping freight flows to spatial demand, and evaluates scenarios using high-level logistics cost analysis, environmental externalities, and Computable General Equilibrium (CGE) modelling to assess broader economic impacts.

Freight as a Constant in Urban Life

Human demand for goods and services is a constant, essential to sustaining urban life — manifesting as freight and distribution activity throughout urban areas. In Sydney, this equates to 76 kg of freight movement per person per day and totals approximately 138 million tonnes annually (2025), excluding bulk agricultural exports passing through to ports or the airport. Despite its critical role, freight planning often receives less strategic attention than passenger transport or housing. While Land Use–Transport Interaction (LUTI) models are widely used for passenger movement, applications to goods movement remain limited. (Allen & Strang, 2017) (Batty, et al., 2013), (Holguin-Veras, et al., 2021) (Debrie & Heitz, 2016) (Lopane, et al., 2023) (Nuzzolo, et al., 2016).

The Metropolitan Context: Sydney's Challenges

Sydney faces rapid population growth (NSW Department of Planning and Environment, 2022), shifting consumer behaviour (notably the acceleration of e-commerce), and increasing Vehicle Kilometres Travelled (VKT)—all contributing to congestion, emissions, and other negative externalities. Logistics activity is increasingly located on the urban fringe, driving up transport costs and environmental impacts. Meanwhile, industrial and employment lands, which underpin the freight network, face competing land use pressures and shortages, particularly in the city's east (NSW Department of Planning and Environment, 2022) (Department of Planning, Housing and Infrastructure, 2025).

The NSW Government's industrial land protection policies have sought to retain scarce land in key areas (Infrastructure NSW, 2012), but industry stakeholders question whether such protection maximises overall economic benefit (NSW Government, 2021). Logistics and distribution account for 42% of Sydney's industrial land use, though the share varies by district. While some goods are suited for distribution from the urban fringe, goods like concrete necessitate proximity to demand; and in other cases, it is highly desirable to improve service and reduce logistics costs. (Aljohani & Thompson, 2016)

The ILUF Modelling Approach

The ILUF model considers multiple metropolitan freight network configurations, each with distinct implications for transport costs, land use, environmental outcomes, and economic performance. It draws on datasets from Transport for NSW's Strategic Freight Model (SFM), the Employment Land Development Monitor (ELDM), TfNSW cost–benefit parameters for externalities, industry benchmarks, and the CGE SIRCNA model (*Spatial Interactions within and between Regions and Cities in NSW and ACT*). (Australian Transport Assessment and Planning Guidelines, 2021), (Lennox, 2023).

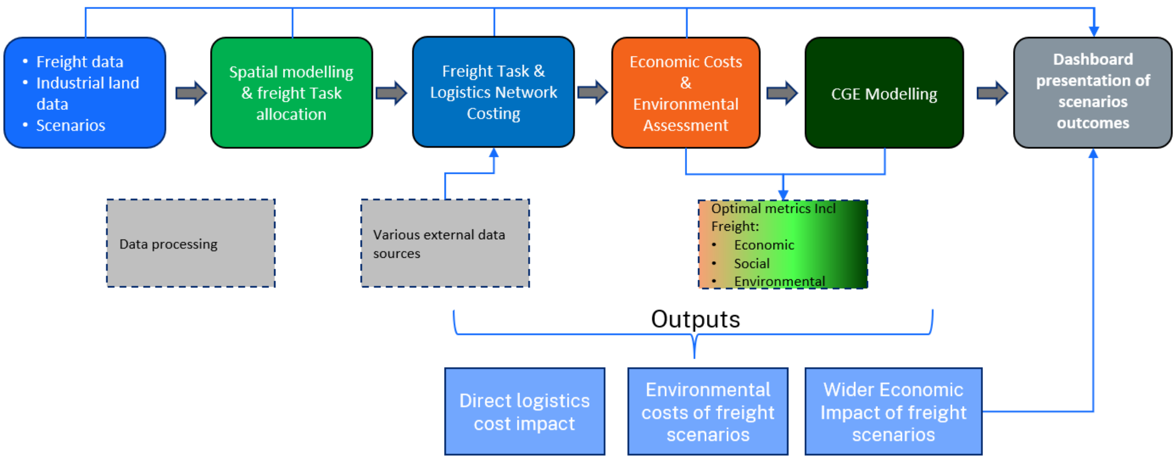

Figure 1 ILUF model approach.

For the proof of concept, ILUF assessed a 2025 baseline against four scenarios for Sydney:

1. Reflect current trend of reducing supply of industrial land citywide, with new capacity on the western fringe.
2. Maintained distributed industrial land, increased electric vehicle (EV) adoption, and expanded micro-logistics for sustainable last-mile delivery.
3. 2036 with productivity gains—greater population and freight task, improved efficiency, and higher EV adoption.
4. 2036 without productivity gains—increased demand with unchanged efficiency.

Measuring Costs, Externalities, and Wider Economic Impacts

The model first establishes freight and logistics outcomes and high-level operating costs, then calculates environmental externalities and whole-of-economy effects. CGE modelling captures how changes in one part of the economy—such as freight costs or industrial land distribution—flow through to other sectors, affecting state-wide welfare. This approach recognises that land use patterns resulting in higher logistics costs might yield broader economic benefits elsewhere, while land use patterns with lower costs could have unintended negative spillovers. (Robson, et al., 2018)

Implications for Policy and Planning

By integrating freight transport and industrial land use into a single metropolitan framework, ILUF enables city governments to assess the trade-offs between logistics efficiency, land use allocation, environmental outcomes, and economic welfare. Applied to Sydney, the model demonstrates that strategic freight planning has the potential to reduce consumer costs, lower externalities, enhance liveability, and support net-zero targets. The findings provide an evidence base for informed urban planning and logistics strategies that align with both economic productivity and community well-being.

Table 1 Summarised logistics modelling results of ILUF modelling for Sydney.

Scenario	VKTs (bn)	Ha ('000) of Industrial Land (IL) used	Transport Cost per Tonne	Cost of living impact per capita
Baseline 2025	4.6	5.5	$135	-
1. **Freight activity moves west**	5 +9%	5.9 +7.5%	$147 +9%	$376
2. **IL is retained across city and increased last mile approaches with small EV use**	4.4 -4%	5.5 -1%	$129 -4.07%	-$87
3. **2036 improved freight and IL use productivity with increased EV use**	5.3 +15%	5.9 +8%	$114 -15.4%	-$1,130
4. **2036 no improvements in logistics or IL use productivity**	6.85 +49%	7.0 +29%	$150 +11%	$396

2025 is planned for 138 Mn tonnes and a population of 5.2m. 2036 is planned for 185 Mn tonnes and a population of 6.4m

Table 2 Environmental externalities and Wider Economic Impact for Sydney

Scenario	Environmental externalities per freight tonne	Annual impact to NSW Gross State Product ($ Mn)
Baseline 2025	$4.33	
1. **Freight activity moves west**	$4.68 +8%	-970.8
2. **IL is retained across city and increased last mile approaches with small EV use**	$4.22 -3%	342.2
3. **2036 improved freight and IL use productivity with increased EV use**	$3.38 -22%	2,739
4. **2036 no improvements in logistics or IL use productivity**	$4.78 +10%	-1,635

Environmental externalities align with transport costs, but the Wider Economic Impacts revealed unexpected effects of freight costs:

- Scenario 1 benefited residential and commercial land needs, but higher freight costs harmed the overall economy.
- Scenarios 2 and 3 reduced logistics costs; despite increased residential land costs, households gained from higher economic activity, wage growth, and consumption.
- In contrast, higher logistics costs led to higher prices, lower wages, and increased housing costs for households.

Based on the CGE modelling, the following conclusions can be drawn:

1. While the trend of converting inner-city industrial land to residential and commercial uses provides economic benefits, it overlooks the potential impact on freight costs.
2. Residential land prices do not tell the whole story—wages and the price for goods and services also matter for households.
3. Freight cost impacts must be considered alongside any benefits from converting industrial land to residential and commercial land.
4. The location of industrial land must be considered carefully to deliver benefits.

5. The productivity of industrial land is important in maximising economic benefits.

Next steps and conclusion

The ILUF proof-of-concept is towards a LUTI-style model assessing the implications of goods supply to a city and relying on extensive and diverse data. With additional funding, the model can be further developed to generate faster responses and support the refinement of new scenarios.

While trade-offs between land use and transport were expected, the CGE modelling revealed surprising wider economic impacts—highlighting that the hidden economic costs of freight provision can outweigh benefits often prioritised in urban planning.

This underscores the need for integrated urban planning that recognises logistics as essential to city populations and delivers greater economic benefits by improving cost of living. Such integration contrasts with current siloed approaches to land use, transport, and economic assessments, which often overlook freight cost impacts.

As industrial land becomes an increasingly prominent issue, the ILUF and CGE framework equips city governments to envision efficient freight management, formulate policies, and guide regulations for a more productive logistics network. This approach helps government understand scenario trade-offs, optimise freight productivity, minimise externalities, and prioritise outcomes for residents. Crucially, it calls for a shift in perspective—recognising goods and services provision as a constant, vital utility underpinning urban life.

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Wednesday 10th December: 4pm-5.30pm
Parallel Session 1 (Level 17, Lecture room 3)
Theme: Innovations in Travel Demand Management, Session Chair: Dr. Yuting Zhang
The knife, the fork, and the spoon: 3 trip charges for the TDM toolbox (Harry Barber)
Health Impacts of Sydney's Bankstown Rail Line Closure: Implications for Travel Demand Management (Christopher Standen, Esther Tordjmann and Fiona Haigh)
Demographic-Based Correction Framework for Cross-Regional Transfer of Activity-Based Travel Demand Models (Yuanchen Ma, Taha Rashidi and Ali Najmi)

The knife, the fork, and the spoon:
3 trip charges for the TDM toolbox

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TDM requires effective behavioural interventions that moderate motor vehicle use. Among these effective interventions are price signals. Price signals can temper motor vehicle ownership and thereby reduce motor vehicle trips. These price signals can be aimed at the cost of ownership,[1] or the cost of vehicle storage.[2]

Once people become vehicle owners, they become highly resistant to the use of alternative modes. For the vehicle owner, all the enabling costs of a motor vehicle trip are sunk, and they perceive their next car trip to be free. To use a different mode, the owner must bear both the perceived loss of sunk costs and the costs imposed by the alternative modes such as a transit ticket.[3] This is TDM's great challenge.

A car owner's resistance to alternative modes can be overcome by physical measures that reconfigure the street network.[4] Another effective intervention is a price signal that targets the car trip. Trip charges can be applied through a sensor or camera on the road, or a parking meter at the destination. These mechanisms are agnostic to the type of price, allowing the system operator to choose one of three quite different prices: a revenue-raising toll, a cigarette-tax style discouragement charge or a load-based fee that prevents over-load.

Each price generates a different outcome and has a different impact on TDM. Notwithstanding their different characters, these three prices are often conflated, even by academics and transport professionals.[5] To help you distinguish their different characters, I will refer to them as the Spoon, the Knife, and the Fork. The Spoon is used to slurp up revenue, the Knife to cut consumption. You use the Fork like a cook to determine if something is undercooked, overcooked or ready to serve.

Here we will examine how well each price supports TDM. Examples will be restricted to prices on roads as each price behaves the same way on the road and at the kerb.

The Spoon

The Spoon price (which scoops up revenue) has been in use for at least two thousand years.[6] The reference point for the Spoon is a cost and revenue budget, typically a loan. The charge can collect revenue in arrears to discharge a loan or in advance to secure a loan.[7] Consent for the charge is derived from the loan purpose.

Spoon fees are usually set low to preserve traffic volumes and maximise revenue. These low fees have little influence on trip decision-making and offer no TDM benefit.

Higher Spoon charges can raise revenue and simultaneously influence trip decision-making.[8] However, where Spoon fees are set high and drivers can detour around the toll, traffic volumes are cut severely leaving an underused asset, unmet loan payments and a heavier load on surrounding streets.[9] Alliances between Spoon charges and TDM also carry a long-term risk. When the loan is paid off, the argument will be made that the charge can be removed. Without a charge, the TDM benefit will evaporate.[10]

The Knife

The Knife price (which cuts consumption) has also been around for centuries.[11] The reference point for the Knife charge is a harm and the desired level of harm reduction. Consent is derived from aversion to the harm. Revenue is a byproduct.

Knife charges are widely used in Europe to increase vehicle quality and reduce the harm of air pollution. These effective, quality-oriented charges have a weak and fleeting effect on TDM as drivers can switch to electric vehicles to avoid the charge.[12]

Cities, such as London, have sought to use a Knife charge to reduce vehicle quantity. There the approach is marketed as a ‘congestion’ charge. Some cities apply a period of Knife charges in-between periods when vehicles are banned completely or are permitted without controls. These quantity-oriented Knife schemes can reduce, even eliminate some segments such as in-bound drivers with conventional vehicles. However, all these schemes permit exemptions (such as resident or electric vehicles). Typically, the number of exempt vehicles increases to occupy the road space vacated by those facing the charge, leaving total quantity (trips and congestion) unchanged.[13]

For TDM, the net effect of these quantity-oriented Knife charges is neutral.

The Fork

Fork charges are a relatively recent type of price.[14] The reference point for the Fork is the maximum capacity of the road (or parking system). Consequently, the Fork price fee applies to all vehicles present in the system. The aim (and the promise to motorists) of a Fork charge is that the system will never be over-loaded. Consent is derived through convenience and reliability (no delay) – the mirror of congestion. Revenue is a byproduct.

The Fork price is sometimes called a time-of-use charge. But it is better to think of it as a time-of-stress charge. As the load rises towards the system limit, the fees rise sufficiently to moderate the load. As the load falls away leaving spare capacity, the fees drop. To ensure the Fork fees are aligned with the actual load, the fees are frequently reviewed and adjusted. As a result, fees decrease as well as increase.

Fork charges are used on roads in Singapore, on expressways in some US States, and are being considered in Auckland. This type of price is also used by Seattle and San Francisco at the kerb.[15]

The Land Transport Authority in Singapore describes their on-road Fork price as ‘a pay-as-you-use system [that] manages congestion by nudging motorists to change their mode of transport, route, or time of travel.’ [16]

In the off-peak, a Fork price does not send a price signal, and so does not support TDM. However, in shoulder and peak times, the Fork price imposes a salient trip charge on the motorist while simultaneously ensuring that road-based public transport runs without delay.[17] This provides a level playing field where both car and transit operate optimally, and both modes require users to pay a trip charge.

Of all the prices, the Fork does the most to reinforce TDM.

[1] Singapore elevates the cost of the vehicle including through a Certificate of Ownership. COE costs 2025. Japan elevates the cost of ownership by requiring frequent, then annual Shaken inspections.

[2] In English speaking countries it is becoming more common to aim price signals at storage as storage costs influence ownership which in turn determines the level of use. Where the planning scheme requires new dwellings to include a vehicle storage bay, the cost of storage is sunk and the default set to ownership. Non-owners must opt out and through the unused space, bear a loss. Where access to storage is only available through a separate purchase or lease, the default is set to non-ownership. Owners must opt in and, through the lease, bear a loss. See for example, *Broaddus 2010,* De Gruyter et al 2023, *De Gruyter et al* 2024

When people move to a place shaped by one or other of these default settings (storage included or storage at cost), their level of car ownership reflects the default. Millard-Ball 2022

Ownership can be muted at the kerb. Trivial fees for kerbside storage permits do not influence ownership. (City of Melbourne $53.50 a year) Where the fee is non-trivial, owners must opt in and bear the loss. (Inner Stockholm $3,000 a year)

[3] Sunk costs. In most places, the next car trip is perceived to be free, as all the enabling costs are sunk. In the rear-view mirror are purchase, depreciation, finance, insurance, maintenance and fuel. Ahead there is the possibility of a toll or a parking charge, but many trips will be possible without an additional charge. This combination of high sunk costs and low or no trip sets the default towards the car trip. To opt out of a car trip, the car owner must suffer a sunk cost loss. Likely, the car owner will perceive the cost of the transit ticket and the need to be outside in the weather as further losses. See also Hawthorne

[4] Some cities rely on physical measures that increase vehicle travel time and distance to reduce the number and proportion of car trips. Barcelona, Ghent, Mechelen, Groningen and Oslo are examples. *Sustainable mobility strategies deconstructed: a taxonomy of urban vehicle access regulations*. Fransen 2023

[5] For example: 'The purpose of this paper is to assess the policy approaches to mitigating urban road traffic congestion in the light of the available evidence from the three major cities in which congestion charging has been implemented – London, Stockholm and Singapore' Metz 2018. 'Cordon-based congestion pricing charges motorist for entering a congested 'cordon' area, such as a central business district. London, Stockholm, Singapore, and Milan have all implemented some form of cordon-based congestion pricing' Simeone 2023

[6] The Koptos Tariff 90AD lists the user-based and trip purpose charges that applied to a road segment of a Roman trade route to India. Rathbone 2002

[7] The Sydney Harbour Bridge was built, then tolled. The Manhattan cordon charge aims to provide a reliable and sufficient stream of revenue to service a yet-to-be-negotiated loan.

[8] In 2003, the tolls for the road trunnels in Hong Kong were too low to influence trip choice. Loo 2003. The low Gothenburg tolls reduced trips by 5% Börjessona 2015. The Manhattan charge at $15AUD has proved sufficiently high to reduce cordon crossings by 11%.

[9] The Spoon tariff on Sydney's Cross City Tunnel has bankrupted two companies and continues to provide an incentive to drivers to travel through the Sydney CBD.

[10] Like the Sydney Harbour Bridge, the Lee Memorial Bridge in Virginia was built during the 1930s to provide a road link and employment during the depression. Tolls were collected to pay off the finance bonds. When this was achieved in 1946, the tolls were removed. Berger & Associates 1993.

[11] In 1751 Britain introduced a tax intended to reduce the consumption of gin. More recently the UK (and other countries) have introduced levies to reduce consumption of sugar. Consumption reduction levies on tobacco are widely used.

[12] Milano: Electric vehicles can enter the ZTL (limited traffic zone) and park for free in the parking spots that are marked blue or yellow. London: Zero emission vehicles that meet the criteria are eligible for a 100% discount on the Congestion Charge.

[13] (The London congestion charge has been in place since 2003.) 'Traffic congestion in London is getting worse. Since 2012/13, vehicle speeds on major roads have gone down and journey time reliability has got worse. Time lost to traffic delay has gone up, as have excess waiting times for buses.' London Assembly 2017

[14] Seattle introduced water use charges that rose in summer in 1985. Time of use tariffs for energy were introduced in Australia in the 1990s. Load-shifting early bird fares on Melbourne trains ($0 <07:00 on weekdays) were introduced in 2007. Currie 2009. Singapore switched to load-based pricing on roads in 1998.

[15] Roads: Singapore, HOT lanes Washington State, USA, Auckland Transport Kerbside parking: San Francisco, Seattle,

[16] LTA commitment – see ERP section in *Managing Vehicle Population & Traffic Flow*

[17] When Fork fees were introduced at the kerb in San Francisco, bus patronage increased by 11%. Krishnamurthy 2020

Health Impacts of Sydney's Bankstown Rail Line Closure: Implications for Travel Demand Management

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Introduction

Research on the health and equity impacts of planned long-term transport disruptions – and travel demand management (TDM) and other measures that can mitigate these impacts – remains sparse. Previous studies have predominantly focused on short-term disruptions, leaving significant gaps in understanding (a) how extended disruptions affect population health and health services, (b) which populations are most affected, and (c) how these impacts can be mitigated.

The closure of a major suburban rail line in Sydney (New South Wales, Australia) from September 2024 for over a year to enable its transformation to a high-frequency, driverless 'Metro' service provided a unique opportunity to address these gaps. While the future Metro service should offer improved frequency, reliability and safety, there was concern that the extended closure could have significant impacts on health and health services. This study aimed to appraise these impacts and develop evidence-based mitigation measures for health service providers. Further monitoring and research are needed to determine to what extent the predicted impacts eventuated, whether there were others not identified, and how effective the mitigation measures were.

Methods

We used an *ex-ante* health impact assessment approach, including screening, scoping, data identification, impact assessment, and recommendations formulation. Mixed methods were used for the data identification step. A literature review was performed to identify previously studied health impacts of long-term transport disruptions. A community profile was developed to provide an overview of the affected population, and to identify geographic areas and population groups likely to be disproportionately affected. An online survey of affected healthcare workers was conducted to understand the nature and the scale of the potential impacts on them and the services they provide.

We collaborated with the two Local Health Districts that are responsible for providing public hospital, community health, and other health services in the affected area, as well as being major employers. We also collaborated with the state transport department's travel demand management team, which was responsible for developing behaviour change and communication strategies to support affected communities and employers during the closure.

Results

According to the community profile, the affected area is characterised by high levels of socioeconomic disadvantage and dependence on public transport (relative to the rest of Sydney), with the proportion of households not owning a motor vehicle ranging from 22% to 34% at the suburb level. Although the government provided a free rail replacement bus service during the closure, there was little bus priority and journey times were significantly longer than those for the rail service it replaced. The area was found to have little bicycle/micromobility infrastructure, restricting the potential of TDM initiatives focused on these modes that were implemented by the state transport department (e.g., cycling courses, guided rides, bike buses, etc.).

The impact assessment identified several potential health risks, largely associated with long travel times, reduced travel comfort, and resulting reductions in accessibility. Of the affected healthcare workers surveyed, more than 90% anticipated increased stress or fatigue during the closure and 37% considered seeking alternative employment. Other potential risks for healthcare service provision included increased absenteeism, reduced punctuality, and recruitment challenges.

Among the broader population, reduced access to healthcare, employment, education, services, and social and recreational opportunities was identified as a risk to health and wellbeing. A particular concern was decreased participation in preventive health, such as cancer screening and antenatal care. Households without private transport, or only one motor vehicle for two working adults, were expected to be disproportionately affected.

Recommended mitigation measures for health service providers included information provision for staff and the community, including updated transport access guides, and greater promotion of virtual health services.

Discussion

The findings from this assessment align with those of previous studies on transport disruptions, highlighting increased stress, fatigue, and healthcare accessibility challenges (James *et al.*, 2014; Stanley *et al.*, 2016; Sunio *et al.*, 2023). Similar impacts were reported during short-term transport disruptions in other contexts, including reduced physical activity, increased commuting stress, and heightened health inequalities, particularly among disadvantaged populations (Khan *et al.*, 2021; Wang *et al.*, 2021; Alhassan *et al.*, 2023). Unlike shorter disruptions studied previously, this assessment uniquely highlights risks for healthcare workforce retention and service continuity, as well as participation in preventive healthcare.

Conclusion

This study has highlighted a blind spot in the way health is considered in transport planning. While environmental health risk assessments are typically mandated to assess the construction and operational impacts of new transport infrastructure projects, there is no mandate (in New South Wales) to assess the health and broader social impacts of major planned disruptions. While this study highlighted some potential health risks in the context of an extended suburban rail line shutdown in a major city, further research is needed. Future studies could include longitudinal evaluations to assess the health impacts of planned long-term disruptions, and the effectiveness of TDM initiatives and other mitigation strategies.

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Demographic-Based Correction Framework for Cross-Regional Transfer of Activity-Based Travel Demand Models

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Introduction

Activity-based travel demand models (ABMs) like ActivitySim are powerful transportation planning tools, but transferring them between regions is a major challenge (Yasmin et al., 2015). The accuracy of a transferred model depends heavily on aligning the source region's travel patterns with the target area's demographics, often leading to unreliable predictions (Bowman and Bradley, 2017; Koushik et al., 2023). Traditional ActivitySim calibration is a laborious and inefficient process, requiring extensive manual coefficient adjustments and expert involvement (Chen et al., 2020; Agriesti et al., 2023).

To address these limitations, this study proposes two novel frameworks that optimize **demographic inputs** rather than directly tuning model coefficients. By strategically reweighting population attributes to match a new region's observed travel behavior, this approach simplifies the adaptation process and reduces computational demand. Our research contributes a systematic method for demographic-based adjustments that maintains behavioral consistency without complex coefficient modifications, tested using three optimization algorithms: CMA-ES, LSTM, and reinforcement learning (Hansen and Ostermeier, 2001; Hochreiter and Schmidhuber, 1997; Tian et al., 2020).

2. Methodology

In doing so, two correction mechanisms are proposed. The primary mechanism uses a **hierarchical demographic weighting** strategy, targeting key attributes like vehicle ownership, income, age, and employment status (Bowman and Ben-Akiva, 2001). When optimization stagnates, an adaptive K-means algorithm dynamically refines demographic clusters. A warm-start feature ensures a smooth transition by transferring weights from parent to child clusters, preserving optimization continuity.

The second mechanism is a **subsampling-based approach** that generates random household subgroups and uses replication weights to adjust their representation. This allows the optimization algorithm to explore and identify effective population combinations that match behavioral outcomes. Although limited to existing household profiles, this method’s randomness can uncover effective population compositions that are less obvious.

3. Preliminary Results and Discussion

By the submission deadline, the two proposed correction mechanisms remain at different development stages. The demographic weight correction mechanism has reached relative maturity and entered the comprehensive testing phase, enabling preliminary validation assessment. Conversely, the subsampling correction pipeline continues under major development, with core algorithmic components requiring further refinement before empirical evaluation. Consequently, this section presents preliminary results exclusively from the demographic weight correction framework, while subsampling approach findings remain on hold pending completion of the development phase.

3.1 Preliminary Framework Validation

Initial validation of the demographic weight correction mechanism demonstrates promising behavioral alignment capabilities through 12 optimization iterations, where each iteration sits 10 candidates using CMA-ES as the optimizer. Figure 1 reveals characteristic convergence patterns with the mean candidate loss declining from 19.8 to 19.25, representing substantial improvement in multi-objective alignment targets. The optimization trajectory exhibits rapid initial exploration followed by convergence stabilization, indicating effective capture of demographic-behavior relationships.

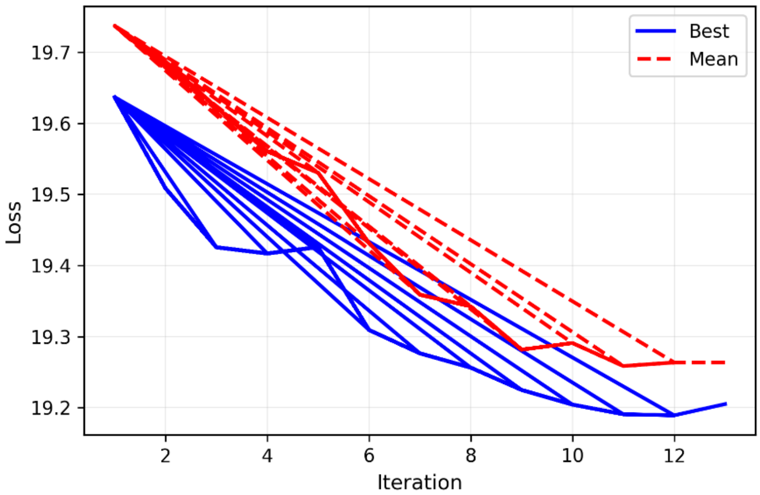

Figure 1. Trial Run of the Demographic Weight Pipeline

Preliminary validation against Melbourne travel survey targets demonstrates significant improvement over baseline ActivitySim performance across multiple behavioral dimensions. The demographic weight mechanism achieves 94.2% trip generation accuracy compared to 87.4% baseline, representing a 6.8-percentage-point improvement through demographic modifications alone. Mode choice distribution alignment shows improved Kullback-Leibler divergence of 49.45 versus 55.06 baseline, while trip purpose distribution achieves superior χ^2 statistics of 5.37 compared to 7.24 without correction. These improvements validate the framework's core premise that strategic demographic adjustments can effectively replicate coefficient modification effects while maintaining model theoretical integrity. The convergence within 200 iterations demonstrates computational feasibility for practical applications, contrasting favorably with traditional calibration approaches requiring weeks of manual parameter adjustment.

Table 1. Preliminary Behavioral Alignment Results

Pipeline	Trip (%)	Mode (D_{KL})	Purpose (χ^2)	Convergence(I)
Demographic	94.2%	49.45	5.37	200
Subsampliing	[On hold]	[On hold]	[On hold]	[On hold]
Baseline	87.4%	55.06	7.24	N/A

When it comes to the computational performance, the designed pipeline exhibits significant advantages in implementation efficiency compared to conventional calibration methods. Setup time reduces from 40+ hours to 2 hours, eliminating extensive coefficient identification procedures. Runtime performance averages 8 minutes per iteration with 4 GB memory usage, enabling high parallelization potential through independent candidate evaluation processes, representing a substantial improvement over traditional 15-minute iteration cycles.

Table 2: Computational Performance Comparison

Approach	Setup Time	Run Time/Iter.	Memory(GB)	Parallelization
Demographic	2 hours	8 mins	4 GB	High
Subsampling	[Testing]	[Est. 5-8 mins]	[Est. 4-8GB]	Very High
Traditional Calibration	40 hours +	15 mins	8 GB	Limited

3.2 Implementation Challenges and Future Work

Despite encouraging preliminary results from the demographic weight mechanism, the extended convergence requirement of 200 iterations indicates need for optimization algorithm refinement and parameter tuning strategies. Future work will prioritize completion of the subsampling correction mechanism development, which demonstrates promise for very high parallelization potential and potentially accelerated convergence characteristics. Subsequent research efforts will concentrate on comprehensive comparative analysis between both correction approaches, incorporating sensitivity analysis to evaluate the impact of predefined parameters within each correction pipeline. Additionally, systematic assessment of optimizer performance across CMA-ES, LSTM, and reinforcement learning candidates will establish evidence-based selection criteria for different application contexts and demographic complexity scenarios, ultimately enhancing framework robustness and practical deployment guidelines.

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Wednesday 10th December: 4pm-5.30pm
Parallel Session 2 (Level 16, Seminar room)
Theme: Understanding Traveller Behaviour and Mode Choice, Session Chair: Mr. David Surplice
Integrating the Node-Place Model and Urban Resilience Based on Vitality Changes in Response to COVID-19 : Classifying and Evaluating Station Areas in Aichi, Japan (Hyundo Kang and Tomio Miwa)
Exploring travel behaviour change through user-centric incentives (John Nelson, David Hensher, Corinne Mulley, Chinh Ho, Edward Wei, Camila Balbontin, Wen Liu and Thiranjaya Kandanaarachchi)
Examining the Trade-off between Travel Time vs. Travel Opportunities in Choosing Multimodal Travel Options (Ishani Shehara and Shamsunnahar Yasmin)

Integrating the Node-Place Model and Urban Resilience Based on Vitality Changes in Response to COVID-19 : Classifying and Evaluating Station Areas in Aichi, Japan

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Introduction

Public transit has come to play an increasingly critical role in achieving sustainable cities. There has been a global trend toward discussing and implementing Transit-Oriented Development (TOD), as well as land-use and transport integration (Caset et al., 2020; Yang et al., 2022). In response, extensive research has been conducted to classify and assess station areas in terms of built environment and transit accessibility. Notably, the node-place model developed by Bertolini (1999) and the TOD principles initiated by Calthorpe (1993) have been commonly employed as key instruments. The node-place model has been most actively developed in TOD typology research as a framework that intuitively conceptualizes interrelationship between land use and transportation.

