

How will Autonomous Vehicles Impact Urban Cycling?

A study on urban living labs and street dynamics in transition

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I. Declaration

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Alexander Gaio

10 March 2025

II. Summary

Methods

This dissertation employs a mixed-methods approach to examine the impact of autonomous vehicles (AVs) on urban bicycle users. Research was conducted across four international living lab sites where Society of Automotive Engineers (SAE) Level 3+ classified AVs shared the right-of-way with bicycle users: Aalborg (Denmark), Montréal (Canada), Linköping (Sweden), and Stavanger (Norway). These sites were chosen to reflect varying levels of bicycle urbanism and levels of traffic stress (LTS).

Data collection included online surveys, semi-structured interviews, and focus groups. Survey participants were sampled from a strata of the local population, specifically recruiting residents living within 150 meters of AV shuttle routes using GIS and open data. Likert scale questions assessed attitudes, comfort, and trust regarding cycling near AVs.

Qualitative data were analyzed using an adapted Constant Comparison Analysis (CCA) and a Grounded Theory-influenced approach. Open-ended survey responses underwent thematic analysis. Quantitative data were examined using nonparametric statistical tests, including ordinal logistic regression and the Wilcoxon rank-sum test, to assess factors influencing bicycle users' perceptions. Bicycle user classification and traffic stress theory framed the analysis.

Major Findings

Key findings on AVs' impact on urban cycling include:

- Bicycle users' perceptions of AVs are shaped by safety, comfort, and an (unestablished) sense of trust.
- A strong preference for physically separated cycling infrastructure persists, suggesting its importance may outweigh automation levels.
- Communication challenges exist, underscoring the need for clear AV-to-bicycle user cues in the absence of human interaction.
- Safe, high-quality, separated infrastructure is the foundation for positive attitudes toward AVs.
- The AV transition period, with mixed vehicle types, requires bicycle users to adapt defensive riding strategies.
- AV shuttles' slower speeds and absence of road rage were seen as positive for shared spaces.
- Comfort in separated infrastructure was largely unaffected by vehicle type, while differences were more pronounced in shared spaces.
- Traffic calming and speed management are crucial for improving interactions with AVs and conventional vehicles.
- Policy recommendations stress the need for context-specific strategies that integrate AVs while prioritizing active transportation, advocating for sustained investment in separated bicycle infrastructure.

This research provides critical insights into bicycle users' experiences with AVs, offering guidance for urban planners, policymakers, and AV developers to foster more inclusive transportation systems.

Table of Contents

1.	<i>Situating Bicycle User Research in an Auto-dominant Transport System</i>	<i>21</i>
1.1	Introduction	21
1.2	Research Questions	24
1.3	Autonomous Vehicles: Eventuality or Immediate concern?	25
1.4	What This Dissertation is About: Blending theories to address a gap in research.....	28
1.5	Addressing the impact of AVs on a specific road-user group and defining the scope	29
1.6	Transport Subordination Cycles	30
1.7	The Established Dominance of Automobility.....	32
1.8	The Intricate Balance of Mobility Systems	34
1.9	Terminology	34
1.10	Structure and Format.....	36
2.	<i>A Systematic Overview of AV and Bicycle User Discourse.....</i>	<i>37</i>
2.1	Introduction	37
2.2	Systematic Literature Review	38
2.3	Discussion	48
2.4	Adjacent Subject-matter	66
2.5	Urban AI.....	70
2.6	Conclusion.....	72
3.	<i>Background & Theory.....</i>	<i>75</i>
3.1	Introduction	75
3.2	Background	75

3.3	Theory.....	77
3.4	Linking Theory to Research Questions.....	87
4.	<i>Methods</i>	89
4.1	Introduction.....	89
4.2	Living Lab Approach and Site Selection	90
4.3	Surveys.....	112
4.4	Interviews and Focus Groups.....	123
4.5	Data Preparation.....	126
4.6	Data analysis process	136
4.7	Consent and privacy.....	141
4.8	Methodological contributions	141
4.9	Conclusion	142
5.	<i>Attitudes of ‘living lab’ Bicycle Users Towards AVs</i>	145
5.1	Introduction.....	145
5.2	Research question 1	147
5.3	Attitude influence on bicycle use and urban mode choice (Theory: Planned Behaviour) 147	
5.4	Methods.....	148
5.5	Results.....	153
5.6	Discussion.....	170
5.7	Conclusion	172
6.	<i>AV Impact on cycling trips and behaviour</i>	175

6.1	Introduction	175
6.2	Research question 2.....	176
6.3	Bicycle user typology behaviour and tolerance (Theory: Bicycle User Classification) 176	
6.4	Methods.....	177
6.5	Results	185
6.6	Discussion	212
6.7	Conclusion.....	215
7.	<i>Influence of AVs on cycling infrastructure preference</i>	<i>220</i>
7.1	Introduction	220
7.2	Research question 3.....	222
7.3	Factors influencing safety and comfort (Theory: Traffic Stress)	223
7.4	Methods.....	223
7.5	Results	225
7.6	Discussion	244
7.7	Conclusion.....	246
8.	<i>Conclusion.....</i>	<i>251</i>
8.1	Synopsis of Contextual Chapters.....	252
8.2	Research Question 1: Attitudes of ‘living lab’ Bicycle Users Towards AVs.....	253
8.3	Research Question 2: AV impact on cycling trips and behaviour	254
8.4	Research Question 3: Influence of AVs on cycling infrastructure preference	255
8.5	Theoretical contributions	256

8.6	Methodological Contributions	259
8.7	Policy Implications	259
8.8	Reflections on Mobility Justice	261
8.9	Limitations.....	263
8.10	Recommendations for Future Research.....	264
9.	<i>References</i>	267
10.	<i>Appendices</i>	305
10.1	Bicycle Urbanism Maturity Table	307
10.2	Sample Participation Invitations	312
10.3	Ethics Approval	317
10.4	Focus Group/Interview Discussion Guide	336
10.5	Survey Questions	339
10.6	Supplementary Acknowledgements.....	353

III. Abstract

This dissertation examines the impact of autonomous vehicles (AVs) on urban bicycle users through a mixed-methods study conducted in real-world living labs. Bicycle users are a vulnerable road user (VRU) group often overlooked in AV research. The research addresses a gap in current discourse by focusing on the lived experiences of bicycle users rather than simulations or hypothetical scenarios. Drawing from urban geography, behavioural psychology, and cycling studies, this work explores the complex interplay between AVs and bicycle users' attitudes, behaviours, and infrastructure preferences. The study employs surveys, interviews, and focus groups across various sites, informed by the Theory of Planned Behaviour (TPB), traffic stress theory, and bicycle user classifications. Key findings reveal that bicycle users' attitudes are strongly shaped by their perceived safety and comfort, and an unestablished sense of trust when interacting with AVs. The research highlights a persistent preference for physically separated bicycle infrastructure, demonstrating that this desire remains even when interacting with AVs. Furthermore, the study identifies communication challenges between bicycle users and AVs and emphasises the importance of clear cues. The research offers practical policy implications for urban planners, emphasizing the need for context-specific strategies that ensure safe integration of AVs without compromising active transportation and bicycle use. It further offers reflections on the future of urban transportation systems informed by principles of mobility justice. This research provides a baseline for further studies to understand the impact of AI-mediated transport systems on non-occupant road users.