Concerning COVID-19 pandemic, TOD's vibrant, high-density, and mixed-use environments are paradoxically thought to increase vulnerability to disruptions such as epidemic; however, opposing views suggest that there is no such significant correlation exists (Forouhar et al., 2025). Nevertheless, what remains evident is that the importance of urban resilience is particularly critical in areas surrounding transit stations (Ollivier et al., 2021). Resilience, which originated from Holling (1973) in ecological science, has been widely applied in multiple fields. Within the context of urban transportation, it has mainly been employed to investigate the effects of sudden disruptions, particularly focusing on the sharp decline in transit ridership and the resulting changes in travel behavior (Lee et al., 2024). However, the examination of vitality changes in station areas has been limited to a few studies, such as Xiao et al. (2025), indicating the need for further research. Although the node-place model for TOD typology has attracted substantial academic attention due to its importance, most studies have relied on the static perspective, with the exception of a few works such as Yang et al. (2024). To achieve resilient TOD, it is necessary to monitor the dynamics of stations at the metropolitan level and to examine changes in vitality that reflect actual human mobility.

This study proposes a station evaluation framework based on the node-place model, into which urban resilience is incorporated. It seeks to classify station areas according to their land-use and transport characteristics, and to analyze the corresponding changes in vitality before and after COVID-19 pandemic. This study targets the station areas within Aichi prefecture, Japan, and adopts the years 2019 and 2021 as the temporal scope. The year 2020, which follows the pandemic shock, was excluded from the analysis to account for data limitations and eliminate complexities stemming from rapid policy shifts. That is, the scope is explicitly limited to analyzing changes in vitality between the pre- and post-pandemic phases.

Methodology and results

The main analytical process of this study consists of four steps (Figure 1). First, the key indicators and vitality of station areas are examined in terms of their spatial distribution and descriptive statistics. Second, exploratory factor analysis is conducted to extract latent factors from the station indicators. Third, hierarchical clustering is performed using factor scores to identify typologies of station areas. Finally, rate of change in vitality between the pre- and post-pandemic is calculated for each station area, and the node-place model is constructed to visualize both the vitality change and the latent factors (dimensions), facilitating detailed comparisons across station areas.

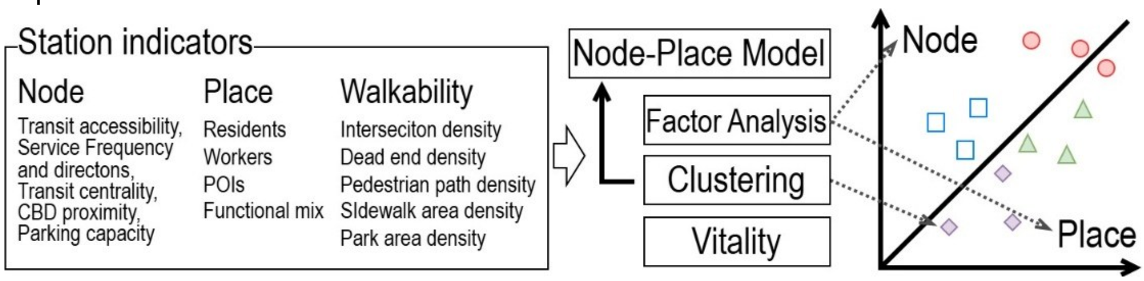

Figure 1. Analysis framework and indicators

The indicators were measured and categorized into node, place, and walkability, as presented in Figure 1. Vitality was measured using the human mobility data based on mobile phone provided by the Japanese telecommunications company KDDI. As the data are available in 500-m grid cells, area-weighted aggregation was performed within each station area, excluding green spaces, to improve accuracy.

The key findings and discussion are summarized as follows. First, the node-place model based on factor analysis and clustering effectively reflected the actual urban structure and established theories, and was also found to be associated with vitality. It suggests that vitality is well associated with the land-use and transport conditions, and can be utilized as a suitable output of TOD typologies.

Second, station types in city centers tended to exhibit a significant reduction in vitality, whereas certain suburban types showed moderate trends. As the analysis focusses on the immediate post-pandemic period, notable differences remain compared to the pre-pandemic baseline, indicating a slow recovery. Accordingly, the results can be interpreted as manifestations of disruption. The Nagoya metropolitan area, including Aichi prefecture, exhibits a concentrated pattern of urban activities around urban hubs, coupled with TOD and car-dependent suburbanization. Within this context, residents appear capable of readily adapting their travel behavior and urban activities in response to disruptions, suggesting that spatial dispersion and reconsolidation may differ according to the condition and location of each station area.

Finally, the rate of change in station area vitality exhibited both increasing and decreasing trends, with spatial disparities observed across urban and suburban areas. Central stations were characterized by high levels of transit accessibility and activity demand, but were also more vulnerable to disruptions such as pandemics. In contrast, while some suburban stations exhibited extremely low development and vitality, others showed a relatively balanced structure and experienced minimal decrease.

This study incorporated the change in vitality as a means of integrating urban resilience into the node-place model. However, to better capture resilience, it is necessary to observe long-term adaptation over time. Future research could incorporate human mobility data from at least after 2023, enabling time-series analysis. To derive more detailed policy implications, it is essential to develop a more robust linkage between vitality and resilient TOD.

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Exploring travel behaviour change through user-centric incentives

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Introduction

There is a growing emphasis on developing strategies and policies aimed at reducing emissions and promoting more sustainable lifestyles. This trend is evident in the increasing number of net-zero roadmaps adopted by various nations (Bistline, 2021). However, designing effective and lasting interventions necessitates insight into how transport policies can be structured to successfully encourage behavioural change (Cleland et al., 2023; De-Toledo et al., 2022). While some literature addresses behaviour change in sustainable transport, evaluations of interventions through the lens of behaviour change theories, particularly from the user perspective, remain limited. Nelson et al. (2025) examined major behavioural change theories within the context of sustainable mobility, aiming to uncover their nuanced complexities. Building on this foundation, the present study evaluates the effectiveness of sustainable mobility interventions from a user perspective, recognising the contextual and demographic variations among different user groups by means of a survey which is described below.

Methods

The survey was informed by a comprehensive literature review and stakeholder roundtable discussions with industry practitioners and experts. The survey is focussed on identifying the most effective transport and non-transport interventions, understanding how life events and other "windows of opportunity" influence travel behaviour, assessing the impact of aligning initiatives with behavioural triggers. Four "windows of opportunity" areas are explored: lifestyle and household changes (e.g., family structure, personal habits), work and commuting-related changes (e.g., employment, workplace incentives), transport and mobility changes (e.g., vehicle ownership, public transport use), and social and environmental considerations (e.g., peer influence, awareness).

The survey begins by exploring changes in respondents' travel behaviour over the past two years (2023–2025) and planned changes over the next three, linking them to key moments of transition. It then examines perceptions of various interventions, including changes to public transport pricing and frequency, promotion of active travel, road user charges, and employer-led incentives (see Figure 1). It also explores how future policy, technological innovation, and new mobility services may influence travel behaviour. Finally, the survey investigates interest in integrated mobility platforms that package mobility and non-mobility services within a single App, assessing features most likely to drive adoption and long-term behaviour change.

Following a pilot with 100 participants across Australia, Finland, New Zealand, the USA, the UK, Singapore, and Sweden the full survey was the launched in May 2025 with a target of 4,000 participants (1,000 each from Australia and the USA, and 400 each from Finland, New Zealand, the UK, Singapore, and Sweden).

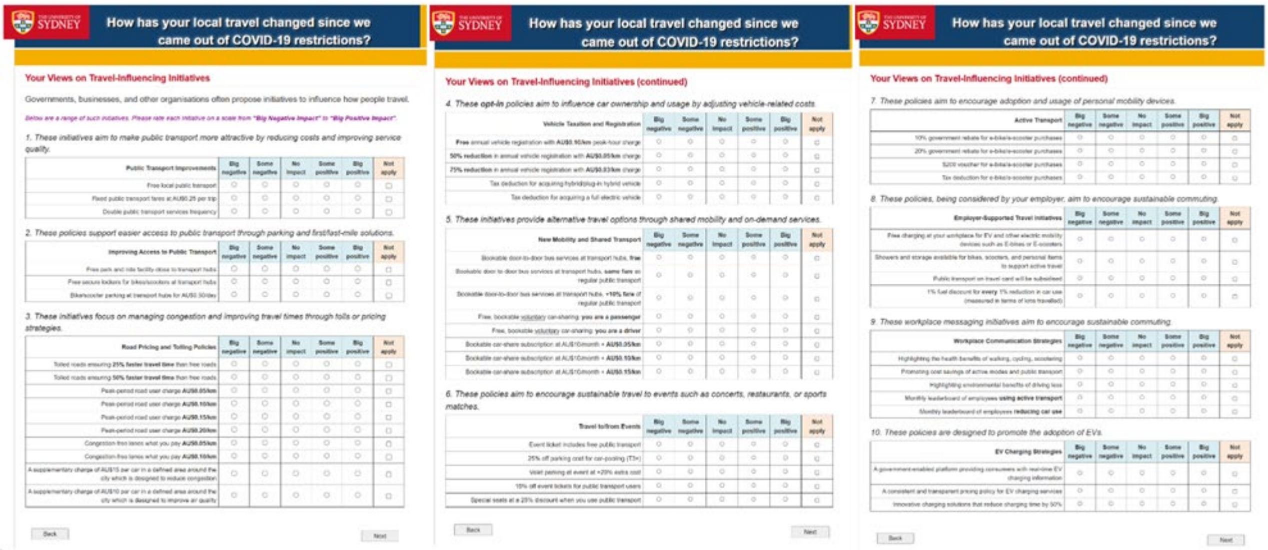

Figure 1. Travel influencing initiatives included in the survey

Results

The survey was completed at the end of May 2025 and a detailed analysis of findings will be presented at the Symposium. Findings will enable a better understanding of how users perceive different behaviour change interventions and how these perceptions may vary based on individual circumstances. The analysis will also examine the effectiveness of various interventions, particularly those involving incentives and rewards in influencing travel behaviour. Additionally, cross-country comparisons will be undertaken to assess how the impact of interventions may differ across contexts, including an examination of the relevance of market segmentation when designing and implementing sustainable transport strategies.

Concluding remarks

The study will provide an increased understanding of the effectiveness of sustainable mobility interventions from a user perspective, identifying those more likely to be successful and for which user groups they would be successful. The study also provides an empirical testing of the various travel behaviour theories to understand which theory or theories are best for explaining the contextual and demographic variations among different user groups.

Acknowledgements

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Examining the Trade-off between Travel Time vs. Travel Opportunities in Choosing Multimodal Travel Options

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Introduction

Multimodal travel entails situational combination of different modes within a trip (Hoogendoorn, 2006), (Buehler and Hamre, 2015). The underlying desire to promote multimodality is to de-prioritize car-dependency through a partial modal shift. It encourages higher adoption of public transport and active modes, while emerging mobility services (ride-hailing and micromobility) provides solution to the first and last-mile problem. However, it is important to realize that travellers are constrained by inadequate multimodal travel opportunities. Therefore, it is obvious that more travellers would adopt multimodality only within an optimal multimodal service area. This study hypothesizes that - (a) multimodal travel behaviour is endogenous to multimodal travel opportunities, and (b) travel time by multimodal choice is lower (higher) for a location with higher (lower) multimodal travel opportunity. In examining this, the study proposes and estimates a joint model for trip mode choice and travel time by modes while also controlling for travel opportunities by different travel options. Simultaneous and recursive structures are utilized to account for endogeneity and indirect effects associated with multimodal travel opportunities through travel time in the mode choice estimates. In the joint model, mode choice component is estimated by using Multinomial Logit formulation and the choice set includes unimodal walking, cycling, shared motorized, multimodal public and multimodal private options. In the joint model formulation, travel time by modes component is modelled by using Linear Regression. In the context of travel behaviour, a trip is a single, one-way movement with a specific purpose from origin to destination, while a journey encompasses the broader sequence or experience of travel, often involving multiple trips. For the study context, multimodal trips are defined as those integrating two or more modes of transport within a single trip and travel opportunity is defined as average travel time required to access different service locations relevant to trip origin. The dataset utilized is the 2017-2024 Household Travel Survey (HTS) data of Southeast Queensland (SEQ) and this is integrated with other external data sources. The examined Marginal Rate of Substitution (MRS) between accessibility time to services (opportunity) and travel time denote the varying trade-offs that travellers are willing to make, conditional upon the nature of their trips. The study outcomes will inform policies to encourage adoption of multimodality where feasible and for achieving sustainability goal in transport.

Data Description

The main data source for the research is the daily travel pattern data obtained from the HTS in SEQ from 2017-2024. This is integrated with other external data sources; Land Use and Public Transport Accessibility Index (LUPTAI) data from 2017-2021 which represents the accessibility time to different service categories (which represented the physical travel opportunity). **Figure 1** represents the overview of observed travel time and travel opportunity representation from the mean accessibility time to services lens. The service categories are considered based on the temporal flexibility and the behavioural nature of the different trip purposes which includes subsistence, essential, maintenance, discretionary and other services.

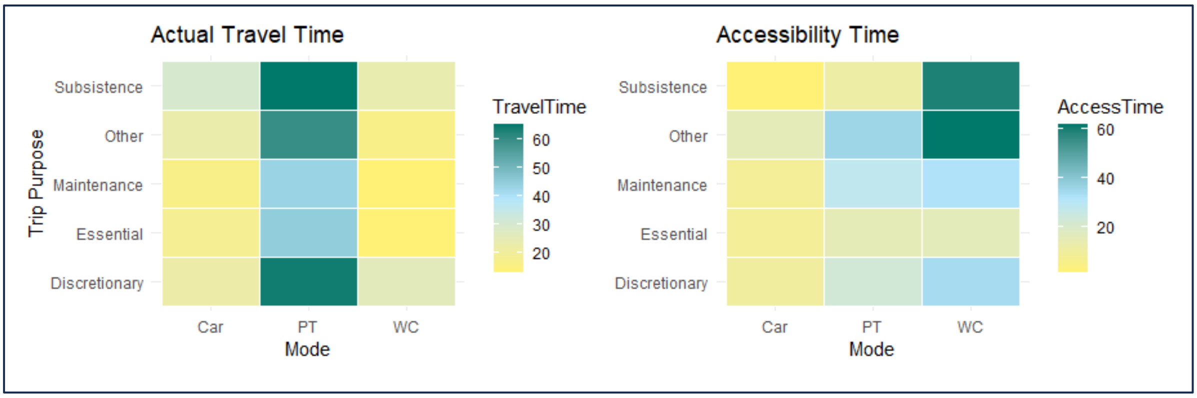

Figure 1. Average travel time and mean accessibility time (opportunity) to different services (Note: W/C= Walking or Cycling, PT=Public transport, Car=private cars/shared motorized)

Empirical Results and discussion

From the initial independent model estimation, the following MRS values denoted in **Figure 2** are determined to examine the cross-modal sensitivities for travel time and travel opportunity. For example, MRS value of 2.17 represents that travellers are like to accept additional 2.17 minutes of travel opportunity by public transport to save 1 minute of travel time by car. The estimated MRS values underscore the varying degrees of trade-offs (threshold acceptability) that travellers are willing to make, conditional upon the nature of their trips. In the context of multimodal trips, where travellers engage with two or more modes, understanding MRS is especially significant because these trips inherently involve transfers, modal coordination, and additional travel components, which compound both perceived effort and accessibility potential.

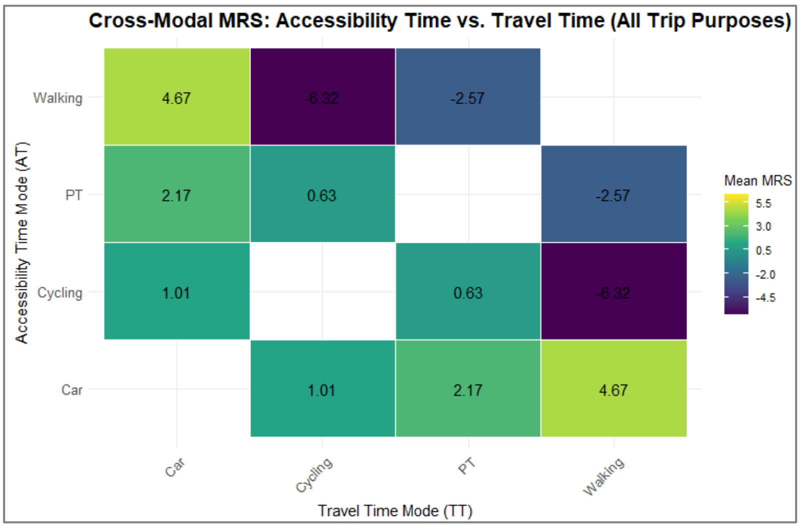

Figure 2. Cross modal Marginal Rate of Substitution

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Wednesday 10th December: 4pm-5.30pm
Parallel Session 3 (Level 16, Lecture room 5)
Theme: Urban Freight, Electrification, and Emerging Logistics Systems, Session Chair: Prof. Michael Bell
Quantifying Bias and Fairness in Large Language Models for Electric Vehicle Charging Demand Management (Artur Grigorev)
Comparison of charging behaviour for private and fleet company EV users using a data-driven approach (Tuo Mao, Adriana-Simona Mihaita, Artur Grigorev and Yuming Ou)
Micrologistics Challenges and Opportunities (Michael Stokoe)

Quantifying Bias and Fairness in Large Language Models for Electric Vehicle Charging Demand Management

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Introduction

Increasing electric vehicle (EV) charging demand requires an equitable allocation of constrained infrastructure resources. Large Language Models (LLMs) show potential for automated management of such situations, yet their fairness and inherent biases require careful consideration.

This study evaluates six leading LLMs in a simulated, constrained EV charging allocation task, an automated Travel Demand Management process where LLMs simulate decision-support for human operators (e.g., "Allocate charging time: Driver A vs. Driver B"). We use thirteen predefined driver scenarios, each made to implicitly represent a distinct demographic group. LLMs allocated a fixed 10-minute charging duration between systematically generated pairwise combinations, explicitly prohibiting equal splits, thereby forcing preferential decisions. Key findings reveal statistically significant group-level biases (e.g., 'Unemployed' often favored; 'Low-Income' often disfavored) and imperfect consistency in pairwise preferences. This research quantifies these biases, highlighting important ethical considerations for Generative AI deployment in infrastructure decisions that may affect various social groups.

The task's real-world relevance is validated by emerging infrastructure capabilities: networked cameras detect queue lengths via computer vision [1], while voluntary driver registration (e.g., via app profiles) enables demographic-aware allocation [2]. This aligns with the evolving focus of travel demand management from measuring bias (e.g., fare barriers that overestimate low-income access [3]) to preventing algorithmic inequity in real-time systems.

Methodology

A controlled experiment assessed LLM performance using thirteen distinct, pre-defined driver scenarios. Each scenario's textual description was designed to represent an implicit demographic linkage (e.g., 'Single Parents', 'Unemployed'). LLMs were prompted with systematically generated pairwise scenario combinations from these scenarios (resulting in 78 unique pairs per model). The task involved non-equally allocating a 10-minute total charging duration between two drivers with no direct communication. The primary LLM generated a natural language response with reasoning and allocation. Invalid responses, defined as non-numerical outputs, sums not equal to 10 minutes, or equal allocations, were excluded. Analysable data rates, reflecting task success in adhering to constraints and providing valid numerical splits, varied; GPT-4o performed well, while GPT-4 and Gemini-1.5-flash showed lower success, often due to 'NA' responses or constraint violations. Key metrics included overall pairwise group bias (mean difference in minutes allocated between groups), consistency (RMSE of transitivity deviations), and data availability. One-sample t-tests ($\alpha = 0.05$) assessed group bias statistical significance.

Findings and Discussion

Group-Level Biases

Statistically significant group-level biases, representing average differences in allocated minutes, emerged across models. The 'Unemployed' group, often in scenarios mentioning a "job interview," was consistently favored by models like GPT-3.5-Turbo (mean bias $+6.8$ minutes, $p = 0.000$). Conversely, 'Low-Income' (e.g., GPT-4o mean bias -2.0 minutes, $p = 0.013$; GPT-4o-mini mean bias -3.0 minutes, $p = 0.001$) and 'Elderly' (e.g., GPT-3.5-Turbo mean bias -4.4 minutes, $p = 0.0058$) were frequently disfavored, potentially due to implicit associations or situational constraints learned from patterns in training data. 'Minorities' also experienced significant disfavor from GPT-4o-mini (mean bias -2.3 minutes, $p = 0.0009$) and GPT-3.5-Turbo (mean bias -4.4 minutes, $p = 0.002$).

Consistency of Biases

Models did not achieve perfect transitivity in its pairwise biases. GPT-4 was most consistent (lowest RMSE $= 2.51$), GPT-3.5-Turbo least (RMSE $= 6.81$). This imperfect consistency, where relative preferences between groups are not always stable, suggests potential unpredictability in complex scenarios and may interact with observed group-level biases to produce varied outcomes.

Conclusion

This study shows that LLMs exhibit discernible biases in a constrained EV charging allocation task. Statistically significant group-level biases favoring certain demographics (e.g., 'Unemployed') while disfavoring others (e.g., 'Low-Income', 'Elderly', 'Minorities'), alongside imperfect decision consistency, were observed across all tested LLM architectures. These biases likely stem from training data patterns and could potentially precipitate inequitable outcomes if LLMs are deployed without appropriate controls and mitigation.

This study quantifies the operational risk of deploying LLMs without bias audits These findings highlight the importance of careful fairness and equity evaluations before LLM deployment in automated systems affecting vulnerable populations. Future research should broaden scenario set and develop effective bias mitigation methods. Addressing these challenges is crucial for ensuring AI technologies contribute positively and equitably to society.

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Comparison of charging behaviour for private and fleet company EV users using a data-driven approach

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Introduction

An increasing number of companies are converting their traditional combustion engine fleets to electric vehicle (EV) fleets with the aim of achieving Net Zero in Australia. This research seeks to investigate the charging behaviour during the early stages of adapting to EV fleets. By comparing the behaviour of EV users from fleet companies to that of private EV users, the findings indicate that EV fleet companies are encountering challenges in maximising the utilisation of their chargers and balancing their daily non-charging and charging electricity consumption.

Comparison in the literature

The major differences in charging behaviours between fleet company EV users and private EV users can be classified into the following categories:

Table 1 Comparison summary table (Ausgrid, 2023, Lee et al., 2020, Corchero et al., 2014)

Aspect	Private EV User	Fleet Company EV User
Main Charging Location	Home (overnight/off-peak)	Depot (centralised, managed)
Charger Type	Level 1/2 (home), occasional public chargers	Level 2 (depot), DC fast chargers (P2/P3)
Charging Frequency	2–4 times/week, often based on need/convenience	Daily or as needed, based on operational needs
Charging Management	User-driven, sometimes smart home integration	Centrally managed, optimised for efficiency
Priority	Cost savings, convenience	Minimising downtime, operational readiness
Use of Fast Charging	Limited (mostly for long trips)	Frequent, especially for high-utilisation fleet

Charging locations and infrastructure are vital for electric vehicle (EV) adoption and efficiency in Australia. About 83-84% of private EV users primarily charge at home, often during off-peak hours to benefit from lower electricity rates or solar power. Many have installed Level 2 chargers for faster and more efficient charging (Ausgrid, 2023, Andrenacci and Valentini, 2023).

In contrast, fleet EV users rely on centralised depot charging, utilising a mix of Level 2 and DC fast chargers to minimise vehicle downtime. This infrastructure is optimised for efficiency, often featuring smart scheduling to manage costs and respond to grid demands. Public charging stations are secondary to their main depot systems (BP Pulse Fleet, 2025, Violetka, 2023).

Charging frequency also varies: around 22% of private owners charge daily, while nearly half charge three times or fewer each week, reflecting lower daily mileage and the convenience of home charging. Fleet users often charge daily or multiple times, especially for high-utilisation vehicles, prioritising rapid charging to ensure service readiness (Ausgrid, 2023, Patricia and Carmen, 2021, Andrenacci and Valentini, 2023, Zhan et al., 2025, BP Pulse Fleet, 2025, Exro Technologies, 2024).

While private users typically use Level 1 or Level 2 chargers for longer, cost-effective sessions, fleet operators favour higher-power options to maintain operational efficiency. Private users generally adopt a “set and forget” approach to charging, occasionally leveraging smart chargers for optimisation. In contrast, fleets utilise centralised management systems to enhance operations, minimise costs, and ensure vehicles are prepared for service (Zhan et al., 2025, Exro Technologies, 2024).

Understanding the distinct charging behaviours of private and fleet users is essential in meeting the evolving needs of EV users in Australia (Patricia and Carmen, 2021).

Methodology

Data is collected using the latest AC/DC chargers from Jetcharge and compiled by ARENA. The data includes power meter readings, timestamps, voltage, charging speed (kW), state of charge (%), and anonymised user information.

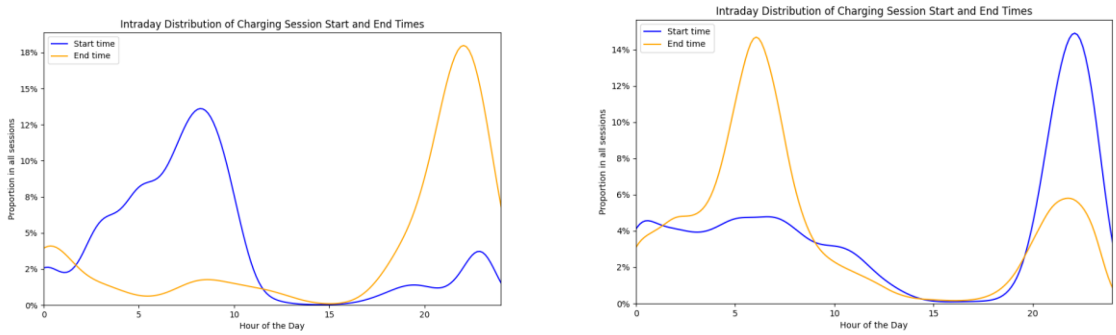
Major observations focus on preferred plug-in time, preferred unplugging time, charging duration, power consumption, and charger utilisation rates. Additionally, the seasonality of charging behaviour is examined, looking at monthly patterns, weekday versus weekend patterns, and charging at home versus at work. A comparison of AC versus DC chargers is also conducted to observe differences in charging behaviour and charger performance profiles, such as voltage, charging speed, and current over time.

Findings so far

Most companies mainly install slow chargers, with a few fast chargers being used during the transition phase, resulting in an average charging time of over 10 hours per charge. Fast chargers typically have an average charging time of under 2 hours. Due to daily duty patterns, slow chargers experience significant periods when they are plugged in but not charging (which we call idle time), whereas fast chargers have much less idle time.

Figure 1 illustrate the histogram of the plugging time (start time) and unplugging time (end time) histograms for all chargers and connectors for two types of chargers (charging at home and charging at work). (a) shows that the majority of work charging sessions start around 8:00 in the morning and end at around 11:00 p.m. (b) shows that the majority of home charging sessions start at around 8:00 p.m. and finish at around 8:00 in the morning.

We also found that the home charging patterns are stable across multiple states in Australia (all of the chargers are AC slow chargers), while the charging at work patterns vary significantly due to the policy, duty shifts, EV usage patterns and charger setup.



(a) Charging at Work (fleet company) (b) Charging at Home (private)

Figure 1 Typical charging start and end time for (a) charging at work users and (b) charging at home users.

Discussion

During our investigation, we measured the charger's utilisation rate, which is the charging time divided by the total plugging time. We observed an average utilisation rate of 60% after installing the chargers for more than one year at one company, indicating that potential improvements could be made through additional management.

The challenge lies in increasing the utilisation of the chargers by scheduling the charging demand during off-duty hours, and in balancing daytime charging with other power consumption needs due to the limited total power supply at a given site.

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Extended Abstract

Microhubs and Micro-logistics Challenges and Opportunities

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1 Introduction

Micro-logistics using Light Electric Freight Vehicles (LEFVs) is gaining traction globally as a sustainable solution for last-mile urban freight deliveries. These low-impact vehicles support urban planners environmental and social goals by reducing congestion and pollution. However, their adoption in Australian and other cities faces challenges, including the need to simultaneously develop urban freight microhubs—facilities that transfer goods from large trucks to LEFVs for efficient last-mile delivery in dense, pedestrian-friendly areas.

City governments back LEFVs and microhubs for their potential to lower emissions, ease traffic, and support urban design objectives (International Transport Forum, 2024). In contrast, businesses focus primarily on cost, efficiency, and customer service, with sustainability as a secondary concern. Yet, global trends show increasing alignment between city goals and business interests, creating opportunities for broader micro-logistics adoption. Success depends on aligning the priorities of local governments and interests of logistics companies through collaboration.

While trucks and vans will continue dominating urban freight and kerbside access, climate targets, safety, and congestion pressures push cities to explore innovative, lower-impact delivery systems (Cairns & Sloman, 2019). LEFVs are favoured for reducing truck traffic, but spatial, regulatory, commercial, and infrastructure challenges remain—particularly in securing land for microhubs close to delivery points to make LEFV journeys feasible (International Transport Forum, 2024).

Cities like Paris demonstrate that integrating logistics with urban planning, including vehicle access regulations, can improve quality of life. With over 340 European cities adopting similar policies, LEFVs and microhubs are becoming essential tools for sustainable urban freight (Harlan, 2025), (Kin & Quak, 2023) (Fransen, et al., 2023).

2 Commercial viability and challenges

Logistics decisions are fundamentally commercial, aiming to deliver goods on time with optimal service and cost-efficiency. City regulations and policies shape these decisions by defining legal frameworks within which companies operate. Policy changes can either encourage lower-cost alternatives or impose unavoidable costs that are ultimately passed on to customers.

Light Electric Freight Vehicles (LEFVs) offers a potentially sustainable and efficient alternative to traditional van deliveries that in the right circumstances can be a lower cost alternative. However, widespread adoption remains limited due to practical barriers. Current research suggests that only 10–15% of freight deliveries can realistically shift to LEFVs, meaning 85–90% will still be undertaken by standard size vans or trucks regardless of their engine type.

This ongoing traffic demand must be factored into urban planning, even with world leading LEFV integration.