IV. Acknowledgements

This dissertation really took a village. There are so many people I owe an immense debt of gratitude to for helping in so many ways. Whether it was offering advice, a place to stay, hosting me as a visiting researcher, setting aside time to have informal meetings to share ideas, review papers and publications, or to simply offer words of motivation to ‘keep going’; it was all invaluable and made all the difference. There are a few people who I’d like to specifically name for their disproportionately generous involvement in my personal growth, the development of this research, and pushing me to get it to the finish line.

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To my Trinity family: Alexia, Cian, Wahaj, Orla, Abbie, and so many other colleagues who I have bounced ideas off, asked for a favour, shared an office, sent a meme to, and/or vented about a stressful, overwhelming, or seemingly insurmountable challenge—thank you for being there. Even if you didn’t know how much it meant, it meant a lot to me.

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V. Land Acknowledgement

There are many lands on which the research for this dissertation was carried out. I acknowledge research was conducted on traditional, ancestral, and unceded territories. Specifically, I acknowledge and reflect on the lands of two of the research locations in Canada.

I would like to acknowledge that one living lab site is located in Tiohtiá:ke/Montreal and is on the unceded traditional territory of the Kanien'kehà:ka, a place which has long served as a site of meeting and exchange amongst many First Nations including the Kanien'kehà:ka of the Haudenosaunee Confederacy, Huron/Wendat, Abenaki, and Anishinaabeg. I would like to recognise with humility and respect the Kanien'kehà:ka as the traditional custodians of the lands and waters on which a portion of this project was carried out.

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Why Acknowledge?

In Canada, a land acknowledgement is a formal statement recognizing Indigenous Peoples as the original stewards of the land. It acknowledges their historical and ongoing connection to the territory and is often shared at the beginning of meetings, events, or in written materials. While symbolic, a land acknowledgement serves as a reminder of the lasting impacts of colonization and the need for reconciliation.

Its importance lies in recognizing Indigenous rights, fostering education and awareness, and demonstrating respect for Indigenous communities. It aligns with reconciliation efforts, such as the Truth and Reconciliation Commission's Calls to Action, and encourages meaningful engagement.

VII. Glossary

Abbreviation	Term	Definition
[unabbreviated]	Bicycle urbanism maturity	The level of integration, infrastructure, policy, and culture supporting cycling as a mode of urban transportation.
AI	Artificial intelligence(s)	The simulation of human intelligence in machines, enabling them to perform tasks like learning, problem-solving, and decision-making.
AV	Autonomous Vehicle	A self-driving vehicle that can operate without human intervention using sensors, AI, and automation technologies.
AVL	Automated vehicle location	A technology used to track and monitor vehicle positions in real-time, often via GPS.
CAD	Canadian Dollar	The official currency of Canada.
COV	Conventionally operated vehicle	A vehicle that is controlled by a human driver; contrast with autonomous vehicle (AV).
CROW	Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek	A Dutch research institute that develops guidelines for infrastructure, including cycling facilities. The name is translated as 'Centre for Regulation and Research in Civil Engineering, Hydraulic Engineering, Road Construction and Traffic Engineering'.
CSV	Comma-separated values	A file format that stores tabular data using commas as delimiters between values.
DKK	Danish krone	The official currency of Denmark.
DOI	Diffusion of Innovations	A theory that explains how new ideas spread through society based on innovation characteristics, adopter types, and communication channels.
EN	English	A language spoken worldwide, primarily in countries such as the UK, USA, Canada, and Australia.
EU	European Union	A political and economic union of 27 European countries promoting integration, trade, and governance cooperation.
EV	Electric vehicle	A vehicle powered by electricity, typically using batteries instead of an internal combustion engine.
GDPR	General Data Protection Regulation	A European Union regulation that protects individuals' personal data and privacy.
GIS	Geographical Information Systems	Systems that capture, analyze, and visualise spatial or geographic data.
GPT	Generative pre-trained transformer	A type of LLM designed to generate coherent and contextually relevant text based on input prompts.
ICE	Internal combustion engine	An engine that generates power by burning fuel (e.g., gasoline or diesel) inside a combustion chamber.
IRR	Irrelevant	Something that is not related or applicable to the context in question.
LiU	University of Linköping	A Swedish university known for research and education in technology, science, and social sciences.

LLM	Large language model	A machine learning model trained on vast amounts of text data to understand and generate human-like language.
LTS	Level of Traffic stress	A classification system that assesses the safety and comfort of bicycle infrastructure based on factors like traffic speed and separation.
NACTO	National Association of City Transportation Officials	An organization that represents cities and transit agencies across North America focusing on improving urban transportation design and policy.
NOK	Norwegian krone	The official currency of Norway.
ORU	Other road users	Individuals or vehicles that share the road but are not classified as motor vehicles.
PBC	Perceived Behavioural Control	An individual's belief in their ability to perform a specific behaviour, influencing their likelihood of taking action.
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses	A set of guidelines designed to improve the reporting quality of systematic reviews and meta-analyses.
QGIS	Quantum Geographical Information Systems	An open-source GIS software for analyzing and mapping spatial data.
REV	Réseau express vélo	Montréal's high-quality network of bicycle focussed routes with separated infrastructure.
RR	Response rate	The proportion of respondents who complete a survey or study relative to the number of people invited.
SAE	Society of Automotive Engineers	A global professional organization that develops standards and advances engineering in mobility industries.
SEK	Swedish krona	The official currency of Sweden.
SPSS	Statistical Package for the Social Sciences	A software suite used for statistical analysis in social science research.
TAM	Technology Acceptance Model	A model that explains technology adoption based on users' perceived usefulness, perceived ease of use, and resulting attitudes toward the technology.
TPB	Theory of Planned Behaviour	A psychological theory explaining how attitudes, subjective norms, and perceived behavioural control influence intentions and behaviours.
VRU	Vulnerable Road User	Pedestrians, bicycle users, and other non-motorised road users who are at higher risk in traffic environments.

VIII. How to Read this Dissertation

This dissertation was written both as an original contribution to the field of urban geography/transportation planning to engage with academic discourse as well as to provide planning practitioners with empirics to inform policymaking. Given the dual academic and practical nature of this composition, as well as the diverse audience it intends to inform, a reader can engage with it on three levels.

Please note all cross-referenced items mentioned below are linked and can be selected for quick reference.

10-minute read

To gain a quick overview of the key takeaways of this project, read section 1.2 Research Questions, then read the conclusions of each empirical chapter in sections 5.7, 6.7, and 7.7 taking note of Figure 5.7.1 Hierarchy of bicycle user needs in AV environments, Table 6.7.1 AV/Bicycle User Readiness Recommendations, and Figure 7.7.1 Infrastructure preference factors.

45-minute read

Focus on sections 1.2 - 1.4 to understand the core context of the project, then read section 3.3 for theoretical framing. In each empirical chapter (Chapters 5 - 7) read the section about each research question, the discussion sections, and the conclusion sections. Finally, read the concluding chapter, Chapter 8.

5-hour read

The entire monograph gives a comprehensive overview into the context, theory, methods, and empirics of how the AVs will impact urban bicycle users based on data collected and interpreted from living lab sites in four cities.

IX. List of Figures

Figure 2.2.1 PRISMA screening process	47
Figure 2.5.1 The Web of Urban AI (Cugurullo et al., 2023, p. 11).....	71
Figure 3.3.1 Theoretical framework structure	87
Figure 4.2.1 Bicycle urbanism maturity scores (author's original)	93
Figure 4.2.2 Typical streetscape of autonomous shuttle in Aalborg living lab site (author's original)	95
Figure 4.2.3 Typical streetscape of autonomous shuttle in Linköping living lab site (author's original)	98
Figure 4.2.4 Typical streetscape of autonomous shuttle in Montréal living lab site (author's original)	100
Figure 4.2.5 Typical streetscape of autonomous shuttle in Stavanger living lab site (author's original)	104
Figure 4.3.1 Aalborg shuttle route and catchment addresses	118
Figure 4.3.2 Montréal shuttle route and catchment addresses	119
Figure 4.3.3 Linköping shuttle route and catchment addresses	119
Figure 4.3.4 Stavanger shuttle route and catchment addresses.....	120
Figure 4.3.5 Example of electronic study invitation in Stavanger (photo by Mikal Fuglestein)	121
Figure 4.5.1 Bicycle user classification question	133
Figure 5.5.1 Theme frequency in focus groups.....	154
Figure 5.5.2 Likert-scale response summary chart	169

Figure 5.5.3 Bicycle user classification summary chart	170
Figure 5.7.1 Hierarchy of bicycle user needs in AV environments	173
Figure 7.5.1 Photo of St-Denis Bicycle Infrastructure Example (Author's original)	232
Figure 7.5.2 General AV sentiment in open-ended survey responses	235
Figure 7.7.1 Infrastructure preference factors	247

X. List of Tables

Table 2.2.1 Preliminary Search Terms & Results (Jan 2021)	40
Table 2.3.1 Literature review summary table	55
Table 3.3.1 Levels of Traffic Stress (Furth et al., 2016).....	84
Table 4.2.1 Third party adjudicators	92
Table 4.2.2 AV/bicycle route sections in Linköping	99
Table 4.2.3 Criteria for Mixed Traffic at Linköping living lab site, adapted from (Mekuria et al., 2012, p. 21)	100
Table 4.2.4 AV/bicycle route sections in Montréal	101
Table 4.2.5 Criteria for Bike Lanes Alongside a Parking Lane at Montréal living lab site; adapted from (Mekuria et al., 2012, p. 18).....	103
Table 4.2.6 Criteria for Mixed Traffic at Montréal living lab site, adapted from (Mekuria et al., 2012, p. 21)	103
Table 4.2.7 AV/bicycle route sections in Stavanger.....	105
Table 4.2.8 Criteria for Bike Lanes Alongside a Parking Lane at Stavanger living lab site; adapted from (Mekuria et al., 2012, p. 18).....	106
Table 4.2.9 Criteria for Bike Lanes Not Alongside a Parking Lane at Stavanger living lab site; adapted from (Mekuria et al., 2012, p. 18).....	106
Table 4.2.10 Criteria for Mixed Traffic at Stavanger living lab site, adapted from (Mekuria et al., 2012, p. 21)	106
Table 4.3.1 Question and theory connections	114
Table 4.5.1 Education level equivalency table	129
Table 4.5.2 Income classifications	131

Table 5.4.1 Living-lab sites	148
Table 5.4.2 Data analysis and interpretation process	151
Table 5.4.3 Descriptive statistics of Likert-scale attitude and stress responses	153
Table 5.5.1 Likert-scale response summary	168
Table 6.4.1 Variable reliability and significance crosstabs (Author's original).....	181
Table 6.4.2 Trust and comfort variables for pairing.....	184
Table 6.4.3 Paired variable significance and test statistics	184
Table 6.5.1 Selected key demographics of study participants.....	186
Table 6.5.2 Parameter estimates for bicycle user classification and behaviour change ..	189
Table 6.5.3 Parameter estimates for general comfort and location	191
Table 6.5.4 Parameter estimates for general acceptability and site location.....	192
Table 6.5.5 Parameter estimates for shared infrastructure behaviour and site location.	193
Table 6.5.6 Parameter estimates for separate infrastructure behaviour and site location	194
Table 6.5.7 Parameter estimates for general acceptance and age classifications.....	197
Table 6.5.8 Parameter estimates for shared infrastructure behaviour change and age classifications	198
Table 6.5.9 Parameter estimates for shared infrastructure behaviour change and gender	201
Table 6.5.10 Parameter estimates for general acceptance and employment.....	203
Table 6.5.11 Parameter estimates for general comfort and ethnic origin.....	205
Table 6.5.12 Parameter estimates for general acceptability and income category	207

Table 6.5.13 Parameter estimates for separated infrastructure behaviour change and technology acceptance	209
Table 6.5.14 Trust pre- and post-interaction descriptive statistics	211
Table 6.7.1 AV/Bicycle User Readiness Recommendations	218
Table 7.4.1 Open-ended survey subject and prompts	224
Table 7.4.2 Infrastructure preference proxy variables	225
Table 7.5.1 Open-ended survey theme summary.....	226
Table 7.5.2 Participant descriptive statistics	237
Table 7.5.3 Comparison of r-values between AV/COV comfort Likert responses.....	239
Table 7.5.4 AV and COV comfort response mean values	240
Table 7.5.5 Correlations table	242

1. Situating Bicycle User Research in an Auto-dominant Transport System

A high-level introduction to the nature of urban bicycle use, its benefits, and challenges for society as AVs are introduced

*Bicycles are the indicator species of a healthy community,
like shellfish in a bay.*

—P. Martin Scott

(The more you see, the healthier the community)

1.1 Introduction

To truly understand what it is like to use a bicycle in a city, there is no better way than experiencing it firsthand. Urban environments are chaotic, noisy, and stressful. They inflict a symphony of stimulants on a bicycle user. Bicycle users are unshielded and fully experience the world around them with all of their senses. There are impacts of scale and place through urban morphologies that influence the use of bicycles in cities. At the most basic level, stimulants in the urban environment contribute to an individual's perceived level of comfort and safety. The decision to use a bicycle in a city is significantly influenced by a blend of these psychological stimulants with a primary importance being the perception of safety (Heinen et al., 2010; Whannell et al., 2012). This is further backed by a study by Cabral et al. (2018) where even the *perception* of safety was a sufficiently important factor in choosing to use a bicycle. The acceptable threshold for comfort and safety is individual and varies from person to person. The threshold can be raised or lowered depending on how transportation facilities are designed, the degree of space sharing with (dis)similar types of road users, and the ability to communicate and negotiate (Al-Taie et al., 2023; Berge et al., 2022; Cabral & Kim, 2020; Dill & McNeil, 2016).