3 Opportunity size in Australian cities

The CycleLogistics European project (Reiter & Wrighton, 2013) estimates that freight and servicing traffic make up 25% of total traffic, with 8% of this potentially shiftable to cycling-based delivery methods. Similarly, the LEFV-LOGIC project (Ploose van Amstel, et al., 2018) suggests that 10-15% of freight deliveries across various sectors could be cost-effectively carried out using Light Electric Freight Vehicles (LEFVs).

Applying this to a 2014 TfNSW traffic count of 35,000 commercial vehicles entering Sydney CBD, the findings indicate that approximately 5,000 to 10,000 freight and servicing trips could be replaced by LEFVs. However, this estimate does not account for trip origins. LEFVs are best suited for trips up to 3 km (Gruber, 2023), (c40 Knowledge, 2025). Such short trips typically require transhipment from larger vehicles at microhubs near the destination CBD.

To support such a shift, significant microhub space close to the CBD would be necessary. In compensation, this could reduce parking demand at CBD delivery destinations and free up space assuming consideration is given to access for LEFVs. Based on the existing Courier Hub in Sydney—which handles about 50 vehicle drop-offs daily in a 125 m² space—between 8,500 m² and 17,000 m² of microhub space, on appropriately zoned land, would be needed to accommodate the estimated switched freight volumes. Additional space would also be required to park LEFV equipment.

4 Global business and city references for micro-logistics and microhubs

Leading businesses and cities are developing micro-logistics and microhub solutions, indicating operational productivity and economic viability despite limited public data. Recent examples include:

Businesses:

- UPS Hamburg: Operating microhubs and LEFVs since 2015 with city support.
- Amazon Europe: Established 50 microhubs supported by e-cargo bike fleets.
- DHL Europe: Early adopter of cycle-based logistics, continuing expansion.
- DPD: Opened a microhub in Westminster, London (2018) on TfL land; expanding e-cargo fleets across Europe.

Cities:

- Berlin: KoMoDo pilot (2018-2019) sponsored by the Federal Environment Ministry.
- Hamburg: Identified 32 potential microhub locations via their city investment agency.
- German program for cargo bike testing *Ich entlaste Städte* (“I relieve cities”) program, (2017-2020) supported 755 companies and public institutions to test equipment
- New York: Launch of a microhub program in 2025 with three initial sites, aiming for 36.
- Sydney: Established a microhub in 2015 to support CBD access during infrastructure works; achieved a Benefit-Cost Ratio of +5.85. (SGS Economics, 2023) (Transport for NSW, 2021)

5 Establishing an approach for authorities and stakeholders

To Foster scalable, sustainable urban micro-logistics, stakeholders should focus on:

- **Vision and Planning:** Embed logistics into human-centric urban design to minimize vehicle impacts and enhance liveability.
- **Funding Models:** Use initial public investment to catalyse projects, with a roadmap to commercial sustainability.
- **Site Selection:** Prioritize locations close to delivery destinations with suitable regulatory and physical conditions.
- **Microhub Design:** Ensure accessibility, security, and operational efficiency while accommodating driver and product needs.
- **Vehicle Compliance:** Standardize LEFVs to meet safety and environmental standards.
- **Business Integration:** Address workforce management, technology adoption, contractual frameworks, and data sharing to support seamless operations.
- **Collaboration:** Promote cross-sector cooperation between governments, businesses, and communities to align goals and resolve implementation challenges.

Insights for the above are drawn from (International Transport Forum, 2024) (c40 Knowledge, 2025) (Seeck & Engelhardt, 2021) (Apur.org, 2020), (Transport for London, 2023) (Transport for NSW, 2021), (ANC, 2024)

6 Conclusions

Major cities and businesses are increasingly adopting scalable micro-logistics solutions, reflecting a growing commitment to sustainable urban freight. To ensure success, it is essential to recognize and balance the diverse economic, environmental, and social interests of all stakeholders. Effective collaboration among these stakeholders is critical to overcoming ambiguities and enabling meaningful progress. Equally important is the integration of freight considerations within urban planning frameworks, moving beyond high-level visions to address practical challenges on the ground. Regulatory frameworks must be adapted to support and encourage innovation in freight delivery. Additionally, a comprehensive understanding of spatial factors is vital for operational success, while acknowledging that approximately 90% of freight movements will continue to rely on traditional truck and van access. Together, these insights provide a potential but challenging pathway for advancing sustainable and efficient urban freight systems.

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Wednesday 10th December: 4pm-5.30pm
Parallel Session 4 (Level 17, Lecture room 2)
Theme: Transport Equity, Behaviour, and Urban Change, Session Chair: Prof. Stephen Greaves
Equitable for whom? Parking policy reform in Sydney's Inner West (Kendall Banfield, John Nelson and Stephen Greaves)
From Car Seats to Walking School Bus (WSB) Stops: Understanding Parental Mode Choice Preferences Through a Stated Choice Experiment (Khatun E Zannat, Maximiliano Lizana Maldonado, Judith Y. T. Wang and David Watling)
Exploring aspects of transport-induced gentrification: the case of Sydney's CBD and South-East Light Rail Project (Lara Mottee, Wei-Ting Hong and John Nelson)

Equitable for whom?
Parking policy reform in Sydney's Inner West

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Introduction

Parking policy has a role to play in planning for affordable, equitable and liveable neighbourhoods and cities around the world. In Australia, there has been a knowledge gap around what constitutes good practice parking policy. Inner West Council (IWC) in Sydney, Australia, is in the process of developing a parking strategy (IWC 2025b), and places it in the context of a literature review of good practice locally and internationally (Shoup 2005 & 2018, CfS 2022, TfNSW 2024). The strategy is structured around ten good practice objectives, shown in Figure 1, supported by an action plan. Whilst all the objectives have some relevance to parking equity, the focus here is on three that have a strong connection. For this purpose, parking equity is defined as the fair distribution of parking resources, costs, and impacts across different groups delineated by income, mobility, location, and access. It is contended that parking policy should not unreasonably burden some communities while privileging others.

Figure 1: Parking strategy objectives

Discussion

Parking equity is a consideration from the broadest and the most detailed level of urban planning. At the broadest level, strategy Objective 4 is "*to reduce the need for car ownership and constrain parking*" (IWC 2025b). Parking contributes to urban sprawl, increasing per-household infrastructure costs and the degree to which households without a car can access services (Newman & Kenworthy 1999, Marohn & Herriges 2024). Reducing the need for households to purchase and run a car (or second car) reduces weekly transport costs, improving affordability (Litman 2025). This allows lower-income households to afford to live in places with high levels of access and amenity, including the transit-oriented development precincts now being planned for the Inner West. Pricing of parking reduces the need for all households, including those without a car, to pay for parking (Litman 2024, Shoup 2018, Willson 2012).

Ojective 4 is supported by Objective 6, which is *"to mandate constrained maximum parking rates for new developments in accessible areas and encourage flexible provision"* (IWC

2025b). Traditionally councils have mandated *minimum* parking rates, which has resulted in the over-provision of parking and has reduced the viability of affordable housing because of the added costs of parking. Minimum rates have also been used as a tool by opponents of development to prevent new housing, further reducing affordability (Taylor 2014). *Maximum* rates allow for flexible provision, whilst decoupling parking spaces from the title of apartments allows for efficient, cost effective use of parking space (Litman 2024, Shoup 2005 & 2018, IWC 2025b, CfS 2022, Mepham 2024).

At a more detailed level, draft strategy Objective 9 is *"to prioritise parking for targeted users to improve equity and efficiency of access"* (IWC 2025b). In managing *public domain* parking, Council facilitates parking equity by prioritising targeted users, as listed in Table 1. Apart from dedicating space, Council may grant timing and pricing concessions to these users (IWC 2025b, TfNSW 2020 & 2024). Management of *private domain* parking is the role of the relevant property owner, although Council encourages or mandates parking for targeted users in the private domain through its Development Control Plan (DCP) (IWC 2025a & 2025b, TfNSW 2020 & 2024). Bulky goods stores and shopping malls for example have loading facilities and allocate priority parking space for mobility parking, pick/up-drop-off, bicycles, motorcycles, parents/carers with prams and EV charging to comply with Council's DCP or as part of their general business practice.

Table 1 below is a list of the draft strategy's main targeted users, with justification for positive discrimination of these users over conventional private motor vehicles. Users are listed from highest to lowest priority. Considerations associated with implementation of these special parking arrangements include: ensuring positive discrimination is justified; ensuring the extent and location of parking space to be allocated is optimised; and ensuring there is effective enforcement.

	Targeted user	***Justication for positive discrimination***
1	*Mobility pass holders*	To enable people with mobility difficulties to access parking within reasonable proximity to destinations
2	*Parents with prams*	To enable parents/carers to access parking within close proximity to destination
3	*Pickup & dropoff*	To enable very short term access to destinations for pickup & dropoff of people and goods
4	*Emergency vehicles*	In most instances to enable ambulances to access parking within close proximity to destination - usually applies to medical uses or very large developments
5	*Bicycles*	To encourage bicycles for health and traffic reduction benefits and enable bicycles to be parked securely in close proximity to destination
6	*Motorcycles*	To encourage motorcycles for space efficiency benefits
7	*Delivery & service vehicles*	To enable delivery & service vehicles to access short-term parking space within close proximity to destination & carry out functions safely
8	*Carshare*	To encourage carshare in recognition of transport affordability and reduced parking demand benefits, and to enable access dedicated parking
9	*Electric vehicle charging*	To encourage electric vehicles to reduce emissions and to provide dedicated short-term parking for charging

Table1: List of targeted parking users, with justifications for positive discrimination

Concluding remarks

Parking equity is an important consideration in the development of parking policy, from the broadest to the most detailed level of urban and transport planning. In Australia there is a knowledge and policy gap around good practice parking policy and parking equity, and it is intended that Inner West Council's draft parking strategy will help close this gap, enabling the range of parking equity and other benefits of good practice to be realised.

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From Car Seats to Walking School Bus (WSB) Stops: Understanding Parental Mode Choice Preferences Through a Stated Choice Experiment

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May, 2025

Introduction

The Walking School Bus (WSB) is a promising intervention to promote active travel to school (ATS). A WSB consists of a group of children walking to school, accompanied by one or more adults, usually along a predetermined route with designated stops [1]. WSB can help address key challenges that parents face when considering walking as a school travel option for their children [2]. For instance, a well-adopted WSB program can reduce the overall number of school-bound vehicles, alleviating parental concerns about traffic dangers [3]. Moreover, reducing the car use around the school will not only help decrease the danger from traffic but also lower vehicular emission, thereby reducing children's exposure to air pollution. Additionally, WSB allows parents to drop-off their children at a nearby WSB stop rather than accompanying them all the way to school, helping to mitigate time constraints due to work or household obligations [2]. When WSB is integrated with park-and-stride, WSB offers even greater flexibility for car dependent families. For example, parents of children who live further away from school can drop them off at the park-and stride, allowing the children to walk the rest of the way to school using the WSB. The implementation and operation of WSB present multiple benefits [4]. For children, it fosters physical activity, enhances cognitive development, and promotes social interaction [5, 6]. Parents, in turn, gain extra time to focus on their responsibilities, while schools may experience reduced demand for parking spaces. Moreover, app-based professional monitoring of WSB can provide parents with real-time updates, ensuring their child's safety and security [7].

Various models of WSB programs have been implemented in different countries, albeit often on a limited scale [8]. Despite their potential, most WSB initiatives have operated at a relatively small scale, and few studies have examined how the implementation of WSB influences parental mode choice. Moreover, limited attention has been given to identifying the factors that encourage or discourage participation in such programs. One notable exception is the pioneering work by Pérez Martín [7], who administered a pilot WSB program in a school in Córdoba, Spain. This pilot project enabled the researchers to analyse early adopters, dropout patterns, and associated barriers. While these studies provided valuable descriptive insights into potential obstacles and operational considerations, there remains a significant gap in the literature: no existing research has quantitatively modelled how psychological factors—such as parental habits and preferences—combined with facilitating elements like time, cost, and exposure to emissions, influence mode choice behaviour following WSB implementation.

This study addresses that gap using a stated choice experiment through the development of a hybrid choice model using RP and SP data. The model offers insights into how various psychological and contextual factors affect parental decisions regarding school travel modes in the context of WSB programs, thereby informing future implementation and policy strategies.

Data

The data for this study were collected from the Bradford district, UK, through a two-stage survey conducted between November 2024 and May 2025. We specifically targeted parents of primary school-aged children, as school travel mode choice at this stage is largely determined by parental decisions. Almost 212 parents from 21 primary schools participated in the survey. In the first part of the survey, parents were asked about their children's current school travel plan (e.g., current mode, desired mode for school trip, escorting type, trip chaining, return mode). The second part of the survey includes the stated choice experiment. In the choice experiment, participants were allowed choose between three alternatives: car, walking and WSB. The four attributes in the SP survey are the (1) Travel time of parents (as WSB involves less travel time for parents), (2) Travel time of children, (3) Travel cost, (4) Exposure to emission. The stated choice experiment was developed using a D-efficient design approach. Prior parameter estimates (β_{tt} = –0.48, β_{tc} = –1.4) were derived from the pilot survey conducted to assess parents' current mode choice behavior. For the exposure variable, a very small prior value (β_{exp} = –0.001) was used in the design of the SP scenarios.

Results

The mode choice behavior of parents was analysed using a hybrid choice model. The model was estimated using combined RP and SP data, with the scale parameter for the SP data estimated at 0.7634, indicating greater variability in SP responses compared to RP data. The alternative-specific constants (ASCs) capture the inherent preference for each mode relative to the base category, car travel. Parents' and child's marginal utility of travel time were both negative ($\beta_{tt(parent)}$=-0.08, $\beta_{tt(child)}$=-0.11), indicating dis-utility, as expected. However, parents exhibit greater sensitivity to increases in their child's travel time compared to their own. This suggests that travel modes or policies that reduce children's school travel time are likely to be more appealing to parents. Consequently, when designing WSB, longer routes may be less attractive to parents. Travel cost also had a significant negative effect on mode choice (β_{tc}=-0.37). Exposure to emissions had a small but negative effect (β_{exp}=-0.01), suggesting that parents may be sensitive to environmental quality when choosing travel modes for their children.

Habitual car use emerged as a strong predictor of continued car-based commuting. Parents who regularly used the car were significantly less likely to choose walking or WSB (β=-0.22), reflecting a strong inertia effect and highlighting the persistence of car dependency. This underscores the behavioral resistance among parents to shift away from car travel. To investigate further, we interacted other psychological and sociodemographic factors with the utility. For instance, the number of children (aged below 15) in a household negatively affected the likelihood of selecting the WSB (β = –0.260), possibly due to the added logistical complexity or time demands of coordinating travel for multiple school-aged children. Full-time employment among parents was also negatively associated with choosing walking or the WSB (β = –0.525), potentially reflecting constraints related to inflexible work schedules or commuting distances. Mothers who typically escorted their children to school were more likely to choose walking (β = 0.589), indicating that WSB promotional efforts may be particularly effective if targeted toward this demographic, potentially encouraging greater participation as volunteers or WSB coordinators [9]. Respondents who perceived walking as the most desirable mode and currently used walking as their primary travel mode were more likely to either adopt the WSB, if introduced, or continue walking. Furthermore, satisfaction with the existing school travel arrangements was negatively associated with the likelihood of choosing the WSB in the future. This suggests that parental satisfaction is a key covariate; improving satisfaction with alternative travel options is essential to increase the uptake of WSB initiatives.

Conclusion

This study provides valuable insights regarding the level of service attributes, psychological and demographic determinants of parental mode choice preferences. The findings underscore the importance of reducing travel time, and associated cost (cost of travel by WSB, and exposure) to increase uptake of WSB. The current model is still under development and will be further enhanced by incorporating built environment factors—such as density, diversity, and design—to improve the prediction of demand for the WSB. The proposed modelling framework will be useful in designing an efficient WSB program, which will eventually promote active travel to school.

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Exploring aspects of transport-induced gentrification: the case of Sydney's CBD and South-East Light Rail Project

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Introduction

Public transport projects reshape neighbourhoods and livelihoods, creating opportunities for delivering social benefits through urban renewal, place-based and transit-oriented development (TOD). At a strategic metropolitan-scale, new development and urban renewal may be encouraged as TOD around light rail or Bus Rapid Transit stations, to promote centrally accessible services needed for everyday life (Padeiro et al., 2019). At the local project-scale, planning requires an understanding of local communities and their neighbourhoods, including social aspects such as wellbeing, culture, personal and property rights, level of socio-economic disadvantage and social determinants of health (Lucas et al., 2022). However, public transport projects can also create social disbenefits and inequalities should they be planned without consideration of the physical environment and socio-demographic context they intervene into (Whyte and Mottee, 2022). Gentrification is one such process that may occur in an area, potentially unnoticed, over a period of many years, whereby there is an influx of capital investment and higher-income residents, displacing existing residents (Chapple and Zuk, 2016). One of the critical discussions about transit-induced gentrification concentrates on understanding the engagement with potential communities affected before, during and after project delivery, and analysing the potential for gentrification effects over time. However, the dominant focus on the technical and financial aspects of conversations in the public engagement at the early-stage government-led project design often steers public attention away from the broader, long-term social outcomes. This practice gap is particularly critical in the context of gentrification related to public transport projects.

Approach

This paper investigates the relationship between light rail, and urban renewal and gentrification processes by analysing public engagement. We adopt a case study approach using the CBD and South-East Light Rail Project in Sydney. Our study involves a mixed-methods case study analysis comprising two parts: 1) Desktop document review and 2) Natural Language Processing (NLP) of social media and public engagement reports. Two research questions guide our study:

1. *What key aspects of transport-induced gentrification processes are identifiable across project phases in the case of Sydney's CBD and South-East Light Rail?*
2. *Using NLP of publicly available online sources, how can we learn about the effects of these key aspects across project phases?*

CBD and South-East Light Rail is a public transport project in Sydney that connects the Central Business District (CBD) to the eastern suburbs of Surry Hills, Moore Park, Kensington, Kingsford and Randwick, along a 12-kilometre route, with 19 stops and two branches (L2

Randwick Line and L3 Kingsford Line). Given the complex interdependencies of gentrification in the urban environment and local planning policies identified in the literature, and the diverse local communities at several locations along the Light Rail route, we selected one suburb to highlight the local geographical context more deeply. Kensington is the location of 3 light rail stations and has a significant history in the urban development of Sydney.

Data collection and analysis

The primary data collected for the NLP analysis is drawn from multiple sources to capture the view of public discourse and concerns relating to the impacts of gentrification across each phase. The data used in the *design phase* is the Environmental Impact Statements (EIS) submissions to the Sydney CBD and South-East Light Rail proposal (see Parsons Brinckerhoff, 2013; Cox and Gold, 2013). For the *construction phase*, the public submissions to the Parliamentary Inquiry into the CBD and South-East Light Rail project were examined (Public Accountability Committee, 2019). In the *operation phase*, tracking public discourse became challenging due to a reduction in formal public submissions. Therefore, the social media posts retrieved from Reddit were used as an alternative data source to capture a contemporary reflection of ongoing public engagement regarding the project's impact. The document review was undertaken as the initial step in forming the methodological analysis pipeline proposed and used to support the NLP analysis. Subsequent steps in the analysis included topic modelling, topic interpretation and theme conceptualisation and evaluation (Hong et al., 2024).

Findings

Our study demonstrates that in the early phases of the project, while key aspects of gentrification processes may be reflected in increased property and land values, the public is focused on the direct amenities (noise, dust etc) of a project that are likely during construction. As a project moves into construction, the public becomes more aware of the potential effects, as they are impacted by tangible and intangible impacts in their daily lives such as the impact of construction on travel patterns and traffic which proved to be significant in this project and formed part of a public inquiry into the impact of the light rail project on residents and businesses in the vicinity of the construction corridor. From operation onwards, the prediction of possible gentrification becomes more visible and tangible as there is a catalyst for TOD and urban renewal around station nodes; this begins the most challenging time for policymakers and governments to reverse. Our study shows that gentrification is generally overlooked by the state government in TOD plans for metropolitan Sydney. While commitments to affordable housing are required by the state government, it is not certain whether this is sufficient to prevent or even ameliorate the impacts of gentrification on local communities once occurring. Governments must make a conscious decision to baseline and monitor gentrification, as a key societal issue, due to its complex and indefinite timeline. This should acknowledge that socio-economic changes arising from urban renewal are inevitable but recognise the potential negative impact that may arise for local communities. Whether urban public policy objectives are met through TOD that supports renewal, regeneration or new construction, proposals must include the perspective of local communities.

Whether framed as gentrification or revitalisation, the full extent impacts of light rail on Kensington Town Centre will become apparent in the years to come. The neighbourhood changes will be visible as Randwick LGA's urban renewal zoning plans for Kensington are delivered and in the demographics at the next ABS Census in 2026 and 2031. This will aid exploration of the extent to which LRT-induced gentrification results in less active transport or increased levels of car ownership. It remains the case though that gentrification processes – while accelerated by LRT – will need to be managed by local planning strategies/controls.

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Thursday 11th December: 9am-10.30am
Parallel Session 1 (Level 17, Lecture room 3)
Theme: Network Optimisation and Intelligent Traffic Systems, Session Chair: Prof. Michael Bell
Penalty decomposition methods for second-best congestion pricing problems on large-scale networks (Lei Guo, Wenxin Zhou, Xiaolei Wang, Hai Yang and Tijun Fan)
Zone-cut based approach for path-independent OD trip matrix estimation (Ruri Sase, Satoshi Sugiura and Fumitaka Kurauchi)
Application of Gamification to Alleviate Traffic Congestion on Expressways ~ Game Development and Demonstration in Hiroshima area ~ (Yoshiro Azuma, Fumitaka Kurauchi, Toshiyuki Nakamura and Taro Shibagaki)

Penalty decomposition methods for second-best congestion pricing problems on large-scale networks

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1 Introduction

The second-best congestion pricing (SBCP) problem is one of the most challenging problems in transportation due to its bilevel hierarchical structure. The upper-level traffic manager determines toll level on tollable links to minimize system total travel time, while the lower-level users choose routes based on user equilibrium conditions with given toll level. Existing solution methods for SBCP can be categorized into three types: (1) Replace the lower-level optimization problem by its implicit solution. Gradient based method like sentivity analysis-based method [2] can be used. However, the availability of gradients is not always guaranteed. (2) Replace the lower-level problem with its optimality conditions to reformulate the SBCP as a mathematical problem with equilibrium constraints (MPEC). A heuristic cutting constraint algorithm (CCA) proposed by [1] replaces the variational inequality constraint with its extreme-point representation. The worst-case performance of CCA depends on the cube of No. of extreme points and hence CCA is not applicable to large-scale networks. (3) Replace the lower-level problem with a level set constraint of its value function. The standard augmented Lagrangian (AL) method is adopted to solve the non-linear program [2]. Nevertheless, the reformulation does not satisfy MFCQ, so the multipliers may be unbounded; AL may be quite inefficient without the boundedness of the multipliers.

To summarize, in spite of various intriguing attempts for solving SBCP, existing solution methods are either heuristic without convergence guarantee or suitable for solving SBCP on small networks only. In this paper, we reveal some convexity-based structural properties of the marginal value function reformation of SBCP and propose two dedicated decomposition methods for solving SBCP on large-scale networks. We establish the convergence of the two decomposition methods under commonly used conditions.

2 Solution method

The SBCP problem is a bilevel programming problem:

$$\min_{u} F(v) = \sum_{a \in A} v_a t_a(v_a) \tag{1a}$$

$$\text{s.t. } u \in U_0 = [0, \hat{u}]^{|A|}, u_a = 0 \ a \in A \backslash \bar{A}, \tag{1b}$$

$$v \in S(u), \tag{1c}$$

where A is the set of links, $\bar{A}$ denotes the set of tollable links, v_a represents the flow on link $a \in A$, $U_0 = [0, \hat{u}]$ stands for a box constraint restriction for the toll vector. $S(u)$ is the optimal solution set of the following traffic assignment problem

$$\begin{aligned} \min_{v} \quad & f(u, v) = \sum_{a \in A} \int_0^{v_a} (t_a(x) + u_a) dx \\ \text{s.t.} \quad & v \in \Omega = \{v' : v' = \triangle h, \ \Lambda h = d, \ h \geq 0\}. \end{aligned} \tag{2}$$

We consider the value function reformulation of the SBCP problem:

$$\min_{u,v} F(v) \tag{3a}$$

$$\text{s.t. } u \in U, \ v \in \Omega, \ f(u, v) - V(u) \leq 0 \tag{3b}$$

where $V(u) = \inf_v \{f(u, v) : v \in \Omega\}$. Then, the solution set $S(u)$ of the lower-level problem is now defined by $S(u) = \{v \in \Omega : f(u, v) - V(u) \leq 0\}$. We show that the marginal value function $V(u)$ is concave, and the function $f(u, v) - V(u)$ in (3b) has a convexity-convexity structure in the sense that it is convex with respect to the upper-level variables u for any given v and convex with respect to the lower-level variables v for any given u. So, if we penalize the constraint $f(u,v) - V(u)$ to the objective function of Problem (2), then the resulting penalized problem can be decomposed into two tractable convex optimization problems w.r.t. v and u, i.e., $\min\ F(v) + \rho f(u^{t-1}, v),$ s.t. $v \in \Omega$ and $\min\ f(u, v^t) - V(u),$ s.t. $u \in U$, where the superscript t denotes the iteration index for the penalized problem. This method is called the penalty decomposition (PD) method When the penalty factor ρ is sufficiently large, the sequence generated by PD converges to a stationary point of Problem (3).

Since we show Problem (3) does not satisfy MFCQ, we then relax the constraint $f(u,v) - V(u) \leq 0$ to be $f(u,v) - V(u) \leq \epsilon$ in order to make the resulting relaxed problem easier to solve, where ϵ is the relaxation factor. Using the similar technique, we can also penalize the constraint $f(u,v) - V(u) \leq \epsilon$ to the objective function and further decompose the penalized problem into tractable convex optimization problems. This method is called the relaxation penalty decomposition (RPD) method When the penalty factor ρ is sufficiently large, the sequence generated by PD converges to a stationary point of Problem (3).

3 Numerical study

We compare the efficiency of the two proposed methods with the CCA method in [1], the SAB method in Subsection 4.3.4 of [2], and the AL method in Subsection 5.2.4 of [2].

Table 1 reports the total travel time cost at the approximate solution derived by the five different methods, and the CPU time in seconds. As can be seen from Table 1, the AL method fails to solve SBCP on all the networks. The other four methods can solve SBCP on all the medium-scale networks (i.e., MA, BER-F, BER-T, BER-PC, BER-MC) within 2,800s, but our proposed PD and RPD methods are substantially faster than the other three methods (in less than 200 seconds). When the network size further increases, the required computational time by the CCA and SAB methods increases drastically. For networks AHM, BER-MPFC, BCN, WPG and CHI, the CCA method fails to converge within 30,000s, and the SAB method becomes incapable for networks BCN, WPG and CHI. However, the PD and RPD methods proposed in this paper can solve SBCP on all the networks in Table 1. And the RPD method can find the best solutions at the fastest speed among the five methods. Even for the CHI network with 93,135 OD pairs, the PD method can find the solution within 8,503 seconds, and the RPD method can find the solution in less then one hour. This demonstrates that the two proposed methods can efficiently solve SBCP on large-scale networks.

Table 1: The total travel time cost and CPU time derived by different methods

Network	AL	CCA	SAB	PD	RPD
MA	——	2.818E4 (105s)	2.818E4 (2010s)	2.818E4 (71s)	2.818E4 (49s)
BER-F	——	7.286E5 (254s)	7.286E5 (1101s)	7.286E5 (194s)	7.286E5 (148s)
BER-T	——	7.168E5 (805s)	7.170E5 (1058s)	7.168E5 (101s)	7.168E5 (77s)
BER-PC	——	1.400E6 (1031s)	1.400E6 (2788s)	1.400E6 (180s)	1.400E6 (137s)
BER-MC	——	1.051E6 (891s)	1.052E6 (724s)	1.051E6 (92s)	1.051E6 (71s)
AHM	——	——	1.430E6 (14054s)	1.418E6 (239s)	1.419E6 (60s)
BER-MPFC	——	——	2.362E6 (21390s)	2.362E6 (460s)	2.362E6 (459s)
BCN	——	——	——	1.365E6 (1096s)	1.365E6 (441s)
WPG	——	——	——	9.254E5 (1777s)	9.254E5 (481s)
CHI	——	——	——	1.835E7 (8503s)	1.835E7 (2131s)

—— means that the method cannot find an approximate UE within 30,000 seconds

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Zone-cut based approach for path-independent OD trip matrix estimation

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Background and advantages of the proposed method

This study proposes an Origin-Destination (OD) trip table estimation focusing on the property of cut, which is distinctive connection structure in road networks. OD trip table is fundamental and crucial information in transportation planning and serves as essential inputs for traffic assignment. Extensive studies have been undertaken, and the main difficulties of OD trip matrix estimation method are following two points: (i) In most cases, the solution becomes indeterminate because the number of observed link traffic counts, which serve as constraints, is typically smaller than the number of OD flows to be estimated. (ii) Link choice proportion is usually derived based on assumed route choice principles under an ideal scenario, such as stochastic models, but these assumptions inherently involve uncertainty.

The proposed method in this study can explicitly address the two aforementioned problems: (i) By establishing estimation variables based on the flow conservation criteria that hold between cuts (link set that disconnects OD zone pairs) existing between OD zone pairs, which are founded on the connectivity structure of the road network, estimation variables corresponding to the dimensionality of observational information can be set, enabling accurate estimation. (ii) Since the estimation is based on observed link traffic volumes and zone-to-zone transition trajectory data obtained from active data including probe vehicles, route choice assumptions that presuppose ideal conditions are unnecessary.

Key idea of cut-based OD trip matrix estimation method

In a directed graph $G(V,E)$, assume that several given zones $z \in Z$ exist, and link traffic counters are installed on all links that form the boundaries of these zones, making the link e traffic volumes v_e known. Under this assumption, as shown in Figure 1(a), the total flow entering or exiting zone z_1, $\sum_{e\in C_{z_1}^{+}} v_e$ and $\sum_{e\in C_{z_1}^{-}} v_e$ can be calculated. These flows are referred to as zonal inflow and zonal outflow, respectively, and collectively called zonal cut flow. Note that zonal cut flows necessarily include all traffic volumes that pass through zone z. When these zonal in- and out-flows are defined as $x_{zd}^{\phi} \mid z \in Z, d \in D, \phi = \{+,-\}$ by distinguishing the destinations of the flows, OD traffic volumes can be obtained from the difference as shown in equation (1), where q_{od} represents the OD traffic volume between (o,d).

$$q_{zd} = x_{zd}^{-} - x_{zd}^{+}, \forall z \in Z - d \tag{1}$$

Therefore, it suffices to determine x_{zd}^{ϕ} in the above equation. Note that the zonal cut flow v_z^{ϕ} obtained by aggregating the observed link traffic volumes has the relationship shown in equation (2).

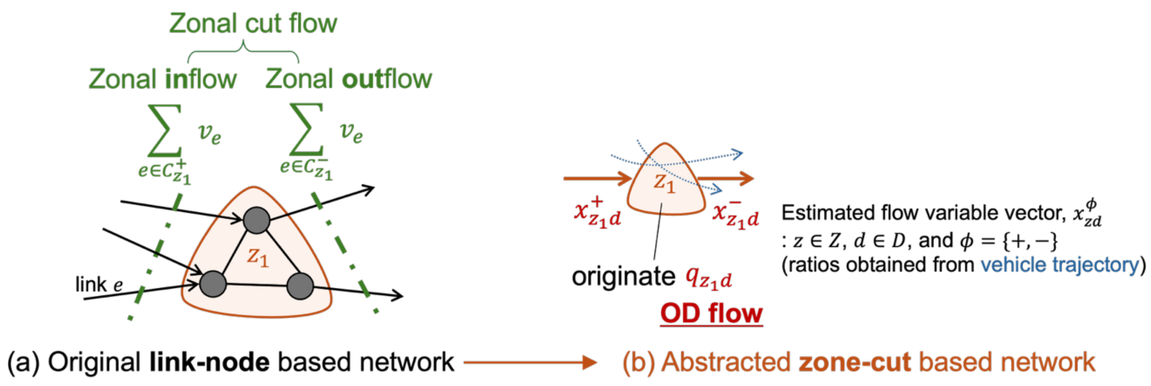

Figure 1. Abstraction from the original network to the abstracted network, and the key concept of estimation

$$v_z^\phi = \sum_{d \in D} x_{zd}^\phi, \forall z \in Z, \phi = \{+, -\} \tag{2}$$

To determine x_{zd}^ϕ, we introduce split ratios by zone $z \in Z$, destination $d \in D$, and in- and out-direction derived from vehicle trajectories. This is necessary because destination-specific traffic volumes cannot be observed from link traffic observations alone. Let w_{zd}^ϕ denote the destination-specific probe in- and out-flows at zone z, obtained by aggregating vehicle trajectories by destination and zone for both in- and out- directions. Using these, the following two split ratios can be obtained:

$$\mu_{zd}^\phi = \frac{w_{zd}^\phi}{\sum_{d \in D} w_{zd}^\phi}, \lambda_{zd}^\phi = \frac{w_{zd}^\phi}{\sum_{z \in Z} w_{zd}^\phi}, \forall z \in Z, d \in D \tag{3}$$

Using the ratios in equation (3), if the observations are accurate, the following equation (4) holds for each split ratio:

$$x_{zd}^\phi = \mu_{zd}^\phi \sum_{d \in D} x_{zd}^\phi \mid \forall z \in Z, \quad x_{zd}^\phi = \lambda_{zd}^\phi \sum_{z \in Z} x_{zd}^\phi \mid \forall d \in D \tag{4}$$

These equations avobe are designed to align the ratios of the estimated traffic volumes x_{zd}^ϕ, aggregated by destination and zone, with the corresponding ratios observed from vehicle trajectories.

Equations (2) and (4), derived from the above discussion, hold as equalities under ideal conditions where link traffic data and vehicle trajectory data are completely observed for all vehicles. However, to account for real-world conditions where observation errors exist, an estimation model should be formulated using x_{zd}^ϕ as the estimation variables.

Concluding remarks

As the most convenient estimation model to handle, we employed a least squares-based model for the analysis. The results confirmed that accurate estimation can be achieved even in the presence of observational errors. At the conference presentation, we will provide comprehensive details of the estimation approach summarized in this extended abstract, along with the corresponding estimation results.

Application of Gamification to Alleviate Traffic Congestion on Expressways ~ Game Development and Demonstration in Hiroshima area ~

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1. Introduction

As methods to alleviate traffic congestion on expressways, several behavioural changes by drivers can be considered, such as shifting departure times, taking breaks at service or parking areas (SA/PA), and using surface roads as alternative routes. Previous studies have investigated various methods to encourage such behavioral changes through means such as information provision displaying congestion levels and travel time, or dynamic toll pricing based on congestion status (Kurauchi et al., 2015). In recent years, gamification—defined as "*the use of game design elements in non-game contexts*" (Deterding et al., 2011)—has garnered increasing attention and has been applied across a wide range of fields. This paper attempts to apply gamification to alleviate congestion on expressways and behavioural changes of drivers are discussed.

2. Driver Engagement for Traffic Congestion Mitigation: Game Development in the Hiroshima Area

(1) Issues in the Target Area: The section of the Sanyo Expressway between Hiroshima IC and Kochi IC serves as a major route connecting central Hiroshima with Hiroshima Airport. The presence of multiple tunnels and sags along this section often causes traffic congestion during morning and evening peak hours; sometimes disrupting the punctual operation of airport limousine buses. **(2) Gamification Strategy:** This study targets congestion occurring in the eastbound direction between Hiroshima-Higashi IC and Saijō IC during the morning hours of 7:00 to 8:00. Through gamification, drivers are encouraged to alter their travel routes (Figure 1) and adjust their departure times. Behavioural changes rarely lead to shorter travel times; therefore, the game is designed to enhance driver satisfaction through means other than travel time saving. **(3) Game Components:** The first component is a behavioural change game themed around "congestion and its mitigation," in which players earn coins by altering their driving behaviour—for example, by avoiding congested highways and instead using surface roads, or by adjusting their travel times to avoid peak hours.The second component involves the use of the earned coins in a majority-choice game called *Ooimongachi*, which is themed around shared preferences and perceptions. This game enables players to explore collective tastes and opinions by attempting to choose the most popular option among multiple choices. **(4) Behavioural Intervention Through the Game:** To encourage behavioural change based on anticipated congestion, it is essential to define both the timing at which drivers are realistically able to alter their behaviour and the information available at those moments. Three key intervention points are established: (1) the night before the intended trip, (2) the morning of the trip, and (3) during highway travel (Figure 2). At each of these stages, information is provided using a forecasting mechanism that

Figure 1: Image of driving on a public road to win coins

indicates four levels of predicted congestion. **(5) Development of the "Ooimongachi, Congestion Mitigation Game!!":** An Android app was developed for use on mobile devices carried by drivers. The story outlines the context and purpose of the game.

3． Field Trials and Results in the Hiroshima Area

A field experiment was conducted from October 10 to December 31, 2023, where drivers who regularly used the target highway section were recruited to use a congestion mitigation game in their daily lives. For the same participants, two experimental phases were set: one without rewards and another with rewards provided based on gameplay content, in order to examine differences in their behaviour. Log data collected from the game included records of behavioural declarations, passage histories of coin collection spots on local roads, and voting histories. A web-based questionnaire survey was conducted, asking participants about their gender, age, daily gaming habits, frequency and purpose of using the target road section, sense of personal relevance to traffic congestion, reasons for participating in the experiment, and perceived attractiveness of each game element. During the experiment period, a total of 820 participants took part, averaging approximately 12 participants per day. We found that the participants were classified into four clusters referring to their behavioural characteristics. In addition, analyses such as recommendation index evaluation and game design heuristic evaluation were conducted.

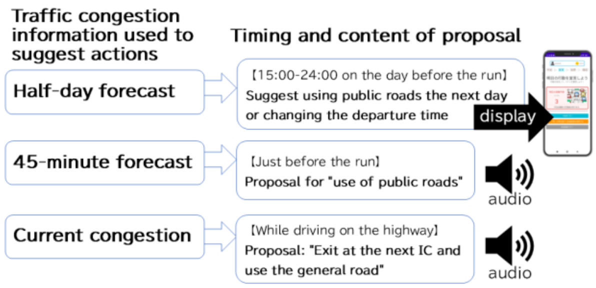

Figure 2: Timing and methods of intervention

4. Discussion, and recommendations for further study

Although the number of participants was limited, several individuals were found to have consistently enjoyed the game and changed their behaviour. Notably, approximately half of the engaged participants did not express a desire for rewards. The participants were found to fall into four distinct categories, and many responded positively to the concept of using a game-based approach for traffic congestion mitigation.One major issue was the limited sample size. This was likely due to several factors, including the requirement for participants to watch multiple instructional videos and complete a lengthy questionnaire prior to app usage, as well as the intentionally strict participation criteria aimed at recruiting individuals for whom the game intervention was expected to be effective. Future developments suggest the need to broaden participation criteria and target behaviour.

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Thursday 11th December: 9am-10.30am
Parallel Session 2 (Level 16, Seminar room)
Theme: Transport Equity, Time Use, and Social Inclusion, Session Chair: Mr. David Surplice
Evaluating Transport Equity for the Public Transport Seasonal Pass: A Case Study of TPASS in Taiwan (Barbara T.H. Yen and Chou-Tsou Chung)
Who Owns Time? Socioeconomic Inequalities in Time Wealth and Well-being in the UK (Wafaa Saleh)
Shared Micromobility and Social Inclusion: A Tale of Two Countries (Yuting Zhang, Helena Titheridge, John D Nelson, Corinne Mulley, Daniel Oviedo Hernandez and Jennifer L Kent)

Evaluating Transport Equity for the Seasonal Public Transport Pass: A Case Study of TPASS in Taiwan

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Introduction

In recent years, cities around the world are attempted to promote sustainable transport and enhancing public transport usage (Yen *et al.*, 2018). Moreover, the government has obligation to provide basic transport service for redisents. Therefore, accessibility has become the core objective of public transport development, and measuring the development of public transport systems has become a key issue. However, apart from accessibility, equity is a critical issue for public transport provision since essential needs of residents are critical (Yen *et al.*, 2022). In order to achieve a more equitable distribution of transportation resources, fare subsidy policies have become one of common strategies for policymakers and/or operators to achieve these goals. Taiwan is no exception. Following successful international practices, Taiwan central government has introduced the first nationwide seasonal public transport passes branded as TPASS in 2023. Other than the TPASS, some regional passes have been introduced (e.g., Taipei 1280 and Kaohsiung MeNGo) since 2018. Although these policies vary in form, they all share the common goal of enhancing public transport usage and improving transportation equity.

There are two types of equity (i.e., horizontal equity and vertical equity) (Abulibdeh *et al.*, 2015; Litman, 2017). Horizontal equity, which ensures equal treatment within the same group, and vertical equity prioritize support for those with special conditions (e.g., disable users). Vertical equity emphasizes that individuals with fewer resources should receive more support or benefits (Delbosc & Currie, 2011). In the implementation of public transport policies, governments often prioritize expanding the coverage of public transport networks as a first step, and horizontal equity can be assessed based on the extent of service coverage. However, once a certain level of coverage is achieved, it becomes essential to evaluate whether those in need can access these services, which introduces the issue of vertical equity. Vertical equity can be reflected in various forms (e.g., fare discount for special users).

As TPASS represents the first nationwide seasonal pass policy in Taiwan, this study aims to conduct an initial exploration of the distribution of transport equity in Taiwan. İn other words, TPASS transition data has been used to reflect travel demand of the users to measure the euqity level in this study. This study will focus on vertical equity and use the "savings per person/median income" (SPI) before and after the TPASS as a measurement indicator of vertical equity. Subsequently, this study uses Lorenz curve (Lorenz, 1905) and Gini index (Gini, 1912) to evaluate the SPI results since those two methods are commonly used in equity measurment. However, the Gini index reflects overall inequality but fails to reveal whether inequality is concentrated among the most disadvantaged or most advantaged groups (Karner *et al.*, 2024). The Palma ratio (Cobham & Sumner, 2013) was also introduced into the study to further examine whether TPASS contributes to reducing spatial barriers and reshaping travel patterns. Further, a gravity model is applied to simulate trip flows between districts based on TPASS usage, while the Louvain community detection algorithm is used to examine spatial integration and detect changes in regional travel structures before and after the policy implementation.

The structure of the study is as follows. The next chapter reviews the relevant literature from three aspects, which are public transport, seasonal pass policies, and equity, followed by an overview of the methodology and a description of the data used in this study. The subsequent chapter presents and discusses the research findings, and the final section outlines the limitations of the SPI indicator adopted in this study.

Literature Review

To better organize the relevant literature, this section reviews several key aspects to clarify the relationship between public transport, seasonal pass policies, and equity. Seasonal pass policy and fare subsidies have been widely regarded as effective tools for the government to increase public transport ridership and reduce commuting costs (Buehler *et al.*, 2017). In addition, it can encourage private car users to switch to public transport (Thøgersen, 2009). In recent years, cities around the world have implemented various seasonal pass policies centered on fare subsidies, which have proven to be effective (Azami *et al.*, 2021; Loder *et al.*, 2024; Wallimann *et al.*, 2023). Seasonal pass policies have increasingly become a key component of travel demand management strategies. By offering fare discounts and reducing the marginal cost of each trip to zero, these policies have significantly increased public transport ridershi (Buehler *et al.*, 2019). Moreover, when seasonal pass policies are combined with fare subsidies for disadvantaged groups, they provide greater opportunity to travel (e.g., shop, leisure activities, medical services, and visit friends and relatives) (Dunkerley *et al.*, 2016). Thus, seasonal passes serve as an important tool for promoting transport equity and social inclusion.

Equity can be divided into horizontal equity and vertical equity (Abulibdeh *et al.*, 2015; Litman, 2017). Horizontal and vertical equity in transport services pursue different goals, and these goals can conflict with one another (Ferrell *et al.*, 2023). For example, the goal of horizontal equity requires all passengers to pay a flat fare, while the goal of vertical equity ensures that low-income or disadvantaged groups receive transportation subsidies. Therefore, in the design of transport demand management strategies, both dimensions of equity should be considered. However, TPASS contributes to the advancement of both horizontal and vertical equity. This study will focus on vertical equity. There are three types of transportation vertical equity, which are inclusivity, affordability, and social justice (Litman, 2017). Among these, this study focuses on the affordability, aiming to measure whether the TPASS policy in Taiwan effectively reduces the transportation cost burden for low-income groups across different districts. and use the SPI to measure the vertical equity of TPASS. Past research has pointed out that the use rate of seasonal public transport passes is higher in low-income areas (Cadena *et al.*, 2016), reflecting that low-income groups rely more on transport seasonal passes, but the average cost of traveling is not much different, so SPI can better reflect the difference in subsidy benefits. To further quantify equity, the Lorenz curve (Lorenz, 1905) and the Gini index (Gini, 1912) are also used for analysis, such as the study of changes in public transport equity in various case studies (Ngoc *et al.*, 2025). Seasonal passes have been shown to increase usage and support car-free groups (Dittmar, 1983), and have the potential to improve vertical equity. However, the effectiveness of policy implementation is still affected by accessibility (Baghestani *et al.*, 2024). Additionally, the Palma ratio is used to determine whether inequality is concentrated among the most disadvantaged or the most advantaged groups.

Trip Distribution is the second step of the four-step model, which is widely used in transportation planning to predict travel demand. Trip distribution is the process by which all trips generated in a study area are allocated among zones. Among various approaches, the gravity model is the most widely used method (Kim *et al.*, 2011). It is based on an analogy to Newton's law of gravity. This distance decay function (e.g., distance-squared, exponential, or power) plays a key role in model prediction and parameter calibration. In recent years, researchers have also applied gravity models to smart card data to simulate spatial behavior. Jung *et al.* (2008) applied the gravity model to capture the spatial effect of smart card data, using a distance-squared decay function, and demonstrated that the model exhibits strong predictive capabilities within a structurally complete transport network. However, while the gravity model can simulate the spatial distribution of trips, it has limited capacity to reveal the structural characteristics of trip networks. To address this limitation, community detection algorithms have been widely applied in transportation research to uncover latent structures within spatial networks (Cazabet *et al.*, 2017; Wan *et al.*, 2023). This study uses the Louvain algorithm, proposed by Blondel et al. (2008) to estimate whether there are obvious groups in the results of the simulation, observe whether the TPASS policy promotes regional integration.

Methodology and data

This study investigates if TPASS has helped achieving social equality with the Lorenz curve and the Gini index that can provide macro scope analysis on distributional inequality. A lower Gini index indicates a more equal distribution of resources. However, the Gini index alone can only reflect changes in overall inequality. Therefore, this study also employs the Palma ratio to capture changes in the SPI index between the top 10% and the bottom 40% of districts, allowing for a more targeted assessment of equity impacts. In order to explore the spatial effects of TPASS, travel network effect measurement via gravity model are conducted for the case study in Taiwan. However, while the gravity model can simulate the spatial distribution of trips, it is limited in revealing the underlying relationships between administrative districts or in detecting whether travel patterns have changed following the introduction of TPASS. To address this limitation, the Louvain community detection algorithm is applied to identify community structures within the travel network and to examine potential changes in regional travel patterns after the policy implementation.

TPASS has been implemented in July 2023, İn order to measure before and after effects, public transport smart card data in March and June 2023 are selected for before TPASS measurement and four months of data are selected for after TPASS (i.e., September 2023, December 2023, March 2024, and June 2024). As for the SPI indicator, it is calculated by dividing travel cost savings by the median annual income for each district in Taiwan. Before the implementation of TPASS, SPI is calculated based on the fare of regional passes. The TPASS data is collected from Transport Data Exchange (TDX) (https://tdx.transportdata.tw/) and the income data is obtained by the Fiscal Information Agency, Ministry of Finance, and it is collected in 2022. The data is collected for all regions in Taiwan since the TPASS is a nationwide policy.

Findings and Discussions

The results of Lorenz curves show that the TPASS policy has significant effects in reducing inequality in resource distribution. In Figure 1, SPI has been used to generate Lorenz curves and Gini index. It is clear that TPASS indeed improve the equity since both before TPASS curves (i.e., red lines) are lower and have higher Gini indices than after TPASS ones. It is obvious that TPASS gradually improves equity. In terms of the Palma ratio, Figure 2 shows that the Palma ratio remains between 4 and 5 following TPASS implementation (i.e., blue bars), indicating a disparity in SPI between the top 10% and the bottom 40% of districts. Furthermore, in Figure 3, areas with higher SPI are primarily concentrated in suburbs that are not far from the city centers, which are characterized by high commuting demand. This spatial pattern suggests that TPASS has contributed to enhancing vertical equity.

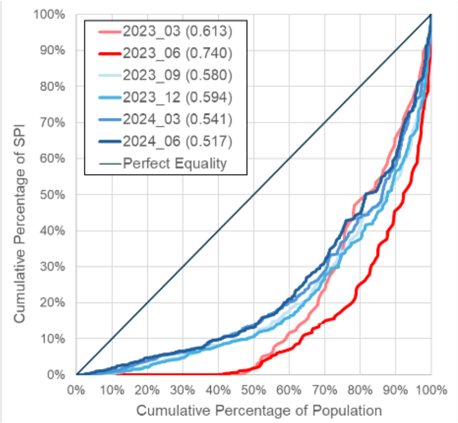

Figure 1 Lorenz curve of TPASS SPI index

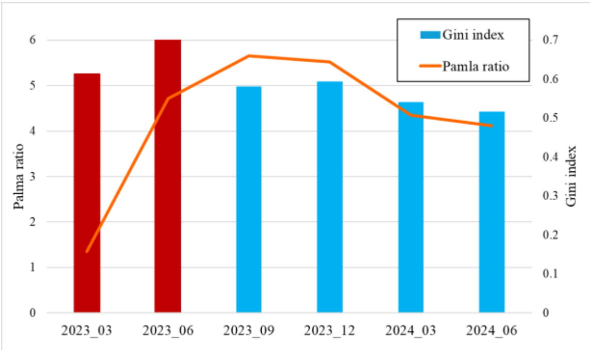

Figure 2 Gini index and Palma ratio of TPASS SPI index

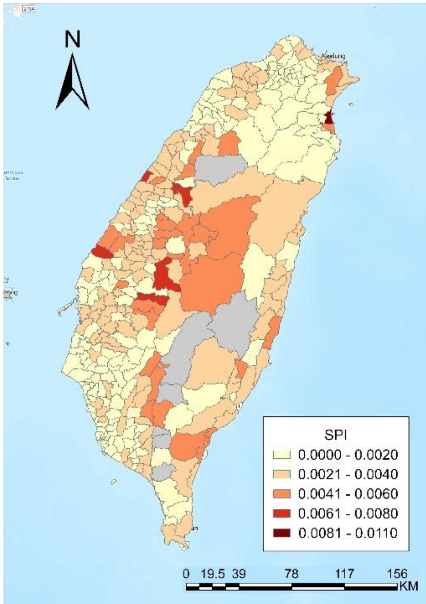

Figure 3 The SPI index after introducing TPASS (June,2024)

In terms of the spatial impacts of TPASS, Figure 4 and 5 show how connection between regions has been enhanced with the example of nothen Taiwan. This model result also shown how TPASS breaks down the regional barriers between administrative regions. In sum, TPASS is not just improving vertical equity and horizontal equity but also improve the accessibility and break the spatial boundary between cities.

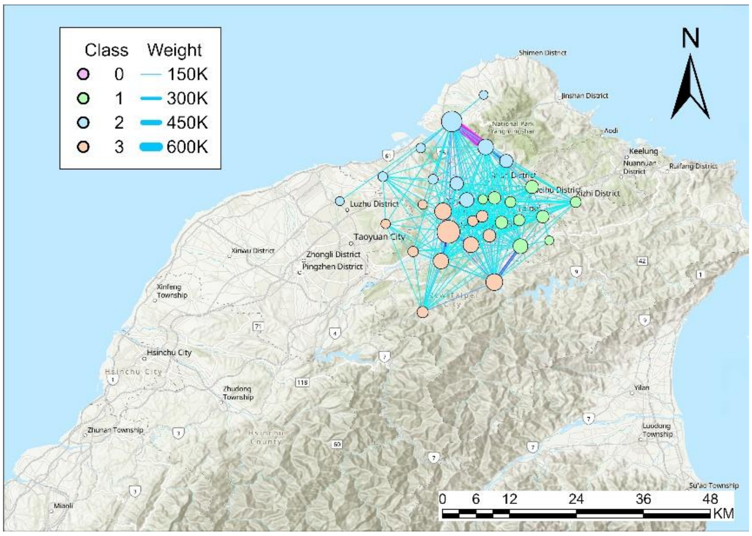

Figure 3 Travel network in June 2023

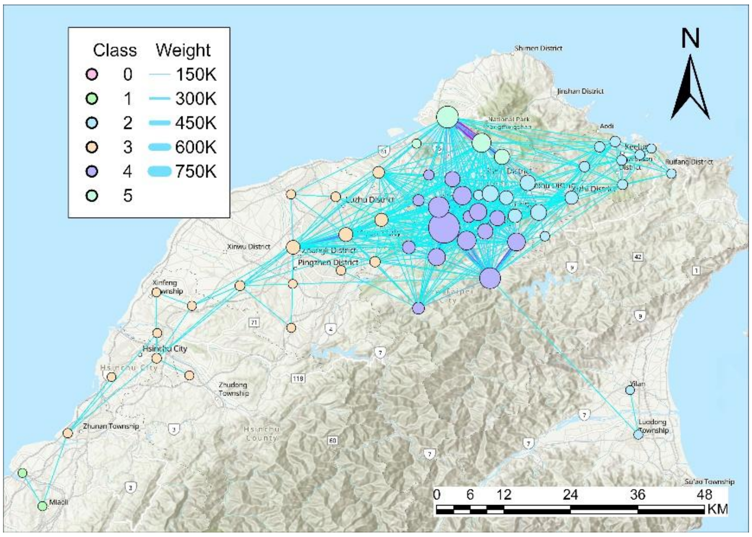

Figure 4 Travel network in June 2024

Conclusion and recommendations for further studies

This study evaluates the vertical equity of public transport seasonal pass with the case study in Taiwan (i.e., TPASS). Analysis of the Palma ratio and the spatial distribution of SPI shows that vertical equity was present at the early stage of TPASS implementation. Further, from the extended gravity model, regional connections is improved after TAPSS. There are some limitations of the study. SPI has been used as the proxy index to measure vertical equity. Some other factors might be wothy to include to measure social inclusion or exclusion level (e.g., social demographics). Regional connection is measured via gravity model and this could be measured via, for example, geographic weight model, to capture spatial effects of each critical variable.

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Who Owns Time? Socioeconomic Inequalities in Time Wealth and Well-being in the UK

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1. Introduction and Literature Review: Time Wealth in Western Contexts

1.1. Definitions of Time Wealth

Time wealth, a relatively recent construct in social science and sustainability literature, broadly refers to the extent of discretionary time available to an individual and the perceived control over how that time is used. It emphasizes both the *quantity* and *quality* of time not allocated to obligatory tasks such as employment, caregiving, or commuting (1). Unlike traditional economic measures such as income, time wealth acknowledges that individuals may be materially affluent yet "time poor" if they lack adequate free time. Geiger et al. (2021) define time wealth as *"the subjective and objective availability of time for personally meaningful activities"* (2), offering a multidimensional lens on well-being.

Studies in Western nations have increasingly focused on how time wealth contributes to life satisfaction, psychological well-being, and autonomy. Kasser and Sheldon (2009) found that greater time wealth—rather than material wealth—was a better predictor of well-being and prosocial behaviour in U.S. adults (3). Similarly, Rosa (2013) and Southerton (2003) argue that modern life, characterized by acceleration and over-scheduling, leads to a sense of chronic time scarcity, even in wealthy societies (4, 5). These findings underscore a cultural paradox: economic development can coincide with a deepening sense of temporal dissatisfaction.

1.2. Factors Affecting Time Wealth

In the West, employment status, gender roles, household composition, and policy design significantly influence time wealth. Dual-income households with children are especially vulnerable to time poverty, as shown by Gershuny and Sullivan (2019), who reported that women's unpaid work burden remains high despite greater workforce participation (6). Work culture also plays a role—long working hours, inflexible schedules, and digital availability expectations reduce time wealth (7). Governmental policies such as parental leave, subsidized childcare, and work-hour regulations (e.g., France's 35-hour workweek) can alleviate time poverty and promote greater time autonomy (8).

Time wealth has important implications for mental health, social inclusion, and gender equity. Empirical evidence from European countries suggests that individuals with higher time wealth are more likely to engage in social and civic activities, exercise, and educational pursuits—all associated with long-term well-being (9). The OECD (2021) has incorporated time use into its Better Life Index, emphasizing that well-being cannot be assessed solely through income or material conditions (10). Importantly, lack of time wealth has been linked to higher stress levels and reduced life satisfaction, especially among caregivers and low-income workers (1).

Western governments and organizations are beginning to explore how time wealth can be used as a policy metric. Germany, the Netherlands, and the Nordic countries have implemented family-friendly policies aimed at enhancing time autonomy (1). In urban planning, "slow city" and "15-minute city" concepts aim to reduce commuting and create more liveable environments, thereby increasing time wealth (2). From a corporate perspective, companies experimenting with four-day workweeks or flexible remote work policies have reported improvements in both productivity and employee satisfaction (3). These examples suggest that time wealth is a scalable concept with applications in labour policy, urban design, and sustainability planning.

2. Methodology

This study investigates *time wealth,* the perceived abundance and quality of discretionary time, as a distinct dimension of well-being among UK adults. It builds on recent European work that positions time wealth as a complement to financial resources, contributing to life satisfaction, autonomy, and mental health. The UK context offers a diverse setting with regional differences in commuting times, work culture, care infrastructure, and socio-economic inequalities, making it an ideal case for exploring time wealth dynamics. A nationally representative sample of 350 adults aged 18–65 are being surveyed using stratified random sampling, ensuring proportional representation by Region, Urban vs. Rural residence, Gender, Age cohorts (18–29, 30–44, 45–65), Employment status (full-time, part-time, unemployed, self-employed, retired).

3. Data Collection Method

The survey instrument includes both quantitative and qualitative data:

- Quantitative: (Demographics and socio-economic status (income, education, employment), Time use (paid work, care work, commuting, leisure), Time stress and control (subjective scales), Psychological well-being, Perceived time wealth (Likert-scale items based on Geiger et al., 2021).
- Qualitative (open-ended): (Perceptions of time abundance or scarcity, Strategies for time management, Narratives on how time constraints affect decision-making and well-being).

The survey is administered online using Google platform. Telephone interviews (10%) will complement online surveys to ensure inclusivity of digitally excluded populations.

Ethical approval is obtained through Edinburgh Napier University, and informed consent have been secured from all participants.

4. Data Analysis

Descriptive statistics will be used to profile the sample and explore time wealth distributions by gender, age, income, region, and employment status. Cross-tabulations and ANOVA will test group-level differences. A composite Time Wealth Index (TWI) will be developed using Likert-scale items measuring. Principal Component Analysis (PCA) are being used to validate the scale. In addition, to assess factors associated with time wealth, the study is utilising the ordered Logistic Regression (for ordinal TWI). The independent variables include income, work hours, caregiving responsibility, commuting time, remote work access, household size, and regional dummy variables. The Open-ended responses will be thematically analyzed using NVivo. Themes which are explored include: The psychological and social meanings of time abundance, Experiences of time scarcity despite high income, Gendered and cultural norms surrounding time allocation.

5. Results

Initial results show significant disparities in time wealth across socio-economic and demographic groups in the UK. Women, especially those engaged in full-time employment and caregiving, consistently reported lower levels of time wealth, confirming gendered patterns of time poverty. While high-income earners might enjoy financial security, they are not necessarily time-rich, long work hours and lengthy commutes often offset monetary advantages. In contrast, individuals with access to remote or flexible working arrangements reported significantly greater autonomy over their time, higher satisfaction with leisure availability, and better work-life balance. The Time Wealth Index, developed from subjective measures of autonomy, satisfaction, and time sufficiency, demonstrated strong internal consistency and revealed that over 30% of respondents fall into the "low time wealth" category. The initial results from the ordered logistic regression analysis further highlighted that working hours, commuting time, and caregiving responsibilities are the most significant predictors of perceived time wealth, while income was not statistically significant once these time-related burdens were considered. Thematic analysis of open-ended survey responses reinforced these patterns: many participants described daily routines as "overpacked" or "chronically rushed," with a strong emotional undertone of frustration and exhaustion. The full results will be reported in the paper.

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Shared Micromobility and Social Inclusion: A Tale of Two Countries

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Introduction

Shared micromobility, a rapidly growing and widely adopted sector, has emerged as a pivotal area of interest in both research and practice in recent years. Beyond offering a flexible transport option, shared micromobility plays a potential role in travel demand management by addressing first- and last-mile gaps and encouraging a mode shift to public transport. This paper explores the influence of shared micromobility on social inclusion in urban settings, focusing on data from selected jurisdictions of Australia and England. The research aims to explore how technology-enabled shared micromobility[1] hinders or can improve transport accessibility and equity, particularly for marginalised groups such as women, the aged, low-income individuals, and people with disabilities. Specifically, it seeks to address the following research questions:

1. To what extent do technology-enabled tools, such as smartphones and online payment systems, serve as enablers or barriers to accessibility to shared micromobility for marginalised groups?