Safety and comfort can be influenced by how a city is designed, its urban morphology, and what types of transportation are afforded space and priority. A city with wide streets, high

speed limits, and that treats bicycle users like vehicles fosters a prohibitively stressful and unsafe environment to ride a bicycle (Khayesi, 2020). Few bicycle users deem this type of environment to be an acceptable threshold for them to use a bicycle for their everyday means of transportation (Mekuria et al., 2012). Conversely, a city that has narrow streets, low speed limits, greenery, and affords bicycles smooth, separate, and protected bicycle lanes substantially lowers the barrier to cycling. Providing bicycle-oriented infrastructure that is cohesive, direct, safe, comfortable, and attractive increases the viability of cycling as a practical option for daily transport needs (Groot, 2016).

Overall, core to understanding the propensity of urban bicycle use are two basic elements: comfort and safety (Campos Ferreira et al., 2022). As described above, these are experienced differently and vary depending on factors such as tolerance to traffic stress (Furth et al., 2016), experience (Heinen et al., 2010; Winters et al., 2011), age (Dill & McNeil, 2013), and type of infrastructure (Groot, 2016). Current bicycle users are faced with a hostile, auto-oriented environment in most cities where their experiences are neither safe nor comfortable enough for a broad base of the population to choose a bicycle for their everyday transport needs (Cabral & Kim, 2020; Popan, 2020). Under the current situation, bicycle users can establish a minimum level of communication with drivers (Botello et al., 2019). This is important when verbal communication is not possible through glass windshields and when vehicles, already unequal in size, speed, and weight to a bicycle, continue to grow and subordinate other road users (Allam, 2024; Claus & Warlop, 2022; Transport & Environment, 2024). Increasing a bicycle user's sense of safety and comfort knowing that a driver sees them, acknowledges their presence, and allows them unimpeded passage is vital for bicycle users who already feel threatened in an unequal transportation system (De Ceunynck et al., 2022). Ushering in a future of Autonomous Vehicles (AVs) eliminates virtually all possibility of communication.

AVs are propagating a jarring departure from conventional transportation communication and negotiation between vulnerable road users and other vehicles (Pelikan, 2021). There is also a "wide and profound connection between AVs and the urban" (Cugurullo & Kassens-Noor, 2023, p. 70). This novel technology now exists in many cities around the world as private household vehicles, transportation network company (TNC) services, and as driverless buses (Boersma et al., 2018; Pelikan & Jung, 2023). As explained in Section

1.6, AVs could represent a forthcoming transportation evolution cycle that could tip the scales away from urban bicycle use which already hangs in a delicate balance. For an increasing number of people, these applications of AV technology are available to interact with on a daily basis. Driverless buses, the focus of this dissertation, have been deployed to provide a last-mile service on short, circuitous routes where other modes of transportation share the road. These driverless busses compete directly and share space with other forms of transportation, namely active transportation, such as walking and cycling. Noting that 60 percent new vehicles purchased by 2030 will likely have autonomous capabilities (Winton, 2022). There remains a notable degree of uncertainty in how this artificial intelligence (AI) will impact vulnerable road users (VRUs), such as bicycle users, who rely on communication and negotiation to travel safely among other road users, especially vehicles.

This introductory chapter provides an overview of some key concepts that contextualise the importance of the work carried out in this dissertation. First, in section 1.2 the three research questions that will be answered in the empirical chapters of the dissertation are outlined. Following, in section 0, the timeliness of engaging with AVs is outlined and linked to prevailing discourses. In section 1.4, the overarching purpose and intent of the dissertation is introduced through the approach of theory that is applied to address a research gap. Thereafter, in section 1.5, the scope and focus on a specific road user group (bicycle users) is highlighted and substantiated. Thereafter, in section 1.6 a high-level timeline of how the current transportation mode hierarchy came to exist and the position of bicycles in this structure is outlined. Following that, in Section 1.7 the System of Automobility is introduced and its concept is situated with AI-mediated transport systems and AVs including some of the challenges the status quo presents as well as some opportunities to shift auto-oriented dominance. Then, in Section 1.8, a summary of the complex and interconnected nature of transportation systems and the importance of framing this research with all the aforementioned concepts in mind is provided. A brief explanation of terminology is outlined in section 1.9. Finally, in Section 0, the structure of the remaining chapters of this dissertation and a brief overview of each chapter is outlined.

1.2 Research Questions

Three questions have been formulated and, as explained later in Section 3: Background & Theory, each one is carefully developed to gather data informed by theory. There are three major considerations that were made in designing the questions. Firstly, these research questions are designed to address challenges that exist in the form of barriers to cycling by integrating the behavioural and psychological components that contribute to intention and decision-making. They build on existing research by incorporating the novel variables to street dynamics that bicycle users will be faced with as AVs become more ubiquitous. Secondly, the questions are also formulated to directly address gaps in research related to *non-occupant* experience with AVs as well as research involving real-world AV operation where *non-occupants* can experience them firsthand in their daily lives in *uncontrolled* situations. Thirdly, the questions are each designed to solicit a constituent input of the Theory of Planned Behaviour (TPB) with augmented inputs from supporting theories as outlined in Section 3.3. These inputs and the rationale for designing each of the questions are discussed in Section 3.4.

The research questions which are core to the structure and empirical chapters contained herein are:

1. To what extent will the introduction of self-driving vehicles impact attitudes towards cycling in self-driving 'living labs'?
2. How is the introduction of self-driving pilots influencing cycling trips?
3. How can streets be designed to be conducive to cycling with self-driving vehicles, from a non-occupant perspective?

1.3 Autonomous Vehicles: Eventuality or Immediate concern?

“Autonomous vehicles (AVs) are coming” (Cugurullo & Kassens-Noor, 2023, p. 69)— it is expected that cars will remain part of mainstream mobility for the foreseeable future. However, sharing, autonomous driving, and electrification will all significantly impact the urban mobility sensory experience (Popan, 2020). During a period of transition to AVs, bicycle users are only one group of people that will be impacted by cities and societies managed by AI where the risks and benefits are uncertain (Cugurullo & Acheampong, 2023). In a similar way that automobility has impacted vulnerable modes due to fear and risk caused by traffic stress (Furth et al., 2016), the “risks and dangers connected to AI [and AVs are] something that we should not underestimate, but rather be afraid of” (Cugurullo & Acheampong, 2023, p. 2).

It will be important to acknowledge the broad transformative implications AI will have on our collective ability to communicate with AI-mediated mobilities unencumbered by the likes of human-machine interface (HMI) devices (Berge et al., 2022). While the simple presence of AVs stands to impact bicycle user wellbeing, a major component of this is an (in)ability to communicate in the analog sphere with humans (Pelikan & Jung, 2023). The findings from this PhD research contribute to a foundational level of understanding of the impacts that AI-mediated mobilities will have on urban bicycle use as embodied by everyday interactions with AVs that have little ability to communicate with bicycle users in similar ways to human drivers.