2. What are the characteristics of initiatives and policies that can successfully minimise the negative impacts of technology-enabled shared micromobility on social inclusion while maximising benefits to marginalised groups?

3. How do the impacts and policy responses to technology-enabled shared micromobility on social inclusion differ between Australia and England? What lessons can be drawn from each context?

Context

This study applies the transport-related social exclusion (TRSE) framework to examine how technology-enabled shared micromobility affects social inclusion. TRSE highlights multiple, intersecting dimensions of exclusion, including exclusion from facilities, geographical exclusion, space exclusion, physical exclusion, time-based exclusion, fear-based exclusion, informational exclusion, economic exclusion, digital divide exclusion, and discrimination-based exclusion (Church, Frost, and Sullivan 2000; Bruno and van Oort 2023). More recently,

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[1] Technology-enabled shared micromobility refers to digitally integrated systems of lightweight personal transport (such as e-scooters and e-bikes) that are accessed, operated, and managed through technology-based platforms. The "technology-enabled" aspect encompasses both the functional technologies and the user capabilities, institutional arrangements, and social embedding required to access and use these services effectively.

Oviedo, Moore, and Trofimova (2025) examined, within the TRSE framework, how micromobility, specifically e-scooters (both shared and private), affects society. Emerging technologies and mobility innovations play an important role in shared micromobility—both enabling and constraining access. Bruno and van Oort (2023) recognise digitalisation as one of the three most important topics for social inclusion (the other two are 'social exclusion' and 'mobility'). The requirement for smartphones, mobile data, and digital payments can exclude those without access or skills. Prior studies find that elderly populations, low-income groups, and those with limited digital literacy face exclusion due to technological requirements (Oviedo, Moore, and Trofimova 2025). Research also warns of potential bias in AI-driven systems (Gao et al. 2025). Thus, the technology-enabled nature of shared micromobility intersects with multiple TRSE dimensions, including digital, economic, and informational exclusion.

Method

This project uses Australia and England as a comparative case study. Both locations have experienced rapid growth in shared micromobility schemes. The project involves the following research activities, with a focus on Queensland (Australia) and England (UK):

- Rapid Literature Review – Synthesising academic and grey literature on shared micromobility and social inclusion to inform the design of data collection instruments.
- Stakeholder Interviews (N=12) and two roundtables (N=10*2) – Conducted online across both countries, involving representatives from key organisations in relevant fields.
- Panel Survey (N=1000) – Targeting current and potential micromobility users (500 in each country) to explore different forms of digital exclusion.

Results and Discussion

While the data collection is ongoing (June-October 2025), the anticipated findings are expected to offer critical insights into the multifaceted ways in which technology-enabled shared micromobility shapes social inclusion outcomes. Data analysis is expected to suggest that although shared micromobility holds promise for improving transport access in lower-accessibility areas, this potential remains unevenly realised. Digital and economic barriers, such as the need for smartphones and credit-based payments, may disproportionately affect women, older adults, low-income users, and people with disabilities. Comparative insights between Australia and England will help illuminate how different regulatory and planning contexts influence the inclusivity of shared micromobility. We anticipate that policies explicitly targeting spatial and digital equity, such as hybrid docked-dockless models, alternative access methods, and targeted infrastructure investment, will emerge as critical for reducing such exclusion. The findings will contribute to the development of policy and planning strategies that foster inclusive urban mobility solutions.

Acknowledgements

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Thursday 11th December: 9am-10.30am
Parallel Session 3 (Level 16, Lecture room 5)
Theme: Shared Mobility and Ride-Sourcing Innovations, Session Chair: Prof. Stephen Greaves
Reducing Unreliability in Ridepooling Systems Through Shareability Shadow (Amir Elmi, Emily Moylan, Javier Alonso-Mora and Andrés Fielbaum)
Beyond functionality: Psychological and social drivers of car-sharing use among tourists (Ching-Fu Chen and Wei-Lun Tsai)
User-organized Pre-pooled Ride-hailing: Exploring a New Mode (Wenyang Hao, Yixin Fang and David Levinson)

Reducing Unreliability in Ridepooling Systems Through Shareability Shadow

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Introduction

Ridepooling, the practice of sharing a vehicle among multiple passengers, offers a sustainable alternative to private car usage by reducing congestion and optimizing routes. However, the viability of ridepooling depends heavily on perceived reliability. Unlike other travel modes, ridepooling introduces unique sources of unreliability stemming from dynamic passenger assignments. These include unexpected increases in waiting and detour times due to the insertion of new ride requests en route (Fielbaum and Alonso-Mora, 2020). Therefore, in this study, we focus specifically on unreliability caused by changes in a passenger's travel times after their request has already been accepted.

While some studies have aimed to improve ridepooling efficiency, they often address reliability only indirectly. Yet, efficiency and reliability are distinct: optimizing one does not guarantee improvement in the other. Addressing this gap, the current study proposes a direct approach to reduce passenger unreliability through a predictive model, without significantly compromising system efficiency.

Methodology

This study uses a simulation-based ridepooling framework with a modified assignment algorithm based on the method of Simonetto et al. (2019). Passengers accumulate over a fixed time interval and are then assigned to vehicles in batches. The objective is to minimise a combination of new users' travel time, extra time imposed on existing users, and operator cost. Constraints include maximum waiting time (Ω), maximum delay time (Δ), and vehicle capacity.

We define *slack* as the portion of the passenger's maximum waiting/delay time that remains unused after the initial assignment. It determines how much additional travel time the system can impose on a passenger. Lowering the slack would reduce unreliability, but it is at the cost of inefficiency in terms of rejection rate. To address unreliability effectively, we use the concept of the *shareability shadow* (Tachet et al., 2017; Bilali et al., 2019), which defines where a new request can be inserted and shared without violating current constraints. Based on this, we estimate the probability of a change in each passenger's trip.

To study the trade-off between unreliability and inefficiency, we construct a Pareto frontier. Each point on this curve reflects a different slack allocation strategy. A better system would push this curve closer to the origin, improving both objectives.

We compare two scenarios. In the *Ordinary Control Scenario*, the system runs without the shareability shadow model. A fixed percentage of the slack is allocated to all passengers, varied from 0% to 100% to create different trade-off points. In the *Shareability-Shadow Control*

Scenario, slack is controlled more intelligently: passengers with low probability of change are assigned 0% of their slack, while those with high probability of change retain 100%. Varying the threshold that separates high and low probabilities generates the Pareto curve in this case.

Results and Discussion

The simulation is based on data from the 2013 NYC Yellow Taxi dataset in Manhattan that includes seven days of trip requests, each of which spans over two hours. A fleet of 2,000 four-seat vehicles is used, with $\Omega = 5$ minutes and $\Delta = 10$ minutes. The results is shown in Figure 1.

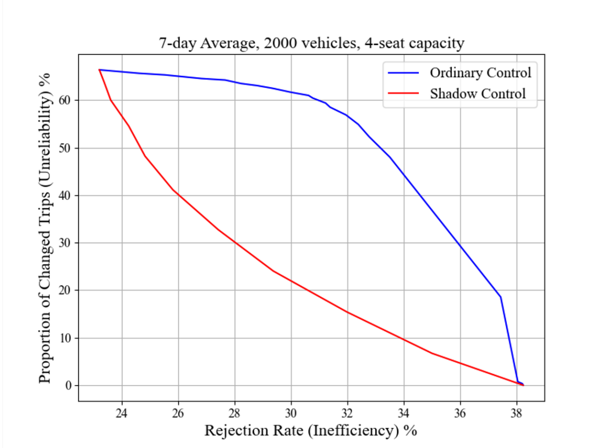

Figure 1: **Result represented in a Pareto frontier plot. Reduction in unreliability is always accompanied by an increase in inefficiency. Shareability shadow enables the system to achieve better performance in terms of both unreliability and inefficiency.**

Several major observations are made in the results. First of all, the two points at either end of the two curves overlap. This is because the two ends represent a ridepooling system in which the slack is either fully allowed or fully restricted, resulting in the same outcome. However, the middle points demonstrate that identifying passengers as low-risk and high-risk can significantly affect the system. The proposed shadow-based strategy creates a closer-to-origin frontier, meaning that the system is operating under more favourable conditions. The strength of the proposed shareability shadow model is that the low-risk passengers are guaranteed not to face any changes throughout their trip. Comparing the middle equivalent points on both curves, we can see that the shareability shadow model is able to break the traditional trade-off in an ordinary ridepooling system by introducing a new condition in which both unreliability and inefficiency is reduced.

Conclusion and Outlook

This study proposes a shareability-shadow-based framework for reducing unreliability in ridepooling systems. By estimating the probability of a change for each passenger and adjusting their slack accordingly, the assignment algorithm is dynamically modified to prevent or allow changes. The approach produces a clear Pareto frontier between reliability and efficiency, providing flexibility for system designers to select the desired operational point. Future work may focus on improving the accuracy of change probability estimates, as well as predicting the magnitude of the change.

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Beyond functionality: Psychological and social drivers of car-sharing use among tourists

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Introduction

Transportation is a major contributor to environmental harm, as about 75% of CO_2 emissions in tourism stem from travel-related activities. The heavy reliance on private automobiles exacerbates congestion, parking shortages, greenhouse gas emissions, and noise pollution in tourist destinations. Shared mobility, particularly car-sharing, has emerged as a sustainable alternative to reduce private vehicle use. Car-sharing services help decrease car dependency and energy consumption, making them environmentally responsible options for both everyday travel and tourism (Ceccato & Diana, 2021). In tourism contexts, they can effectively alleviate local traffic bottlenecks and enhance the overall quality of travel experiences (Singh, 2017). Despite the growing availability of car-sharing services, research on tourists' preferences remains limited. Existing studies have largely emphasized tangible attributes—such as cost, convenience, and availability—while overlooking broader social and psychological influences. These dimensions are particularly salient in tourism, where non-routine travel behaviors often amplify the role of psychological triggers in shaping transport choices (Chen & Huang, 2021).

Social influence, a key driver in innovation adoption, is frequently underexplored in this context. Diffusion theory posits that late adopters rely heavily on interpersonal communication and social validation (Rogers et al., 2014). Within the sharing economy, trust is critical but may be constrained by perceived risks (Ter Huurne et al., 2017). However, trust can also emerge through active engagement; observing others using the service can reduce resistance and build confidence. Importantly, social influence now extends beyond close personal contacts. Ghasri and Vij (2021) found that such digital signals significantly increase consumers' willingness to adopt unfamiliar mobility technologies—an effect especially relevant in uncertain and temporary contexts like tourism.

To address these insights, this study aims to create a comprehensive model explaining tourists' preferences for car-sharing adoption. The model will combine functional service attributes with psychological variables, especially social influence. By exploring external social cues, such as peer usage and social media evaluations, along with perceptions from significant others, this research seeks to facilitate broader sustainability goals in the tourism sector.

Method and Data

This study employed a stated preference-experiment to investigate tourists' preferences for car-sharing services, with a particular emphasis on both functional attributes and psychological factors. A D-efficient design facilitated the generation of 18 choice sets, which were systematically distributed across three versions of the questionnaire. Each respondent evaluated six choice sets, each comprising two car-sharing options along with an opt-out option.

The online survey was conducted between January and March 2025, resulting in 844 valid responses from licensed drivers with prior car-sharing experience.-A Simultaneous Integrated Choice and Latent Variable (ICLV) model was specified by incorporating three latent constructs: Attitude toward car-sharing, Environmental Consciousness, and Social Influence, which were assessed using established psychometric items. Confirmatory factor analysis substantively verified the reliability and validity of these constructs.

Findings and Discussion

The findings identify several key determinants of tourists' preferences for car-sharing services. First, among the functional attributes, rental price, walking time, fuel type, and vehicle size all exert significant effects. The most influential factor is the difficulty of parking at the destination, which substantially reduces the likelihood of choosing car-sharing ($\beta = -0.723$). Second, social endorsement significantly shapes preference. Both the proportion of peers using car-sharing ($\beta = 0.556$) and favorable social media evaluations positively influence tourists' choices, suggesting that perceived acceptance and approval within one's social network and the broader public context are important cues. Model estimation confirms that these social endorsement indicators, alongside functional attributes, play a critical role in shaping behavior in tourism settings. Third, latent psychological factors—particularly attitudes toward car-sharing and perceived social influence—also positively affect preference, indicating that both external cues and internal motivations (e.g., affiliation, credibility) are influential

The findings highlight practical strategies for operators. First, enhancing parking accessibility through collaborations with local governments at travel destinations is vital. By providing dedicated parking spaces for shared vehicles, operators can not only encourage tourists to opt for shared cars but also help mitigate the excessive influx of private vehicles at these locations. Second, improving service quality can significantly boost the reputation of car-sharing systems and cultivate social endorsement. This, in turn, is likely to increase the likelihood of tourists selecting car-sharing as their preferred mode of transportation during their travels. Lastly, given that the influence of significant others is a key factor in tourists' decisions to use shared cars, service providers should consider launching user referral programs. Incentives such as discounts for referring friends and family to use shared car services may resonate more effectively than conventional advertising approaches.

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User-organized Pre-pooled Ride-hailing: Exploring a New Mode

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Introduction

User-organized Pre-pooled Ride-hailing (UPR) is a novel mode of shared mobility emerging at university campuses on China's urban fringe. UPR combines ride-hailing flexibility with social network coordination, enabling spontaneous yet organized trips that lower costs, allow flexible departure times, foster rider interaction, and fill mobility gaps.

In UPR, one traveler initiates a ride request, others respond, and the organizer books a ride-hailing vehicle. Passengers then share the ride at a lower per-person cost than individual ride-hailing or platform-based pooling. Two main patterns have emerged: trips to nearby metro stations for onward travel, and direct trips to final destinations.

Most students live on campus in suburban university towns, where high-quality transit service is often insufficient to meet demand (Sum, 2018). The resulting concentrated and predictable travel demand drives students to seek alternatives, creating favorable conditions for UPR to emerge as a cost-effective and flexible mobility solution.

This gap persists because user-organized carpooling is privately arranged, with dynamic and dispersed patterns that are difficult to observe. General census data can provide researchers with traveler numbers, socioeconomic characteristics, trip attributes, and motivations, but it often mixes all types of carpooling together. That limitation hinders the isolation and analysis of user-organized carpooling behavior(Tavory et al., 2020). As Shaheen and Cohen (2019) noted, observing and documenting carpooling behavior is inherently challenging, leading Paul Minett to describe it as an "invisible mode" (Chan and Shaheen, 2012). Therefore, tracking travel patterns, identifying initiators, and evaluating participants' attitudes toward carpooling and its user-organized forms are challenging.

Understanding UPR adoption requires examining travelers' trust, perceived convenience, and relative cost advantages. This study addresses the gap by asking: which sociodemographic, attitudinal, and contextual factors drive UPR choice, and how do perceptions of safety, convenience, privacy, and cost shape adoption?

Literature Review

Socioeconomic and demographic attributes of users have been analyzed in travel behavior research on carpooling and ride-pooling (Dolins et al., 2021). Existing research on perceptual factors influencing carpooling or ride-pooling behavior generally falls into three main categories.

The first concerns environmental and societal motivations for pooling rides, such as the effect of reducing emissions and alleviating traffic congestion. Carpooling and ride-pooling are considered more sustainable than ride-hailing, which can increase vehicle distance traveled

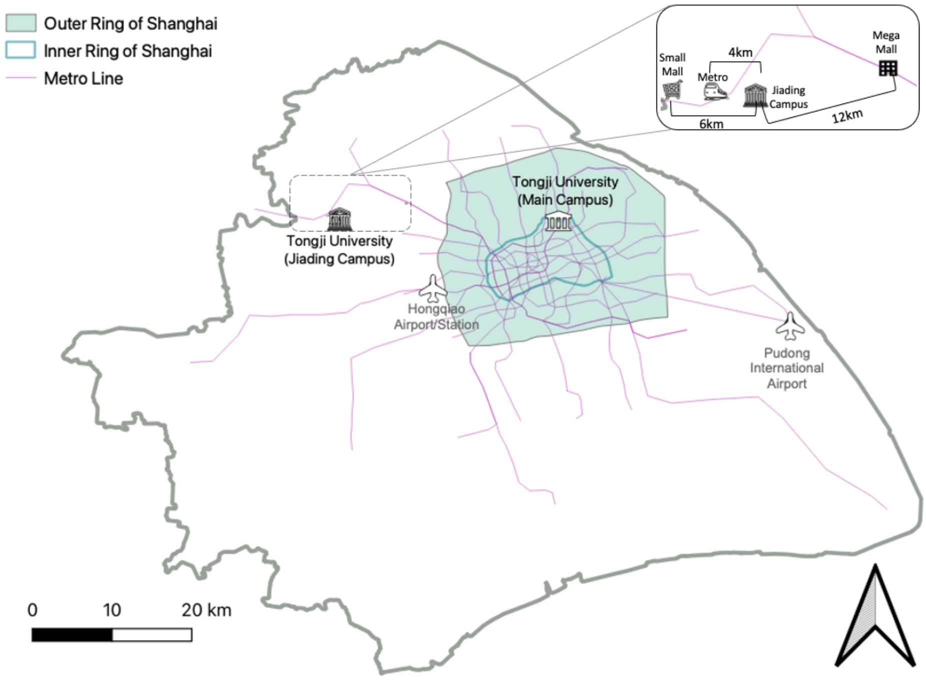

Figure 1: Position of Tongji University's Jiading Campus Relative to Shanghai's Urban Layout

and substitute for transit, thereby raising traffic and emissions(Talandier et al., 2024; Minett et al., 2011; Anderson and Donald, 2014; Henao et al., 2019; Tirachini et al., 2020).

The second category centers on interpersonal concerns, particularly issues of trust, privacy, and safety when sharing rides with strangers. Perceived risks and biases toward unfamiliar co-riders constitute significant obstacles to the adoption of carpooling services (Moody et al., 2019).

The third relates to practical mobility considerations, including perceived flexibility in departure times, convenience of coordination, travel time, and cost. Carpooling decisions often reflect a trade-off between time and cost savings (Hou et al., 2020).

Data and Methodology

Shanghai was selected as the study site due to its extensive transport system and concentration of universities. The survey focused on a suburban campus, which is located about 35 km from the city center (Figure 1) and hosts about 13,000 students. Over two weeks, 1122 responses were collected, of which 800 were valid, covering students and staff residing or working on campus.

A mixed logit (ML) model was used to analyze factors influencing UPR adoption. This approach relaxes the fixed-coefficient assumption of multinomial logit, allowing individual-level preference heterogeneity such as variations in cost sensitivity and value of time.

Key Findings and Conclusion

The findings (Table 1) highlight that female and younger respondents show a greater propensity to adopt UPR as a travel solution. This suggests UPR development is shaped by group-specific trust and financial constraints. Matching passengers from the same campus can alleviate female safety concerns. For UPR users, they are more willing to save travel time by paying more. They also agree that using more UPR and public transport could mitigate climate change. Meanwhile, travelers' concerns about travel privacy could be a constant challenge for UPR. These insights underline the importance of fostering trust-based communities, strict data management, and well-established communication channels in the UPR platform.

Table 1: **Mixed Logit Estimation Results (Parsimonious Model)**

Variable	Type	Coef.	Signif.	Std. err.	z	OR change (%)
Departure time (14:00)	Dummy	0.704	***	0.070	10.10	102.2
Trip distance (km)	Continuous	0.721	***	0.038	19.11	105.6
Age group	Continuous	-0.335	***	0.077	-4.34	-28.5
Owns private car	Dummy	0.394	**	0.158	2.49	48.3
STEM major	Dummy	-0.451	***	0.088	-5.15	-36.3
Female	Dummy	0.210	***	0.076	2.78	23.4
Living expenses	Continuous	-0.265	***	0.042	-6.34	-23.3
Used UPR before	Dummy	0.352	***	0.081	4.34	42.2
UPR via group chats	Continuous	0.066	***	0.018	3.60	6.8
Ride-hailing freq.	Continuous	-0.010	**	0.005	-2.12	-1.0
Shared bike freq.	Continuous	-0.005	***	0.001	-3.43	-0.5
Ride-pooling freq.	Continuous	-0.028	***	0.009	-2.98	-2.8
WTP for time saving	Dummy	0.149	*	0.085	1.76	16.1
PT reduces emissions	Continuous	-0.066	***	0.015	-4.32	-6.4
UPR reduces emissions	Continuous	0.084	***	0.016	5.08	8.8
Privacy concern (posting)	Continuous	0.037	**	0.017	2.19	3.8
Trust in co-riders	Continuous	-0.079	***	0.021	-3.86	-7.6
Prefer schoolmates (UPR)	Continuous	0.041	**	0.017	2.47	4.2
Travel cost (¥)	Continuous	-0.031	***	0.002	-13.06	-3.1
Travel time (min)	Continuous	-0.015	***	0.003	-5.41	-1.5
Log likelihood						–10,345.03
Prob > chi2						0.0000

Note: Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Odds-ratio change calculated as $(e^{\beta} - 1) \times 100\%$; for dummy variables, it reflects the change in odds when switching from 0 to 1.

Table 2: **Mixed Logit Results for UPR Organizers and Followers**

Variable	Coef.	Std. err.	P>z	OR %	Coef.	Std. err.	P>z	OR %
	Organizer				Follower			
Departure time (14:00)	0.932***	0.107	0	154.0	0.604***	0.124	0	82.9
Trip distance (km)	0.638***	0.058	0	89.3	0.701***	0.065	0	101.6
Age group	–0.376***	0.109	0.001	–31.3	–0.426***	0.126	0.001	–34.7
STEM major	–	–	–	–	–0.624***	0.158	0	–46.4
Living expenses	–0.181***	0.059	0.002	–16.6	–	–	–	–
Bus use freq.	0.011**	0.005	0.029	1.1	–	–	–	–
UPR via group chats	–	–	–	–	0.135***	0.034	0	14.5
Shared bike freq.	–0.007***	0.002	0.002	–0.7	–	–	–	–
Ride-pooling freq.	–	–	–	–	–0.048***	0.014	0.001	–4.7
Transport convenience	–	–	–	–	–0.173***	0.040	0	–15.9
PT reduces emissions	–0.062**	0.025	0.013	–6.0	–0.091***	0.021	0	–8.7
UPR reduces emissions	0.113***	0.027	0	12.0	–	–	–	–
Privacy concern (daily)	–0.074**	0.033	0.027	–7.1	–	–	–	–
Privacy concern (posting)	0.132***	0.033	0	14.1	–	–	–	–
Destination disclosure	–	–	–	–	0.061**	0.023	0.010	6.3
Trust in co-riders	–0.078**	0.031	0.011	–7.5	–	–	–	–
Prefer schoolmates (UPR)	–	–	–	–	0.079***	0.026	0.002	8.2
Travel cost (¥)	–0.040***	0.004	0	–3.9	–0.023***	0.003	0	–2.3
Travel time (min)	–0.031***	0.004	0	–3.1	–	–	–	–

Note: Significance codes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Odds-ratio change (%) calculated as $(e^{\beta} - 1) \times 100\%$.

The subgroup differences between organizers and followers reveal the different roles of users within the UPR system (See Table 2). Organizers tend to be proactive, mission-driven individuals who initiate shared trips despite environmental or infrastructural constraints. Their decision-making reflects stronger concerns about coordination responsibility, privacy management, and long-term commitment to UPR as a sustainable travel option. Followers exhibit more passive, convenience-oriented behavior, relying on community cues such as group chat messages or peer trust to inform their travel decisions. They are more responsive to perceived environmental messaging and social familiarity, especially when comparing UPR with algorithm-driven, impersonal ride-pooling modes.

Beyond the representative cases of suburban university campuses with large student populations, there may exist other spontaneously emerging UPR communities. Future research should explore longitudinal adoption trends, expansion beyond campuses, integration with formal planning, and test interventions such as personalized nudges or interface designs.

Acknowledgements

The authors would like to express their gratitude to Professor Jianhong Ye for his funding, invaluable guidance, and support throughout this research.

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Thursday 11th December: 11am-1pm
Parallel Session 1 (Level 17, Lecture room 3)
Theme: Passenger Behaviour and Innovation in Public Transport, Session Chair: Prof. Corinne Mulley
Passenger acceptance of personalized passenger information in public transport (Michelle van Ardenne, Matej Cebecauer, Oded Cats and Zhenliang Ma)
Personalised Incentives for Demand Management in Public Transport: A reverse-engineering Approach (Xia Zhou, Daniel D. Harabor, Mark Wallace and Zhenliang Ma)
Stakeholder expectations towards the testing of autonomous, on-demand e-buses in the Maltese Islands (Karyn Scerri and Maria Attard)
Redefining Success in Demand Responsive Transport: A Context-Dependent Performance Evaluation Based on Service Intentions (Chia-Jung Yeh, Chinh Q. Ho and John D. Nelson)

Passenger acceptance of personalized passenger information in public transport

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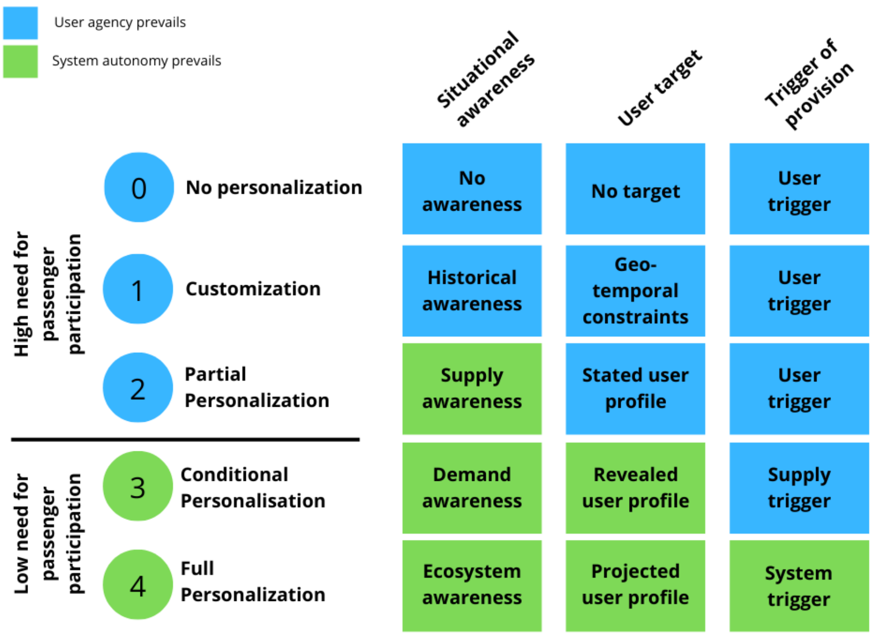
Introduction

Providing relevant information to passengers is essential for the functioning of the public transport system (Zurob et al., 2016). With the digitalization of passenger information systems (PIS), passengers currently have access to large amounts of information. To avoid cognitive overload among passengers, public transport systems experiment with applying personalization to PIS, allowing for the provision of tailored information according to the individual needs and desires of passengers (Vrendenborg et al., 2025).

Due to the ambiguity of personalization, a framework comprising levels of personalization was developed to bridge the gap between theoretical conceptualizations and practical implementations of personalization in PIS (van Ardenne et al., in press). This framework illustrates how advancements in system autonomy can gradually reduce the need for active passenger participation the planning of trips with public transport. Five levels of personalization have been identified, see figure 1. At lower levels, user agency has the upper hand, requiring passengers to actively personalize their experience by manually inputting preferences or interpreting the relevance of provided information. In contrast, at higher levels, system autonomy becomes the primary driver, as advanced PIS employ automation to deliver personalized information tailored to individual passenger needs.

Figure 1: framework for levels of personalization in passenger information systems



Although research has advanced the understanding of personalization in passenger information systems, the public's demand for personalization remains unclear. It is unknown which personalization applications passengers accept or are willing to use. Moreover, it is unknown how passengers' attitude towards privacy and the intrusiveness of personalized system influences the demand for personalization. This uncertainty can hinder stakeholders from investing in personalized passenger information systems or other systems that focus on nudging travel behaviour of passengers. To address this gap, this study introduces the Personalized Passenger Information Acceptance model (PPIAM). The model serves as a tool to analyze passenger acceptance of various personalized PIS in line with the levels of personalization defined by Van Ardenne et al. (in press). This approach provides general insights into passengers' perspectives on the decreasing need for their active participation in the personalization process. Additionally, this study examines the influence of privacy concern on the acceptance of personalization, as passengers might hesitate to share personal data for personalization if they feel it is too intrusive.

Methodology

The PPIAM adapts the Technology Acceptance Model (TAM) (Davis, 1989) to the context of personalized passenger information in public transport. The original TAM argues that the intention to use a new technology (UI) is primarily influenced by two key factors: perceived usefulness (PU) and perceived ease of use (EoU). In the context of passenger information, the attributes of PU and EoU were derived from the information quality framework (Stvilia et al., 2007) and reduced to availability, clarity, correctness, completeness, and findability based on their internal consistency together (Kasteren et al., 2024). In addition, the acceptance model includes attitude toward privacy concerns (PC) as external factors that influence the UI of personalization in PIS.

A questionnaire was distributed to public transport passengers in the Stockholm region to test the proposed PPAIM. Participants first evaluated Stockholm's current PIS and were then randomly assigned to a PIS representing the functionalities of one of three personalization levels (level 2, 3 or 4). After viewing the PIS, participants evaluated the presented PIS according to the attributes of the PPAIM. The questionnaire was tested with a pre-study containing 80 participants. For the main questionnaire, 1000 participants will be recruited and date collection will take place in september 2025. With the pre-study database, the relationships described in the PPAIM were tested using partial least squares structural equation modelling. Following, the differences in user acceptance over the personalization levels are analysed with descriptive analyses and regression models with UI as dependent variable and PE, EoU and PC as independent variables.

Findings and Discussion

The results of the pre-study show significant path coefficients between PE, EoU and UI, and strong R2-values for UI (between 0.51 and 0.72) over the different levels of personalization. These results indicate that the PPAIM succeeds in measuring the user acceptance of personalization in passenger information systems. Looking at the user acceptance over the levels of personalization, the findings indicate increased PE, EoU and UI scores for level 3 and 4 compared to the PE, EoU and UI values for the currently implemented PIS in Stockholm.

However, also privacy concerns tend to increase alongside the level of personalization. For the advanced levels (level 3 & 4), the regression analyses showed a significant negative relationship between PC and UI (L3: coëfficiënt:-0.63, p: 0.012; L4: coëfficiënt:-0.54, p: 0.005). These results underscore the importance of privacy considerations in the development of personalized passenger information systems. Future research should focus on integrating privacy-enhancing functionalities to ensure that passengers in public transport are willing to use personalized PIS. Interviews exploring passengers' privacy concerns can provide insights into the concerns that passengers experience, and provide solutions that take away these concerns.