AVs are quickly maturing as a technology (Winton, 2022). They exist in different forms, use different technologies, and rely on a range of detection software (Ahmed et al., 2019a; Mahmoodi Nesheli et al., 2021). One of the most widely accepted classifications of AV technology is from the Society of Automotive Engineers (SAE). According to SAE, AVs can be classified in a zero to five capability matrix (Society of Automotive Engineers, 2018). On this matrix, level zero is no driving automation and level five is full driving automation. Levels three to five are sometimes referred to as ‘self-driving’. In some cases, ‘self-driving’ is only used to describe vehicles with capability levels four and five (Tabone et al., 2021). In the present study, the AVs that participants were exposed to were SAE level 2 or higher and operated at speeds of around 20-30 km/h and these fixed-route AVs form the empirical

focus. These operating speeds combined with the level of activity that these early examples of AVs are well suited for the neighbourhood scale.

This research focuses on the neighbourhood scale as the primary spatial unit for investigation. Increasingly, neighbourhoods are being developed or designated as experimental zones, commonly referred to as living labs, that enable the testing of smart city technologies in the context of everyday life, including interactions with AVs (Cugurullo et al., 2023; Dowling & McGuirk, 2022). These living labs exemplify a form of urban experimentation wherein “interactions of vehicles and technologies with urban infrastructures (streets, buildings, sensors, Wi-Fi), urban socio-natures (humans, animals, topographies, surfaces), and urban regulation (of driving, licensing, liability)” are trialed and observed (Dowling & McGuirk, 2022, p. 5). Importantly, this includes interactions with vulnerable road users such as cyclists, whose presence introduces complexity into otherwise vehicle-centric testbeds. This study pays particular attention to the lived experiences and perspectives of residents within these environments—individuals who engage with AVs not as abstract users but as everyday participants in an evolving mobility ecosystem. These living labs provide early, tangible examples of how urban mobility innovation policy is being shaped on the ground. However, they also risk reinforcing technocratic approaches that privilege vehicles and automated systems over more inclusive, multimodal transport futures (Behrendt, 2020).

While much existing research investigates a hypothetical future state with AVs, the research in this dissertation has identified current AV operations accessible by the general public. Most studies at the intersection of AVs and the built environment do not focus on cyclists and pedestrians (Botello et al., 2019). In response to this, the overall aim of this PhD research is to gain an understanding of how AVs will impact the physical realm and travel behaviour from the bicycle user’s perspective. This research acknowledges that the current state of AV technology is in a *transitional* phase (Cugurullo et al., 2021) between pre-implementation and mainstream adoption. Right now, in this transition, AVs are not widely deployed and currently exist in niche situations, which stands to change rapidly as permissions are granted and the technology matures. As this unfolds, there will be a further transitional phase where AVs and conventional vehicles will exist together, and eventually might form the majority. The timeline of this transition is unknown; however,

some scholars hypothesise it could be by 2040 (Cugurullo et al., 2021) or 2050 (Shaheen & Cohen, 2019). It will be important to pre-empt this transition to ensure that urban form does not allow AVs to dominate places that are meant for people in similar ways that mainstream car ownership did in the post-war era (Gartman, 2004; Urry, 2004). The prevailing socio-technical regimes stand to be uprooted, and it will be critical to have policies, frameworks, and design standards in place to regulate private operators of AVs to ensure the sustainability of human-scale urbanism.

Throughout this dissertation, AVs are described as ‘forthcoming’ and in a ‘transition period’ when AVs will coexist with conventionally operated vehicles (COVs) in acknowledgement current transport policy inertia. This is a deterministic view that is approached with a degree of skepticism. While many scholars address acceptance to some extent (usually after a period of exposure), this may imply that, in a techno-centric view, there is no valid opposing argument to the adoption of a technology. Instead of the technology being the problem, the problem is that of public uptake. In this frame of mind, the behaviour of society is seen as the problem, which is perhaps a misguided and prescriptive approach to adopting novel technology (Stilgoe & Cohen, 2021). In taking this view, society is seen as a barrier. In the case of AVs, their adoption may not be the most pressing problem but perhaps one of broader mobility justice. Mobility justice can be summarized as the phenomenon where equity-deprived groups who seek equitable access to mobility are subordinated to privileged classes and groups of the mobile elite (see Sheller, 2018) where the latter would have earlier and easier access to AVs, raising questions of urban transport equity.

It should be further acknowledged that auto-oriented determinism is somewhat problematic. The very concept of a ‘vulnerable road user’ accepts a degree of power imbalance and inequality where the idea of seamless movement is the overarching motive. The infrastructure, policies, and planning approaches that have birthed this concept are fundamentally rooted in car-centric planning that has systematically limited options for bicycle users and people walking. To this end, Khayesi (2020) explains how the road users themselves may not necessarily be vulnerable (re: car-inflicted injury and death), but that auto-oriented planning neglects the needs people walking and cycling thereby fabricating

their vulnerability through what Khayesi coins as “vulnerable transport planning” (2020, p. 1).

1.4 What This Dissertation is About: Blending theories to address a gap in research

Discourse in the realm of AVs, urbanism, and human behaviour tends to focus on occupant travel behaviour. An occupant is an individual who is inside an autonomous vehicle. At the time of this writing, non-occupants are more common than occupants and should be prioritised in research to better understand the behavioural and psychological impacts that AVs will inflict on them. While ‘non-occupants’ is a broad category, this dissertation focuses exclusively on bicycle users. There is an important distinction to make when considering those that will be impacted by the introduction of AVs. In a city, both occupants and non-occupants will interact with and be affected by the ubiquity of AVs in cities and on public streets. On the one hand, an *occupant* is an individual who uses an AV for transportation. Occupants are inside the envelope of an AV and experience the world similar to how an individual driving or riding in a conventionally-operated vehicle would— separated from their surroundings by metal and glass. On the other hand, a *non-occupant* is an individual who is external to the AV and may not have the perspective or understanding of an occupant. Non-occupants are unprotected and may be co-defined as vulnerable road users (VRUs); this group includes (but is not limited to) people walking and bicycle users.

All people, at one point or other, are non-occupants. An occupant will have experienced the perspective of a non-occupant either before or after using an AV. However, during this transition period when AVs coexist in a world with conventionally operated vehicles, non-occupants may not have experienced the occupant’s perspective. It is this non-occupant perspective that is important to gauge to understand how AVs will impact the safety and comfort of those who ride bicycles.

This dissertation aims to understand the impact that AVs will have on urban bicycle use through the study of driverless shuttle buses in living labs. Living labs are real-world environments that test new ideas and experiment with them in real-time. The living labs that are discussed in this dissertation are those that have residents living their everyday

lives and share their neighbourhoods with AVs as part of pilots or time-limited deployments meant to evaluate their feasibility and practicality. The living lab approach is intersected with a set of theories to design the research in a way that encompasses different types of traffic stress using traffic stress theories (detailed in Section 3.3.3) in the identified living lab sites outlined in Section 0, a wide range of bicycle user habits, safety tolerances, and comfort levels using a bicycle user classification theory outlined in Section 3.3.2, and aims to understand attitudes and behaviours of bicycle users informed by an augmented Theory of Planned Behaviour.

The data collection methods involved surveys, interviews, and focus groups with individuals who can ride a bicycle and interact with an AV in their daily lives. In so doing, the empirical approach and findings of this study aim to establish a baseline understanding of how a variety of classifications of bicycle users' behaviour (through perceptions of safety and comfort) under different traffic stress scenarios will be impacted by eventual increase in ubiquity of AVs.

1.5 Addressing the impact of AVs on a specific road-user group and defining the scope

The rapidly evolving space of AI-mediated transport systems, smart cities, and AVs is broad and potentially boundless, especially when the innumerable undiscovered impacts are factored into the forthcoming transport evolution. In keeping the project focussed, a few bounds were drawn to ensure that the work could remain manageable for a single researcher and to ensure that sufficient depth could be afforded to the subject matter in within the constraints of a PhD project. In writing this, however, the scope began broad and was narrowed to ensure that fieldwork could be completed, and that the quantity of data remained sufficient for sampling and the quality ensured that adequate findings and conclusions could be drawn.

In considering the above, the scope of the work in this dissertation is intentionally confined to the bounds set out in the research design to one research site per Level of Traffic Stress and to AVs that operate on fixed routes with predictable headways, automated vehicle location (AVL) and/or timetables which is further explained in Chapter 4: Methods. Free-

floating AVs, although a more progressed version of AV technology, is excluded from this study due to the complex nature of collecting information from a broad base of study participants in a large area. Given the constraints of the PhD timeline and budget, this was deemed to be out-of-scope. Fixed-route AVs allow for more regular (daily) interactions where study participants can develop a greater appreciation for AVs and speak more in-depth about their encounters. If a similar study were conducted under similar constraints with free-floating AVs at a time when their adoption rate is low, a useable dataset would not be practically attainable. The work in this PhD project establishes a baseline study that can be built on, adapted, or repeated as AVs become more common or an update is needed. This is expanded on in Section 8.10: Recommendations for Future Research.

Another important distinction to make is that of occupants and non-occupants. This study does not concern itself with the occupant perspective. This includes the behaviours, attitudes, and preferences of those who may use AVs as passengers. While (prospective) AV occupants are somewhat more extensively studied than non-occupants (Haboucha et al., 2017a; Keszey, 2020; Saeed et al., 2020), the scope creep that examining this population subset is deemed out-of-scope for the work contained in this dissertation.

1.6 Transport Subordination Cycles

Cities are places that experience frequent and rapid change. The urban transportation sector is no stranger to this phenomenon. Historically, changes to urban transportation have been cyclical and ushered in systematic subordination of incumbent transportation methods to make way, often exclusively, for novel transport methods (Cugurullo et al., 2021). Broadly speaking, this cyclical subordination of previous-generation transport methods can be observed as cities have evolved. As described by Cugurullo et al. (2021), the cycles of subordination arose in three evolutionary approaches of city and state politics through the baroque, modernist, and contemporary periods. The often-overlooked political context in which each of the eras was predicated influenced how certain transport modes were prioritised and how others were subordinated (Cugurullo et al., 2021).

For example, in the Baroque city, during the seventeenth century, pedestrians were deemed subordinate to the stagecoach as advanced by aristocratic politics. This first wave

of subordination negated the impact to the pedestrian realm and the negative impacts to this group of road users' comfort and safety. In the Modernist city, the car dominated public rights-of-way and remains superordinate over all other modes of transportation (Cugurullo et al., 2021; Hall, 2014). There has also been extensive documentation in academic literature demonstrating that "vehicles, historically, regardless of who (or what) is driving them, have been intrinsically connected to the governance, planning and design of cities" (Cugurullo & Kassens-Noor, 2023, p. 80). Borenstein et al. (2020) highlight the divide between novel and previous-generation transportation methods through a debate between 'occupant' and 'non-occupant' safety where 'occupants' are the future users of AVs and 'non-occupants' are those that interact with AVs as other road users.

Bicycles have fallen victim to cyclical subordination. Bicycle travel behaviour is influenced by sense of comfort and safety that depends on the infrastructure extended to them, e.g. a grade-separated cycle track is preferential to a painted bike symbol on a busy street (Cabral & Kim, 2020; Caulfield et al., 2012; Dill & McNeil, 2013; Garrard et al., 2008). Compromising safety and comfort dissuades individuals from cycling (Pucher & Buehler, 2008). Furthermore, by placing vulnerable transport methods such as cycling (non-occupant) in the same arena as AI-mediated (occupant) AVs, perhaps at odds with each other, it hampers the benefits that cycling yields on a population-level. As AVs become more diffuse, similar subordinations appear likely to recur in the contemporary city potentially to the detriment of other modes of urban transport.

Cycling is not the only transport mode that stands to be impacted by AI-mediated transport systems. In many ways, other vulnerable road users (VRUs) such as pedestrians and micro-mobility users (skateboards, roller skates, and wheelchairs) will experience many of the same impacts that cycling will. However, they further stand to be impacted as AI-mediated transport systems encroach on sidewalks as demonstrated by the proliferation of adjacent applications such as dockless e-scooters and sidewalk delivery vehicles. Public transport, also subject to historical subjugation, stands to be similarly impacted. In direct competition to transit, *shared* autonomous vehicles (SAVs) may be able to offer a greater value proposition (McCarroll & Cugurullo, 2022). Instead of each AV being privately owned, SAVs are either collectively owned or deployed via sharing services such as ride hailing companies, public transport operators, or transportation network companies (TNCs). If

implemented, foresight analyses indicate that it would lead to a net decrease in private car ownership thereby reducing the number of cars in cities (McCarroll & Cugurullo, 2022). This is corroborated in findings by many other scholars (Fagnant & Kockelman, 2014; Firnkorn & Müller, 2015; Haboucha et al., 2017b; Iacobucci et al., 2018). A city with fewer cars is safer city for VRUs and creates more space for people.

Cugurullo et al. (2021) explain that this presents a unique window of opportunity to repurpose some 80% of space in cities that is currently reserved for cars. Taken together, there are many different transportation modes that stand to be disruptors or disrupted. (S)AVs present a generational opportunity to redefine cityscapes. Automobility has demonstrated its ability to shape cities for a single mode of transportation that is unsuitable for many urban trips and contributes many negative externalities. Urban space and infrastructure priorities can be realigned for the provision of green space, additional housing, pedestrian plazas, active transportation, and urban agriculture, for example.