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Personalised Incentives for Demand Management in Public Transport: A reverse-engineering Approach

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Introduction

To alleviate congestion, public transport service providers can offer monetary incentives that encourage passengers to select alternative routes and travel times (RTs). These incentives are assigned to specific sets of alternative RTs to attract passengers away from heavily used RTs, thereby redistributing demand and reducing congestion. To the best of the authors' knowledge, no existing study on incentive design evaluates scheme performance by explicitly quantifying the deviation of the incentivised system from the exact system-optimal (SO) benchmark. For example, recent state-of-the-art work on incentive design proposes automated control frameworks (e.g., greedy based bi-level methods), that incrementally adjust incentive costs, thus generate a new Incentivised User Equilibrium (I-UE). These methods explore one I-UE after another until eventually (hopefully) reaching a so-called 'SO' state: e.g., Araldo et al. (2019), Xiong et al. (2020), Tang et al. (2020), Saghian et al. (2022), and Liang et al. (2024). In these studies, the so-called 'SO' is redefined at each iteration, converging the I-UE flow toward this moving so-called 'SO' target, which is an intermediate baseline rather than a fixed lower-bound reference, and can not represent the true SO state.

To fill this gap, we develop RE-ESO: a Reverse-Engineering framework using the Exact SO solution for incentive design in public transport. Our algorithm systematically determines specific incentive amounts for each RT combination by iteratively analysing the discrepancies between the current I-UE and the exact SO assignment flows. In particular we show, for the first time, incentives that as nearly as possible result in SO passenger choices. In the experiment, our method achieves approximately a 10% further reduction in congestion costs compared to the conventional greedy-based method.

This study focuses on the theoretical potential of incentive design for congestion relief, while acknowledging several limitations (e.g., ignoring heterogeneous users and equity issues).

Methodology

Our proposed approach adopts a two-level structure: the upper level adjusts incentive schemes, while the lower level evaluates congestion costs under the implemented scheme. It consists of three modules, as illustrated in Fig. 1, which are briefly described as follows: (1) **Solution Analyser**: this module identifies flow gaps between the current I-UE assignment flow and the SO assignment flow. (2) **Incentive Updater**: this module is an incentive scheme generator that updates the incentive costs based on flow gaps identified by the *Solution Analyser*. (3) **System Model**: this module combines a UE model with a simulation-based solution algorithm passengers' reactions to incentives. The system then finds a new assignment flow for the given set of incentives (I-UE assignment flow). See Zhou et al. (2025a) (*UE model* used in *System Model*) and Zhou et al. (2025b) (*exact SO model* used in *Solution Analyser*) for more details.

Experiments and discussion

We compare our method (RE-ESO) against the following methods: (1) Greedy-based framework using UE (**G-UE**) (popularly in the literature e.g., bi-level methods (Xiong et al., 2020)): The incentive design is guided by local descent directions derived from the current I-UE, without considering the global SO solution. (2) Traditional framework using off-peak rules (**T-OP**): The incentive designer incentivises passengers to shift away from peak-hour windows. We select this baseline as the approach is commonly used in the industry, e.g., off-peak fare reward (Currie, 2010; Guo et al., 2021). (3) A variation of our proposed using the Approximate SO solution (**RE-ASO**): We choose this baseline because a related study (Cheung and Shalaby, 2017) adopts a similar reverse-engineering framework while incorporating an Approx. SO solution. (4) **RE-ESO-DT**: A variation of the RE-ESO method where only departure time shifts are considered as available incentive RTs. It offers insights into the potential of incentive schemes when only departure time shifting is feasible in the system. Experiment settings using Hong Kong Mass Transit Railway (MTR) network are same as Zhou et al. (2025b).

In the experiment, our RE-ESO method approaches the theoretical maximum of 36.35% congestion reduction indicated by the exact SO system (see Fig. 2(a)). Notably, our method achieves a 32.74% reduction in congestion costs, substantially outperforming comparative baselines: G-UE (22.18%), T-OP (10.90%), RE-ASO (17.90%) and RE-ESO-DT (26.86%), as illustrated in Fig. 2 (b). A further key insight is derived from the comparison with RE-ESO-

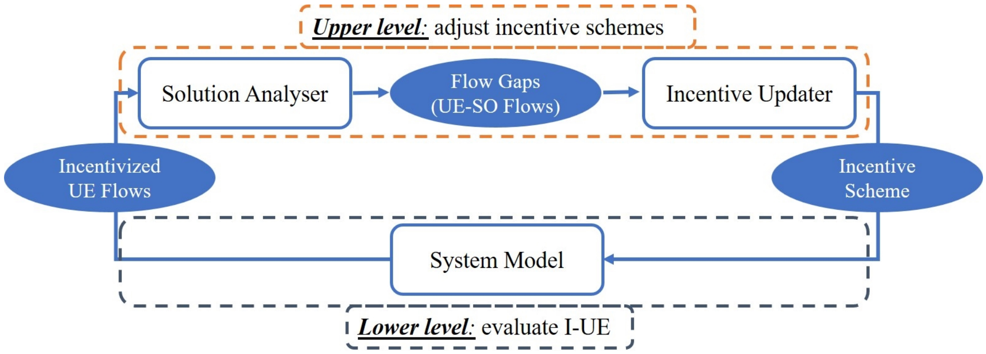
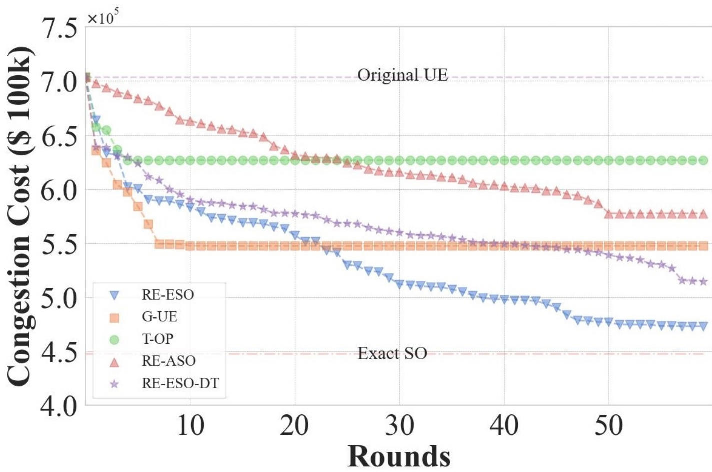


Figure 1: **Overview of the incentive design framework**



(a) Evolution of congestion costs

(b) Comprehensive results

Methods	**C-cost** (**CR-ratio**)
RE-ESO	$473,162 (32.74%)
G-UE	$547,434 (22.18%)
T-OP	$626,787 (10.90%)
RE-ASO	$577,568 (17.90%)
RE-ESO-DT	$514,531 (26.86%)

Original UE: $703,495
Exact SO: $447,780 (36.35%)
C-cost: congestion cost
CR-ratio: congestion reduction ratio

Figure 2: **Comparison of methods on congestion cost reduction (No budget limit, upper bound: original UE (Zhou et al., 2025b), lower bound: Exact SO (Zhou et al., 2025b))**

DT: departure time shifting accounts for 82% of the total congestion relief, underscoring the broad potential of such strategies in transit networks not like Hong Kong, where opportunities for route shifting are inherently limited.

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Stakeholder expectations towards the testing of autonomous, on-demand e-buses in the Maltese Islands

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Introduction

Designing smart, sustainable public transport systems require early and inclusive stakeholder engagement to identify social, operational, and technological barriers, ultimately supporting more context-sensitive mobility solutions (Grandsart et al., 2024). Interest in autonomous vehicles (AVs) is growing, with a lot of research largely focused on individual user acceptance and social context influences following trials and prototyping (Axsen & Sovacool, 2019; Paddeu et al., 2020). However, limited attention has been paid to group-level stakeholder expectations prior to testing and particularly in small island contexts, where planning, governance, and space constraints are unique. This study addresses that gap by investigating how stakeholders in Malta envision the design and operational conditions of on-demand autonomous e-buses, offering early-stage insights before deployment. On-demand autonomous buses are small, electric, self-driving vehicles with app-based booking and are internationally recognised for their potential to enhance efficiency, accessibility, and reduce congestion (Faisal et al., 2019; Tu et al., 2024), yet concerns around data privacy, job displacement, and trust persist (Dolins et al., 2021; Pettigrew et al., 2018). Involving stakeholders is essential to ensure equity, address diverse community needs, and strengthen public ownership (Faherty et al., 2024). This is also important since different stakeholders will play varying roles in the transition towards the adoption of autonomous vehicles (Shibayama et al., 2020). While Malta faces significant car dependence and current legal limitations restricting AV testing to Level 2 (Cassar & Lewis, 2022), this research offers a timely contribution by exploring stakeholder expectations to guide the design of contextually relevant and socially accepted shared, autonomous services.

The research is situated in the Maltese Islands, focusing on Malta and Gozo; the most populous and urbanised of the islands. Malta, the European Union's smallest member state has the highest population density in the EU, with 1,693 persons per km² compared to the EU average of 109 (Eurostat, 2024). The resident population is approximately 563,443, with over a quarter aged 60 or older (NSO, 2023). These demographic pressures, combined with a high rate of car ownership (more than 414,000 registered vehicles), have led to severe car dependence and traffic-related externalities, including congestion, accidents, and rising emissions (Bajada & Attard, 2021; NSO, 2022).

Methods

This study is conducted within the context of the HORIZON EUROPE project metaCCAZE which aims to accelerate the deployment of smart mobility systems in European cities. It adopts a stakeholder-centred methodological framework, based on Faherty et al., (2024), to investigate expectations surrounding the deployment of on-demand, public autonomous e-buses in the Maltese Islands. Stakeholder identification and mapping focused on four key groups: academia, NGOs, public entities, and private businesses/operators, ensuring broad representation across the urban mobility ecosystem. A structured expectations survey was conducted between December 2024 and February 2025 with 50 participants using a snowball sampling approach, enabling access to informed individuals across sectors and expanding the sample through peer referrals (Faherty et al., 2024). Surveys were selected for their ability to generate quantifiable data on stakeholder expectations, including service features, perceived barriers, and enabling conditions, and as a first step to future participatory co-creation workshops, which will aid in uncovering complexities and deeper motivations behind stakeholder responses (Faherty et al., 2024; Ranganathan & Caduff, 2023).

Results and discussion

The 50 survey participants provided a balanced representation of the four stakeholder types. The respondents were predominantly male (64%), and the largest share was aged between 45-54 years (34% of the sample). Overall expectations toward the autonomous e-bus in Malta were moderately positive, with the highest confidence shown towards the expected ease of booking (mean = 3.42), comfort and convenience (mean = 3.18), and anticipated environmental benefits (mean = 3.18). Respondents also expressed relatively high confidence in data security (mean = 3.12) and performance at pedestrian crossings (mean = 3.08). Conversely, expectations were lowest for integration with road infrastructure (mean = 1.72) and traffic (mean = 1.90), highlighting concerns about operational feasibility. Notably, public trust in AVs (mean = 2.26) and impact on congestion (mean = 2.06) scored low, suggesting scepticism about societal acceptance and wider system effects. These results suggest cautious optimism among stakeholders, with significant concerns over technical and contextual challenges. Comparing these findings to existing literature, key factors such as trust in new technologies, privacy, and comfort have consistently been associated with the willingness to use shared autonomous vehicles (Paddeu et al., 2020). Given that this study draws on input from key stakeholders, it is important to acknowledge that expectations can vary significantly depending on each stakeholder’s motives and objectives, in the same way that the adoption of AVs differs across stakeholder groups (Hamadneh et al., 2022). In similar research looking into autonomous vehicles within a public transport context, concerns about the safety and security aspects of autonomous vehicles have also been found (Dong et al., 2019).

Preliminary findings of a Spearman correlation matrix showed strong positive correlation between the expectation rating for safety (How confident are you in the safety of the autonomous e-bus, both for passengers and other road users?) with comfort and convenience (What are your expectations regarding the comfort and convenience of using the autonomous e-bus) ($r = .579$, $p < .001$) and reliability and punctuality (How confident are you that the autonomous e-bus service will be reliable and punctual) ($r = .521$, $p < .001$). This indicates that users who perceive that the bus will be safe also tend to view it as reliable and comfortable. Additionally, road traffic conditions (How well do you expect the autonomous e-bus to integrate with existing road traffic conditions - other vehicles, road users etc...) are significantly related to road infrastructure (How well do you expect the autonomous e-bus to perform on the existing road infrastructure - road markings, surface quality etc.) ($r = .550$, $p < .001$) and comfort and convenience ($r = .394$, $p = .005$). This suggests that user confidence in how well buses will perform on Malta's roads and how well they will interact with existing traffic, is a key driver of ride quality and usability expectations. Previous research has also highlighted stakeholder concern over operational safety, which includes not only the safety on board the autonomous bus, but also the safety for other road users and travellers around the vehicles (Feys et al., 2020).

Conclusions

This study highlights the importance of stakeholder perspectives in shaping the early design of autonomous public transport deployment. The associations imply that for the stakeholders, technical and infrastructural readiness is a foundational component of the overall user experience. Considering that the lowest expectation scores were seen in the integration with existing road infrastructure and traffic conditions, priority should be placed on improving road surface quality and clear line markings for the successful deployment of the autonomous bus. Additionally, low stakeholder confidence in public acceptance reiterates the need for pilot demonstrations and co-creative engagement to build trust. Future research will continue building upon this by involving the broader community to provide a deeper understanding of public perceptions, particularly regarding safety, comfort and trust.

Acknowledgements

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Redefining Success in Demand Responsive Transport: A Context-Dependent Performance Evaluation Based on Service Intentions

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Introduction

Demand Responsive Transport (DRT) has been widely adopted across countries as a flexible mobility solution that adapts to the dynamic needs of users. Designed to address accessibility and financial sustainability issues, DRT was initially implemented in rural areas with patchy travel demand where fixed routes are neither efficient nor effective. In urban settings, DRT is increasingly used to replace fixed-route service in low-demand areas where operating conventional public transport may be financially unsustainable.

While DRT offers a flexible transport service that can address diverse travel demands with various service intentions, it has often been criticised for low patronage and high operational costs. These challenges are among the primary reasons for the cessation of many DRT services after the pilot phase. Indeed, Currie and Fournier (2020) found that, when using service longevity to define success, more DRT systems failed than succeeded. However, DRT performance is closely tied to its service context and original purpose, and hence, overlooking service intentions can bias evaluations. This underlies the need to select performance indicators aligned with intended service goals to redefine success.

This paper collects operational data of 400 paratransit and microtransit systems (collectively referred to as DRT) in the US from the National Transit Database to benchmark the performance of DRT systems. Operational characteristics, such as service hours, operating models, booking and payment methods, are obtained from individual agency websites. The collected data suggests that paratransit that exclusively serves individuals with disabilities is the most common form of DRT in the US; however, microtransit is increasingly used to serve the general public. Given the diverse service intentions of DRT, this paper develops a metafrontier distance directional function (DDF) to evaluate performance, enabling a flexible policy-oriented input and output metric. This approach enables meaningful comparisons across different service types while accounting for their distinct operational contexts. The model results show that microtransit faces greater challenges and generally exhibits lower performance scores, compared to paratransit. The technology gap ratio, reflecting the difference between meta and group performance scores, can serve as an indicator of the extent of demand response. This paper provides a more quantitative and objective measure for identifying the success of DRT systems.

Literature Review

Measuring transport performance is essential for benchmarking provision, enhancing service quality and optimising resource allocation (Eboli & Mazzulla, 2012). Among all existing DRT studies, Mageean and Nelson (2003) were the first to evaluate DRT performance and provide quantifiable measurements, including operating costs, vehicle usage, route directness, service coverage, and system capacity. Similarly, Ferreira et al. (2007) identified potential criteria for evaluating DRT systems operating under different contexts. While not proposing an evaluation process, these two studies offer a comprehensive view of the potential indicators. Considering data availability, total patronage is commonly used as a measure of performance. However, relying solely on patronage without accounting for the context of DRT can lead to biased or misleading results (Kaufman et al., 2021). Hence, the composite or multidimensional metrics have been proposed. Nevertheless, such indicators often have inconsistent units, making it challenging to synthesise a single score to compare among the systems. To address this, some studies employ the analytic hierarchy process to determine weights through surveys (Sandlin & Anderson, 2004), while others utilise data envelopment analysis (DEA) to eliminate the need for predefined weighting (Yen et al., 2023). Besides the overall performance of DRT, some studies focus on assessing the specific roles of DRT services using a simulation approach (Schlüter et al., 2021; Winter et al., 2018) and scenario analysis (Alonso-González et al., 2018; Mulley & Daniels, 2012). Despite various performance evaluation approaches, existing studies have limitations in incorporating service intentions and diverse operational contexts into the assessment, which can lead to unfair comparisons.

Methodology

The directional distance function (DDF) extends the traditional distance function framework in efficiency and productivity analysis. Unlike conventional performance evaluation approaches, such as DEA with radial measures, which proportionally expand outputs or reduce inputs, the DDF enables simultaneous adjustments to both inputs and outputs in a specified direction vector (Zhang & Choi, 2014). Given the diverse service intentions of DRT systems, the evaluation metrics may vary accordingly. To address this, this study introduces a policy-oriented vector to serve as the direction in the DDF framework. The metafrontier DDF analysis is further employed to evaluate the performance of decision-making units that operate under heterogeneous production environments or different technological frontiers (Battese & Rao, 2002). Group frontiers represent the best practices within each homogeneous group, while the metafrontier envelops all group frontiers and reflects the potential maximum efficiency attainable across all groups (O'Donnell et al., 2008). The technology gap ratios (TGR), which measure the closeness of a group's frontier to the metafrontier, can be used to identify the extent of demand response of DRT services. A cross-analysis of both efficiency score and technology gap ratios can further be applied to identify the relative success or failure of DRT.

Findings and Discussion

This paper categorises all 220 selected DRTs based on their service and operational characteristics. Three types of DRT are identified: microtransit (including the fixed-route DRT services), paratransit, and mixed operation service. Figure 1 presents the results of the metafrontier DDF model. Distinct colours are used to represent each type of DRT service. The diagonal dashed lines represent different TGR values, indicating how close each service's group frontier is to the metafrontier. In this study, TGR can be interpreted as the extent of the demand response. Paratransit (marked in red dots) shows the widest spread in efficiency but with the highest average TGR of 0.960. This indicates that paratransit is the most demand-responsive service type. A potential explanation is that paratransit typically offers door-to-door service based on user reservations, making it better suited to the demand of specific population groups. Microtransit services (marked in green squares) generally achieve higher group efficiency; however, in some cases, their meta efficiency falls below 0.7. This highlights that operating microtransit or fixed-route DRT services alone may be less efficient than most paratransit operations. Therefore, a better dissemination of DRT services to the general public is essential to enhance their awareness, thereby increasing the utilisation of microtransit. Lastly, mixed services (marked in blue triangles) record the lowest TGR and meta efficiency, indicating that this operational type is often more complex for operators. The services provided are less demand-responsive than intended, and resources are not allocated efficiently, leading to the poorest performance among the three service types.

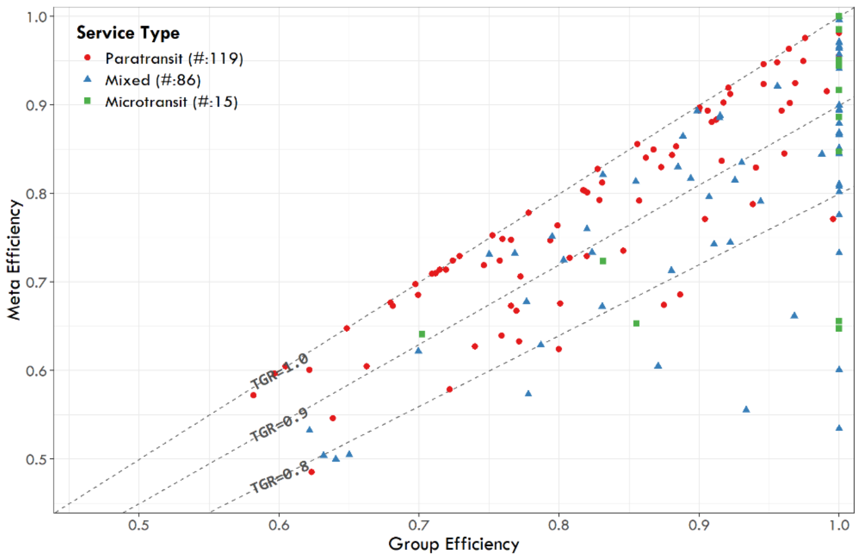

Figure 1. Metafrontier DDF performance of US DRTs across groups

To further investigate the performance patterns revealed by the metafrontier DDF results and their influential factors, a cross-analysis of group efficiency and TGR is conducted for the three DRT service types. Figure 2 illustrates the distribution of decision-making units on both group efficiency and TGR. This analysis enables the identification of service types that achieve strong operational performance while leveraging technology in terms of demand response, as well as those whose inefficiencies result from either technological gaps, operational practices, or a combination of both. Four distinct performance categories are identified based on the median value of both indicators: High Technology–High Efficiency (HTHE), High Technology–Low Efficiency (HTLE), Low Technology–High Efficiency (LTHE), and Low Technology–Low Efficiency (LTLE).

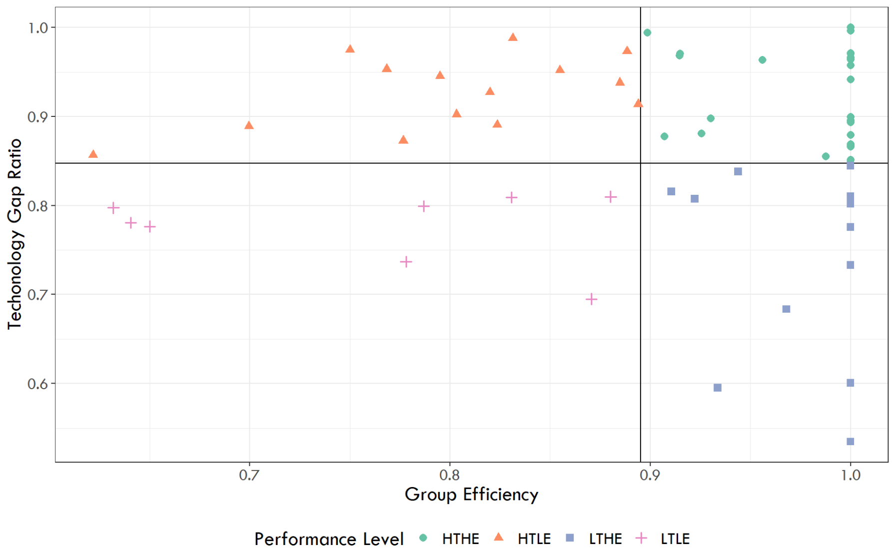

Figure 2. Cross-analysis of group efficiency and TGR

Services in the HTHE quadrant represent the most favourable outcomes, combining strong group efficiency with the most demand-responsive service. The HTLE group shows that even with the higher demand-responsive service, operational efficiencies are lower, suggesting issues in resource utilisation or service planning. The LTHE group achieves high operational efficiency despite offering a less demand-responsive service, indicating that better accommodating on-demand user needs could achieve further improvements. In contrast, LTLE services, positioned in the least favourable quadrant, face both technological and operational challenges, requiring substantial reform to enhance performance.

To further investigate the potential factors influencing performance level, Figure 3 presents the relative proportion of each performance level across operational types and service intentions. These proportions are derived using min-max normalisation, which facilitates clearer identification of the dominant performance level within each operational type and service intention. In terms of service intention, replacement of public transport and service for transport disadvantaged people are more likely to be HTHE, aligning with the concept of demand response and with better performance. This suggests that the public transport replacement would be a highly promising market for transforming and developing DRT services in the US. In addition, serving primarily the transport-disadvantaged populations is a role model of DRT in the US. Transport-disadvantaged groups are defined as those with low income and without access to a private vehicle. DRT can address their essential travel needs and alleviate the barriers to accessing economic activities.

The service intention of connecting to hubs and operational types of point-to-hub both exhibit lower efficiency with relatively higher TGR (HTLE). This implies that on-demand services may better address the demand-responsiveness issues; however, they may also be less efficient due to lower patronage or higher operational costs. This result contrasts with existing literature, which often reports point-to-hub services as the most cost-effective and efficient option. In the US context, this may not hold true, as connecting to hubs does not necessarily guarantee higher public transport accessibility. Accordingly, DRT services aimed at connecting to hubs may be less efficient for transferring compared to similar services in other countries. In terms of the operational type of fixed route DRT, it appears more often in the LTHE category, reflecting good operational efficiency despite lower technological alignment. This implies that the service may not fully meet user demand and is unable to provide transport within a broader network context. LTLE services show an intense concentration in designated stop services, which may indicate rigid service patterns or low adaptability to demand.

Figure 3. Performance level distribution on service intentions and operational types

In summary, the US DRT has developed its ecosystem and unique advantages. This study redefines the success of DRT with a quantitative approach and unveils potential market strategies for promoting its further development.

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Thursday 11th December: 11am-1pm
Parallel Session 2 (Level 16, Seminar room)
Theme: Smart Freight and Urban Delivery Systems, Session Chair: Prof. Michael Bell
Multi-period operations optimization for passenger-freight shared transport: A game-theoretic approach (Yuxin Zheng, Jie Yang and Xiaoning Zhang)
How Fast Is Too Fast? A Multi-Objective Optimization Ensuring Courier Safety in an On-Demand Meal Delivery System (Zongkun Wu, Anke Ye, Michael Bell and Simon Hu)
Extreme Heat and Road Safety: Assessing the Risks Faced by Delivery Riders in Urban India (Kamal Achuthan, Deepty Jain and Taku Fujiyama)
Fleet Sizing and Pricing for a Hybrid AVs-HVs Ride-Hailing Platform under Fulfillment Requirements (Xiaonan Li, Xiaoning Zhang and H. Michael Zhang)

Multi-period operations optimization for passenger-freight shared transport: A game-theoretic approach

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Introduction

In the context of the sharing economy, passenger-freight shared transport emerges as an effective measure to enhance overall resource utilization efficiency and logistics cost savings by leveraging excess bus capacity for freight transportation (Zhu et al. 2023, Liu et al. 2025). Nonetheless, it is challenging to analyze the bus company (BC)'s responses to the logistics company (LC)'s decisions and propose effective operations strategies for the LC considering the impact of the BC's decisions. First, the travel demands of passengers exhibit temporal disparities, necessitating the identification of the effect of decisions made in each period on future operations. Second, both the LC and BC are motivated to participate in the collaborative mode if and only if it offers benefits over not participating (Ma et al. 2022). Therefore, the individual rationality constraints should be incorporated into the theoretical analysis. Moreover, operational decisions, such as bus departure frequency and ticket pricing, have a significant impact on passenger preferences for bus travel, and consequently on the BC's revenue (Cavallaro and Nocera. 2023).

This study explores the dynamic operational decisions of an LC engaged in collaborative transportation with an intercity BC. Intercity buses generally offer one-stop transport services for passengers, and logistics parcels can be transferred through intercity buses to passenger stations from the origin to the destination, as shown in Figure 1. To ensure the safety of passenger and freight co-transportation, the BC needs to separate the carriage space for passengers and freight (He et al. 2023). Upon reaching the destination station, passengers disembark, and the parcels are transferred to nearby courier stations for last-mile delivery. Parcels not transported by the BC require third-party logistics services. In addition to taking the bus, passengers may also opt for other alternative mobility options, such as ride-hailing services. We investigate equilibrium analysis and operational decision optimization within a passenger-freight shared transport system.

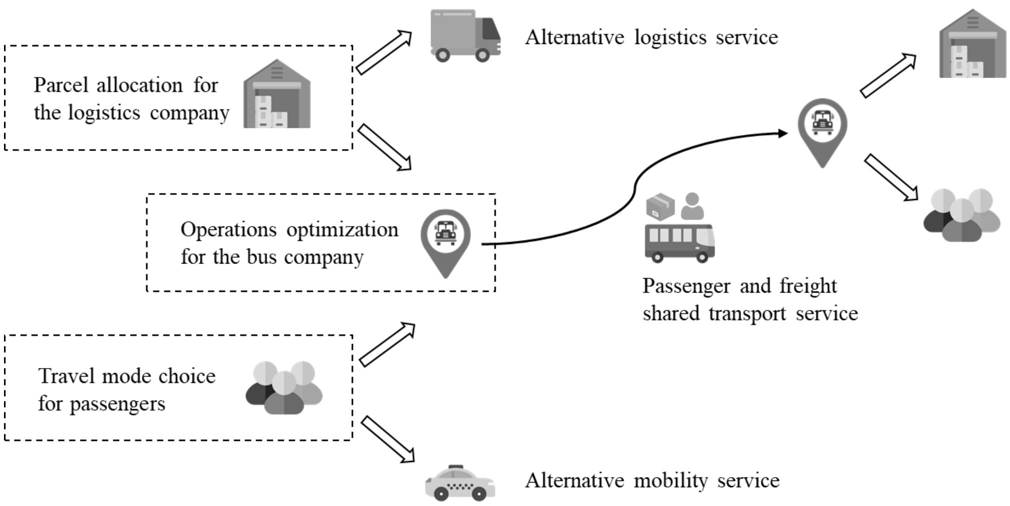

Figure 1. Illustration of the shared transport mode

Methodology

The decision relationships of all stakeholders are illustrated in Figure 2. We characterize the interplay of the decision-making of all stakeholders through a sequential game. Specifically, we utilize a discrete choice model to describe passengers' travel decisions. Passengers decide whether to take the bus based on the perceived overall cost, which includes monetary expenses and waiting time costs. Employing a backward induction approach, we identify the optimal operations decisions for the BC, including ticket prices and departure frequency, to maximize its profits under the LC's decisions regarding service prices and freight volume for co-transportation. Subsequently, we determine the optimal pricing decisions for the LC, ensuring that the BC is incentivized to participate in the co-transportation. Leveraging these theoretical findings, we extract crucial managerial insights into the operations of the co-transportation system. Furthermore, we establish a multi-period optimization model to determine system-optimal decisions for the LC, accompanied by a tailored algorithm. The algorithm iteratively alternates between two groups of decisions: freight volumes, and freight pricing combined with the BC's optimal decisions, until convergence. Finally, we extend the basic model by introducing two additional scenarios: in the first, the BC determines the freight transport price, and in the second, the LC and BC make joint decisions to maximize their total profit.