1.7 The Established Dominance of Automobility

Societal behaviours and preferences have resulted in the current transportation system that can be described as the 'System of Automobility' (Urry, 2004). Automobility has created a ubiquitous sphere of influence over the collective psyche that promotes auto use to the maximum extent possible. This sphere of influence may cause individuals who own a car to misconstrue distances and perceive the city to be less proximal than those who choose active modes (Briggs, 1973; Horn, 2022; Lowrey, 1973). This is demonstrably the case in cities where built forms are generally compact and conducive to walking and riding a bike, however, most short trips are taken by car— for trips between 1-5 miles 68% in the United Kingdom and 64% in the United States were driven (UK Department for Transport, 2019; US Bureau of Transportation Statistics, 2022). It can be argued that automobility is a product of policies that appeased behaviours and preferences without considering the full downstream effects. The effects of automobility are widely understood to negatively impact health (Ding et al., 2014), the environment (Canals Casals et al., 2016), and efficiency of transportation networks causing traffic congestion (Hanna et al., 2017; Hensher & Puckett, 2007). Noting that urban bicycle use can serve as a tool to address

these negative effects of automobility, there is a strong case to better understand the impacts of AI-mediated transport systems in the form of AVs on bicycle users.

By acknowledging the benefits that bicycles have on many aspects of urban live and transport systems, it is important to understand that street dynamics for bicycle users are predicated on prevailing dominant modes of transportation that subordinate other transport modes (Gaio & Cugurullo, 2023). Bicycle users are largely thrust into a world of automobility (Urry, 2004) and are expected to behave like vehicles when the visceral cycling experience is incompatible with this expectation (Green et al., 2012; Popan, 2020). Riding a bicycle must be understood as a multisensory experience which contrasts the fragmented perception that automobility affords through “windcreens, visor helmets, and mirrors” (Popan, 2020, p. 293). This idea of fragmentation is also discussed as “alienation” (Nixon, 2014). In contrast to automobility, bicycle users are vulnerable, exposed, and acutely alert of their surroundings (Popan, 2020). Given the differing sensory experiences and the power imbalance between bicycles and automobiles, despite the former having the conditions of the latter imposed on it, “[decisionmakers] must eliminate regulatory discourse that frames the modes as equal, and instead acknowledge differences and current inequalities” (Nixon, 2014, p. 100). The research in this dissertation further aims to engage with broader bicycle user-automobility theory to integrate the findings discussed in discourse through the lens of the forthcoming AV transition period.

Automobility is detached from its surroundings and discounts the hostile environment it has created to the detriment of all other mobilities. De Cauter describes that much of the modern world uses “transport capsules from one enclave or capsule (home, for example), to another (campus, office, airport, all-in hotel, shopping mall and so on)” (2004, pp. 45–46) and synonyms that corroborate this idea of encapsulated mobility are common in literature (Nixon, 2014). If automobility estranges occupants and desensitises them from the “spaces and beings” (Nixon, 2014, p. 92) they impact, thereby leading them to discount the welfare of others, then advancing AV mobility without regard for non-occupants would be a catastrophic misstep (Burns & Brown, 2006; Hoffman et al., 1996; Nixon, 2014).

It is expected that cars will remain part of mainstream mobility for the foreseeable future, however, sharing, autonomous driving, and electrification will all significantly impact the

urban mobility sensory experience (Popan, 2020). During a period of transition to AVs, bicycle users are only one group of people that will be impacted by cities and societies managed by AI where the implications are undetermined (Cugurullo & Acheampong, 2023). In a similar way that automobility has impacted vulnerable modes due to fear and risk caused by traffic stress (Furth et al., 2016), the “risks and dangers connected to AI [and AVs are] something that we should not underestimate, but rather be afraid of” (Cugurullo & Acheampong, 2023, p. 2). This fear is based on the broad transformative implications AI will have on our collective mobilities given the historical track record of dominant vehicular mobility. The empirical findings arising from the work contained herein contribute to a foundational level of understanding of the impacts that AI-mediated mobilities will have on urban bicycle use.

1.8 The Intricate Balance of Mobility Systems

It is important, and perhaps exigent, to frame this work around the deeply complex and interconnected sphere of urban mobility, its challenges in power dynamics and negative externalities, as well as recognising the opportunities that shifting transportation mode hierarchies can have. AI-mediated transport systems in the form of AVs will impact transportation ‘ecosystems’ in urban regions. Bicycles will be implicated and so will the people that ride them— which are an essential component of solutioning systematic urban transportation and sustainability challenges. These vulnerable road users hang in a delicate balance and deserve the attention and foresight to understand how AVs and AI-mediated transport systems will disrupt their communication and interaction tactics and, by extension, their comfort and safety. Urban transportation opportunities, which bicycles present, have wide-reaching effects on health through active transportation that promotes regular physical activity, a reduction in carbon emissions and particulate matter, and increased transport system capacity through space-efficient and task-appropriate transport modes.

1.9 Terminology

Throughout this dissertation, the terms ‘cycling’ and ‘cyclist’ are used sparingly beyond the abstract. While these terms are generally accepted and used to describe bicycle users,

these terms can be problematic and polarising. Furthermore, they can also exclude a subset of individuals who do not feel they fit the description of 'cyclist'. In a pilot study by Delbosc et al., it was found that around half of those that do not identify as a cyclist view cyclists as "less than 100% 'human'" (2019, p. 7) which was also attributed to greater aggression towards cyclists. Advocacy groups have also employed similar syntax changes with positive results that prevent discourse derailment about safe, low-stress streets. Instead of using language that describe streets as spaces where different forms of transportation "jockey for space" (np) (i.e. driver, cyclist, pedestrian) from the "windshield perspective" (np), there is more value in framing all users of the street as people and describing them as such (i.e. person on a bike, person driving) (Fucoloro, 2015). As a compromise, this dissertation refers to cyclists as 'bicycle users' to reduce the dehumanizing subconscious response as described by Delbosc et al. (2019).

Additionally, the use of the term 'cyclist' may also exclude individuals who do not identify themselves as belonging to a group of people who label themselves as such. Lois et al. (2015) point to how association with a social group "could increase the frequency of bicycle use, or lead to individuals becoming involved in activities stereotypically associated with urban cyclists in the broader sense" (p. 102). In being part of a social group, individuals may develop positive attitudes towards cycling which, in turn, contributes to a greater likelihood to ride a bicycle. Mannetti et al. (2004) expand on this social group association phenomenon by linking it with earlier concepts of self-identity and role-identity variables. In describing a group of people who use bicycles as 'cyclists' many people who do not self-identify with this moniker may feel alienated and dissociate from using a bicycle (or from participating in the present study) because this label-association does not match with their self-identity, despite them knowing to how to ride a bicycle. In many cases, these individuals can be classified into the 'interested but concerned' category of bicycle users who may not identify as 'cyclists' but are interested in cycling more and remain apprehensive because of their perceived comfort and safety.

The following section outlines how this dissertation is structured and how these complexities will be unravelled and interrogated through a blended theoretical frame using established and novel theories. Given the complex and nuanced nature of the experimental design, they will explain the methodological approach of applying theory to

a representative sample of living labs where AVs are present together with bicycle users. The results of which will shed a preliminary overview of the visceral cycling experience in a future with AI-mediated transport systems and lay a foundation for further study to expand this baseline knowledge.