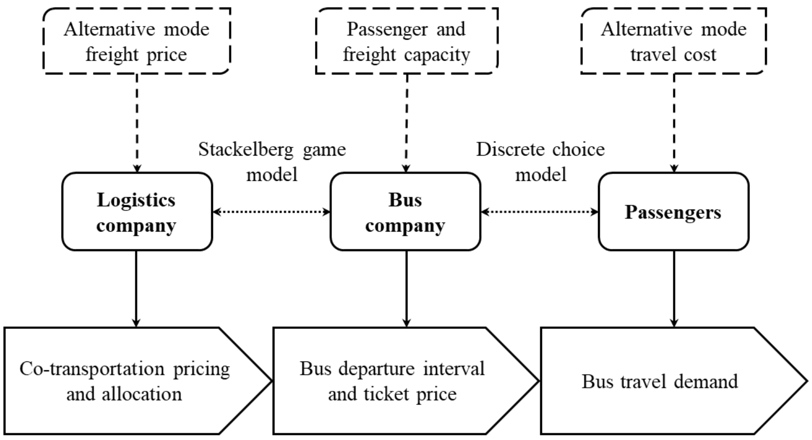

Figure 2. Multi-stakeholder decision-making relationship in the passenger and freight co-transportation service

Findings

Numerical experiments based on a real-world bus route validate the effectiveness of the proposed approach. The results indicate that passenger-freight shared transport generally facilitates a win-win outcome between the LC and BC while reducing bus passenger waiting times. Specifically, the following policy insights are derived:

Synchronizing decisions across multiple periods: In intercity bus systems where freight and passengers typically share the same vehicle, the compartmentalized design may lead to inefficient space utilization during low-demand periods, as areas reserved exclusively for passengers may remain unoccupied. Thus, in implementing co-transportation, it is essential to adopt approaches that go beyond static rule-based methods which rely solely on average bus demand for freight allocation. Instead, joint optimization algorithms should be developed to determine effective allocation strategies across multiple time periods, comprehensively accounting for the temporal heterogeneity of passenger demand and capacity availability throughout the day.

Allocating pricing authority: Our theoretical findings indicate that when the BC holds pricing authority, the system tends to achieve higher freight throughput and increased bus departure frequency. However, this model may result in higher passenger fares. In regions where freight demand dominates, regulators may permit the BC-led pricing schemes. Conversely, in passenger-oriented scenarios, the LC-led or jointly negotiated pricing mechanisms may better align with public service obligations by alleviating passengers' financial burdens.

Reconfiguring the vehicle layout: Since the passenger-freight space ratio is predetermined before service operations, the BC should develop appropriate strategies for dividing space to maintain overall service performance. If an excessive portion of space is reserved for freight, passenger demand may not be adequately met, leading to a reduction in travel experience. In contrast, allocating an insufficient share to freight may fail to generate sufficient revenue to compensate for the decline in passenger transport income and may lead to underutilized capacity during off-peak periods. The BC should thoroughly evaluate passenger and freight demand distributions, and strike an appropriate balance between departure frequency and space utilization by effectively allocating onboard resources.

Transferring co-transport gains to passengers: The incorporation of freight transport may reduce passenger service quality, e.g., reducing seating availability or increasing fares. Our analysis indicates that the impacts of the co-transportation model on passengers are primarily affected by co-transported freight volume and the allocation of onboard space between passengers and freight. The BC should comprehensively evaluate the impact of co-transport on passengers by considering these factors and propose incentive mechanisms to internalize these externalities.

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How Fast Is Too Fast? A Multi-Objective Optimization Ensuring Courier Safety in an On-Demand Meal Delivery System

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Introduction

The pandemic accelerated the growth of the food delivery market, transforming it into a primary mode of food access for millions of consumers. In response to rising demand, platforms have increasingly relied on algorithmic tools to optimize operations and improve delivery efficiency. Routing and delivery time estimation algorithms aim to suggest efficient delivery routes (Chu et al. , 2023); however, putting these 'optimal' routes into practice often faces unexpected challenges. These challenges may include detours due to unforeseen infrastructure disruptions, long wait times at restaurants caused by order backlogs, etc. (Wang et al. , 2021). Moreover, many couriers are incentivized by bonus schemes to complete as many deliveries as possible(Yu et al., 2024). All of these factors create significant pressure on couriers, ultimately fostering faster delivery speeds at the cost of couriers' safety.

To monitor couriers' speeding behaviors efficiently, this study introduces an innovative mechanism called 'Guaranteed Service Time' (GST), which prevents couriers from accepting new assignments if they complete the current task too quickly. GST is a time span given by the platform and sets a minimum duration for the courier to complete the delivery task. Specifically, couriers will not get a new assignment until the GST of the current task has elapsed, even if they finish the delivery ahead of schedule. It is noteworthy that the design of GST is essential to the system. On the one hand, a longer GST can discourage couriers from rushing through deliveries; on the other hand, it may result in longer waiting times for customers, which can diminish the appeal of the service. Therefore, the design of the GST raises a fundamental question: How fast is too fast for couriers?

To address this question, we propose an integrated framework for designing the GST. The GST is designed through a multi-objective optimization that balances the interests of the platform, couriers, and customers. We introduce accident costs to balance the system's overall benefits. In addition, we conduct numerical experiments to evaluate the impacts of the GST mechanism in the system.

Methodology

We formulate the problem in an aggregate system. Consider a monopoly platform providing meal delivery services with a fleet of freelance couriers. We assume (idle) couriers and restaurants are uniformly distributed in the area with densities of Γ (Γ_v), Λ. Orders arrive in each restaurant with a mean arrival rate of λ. Specifically, orders are consolidated into bundles with a bundle size of k; each bundle is deemed as a delivery task to be assigned to a courier. A full description of the service process is demonstrated in Figure 1.

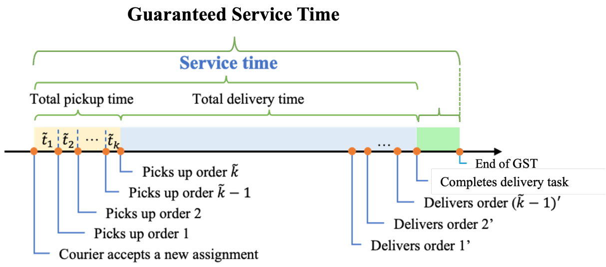

Figure 1: Courier Delivery Task Timeline

The service time estimation model described in Ye et al. (2024) allows us to calculate service time t_s and bundle size k using functions $T(\lambda, \Gamma_v, v)$ and $K(\lambda)$. Note that given λ and Γ_v, v is an affine transformation of t_s. The value of the GST is determined by the optimal system speed v^*, which is the solution to the multi-objective optimization problem. Specifically, the platform sets the GST by calculating the equilibrium service time t_s^*, using the service time function $GST = T(\lambda^*, \Gamma_v^*, v^*)$ with the optimal speed v^* as an input.

Therefore, we formulate the following optimization problem to balance the interests of stakeholders.

$$\max\ \Pi = \omega_1 P + \omega_2 W + \omega_3 C \tag{1}$$

Platform profit: $P = f\lambda\Lambda - q\Gamma$
Courier welfare: $W = q\Gamma - c * \max(v - v_{safe}, 0)^\eta * \Gamma$
Customer surplus: $C = \lambda_0 \Lambda \int_{f+\alpha(\Delta+t_s)}^{+\infty} (x - f - \alpha(\Delta + t_s)) F_D'(x)\, dx$

S.t.

$$\lambda = \lambda_0 F_D(f + \alpha t_s) \tag{2}$$

$$\Gamma = \Gamma_0 F_S(q) \tag{3}$$

$$t_s = T(\lambda, \Gamma_v, v) \tag{4}$$

$$k = K(\lambda) \tag{5}$$

$$\Gamma = \Gamma_v + \frac{\Lambda\lambda}{k} t_s \tag{6}$$

where the objective function consists of the platform's profit, the couriers' profit, and the customer surplus, weighted by w_1, w_2, w_3. Courier welfare consists of two components: the couriers' wage income and the expected cost from speeding-related accidents. We introduce a safety speed v_{safe}, defined as a relatively low threshold below which no accidents are assumed to occur. Following Zhang et al. (2023), the severity of accidents is modeled as a superlinear function of the extent to which a courier's speed exceeds the safety threshold. Eqs. (2) and (3) are the demand and supply model, respectively. We adopt the service time estimation model from Ye et al. (2024) and calculate the corresponding t_s and k in Eqs. (4) and (5). Finally. Eq.(6) is given following Little's Law (Little, 1961).

The delivery system is modeled through two components: a physical process model(Eq. (4)-Eq (6)) and an equilibrium model(Eqs. (2) and (3)), which together form a complex nonlinear system. Based on mathematical analysis, we show that under mild conditions the endogenous variables t_1, t_n, t_d, and k satisfy Brouwer's fixed-point theorem. This guarantees the existence of a market equilibrium for any given set of parameters. Formally, we define $x = (t_1, t_n, t_d, k)$, such that there exists a fixed point $x^* = F(x^*)$, at which the market reaches equilibrium. The pseudo-code of the fixed-point iteration algorithm is provided in Appendix 1.

Results and Conclusion

In the experiments, both customer demand function and courier supply function are assumed to follow normal distributions, with means μ_D and μ_V, and standard deviations σ_D and σ_V, respectively. The baseline parameter settings follow Ye et al. (2024) and are consistent with those commonly used in ride-hailing and ride-pooling studies. The coefficient of accident cost component follows Zhang et al. (2023). Table 1 in the Appendix summarizes the default values and variation ranges used in our numerical experiments.

In our numerical experiments, we analyze the system at market equilibrium. For each given parameter set, this equilibrium is determined using the fixed-point iteration procedure (Algorithm 1), after which the welfare of each stakeholder is computed. We first investigate the impact of speed v by fixing supply and demand parameters and evaluating the stakeholder welfare at equilibrium across a range of speeds. The results of this analysis are depicted in Figure 2. When speed exceeds the optimal value, risks outweigh benefits, putting couriers at high risk and decreasing marginal returns for both the platform and customers. Excessively slow speeds are also unacceptable for the platform, as they fail to maintain an attractive service level. Couriers' optimal choice is to stay below the safety speed, avoiding risk. For customers, faster speeds improve service levels and their surplus. Based on these insights, we identified the optimal speed and designed the GST to regulate courier behavior.

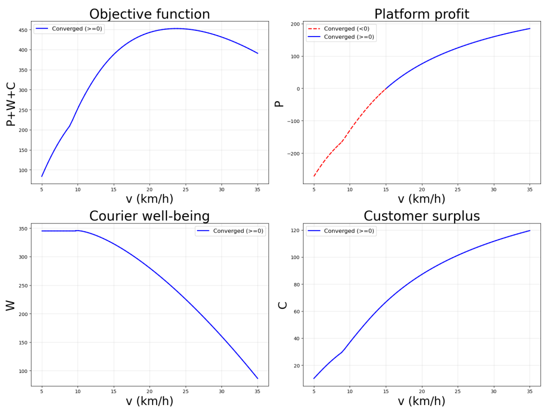

Figure 2: Stakeholder Interests at Different Speeds

In practice, on-demand delivery systems experience distinct peak and off-peak demand periods. To investigate how the system should adjust the GST to regulate courier speed and achieve optimal social welfare under varying supply-demand conditions, we analyzed the equilibrium states in different supply-demand scenarios, as shown in the Figure 3. In the bottom-right corner of the right image, when supply is insufficient (with Γ_v approaching 0), the platform's capacity cannot meet order demand, reaching an approximate equilibrium under the constraints set by the design. In this state, the system operates inefficiently, with service times significantly higher than normal (bottom-right corner of the left image).

We simulated the changes in total social welfare and optimal system speed under varying supply-demand conditions, as shown in the figure 4. When supply is insufficient, couriers are required to work at full capacity, and the GST mechanism fails. In contrast, when the system has adequate capacity (top-left corner), the GST mechanism is effective. With constant demand, as supply increases, the platform can reduce delivery speed to ensure couriers remain in a low-risk state. Conversely, with constant supply, as demand rises, the platform must increase delivery speed to reduce delivery times and meet the required service level.

This study introduces the "Guaranteed Service Time" (GST) mechanism and designs a multi-objective optimization framework aimed at balancing the interests of the platform, couri-

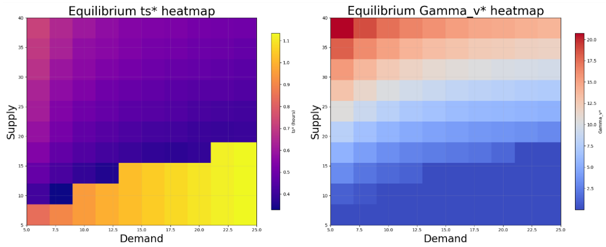

Figure 3: Equilibrium Analysis of the System under Varying Demand and Supply Conditions

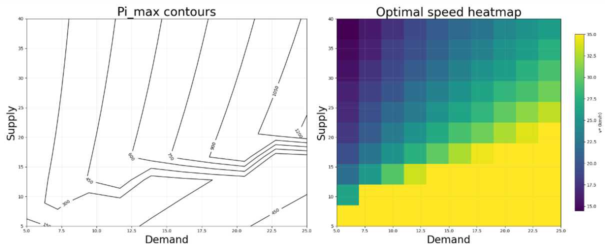

Figure 4: Optimal Social Welfare and Speed under Different Demand and Supply Conditions

ers, and customers. By considering courier safety, platform profit, and customer surplus, the GST mechanism ensures the proper execution of delivery tasks by limiting the couriers' speed, reducing the safety risks that may arise from the pursuit of excessively fast deliveries.

Through numerical experiments under different supply-demand scenarios, we found that appropriate GST settings can effectively regulate courier behavior and ensure a balance between the interests of all parties in the system. Specifically, during meal peak hours, the platform may need to compress the GST slightly to allow couriers to work at higher speeds in order to meet demand and maintain system stability. On the other hand, when demand is low, the GST mechanism should take effect to ensure that couriers do not accelerate excessively, thereby preventing the risk of accidents.

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Appendix A Fixed-Point Iteration Algorithm

Algorithm 1: Fixed-Point Iteration for Equilibrium

Input: Initial $x^{(0)} = (t_1, t_n, t_d, k)$, learning rate $\omega \in (0, 1]$, tolerance $\varepsilon > 0$, small constant $\delta > 0$
Output: $(x, \lambda, \Gamma_v, t_s)$
$x \leftarrow x^{(0)}$;
for $iter = 1, 2, \ldots$ **do**
  $t_s \leftarrow t_1 + (k-1)\, t_n + t_d$;
  $\lambda \leftarrow F_\lambda(t_s)$;
  $\Gamma_v \leftarrow F_{\Gamma_v}(\lambda, k, t_s)$;
  $x^* \leftarrow F_{ts}(\lambda, \Gamma_v)$; // new (t_1, t_n, t_d, k), k from λ
  if $\frac{\|x^* - x\|}{\|x\| + \delta} \leq \varepsilon$ **then**
    break;
  $x \leftarrow (1-\omega)\, x + \omega\, x^*$; // update with learning rate ω
return $(x, \lambda, \Gamma_v, t_s)$;

Appendix B Parameter Settings

Table 1: Default parameter values used in the numerical experiments

Parameter	Notation	Unit	Default value
Mean of customer reservation price	μ_D	USD	15
Standard deviation of customer reservation price	σ_D		5
Mean of courier reservation wage rate	μ_S	USD/h	20
Standard deviation of courier reservation wage rate	σ_S		10
Restaurant density	Λ	km^2	10
Average number of potential customers per restaurant per hour	λ_0		10
Density of potential couriers	Γ_0	km^2	20
Customers' value of time	α	USD/h	4.5
Detour ratio of road network	δ		1.3
Matching time interval	Δ	h	0.1
Searching radius for combining next order	D_p	km	1
Fraction of combinable orders	φ		0.05
Linehaul parameter for estimating delivery time	β_1'		0.6
Bundle-size square-root parameter for delivery time	β_2'	km	4.3
Maximum bundle size	$k_{\max}$		5
Average delivery distance	l	km	3
Service price per order	f	USD	15
Courier hourly wages	q	USD/h	25
Couriers' average travel speed	v	km/h	20
Accident cost coefficient	c		0.15
Accident severity exponent	η		1.5
Absolutely safe speed	v_{safe}	km/h	10

Extreme Heat and Road Safety: Assessing the Risks Faced by Delivery Riders in Urban India

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Introduction

The COVID-19 pandemic significantly accelerated the growth of courier and food delivery services worldwide, transforming them into essential components of urban life (Lobel, 2020). The heightened need for contactless delivery spurred innovations in logistics, AI-driven route optimization, and the expansion of the gig workforce. While this sector provides critical convenience to consumers and flexible employment opportunities, it also exposes delivery riders to a distinct set of occupational hazards. In India, the emergence of quick-commerce startups further intensified market competition, introducing 10-minute delivery models and expanding operations beyond traditional metropolitan hubs into smaller cities. Many of these services rely on gig workers using powered two-wheelers (MTWs), which represent one of the most vulnerable transport modes. India records over 450,000 road accidents annually, with two-wheelers accounting for nearly half of all fatalities. Specifically, MTWs constitute 44.5% of all road-related deaths in India (MoRTH, 2022). Delivery riders engaged in quick-service logistics are likely to exhibit risk-taking behaviors, such as speeding and traffic violations, to meet strict performance metrics.

India is also experiencing more frequent and severe heatwaves due to climate change, with cities like Delhi recording temperatures exceeding 49°C (Looi, 2024). The urban heat island effect exacerbates these conditions, rendering densely populated areas significantly hotter than their surroundings. Unlike car drivers, MTW users lack in-vehicle cooling mechanisms such as air conditioning or weather shields, increasing their direct exposure to ambient temperatures. Delivery riders, often working extended hours outdoors, are thus highly susceptible to dehydration, heat exhaustion, and heat strokes, impairing their ability to operate vehicles safely (Useche et al., 2024). Research has shown that individuals tend to avoid non-essential trips during extreme weather events (Jain & Singh, 2021). Consequently, the demand for e-commerce and last-mile deliveries rises, subjecting delivery riders to prolonged exposure to hazardous environmental conditions.

While Christie and Ward (2019, 2023) have investigated risky riding behaviors among food delivery agents and their occupational safety challenges, there remains limited research on the intersection of road safety and occupational heat stress for gig workers in India. Existing studies predominantly focus on general road safety trends or heat stress in industrial workplaces (Jiang et al., 2024), leaving a significant gap in understanding how extreme temperatures exacerbate delivery rider risks. Addressing this gap is essential for developing policy interventions, improving infrastructure, and implementing worker protection measures to ensure safer conditions for last-mile delivery personnel.

Research Aim and Objectives

This study seeks to examine the impact of extreme heat on delivery riders in urban India, focusing on its implications for road safety. It further aims to explore strategies to enhance rider safety and working conditions within the broader context of climate change. Some of the specific objectives include understanding the exposure level of riders involved in quick service deliveries to high-temperature conditions, and investigate the relationship between extreme heat exposure and rider performance, focusing on physiological effects such as fatigue, dehydration, and impaired cognitive function.

Methodology

The study will employ a field-based survey to assess heat exposure among delivery riders, utilizing wearable health monitoring devices to record air/skin temperature and heart rate, alongside GPS tracking for a full workday. This approach will allow for the measurement of cumulative heat exposure, peak heat durations, and route selections across different times of the day. At the end of work shift, a questionnaire survey will be conducted to evaluate heat-related stress and perceived temperature effects. The study will take place in Delhi during peak summer in June over one week, involving multiple riders 50 samples (10 riders per day recruited through delivery companies and utilizing 5 wearable devices). Additionally, a broader survey will be administered to understand work conditions and potential hazards to be conducted with more than 300 riders (random selection using the intercept method). This comprehensive approach will provide quantitative and qualitative insights into the intersection of extreme heat exposure, delivery rider behaviors, and road safety.

Preliminary survey findings

A preliminary survey was conducted with 50 delivery riders in South Delhi to assess the feasibility of the proposed methodology in terms of recruitment potential, and logistical considerations. This involved a short questionnaire survey designed to capture key insights into rider safety, work conditions, and heat exposure.Regarding mode of delivery, the majority of riders used motorcycles, followed by mopeds. Most relied on personal vehicles, while a notable proportion reported renting them. In terms of helmet usage, only 50% of riders were observed wearing helmets, with all respondents indicating that companies do not provide helmets, requiring them to purchase their own. Alarmingly, 20% of surveyed riders reported sustaining injuries within the past week. While some riders were covered by company-sponsored insurance, granting them access to free medical treatment, others lacked employer support. Reported working hours ranged from 4 to 16 hours per day, with an average of 11–12 hours, highlighting the demanding nature of their schedules.

The survey also examined delivery types and timelines, revealing that 50% of riders delivered food, while the remaining half handled groceries and essential items. Grocery deliveries were typically expected within 10–20 minutes, whereas food deliveries allowed 30–40 minutes per order. Riders completed between 10 and 45 deliveries per day, covering distances ranging from 1 to 10 km per trip. Additionally, many riders reported heat-related health issues, including excessive sweating, dehydration, low blood pressure, dizziness, and headaches. To mitigate heat exposure, most riders adopted protective measures, such as wearing arm gloves and full-sleeve clothing. Some companies incentivized deliveries during peak heat hours, while others provided water bottles at pick-up points to support hydration.

These preliminary findings emphasize the multifaceted challenges faced by delivery workers, particularly in terms of road safety, health risks due to extreme temperatures, and the impact of long work hours. The field surveys planned will substantiate these findings and further the evidence to better understand the challenges faced by delivery riders in India and identify potential solutions that can help reduce exposure and health impacts imposed by high temperatures and unsafe conditions.

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Fleet Sizing and Pricing for a Hybrid AVs-HVs Ride-Hailing Platform under Fulfillment Requirements

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Introduction

Recently, several ride-hailing platforms have launched hybrid operations where autonomous vehicles (AVs) and human-driven vehicles (HVs) services coexist. A salient feature of this hybrid AVs-HVs ride-hailing platform practice is geographic service differentiation. Specifically, robotaxis are typically restricted to geofenced service areas, whereas HVs can service demand both outside of and within the AVs service area. In order to ensure service accessibility in regions outside of the robotaxi coverage area, platforms may impose fulfillment rate requirements on HVs, which implemented explicitly through dispatch prioritization or implicitly via incentive schemes. This requirement plays a critical role in shaping platform decisions on fleet sizing and pricing and introduces additional complexity into the interaction between AVs and HVs.

Prior studies have examined platform's fleet sizing and pricing decisions in a hybrid AVs-HVs ride-hailing system (Mo et al.(2022); Ao et al.(2024)), but seldom take human-driver fulfillment constraints into consideration. Our work differs from prior studies by explicitly separating short-term pricing from long-term fleet sizing decisions. In our setting, we allow HVs to operate across the entire market, a key feature absent from the setting of prior works.

In this paper, we investigate the fleet sizing and pricing decisions of a hybrid ride-hailing platform offering both robotaxi (powered by autonomous vehicles, AVs) and human-driven vehicles (HVs) services, while facing fulfillment rate requirements for HVs services outside the robotaxi service area. We develop a two-period model in which the platform first chooses the robotaxi fleet size to maximize long-term profit, then sets prices and human driver wages to maximize short-term profit, taking into account passengers' service choices and drivers' participation.

Our analysis reveals that, given a fulfillment requirement for HVs, there exists a AVs fleet size threshold that divides the robotaxi service area into two distinct regimes. Below this threshold, demand within the robotaxi operational area is only partially met, with service prices, driver wages, and HVs demand remaining stable. Once the AVs fleet exceeds this threshold, the robotaxi service area becomes fully covered, increasing realized demand for robotaxi service but reducing HVs participation and earnings. Importantly, we show that HVs services retain a positive market share within the robotaxi service area as long as the required HVs fulfillment rate is sufficiently low. Numerical results show that while robotaxi adoption enhances platform profit and social welfare, its impact on customer surplus is non-monotonic and on labor welfare is non-increasing. Moreover, the platform's long-term profit response to AVs fleet expansion critically depends on AVs investment costs: low costs support aggressive deployment, high costs discourage expansion, and moderate costs result in non-monotonic returns.

Body

We use a two-period model to capture the sequential decision-making process among the ride-hailing platform, passengers, and human drivers, as illustrated in the Figure 1. We analyze the two-period model using backward induction.

Our analysis yields several key insights. First, we show that in a mixed ride-hailing platform, even when there exist fulfillment requirements for HVs to serve demand outside the robotaxi

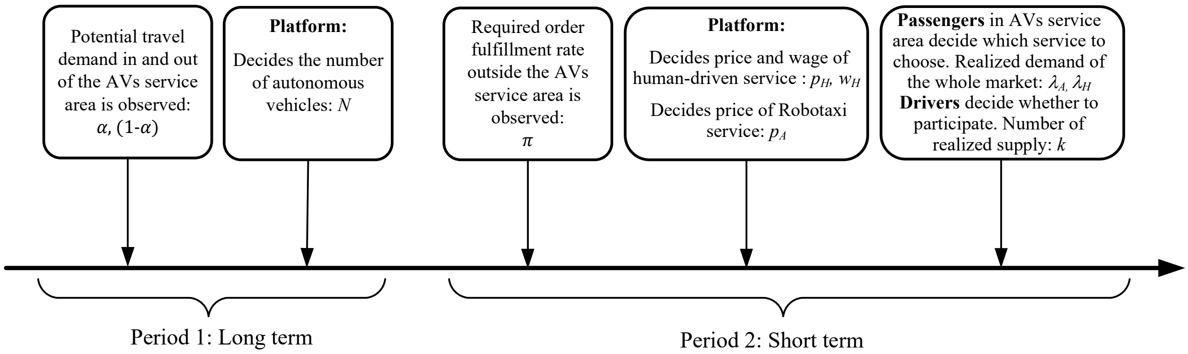


Figure 1: Sequence of Events

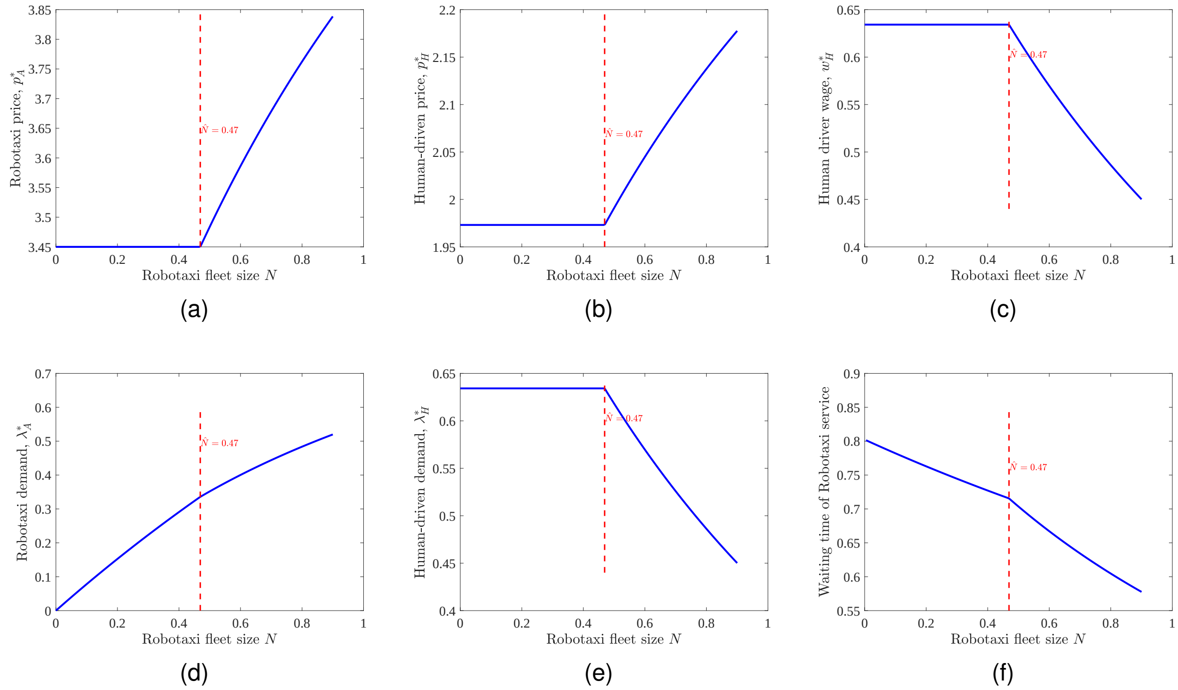
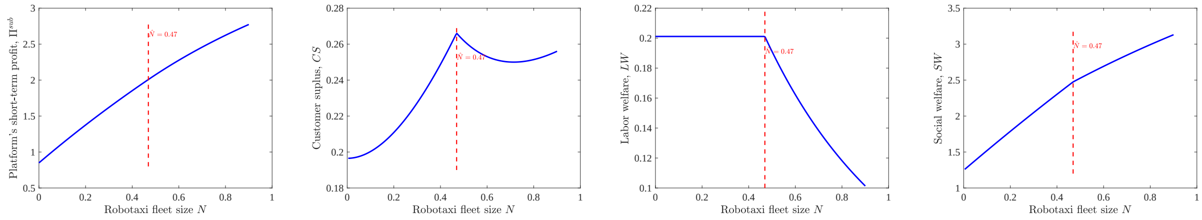


Figure 2: Impact of the Robotaxi Fleet Size on Equilibrium Outcomes. $v = 6.9$, $h = 4.3$, $\pi = 0.7$, $\alpha = 0.9$.

service area, robotaxis cannot fully displace HVs within it as long as the fulfillment rate is sufficiently low. Second, as shown in Figure 2, we identify a critical AVs fleet size threshold that induces two operational regimes. When the robotaxi fleet size is below this threshold, the AVs service only partially covers its operational area, and the platform's pricing, HVs wage, and HVs demand remain unchanged. Once the fleet size exceeds the threshold, full coverage is achieved, leading to monotonic increases in service prices and robotaxi demand, alongside declining HVs wages and demand. Third, as shown in Figure 3, our numerical results show that the platform's short-term profit and robotaxi demand increase monotonically with AVs fleet size, regardless of the regime. Besides, the labor welfare is non-increasing in the AVs fleet size, reflecting the displacement effects of automation. In contrast, customer surplus exhibits a non-monotonic pattern: initially rising as AV coverage expands, then declining due to price increases, and eventually rising again due to reduced waiting times. Despite these mixed effects, total social welfare consistently improves as the AVs fleet size increases, highlighting the system-wide efficiency gains from automation. Finally, as shown in Figure 4, our theoret-



(a) (b) (c) (d)

Figure 3: Impact of the Robotaxi Fleet Size on Platform's Short-term Profit and Welfare Metrics in Each Subperiod of Period 2. $v = 6.9$, $h = 4.3$, $\pi = 0.7$, $\alpha = 0.9$.

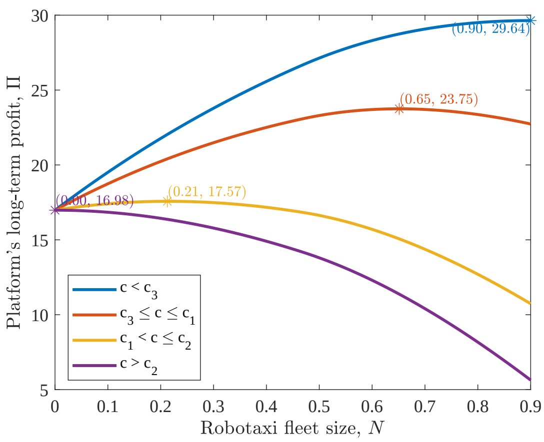


Figure 4: Platform's Long-term Profit under Different Unit Costs of Robotaxis. $v = 6.9$, $h = 4.3$, $\pi = 0.7$, $\alpha = 0.9$, $\delta = 0.95$.

ical results show that that the platform's long-term profit response to AVs fleet size depends critically on the unit investment cost. When AV costs are low (high), the platform's long-term profit increases (decreases) with fleet size. At moderate cost levels, the profit function is non-monotonic, first increasing and then decreasing, with an interior optimal fleet size that balances the marginal cost and marginal benefit of automation.

Future work may consider endogenous service area design or multiple competing platforms, which introduces strategic spatial and competitive interactions. Moreover, incorporating regulatory instruments such as taxes, subsidies, or wage floors would provide deeper insight into the welfare implications of government intervention in partially automated mobility markets.

Acknowledgements

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Thursday 11th December: 11am-1pm
Parallel Session 3 (Level 16, Lecture room 5)
Theme: Walking, Accessibility, and Sustainable Mode Choice, Session Chair: Prof. John Nelson
Pedestrian Destination Choice Set Generation: A Hybrid Graph-Theoretic Approach (Fatemeh Nourmohammadi, Taha Hossein Rashidi and Meead Saberi)
Optimizing Passenger Walking at Drop-off with Anticipatory Methods in Ridepooling Systems (Xinyu Wang and Andrés Fielbaum)
At what break-even distance does people shift to sustainable modes? A generalised cost approach for mode choice in short trips (Dilini Kariyawasam Pathiranalage and Shamsunnahar Yasmin)
Assessing the predictive power of open-access walkability indices for walking behaviour (Hisham Negm and Ahmed El-Geneidy)

Pedestrian Destination Choice Set Generation: A Hybrid Graph-Theoretic Approach

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Introduction

Walking offers significant societal, public health, and sustainability benefits, driving cities to enhance accessibility and walkability. This has spurred research into pedestrian behavior and movement, yet destination choice models remain underexplored, requiring a better understanding of environmental influences and realistic choice set generation.

Realistic choice set generation is crucial since it directly impacts model estimation outcomes. Researchers have used various methodologies—deterministic rules (Ortúzar and Willumsen, 2024) and sampling methods (Ben-Akiva, 1985)—with most studies relying on random sampling. For instance, Clifton et al. (2016) developed a model using ten randomly selected alternatives within a three-mile (4.8 km) network distance from each origin, while Eash (1999) formed sets of 50 possible destinations within a two-mile (3.2 km) X-plus-Y distance. Similarly, Khan et al. (2014) employed 40 alternatives (including the actual destination), and Berjisian and Habibian (2019) used both random and stratified importance sampling, yielding 112 alternatives per pedestrian at the PAZ level.

However, many approaches depend on fixed distance thresholds and alternative counts, which can lead to computational challenges and the exclusion of key destinations when aggregation levels vary. Enhancing choice set generation accuracy is therefore essential for reliable model estimation.

The literature has not thoroughly examined how different choice set generation methods affect destination choice model estimates. This study addresses that gap by proposing a novel graph-based approach and comparing it with distance-based generation using household travel survey data from Melbourne and Brisbane.

Method

The proposed graph-based destination choice set generation method constructs a localized graph around each origin zone by traversing an undirected graph $G = (V, E, A)$, where $V = \{v_i\}_{i=1}^{N}$ denotes the set of N spatial zones (e.g., SA1s), E represents the edges defined by spatial adjacency, and $A \in \mathbb{R}^{N\times N}$ is the binary adjacency matrix. The adjacency matrix A is specified as:

$$A_{od} = \begin{cases} 1, & \text{if the geometries of zones } v_o \text{ and } v_d \text{ share a boundary} \\ & \text{or corner (i.e., Queen contiguity)} \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

For any pair of zones $o, d \in V$, the hop distance $d_G(o, d)$ is the minimum number of edges connecting them. Let

$$\mathcal{P}(o, d) = \{(n_0, n_1, \ldots, n_k) : n_0 = o,\ n_k = d,\ (n_{i-1}, n_i) \in E \text{ for } i = 1, \ldots, k\} \tag{2}$$

be the set of all valid paths from o to d, and define the path length $\ell(p) = k$. The hop distance is then given by:

$$d_G(o, d) = \min_{p \in \mathcal{P}(o,d)} \ell(p) \tag{3}$$

We introduce a hop threshold H to define the hop-based candidate set for each origin o:

$$C_o^{\text{hops}} = \{d \in V \setminus \{o\} : d_G(o, d) \leq H\} \tag{4}$$

To incorporate realistic accessibility, we further restrict this set by a distance threshold $D_{\max}$, using network distance $\delta(o, d)$, to obtain the hybrid candidate set:

$$C_o^{\text{hybrid}} = \{d \in C_o^{\text{hops}} : \delta(o, d) \leq D_{\max}\} \tag{5}$$

Household travel survey data from Melbourne and Brisbane are used, including pedestrian trips aggregated at the SA1 level, observed distances, land use (e.g., commercial, parkland), sociodemographic data (e.g., median household age, income), and urban features (e.g., intersection count, edge density). For each origin–destination pair (o, d), we define a binary indicator:

$$y_{o,d} = \begin{cases} 1, & \text{if } d \text{ is the observed destination for } o \\ 0, & \text{otherwise} \end{cases} \tag{6}$$

Missing distances in the choice set are imputed using centroid-based network distances; for intra-SA1 trips, a fixed distance of 500 meters is used. We train a Long Short-Term Memory (LSTM) network (Hochreiter, 1997) using Binary Cross-Entropy Loss defined as:

$$\mathcal{L}_{\text{BCE}} = -\frac{1}{N} \sum_{(o,d)} [y_{o,d} \cdot \log(p_{o,d}) + (1 - y_{o,d}) \cdot \log(1 - p_{o,d})] \tag{7}$$

The dataset is split into 80% training and 20% testing, and the model is trained for 500 epochs. Model performance is assessed using class-specific accuracy calculated as $\text{Accuracy}_1 = \frac{TP}{TP+FN}$ and $\text{Accuracy}_0 = \frac{TN}{TN+FP}$. Training was conducted on a 2024 Apple Mac mini (M4 Pro chip, 14-core CPU, 20-core GPU, 16-core Neural Engine, 48GB unified memory)

Results

Our analysis shows that over 80% of walking trips occur within 2 hops, and nearly 90% of observed destinations are within 2 km, justifying these thresholds. Table 1 compares network distance, graph-based, and hybrid graph-distance methods for Melbourne and Brisbane. The graph-based and hybrid methods generate smaller, more relevant choice sets, reducing mean choice set size from 66.6 (Melbourne) and 48.8 (Brisbane) in the network distance method to 23.3 and 23.2 (graph-based), and further to 20.6 and 19.5 (hybrid). The hybrid method also improves runtime, reducing computation time from 54 min (Melbourne) and 52 min (Brisbane) in the network distance method to 13 and 12 minutes, respectively. In terms of model performance, the hybrid method improves classification accuracy, with LSTM correctly predicting chosen destinations (1s) at 73% in Melbourne and 42% in Brisbane, compared to 64% and 29% using the network distance method. Overall, the proposed graph-based approach enhances destination choice prediction by producing more efficient choice sets, improving accuracy, and reducing computational costs.

Table 1: Comparison of destination choice set generation methods in Melbourne and Brisbane

Metric	**Melbourne**	**Brisbane**	**Melbourne**	**Brisbane**	**Melbourne**	**Brisbane**
	Network Distance		**Graph-Based**		**Hybrid Graph-Distance**	
Choice Set Size						
Min	1	1	3	5	1	1
Max	178	158	116	90	67	45
Mean	66.6	48.8	23.3	23.2	**20.6**	**19.5**
Std Dev	36.1	31.0	8.1	8.3	6.8	6.4
Observed Destinations (%)						
Chosen (1s)	3.92	4.15	8.70	7.70	**9.65**	**9.01**
Non-Chosen (0s)	96.08	95.85	91.30	92.30	90.35	90.99
Computation Time (Minutes)						
Runtime	54	52	43	40	**13**	**12**
Observed Walking Distance (m)						
Min	10	10	10	10	10	10
Max	5,200	3,980	5,520	6,990	5,200	3,980
Mean	598	706	562	653	556	640
Std Dev	373	504	323	477	302	439
LSTM Model Accuracy						
Chosen (1s)	0.64	0.29	0.68	0.35	**0.73**	**0.42**
Non-Chosen (0s)	0.98	0.98	0.98	0.97	0.97	0.96

Discussion

This study presents a graph-based approach for generating pedestrian destination choice sets, offering a behaviorally relevant and efficient alternative to traditional distance-based methods. Analysis of travel survey data from Melbourne and Brisbane shows that over 80% of walking trips occur within two graph hops and nearly 90% within 2 kilometers, supporting the use of hop-based thresholds. These thresholds produce smaller, more realistic choice sets, reducing average runtime by over 75% and improving prediction accuracy in LSTM models—Melbourne's accuracy increased from 64% to 73%, and Brisbane's from 29% to 42%. Unlike prior methods, this approach incorporates network connectivity, sociodemographic factors, land use, and urban design metrics, enhancing model sensitivity and generalizability. Future research should explore random sampling and compare model performance across different choice set strategies.

Acknowledgements

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Optimizing Passenger Walking at Drop-off with Anticipatory Methods in Ridepooling Systems

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Introduction

Mobility on-Demand (MoD) systems, especially shared ridepooling, have gained global popularity by efficiently serving millions daily. Ridepooling, where vehicles carry passengers with similar routes, improves vehicle utilization, increases driver revenue, and reduces passenger costs. However, ridepooling requires vehicles to take detours to accommodate additional requests. In congested urban environments, these detours can become problematic as they may force vehicles onto narrow lanes with slow traversal speeds or result in lengthy diversions due to one-way restrictions. If passengers are willing to walk a short distance, vehicle routing flexibility can be significantly enhanced, and system efficiency greatly improved, since passengers walk at a consistent speed and are unaffected by road direction constraints. Determining optimal walking destinations for passenger pick-ups is relatively straightforward, as all essential information is available at the time of assignment.

However, recommending effective walking destinations for drop-offs at the moment of assignment is challenging because it involves future conditions, and only limited information is available. Also, deciding the walking destination for drop-off during the trip is majorly unacceptable (Yan *et al.* (2024)). Additionally, since the drop-off location of current passengers influences subsequent requests, optimizing the walking destination at drop-off is as crucial as at pick-up. To date, very few studies have explored the optimization of passenger walking destinations at drop-off. In this research, we propose an anticipatory method that utilizes historical spatiotemporal request data to optimize passenger walking destinations at drop-off. With our approach, both rejection rates and user costs are further improved compared to traditional methods, which focus solely on pick-up optimization.

Methodology and Results

The study by Fielbaum *et al.* (2021) investigates optimizing ridepooling systems by enabling passenger walking at pick-up and drop-off points. Their research demonstrates that appropriate walking can significantly reduce both rejection rates and user costs in ridepooling systems. In our baseline experiment, each request is assigned a walking-based PU/DO if: (1) the distance from the original location is $\leq D$; (2) existing passengers experience waiting time $\leq T_w$ and delay time $\leq T_d$. During ILP, we minimize the rejection rate by using a large rejection penalty P to assign as many requests as possible (Eq. 1); for each vehicle, we search for a walking node which minimize the total delay of all requests of the vehicle (Eq. 2). To consider the delay of individual request, we use the difference between the actual arrival time $t_{r,s,arr}$ and the arrival time $t_{r,p,arr}$ as if the request is served privately (no sharing), with multiplying the number of passengers n_r in the request. Detailed simulation settings are presented in Table 1.

$$\min_{(r,v)\in\mathcal{A}} \sum_{r\in r_{OK}} C(v,r) + \sum_{r\in r_{KO}} P \quad \text{subject to} \quad r_{OK} \cup r_{KO} = \mathcal{R} \tag{1}$$

$$C = \sum_{r\in\Pi} (t_{r,s,arr} - t_{r,p,arr}) \cdot n_r \tag{2}$$

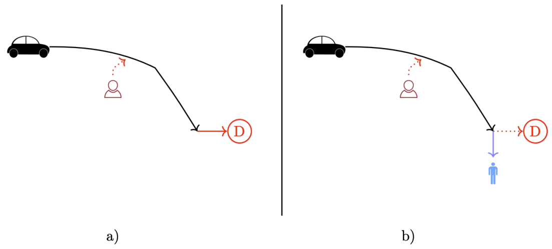

Figure 1: Example of a case where updating the dropoff improves efficiency. Black arrows indicate the vehicle's route; dotted arrows, passenger walking. In a), the red user walks to the pickup point, and a red segment is added for direct dropoff at destination D. In b), a new blue user appears, prompting a route update that replaces the red segment with a blue one, requiring the red user to walk to D.

Nodes	Edges	Zones	Requests	Fleet Size	Area (Land)	Vehicle Capacity	T_w	T_d	Max Walking Distance	Walking Speed
4091	9452	32	17780/h	1000	59.1 km^2	6	300s	600s	200m	1.4m/s

Table 1: Settings of experiments in simulation of Manhattan

We compare simulation results between ridepooling with and without walking. In a 30-minute simulation, 758 requests (48.04%) involved walking at pick-up (PU), and 157 (9.95%) at drop-off (DO), with an average walking distance of 121.53 meters. Fewer DO walking assignments occur because final DOs usually offer no benefit to future requests. Still, walking can help at last stops on narrow or one-way NYC streets where it is faster or avoids detours. We identified 45 requests (2.85%) in such cases.

Future Works

Since requests involving walking at drop-off (DO)—especially when positioned as the last stop—are limited due to insufficient information, we propose an anticipatory method leveraging historical trip data to predict future demand. As illustrated in Figure 1 (Andrea Pellegrinia (2025)), updating the DO walking destination after assignment can improve efficiency, but passengers typically resist changes to assigned drop-offs. Thus, walking destinations must be determined at assignment. We retrieve historical trips originating near the DO location of the target request, within a short time window on the same weekday, and treat them as anticipated future requests. The walking assignment problem is then formulated as an Integer Linear Program (ILP) to optimize the DO walking destination. This method enables most requests to receive optimized drop-offs, improving both rejection rate and user cost.

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At What Break-Even Distance Does People Shift to Sustainable Modes? A Generalised Cost Approach for Mode Choice in Short Trips

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Introduction

Short distance trips which are usually defined as trip distance by car less than or equal to 5km constitute a large proportion of daily travel and car usage. For instance, Li et al. (2015) found that over 40% of all car trips fall into the short-distance category in Beijing. Mackett (2003) highlighted that, in Great Britain, cars remain the dominant mode of transport even for trips just over one mile. Short trips contribute significantly to greenhouse gas emissions due to cold start effects when motor vehicles operate inefficiently during the initial portion of a trip. The over-reliance on cars for short trips indicates a significant opportunity for mode substitution, involving a shift from private vehicles to active transport modes such as walking and cycling. Neves and Brand (2019) estimated that shifting short trips to active modes could reduce CO_2 emissions from cars by up to 4.9%.

Identifying modal shift potential considering the break-even distance (BED) concept incorporating generalised cost is a novel approach in the context of road passenger transportation. By identifying the break-even distance using generalized cost, policymakers can strategically design interventions such as fare subsidies, active transport incentives, or road pricing mechanisms where they are most likely to influence travel behaviour. It also informs urban and transport planning by supporting compact, mixed-use development that reduces reliance on private vehicles. Internalising emission costs within the generalized cost framework further enhances mode comparisons, making sustainable modes more attractive. Thus, in this study, it is hypothesised that lower generalized cost of sustainable modes will increase the likelihood of mode shift from car to sustainable transport modes. Towards that end, the research objective is to examine the mode shift potential of short trips by using generalized cost estimates and break-eve travel distance by considering Southeast Queensland, Australia as a case study. This study answers the following research questions:

1. What are the underlying factors that influence the mode choice of short distance travels?
2. How does travel distance influence the generalised cost and emissions reduction potential for short trips?
3. What are the trip distance thresholds for cost-effective mode shift to sustainable transportation for short trips in terms of emissions reduction?

Methodology

This study utilized the SouthEast Queensland Household Travel Survey (HTS) data from the 2021 to 2024 financial years compiled by the Department of Transport and Main Roads (TMR). The dataset was integrated with land use measures, transport infrastructure measures, Land Use and Public Transport Accessibility Index (LUPTAI), and socio-demographic measures. Travel time and trip distance across different modes were generated from the Southeast

Queensland Strategic Transport (SEQSTM) EMME model. The values were validated by using Google Maps by verifying the geocoded origin and destination locations to ensure the validity of trip distance and travel time. As the first step, the mode choice model using Multinomial Logit Model (MNL) was developed to identify parameter values required to generate the mode specific generalised cost functions. In the second step, the value of time (VOT) and cost sensitivities of Car Drivers, Walkers and Cyclists were generated using estimated model parameters. The third step involves developing a Generalised Cost (GC) function, which combines monetary and non-monetary travel components (e.g., travel time, cost, accessibility measures, and infrastructure characteristics) using the estimated parameters from the MNL model. In the fourth step, emission cost was estimated using mode-specific vehicle kilometres travelled (VKT), emission factor obtained from the National Transport Commission (2024) and emission cost factor obtained from the Australian Energy Market Commission (2024). In the fifth step, external costs are internalised by integrating the calculated emission costs into the generalised cost function. As the final step, the average BED is determined by integrating the generalised cost value with trip distance, identifying the threshold where the cost of sustainable modes becomes lower or equal to private car. The BEDs were identified for four scenarios.

- Business as usual: consider travel time and travel cost
- Opportunity cost: consider travel time, travel cost and opportunity cost to access services
- Emission and opportunity cost: consider travel time travel cost and opportunity cost to access services along with the internalisation cost of emission for car driver mode
- Infrastructure, emission and opportunity costs: consider travel time, travel cost, opportunity cost to access services and infrastructure facilities along with the internalisation cost of emission for car driver mode.

Results and Discussion

The computed Break Even Distance (BED) are presented in Table 1. The BED represents the distance point where walking or cycling is more cost-effective than driving a car. In this study, it was found that the BED has increased due to accessibility measures and infrastructure facilities for walking and cycling. These findings suggest that considering emission cost does not significantly influence short-distance trips. However, facilitating rich infrastructure reduces the burden on sustainable transportation and increases the potential for model shift. These results suggest that good infrastructure facilities encourage car drivers to shift to active transportation without the need for additional penalties for short-distance trips. This is study is the preliminary findings and a survival analysis using the Weibull distribution will be conducted to estimate individual-level mode shift probabilities at various distance points, incorporating generalised cost and sociodemographic characteristics as covariates.

Table 1: Break-even distance for substituting Car with Walking and Cycling for four scenarios

Scenarios	**BED for substituting Car Driver with Walking**	**BED for substituting Car Driver with Cycling**
Business as usual	0.71km	14.82km
Opportunity cost	1.01km	15.35km
Emission and opportunity cost	1.02km	16.94km
Infrastructure incentive and emission and opportunity costs	2.38km	41.31km

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Assessing the predictive power of open-access walkability indices for walking behaviour

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Introduction

The emergence of the 15-minute city concept brought walkability to the forefront of sustainable transport research (Lu & Diab, 2023; Teixeira et al., 2024). Over the last decade, various indices have been developed and promoted by public and private organizations to assess the quality of the walkable environments (Vale, Saraiva, & Pereira, 2015). Although many studies link walkability indices to walking behaviour (Christian et al., 2011; Lam et al., 2022), few have compared open-access indices or assessed their predictive strength (Manaugh & El-Geneidy, 2011; Shashank & Schuurman, 2019). Recently, a number of walkability indices have become publicly accessible in Canada (Ross et al., 2018; Statistics Canada, 2023), eliminating the need for complex calculations. These indices are yet to be validated as predictors of walking travel behaviour, which is essential for their effective implementation in practice. This research aims to assess the reliability of six walkability indices in explaining observed utilitarian and discretionary walking behaviour, providing valuable insights for practitioners, guiding them in selecting the most suitable walkability indices to promote walking.

Methods

We use survey data from the fourth wave of the Montréal Mobility Survey (MMS), conducted in Fall 2023 in Montréal, Canada (Victoriano-Habit et al., 2024). We use data on home locations, travel behaviour, travel identity, residential self-selection, and socioeconomic characteristics. For travel behaviour, we use the number of trips that the participants performed per week for work, school, shopping, healthcare, and leisure by walking. We only maintained participants whose weekly trip count fell within the range of four to thirty trips, reflecting a mobile population with reliably measurable mode shares. This filtering resulted in a final sample of 4,715 participants.

We examine six walkability indices: Walk Score®, Spatial Access Measures, Can-ALE, Can-ALE/Transit and cumulative opportunities accessibility within 15 and 30 minutes of walking. Of these, only Walk Score® is not specific to Canada. Walk Score® is a proximity gravity-based measure that evaluates access to 13 different amenities within walking distance and provides a score from 0 to 100 (Walk Score, 2024). The Spatial Access Measures are gravity-based measures developed by Statistics Canada (2023) in collaboration with Infrastructure Canada. We use the index for walking access to employment, scaled from 0 to 1. Can-ALE measures an area's active-living friendliness based on three components: dwelling density, connected intersections, and number of destinations (Ross et al., 2018) The extended Can-ALE/Transit adds transit stops as a fourth component. Both indices sum the z-scores of their respective components. The cumulative opportunities accessibility by walking measure with 15 and 30 minutes as the travel time thresholds was calculated using the 2016 Canadian commuting flows (Statistics Canada, 2017) and the r5r package in R (Pereira et al., 2021).

We conduct two sets of analyses: one that tests the indices for all purposes (work, school, shopping, healthcare, and leisure) combined, and another that tests them for each purpose individually. For the first set of models (seven models), we predict the percentage of total walking trips for all combined purposes using a multiple weighted linear regression. All models control for the same set of socioeconomic, residential self-selection, and travel identity variables. The first model is a base model where no walkability index was included. Each of the next six models included one of the six walkability indices. For the second set of models, we follow the same approach as in the first set, yet with the dependent variable being the percentage of walking trips conducted for a specific purpose per week. Since seven models were developed for each of the five purposes, this resulted in a total of 35 statistical models. This approach allows for the comparison of the coefficients of determination (R^2) from each model, with the highest R^2 indicating better overall explanatory power, and consequently, better predictability of walking using a particular walkability index.

Findings and discussion

In the first set of models (Table 2), all the models highlight the importance of individual and household characteristics in explaining travel behaviour. Including the walkability indices in the models offers a better goodness of fit for the six walkability models compared to the base model, with all walkability measures being statistically significant and the models incorporating Can-ALE and Can-ALE/Transit having the highest R^2. Table 2 shows the R^2 values from the second set of models. Of the 30 purpose-specific models including a walkability index, all were significant at $p < 0.001$, except Walk Score® for school trips.

For strictly utilitarian purposes (work and school), the cumulative opportunities measure within 30 minutes outperformed the other indices. Although this measure showed the best fit for work trips, its R^2 value was the lowest compared to the best fits observed for other purposes, indicating that walkability indices are poor predictors for work trips. The walking mode share for shopping was best predicted by the Can-ALE/Transit index. For leisure, Can-ALE is the best predictor, closely followed by Can-ALE/Transit. Walk Score® was only best in predicting healthcare trips with only a slight difference compared to the Can-ALE/Transit index.

Overall, the Can-ALE and CAN-ALE/Transit indices were the most effective for all purpose in general, as well as shopping and leisure trips in particular. These two measures were the only ones that explicitly considered dwelling density, street intersection density, and activity/destination density. As these measures account for the popular 3Ds: density, diversity, and design (Ewing & Cervero, 2010), it is unsurprising that they outperform other measures that ignore some of these components. These indices come with a full dataset containing detailed values and z-scores for each of the components per DA. The overall index can help highlight areas for potential enhancements, while the detailed component values enable the development of targeted strategies and interventions.

Table 1 Regression results for the six models with the percentage of total walking trips performed per week as the dependent variable

	Model 0 Base Model		Model 1 Cumulative jobs 15 mins		Model 2 Cumulative jobs 30 mins		Model 3 Walk Score		Model 4 Spatial access measures		Model 5 Can-ALE transit index		Model 6 Can-ALE walk index	
	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI
(Intercept)	**23.64** ***	19.82, 27.47	**20.95** ***	17.15, 24.74	**19.15** ***	15.39, 22.90	**20.44** ***	16.71, 24.16	**21.11** ***	17.40, 24.82	**17.48** ***	13.82, 21.14	**17.31** ***	13.66, 20.96
Gender	-0.07	-1.48, 1.33	0.09	-1.29, 1.47	0.63	-0.74, 1.99	0.16	-1.20, 1.52	0.18	-1.18, 1.54	0.42	-0.91, 1.75	0.49	-0.84, 1.82
Age	0.03	-0.01, 0.08	**0.07** **	0.03, 0.11	**0.09** ***	0.05, 0.14	**0.07** ***	0.03, 0.12	**0.07** ***	0.03, 0.12	**0.13** ***	0.09, 0.17	**0.13** ***	0.09, 0.17
Income [1k CAD]	-0.01	-0.03, 0.00	**-0.02** *	-0.03, -0.00	**-0.02** *	-0.03, -0.00	-0.01	-0.02, 0.00	**-0.02** *	-0.03, -0.00	**-0.01** *	-0.03, -0.00	**-0.02** *	-0.03, -0.00
Household size	**-0.95** **	-1.59, -0.31	-0.57	-1.21, 0.06	-0.38	-1.00, 0.25	-0.48	-1.10, 0.15	**-0.63** *	-1.25, -0.01	-0.19	-0.80, 0.42	-0.14	-0.75, 0.47
Full time empl.	**-6.00** ***	-7.53, -4.46	**-5.29** ***	-6.81, -3.77	**-4.86** ***	-6.36, -3.37	**-5.74** ***	-7.23, -4.25	**-5.73** ***	-7.22, -4.25	**-5.27** ***	-6.73, -3.82	**-5.16** ***	-6.61, -3.71
Available cars	**-8.76** ***	-9.71, -7.82	**-8.22** ***	-9.16, -7.28	**-7.70** ***	-8.63, -6.77	**-6.27** ***	-7.22, -5.31	**-6.53** ***	-7.48, -5.59	**-5.50** ***	-6.44, -4.57	**-5.48** ***	-6.41, -4.55
RSS: Walkable neighborhood	**4.56** ***	2.94, 6.18	**4.09** ***	2.49, 5.68	**3.68** ***	2.11, 5.26	**3.72** ***	2.15, 5.30	**3.21** ***	1.64, 4.78	**2.54** **	0.99, 4.08	**2.37** **	0.83, 3.91
Travel Identity: Pedestrian	**18.79** ***	16.82, 20.75	**18.32** ***	16.38, 20.25	**17.77** ***	15.86, 19.68	**15.91** ***	13.98, 17.84	**16.92** ***	15.01, 18.83	**15.62** ***	13.74, 17.50	**15.69** ***	13.82, 17.56
Standardized Walkability Index ¯			**4.24** ***	3.55, 4.93	**5.91** ***	5.22, 6.59	**6.87** ***	6.10, 7.64	**6.73** ***	6.01, 7.46	**8.87** ***	8.13, 9.61	**8.99** ***	8.25, 9.72
Observations	4715		4715		4715		4715		4715		4715		4715	
R^2 / R^2 adjusted	0.234 / 0.233		0.257 / 0.256		0.278 / 0.276		0.281 / 0.280		0.284 / 0.283		0.314 / 0.313		0.317 / 0.316	

¯ The Walkability index corresponds to the Model name

* p<0.05 ** p<0.01 *** p<0.001

Table 2 Coefficient of determinations (R^2) for multiple linear regressions with walking mode share per purpose as the dependent variable

Trip purpose	N	Walkability Index (R2 / R2 adjusted)						
		Base (No Index)	Cumulative jobs 15 mins	Cumulative jobs 30 mins	Walk Score®	Spatial access measures	Can-ALE/ Transit	Can-ALE
Work	2542	0.050 / 0.047	0.074 / 0.071	**0.095 / 0.092**	0.054 / 0.050	0.056 / 0.052	0.067 / 0.063	0.070 / 0.067
School	569	0.061 / 0.047	0.195 / 0.182	**0.215 / 0.202**	0.067 / 0.052	0.083 / 0.068	0.154 / 0.140	0.168 / 0.154
Shopping	4429	0.269 / 0.268	0.279 / 0.277	0.292 / 0.291	0.349 / 0.348	0.334 / 0.332	**0.361 / 0.359**	0.359 / 0.357
Leisure	3877	0.096 / 0.094	0.106 / 0.104	0.124 / 0.122	0.105 / 0.103	0.121 / 0.119	0.127 / 0.125	**0.130 / 0.128**
Healthcare	3150	0.173 / 0.171	0.179 / 0.177	0.190 / 0.188	**0.246 / 0.244**	0.209 / 0.206	0.243 / 0.241	0.238 / 0.236
All purposes	4715	0.234 / 0.233	0.257 / 0.256	0.278 / 0.276	0.281 / 0.280	0.284 / 0.283	0.314 / 0.313	**0.317 / 0.316**

*Each model controls for age, gender, income, household size, full time employment, car availability, residential selection in walkable neighborhoods, and travel identity as pedestrian
** Bolded indicates the highest R^2 for each purpose

While gravity-based measures were shown to be fairly adequate in predicting overall walking mode share, they primarily focus on the availability and density of destinations, making them less reliable as a comprehensive measure of walkability. It is worth mentioning that the widespread availability and recognition of Walk Score® give it a major advantage over the other measures that are specific to Canada. Our results along with previous ones confirm that it is an adequate predictor of non-work walking trips (Hall & Ram, 2018).

When selecting a walkability measure for practical use, the accessibility and interpretability of an index are crucial for its adoption. A publicly available index allows for a wide range of stakeholders to incorporate it into their decision-making processes, while an easily interpretable index allows for effective communication to the public and policymakers. Designing context-specific walkability indices should prioritize these considerations. Additionally, the availability of data and the technical requirements for calculating the indices are crucial for their potential replication and implementation across different regions. Ensuring the validity of walkability indices by comparing them to actual walking behaviour and perceptions is essential for their reliability and effectiveness in guiding policy and urban planning decisions.

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