1.10 Structure and Format

This dissertation is broken into eight chapters. In this first chapter, the project is introduced by outlining its broader societal importance and contextualizing the challenges that this research aims to address. In chapter two, a comprehensive literature review explains the current discourse surrounding AV and bicycle user interaction and offers insights into where this dissertation aims to contribute by closing research gaps. Chapter three frames the research by outlining and discussing several interconnected theoretical frameworks that have led to the creation of three research questions. In chapter four, the methodological approach to studying AVs in four ‘living labs’, including the rationale for site selection, is explained in detail. Chapter five deals specifically with research question 1 looking at attitudes of living lab bicycle users towards AV. Chapter six focuses on research question 2 taking a closer look into the impact that AVs will have on cycling trips and behaviour. In chapter seven, the results from research question 3 that deals with the influence of AVs on cycling infrastructure preferences is presented discussed. Finally, in chapter eight, overall research conclusions for each research question, policy implications, adapted theories, and recommendations for future research are discussed.

2. A Systematic Overview of AV and Bicycle User Discourse

A review of the literature that inspired this project and how it aims to close gaps in knowledge

“Driverless cars are often called autonomous vehicles – but driving isn’t an autonomous activity. It’s a co-operative social activity, in which part of the job of whoever’s behind the wheel is to communicate with others on the road.”

—Rebecca Solnit

2.1 Introduction

Previously, the systems and the context for studying bicycle users were explained and how they exist in an auto dominant transport system. Comfort and safety in this transport system are major overarching aspects to the propensity of urban bicycle use. By acknowledging the systems and external forces at play, it is important to determine to what extent these systems (system of automobility) and forces (subordination cycles, balance of mobility systems) have been engaged with and how the novel factor of AVs will implicate bicycle users. At present, AI is rapidly developing and being experimented with, often with few clear real-world and tangible manifestations that are available to the general public. “AI is now one of the dominant forces that is transforming our planet and lives, yet its meaning and manifestations are elusive” (Cugurullo et al., 2023, p. 3). It is primarily available to the general public in the *digital* (virtual) sphere as generative AI models in chat interfaces. As discussed in this chapter, early AI-mediated transport experiments with VRUs have been conducted in virtual settings which, while a useful early proxy for understanding the impact of AVs on urban bicycle use, does not elicit the same response as someone immersed in an environment where they interact with an AI-piloted AV. However elusive AI may be, AVs represent a unique, tangible manifestation of how AI will manipulate the physical urban realm (Cugurullo et al., 2021) and how it will impact behaviour through psychology (Berge et al., 2022).

In conducting this systematic review of discourse, this chapter highlights the current approaches that have been carried out, what some of these pertinent findings were (including where they agree or disagree), where they have identified weaknesses, and how when taken together create a strong case for the living lab approach that is advanced as part of this study. In this chapter, the process, search terms, discourse, and relevant adjacent subject matter that has influenced this research are also explained and discussed. This doctoral research blends transportation planning and travel behaviour research in a time when AVs are becoming more ubiquitous and AI, once an abstract concept, is manifesting itself in the physical urban realm in the form of AVs. This approach through the lens of bicycle urbanism, behavioural psychology, urban geography, and mobility justice from the perspective of a bicycle user as further detailed in Chapter 3.

This chapter is extensive and is structured in a way to provide a sufficiently comprehensive overview of the literature while connecting in relevant contextual information to support and add detail to the literature that was part of the systematic review (see sections 2.2.3 to 0). The chapter is set up, firstly, explaining the systematic literature review approach (2.2). Next, in section 2.3, there is a discussion of several interconnected key concepts that arise in the systematically identified literature and draws on additional relevant material to strengthen engagement with broader discourse. In this section, the themes are further structured into umbrella categories (2.3.3) drawing on previous studies that have made similar categorizations which will be useful for interpreting results in the empirical chapters. Finally, in sections 2.4 to 2.5, relevant adjacent subject-matter is explained, the connection to urban geographical concepts of participatory urbanism, human-scale urbanism, bicycle urbanism, and AI urbanism.

2.2 Systematic Literature Review

2.2.1 Underpinning Literature Review Research Questions

The core principle of this review was to understand the current discourse surrounding AV and bicycle user interaction, distinctly, from the perspective of the bicycle user. To achieve this, the systematic literature review implicitly sought to answer the following questions:

1. What current approaches have been carried out regarding AV and bicycle user interaction?
2. What are the pertinent findings from existing research including areas where they agree or disagree?
3. Where have weaknesses been identified in the existing discourse?
4. How do these findings and identified weaknesses create a strong case for the methodological approach used in this study?
5. What are the significant research gaps related to non-occupant experience with AVs, particularly concerning real-world AV operation in uncontrolled situations?

The systematic review process outlined in the following sections, including preliminary scans and updated searches, aimed to gain a current and complete picture of this discursive landscape. The identified research gaps, discussed in greater detail in section 2.6, highlighted the need for more real-world studies, specific attention to public perception (attitudes, trust, and safety concerns), more representative and diverse sample sizes, and longitudinal studies to track changes over time.

2.2.2 Preliminary Literature Review(s)

During this doctoral research, an ongoing literature review was completed to gauge the extent and breadth of discourse related to AVs and Bicycle Urbanism. The first review was completed in January 2021 to establish a baseline and provide a general direction for crafting research design. Although primarily used as a high-level scoping exercise, this preliminary review has been built upon throughout the duration of this research project. It is important to acknowledge this first review fundamentally shaped the project. The initial literature review was updated in October 2023 to form the basis of what is described below, including with a refined set of search terms, to gain a more current and complete picture of the discursive landscape surrounding this project's subject-matter.

Table 2.2.1 Preliminary Search Terms & Results (Jan 2021)

No.	Term	Scopus	Relevant
1	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND "safety"	88	29
2	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND "perception*"	36	7
3	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND "opinion*"	3	1
7	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND "preference*"	5	3
7	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND "stated preference"	2	2
4	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND "communication*"	33	4
5	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND ("detection" OR "detect")	74	
6	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND "infrastructure"	30	
7	("autonomous car" OR "autonomous vehicle" OR "self driving car") AND ("artificial intelligence" OR "AI") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle")	10	7

2.2.3 Search Terms

Following the initial scan in the preliminary literature review the outputs were used to refine the search for the full literature review. The word 'detection' and its derivatives were removed to narrow the scope of the search. The query was also combined into a single search term as follows:

("autonomous car" OR "autonomous vehicle" OR "self driving car" OR "AV") AND ("cycling" OR "cyclist" OR "bike" OR "bicycle") AND ("safety" OR "perception" OR "opinion*" OR "preference*" OR "stated preference" OR "communication*" OR "infrastructure" OR "artificial intelligence" OR "AI" OR "attitude*" OR "behaviour")*

This search query was used to perform searches in Scopus and Web of Science. The above preliminary search was conducted on January 26, 2021 and was updated on November 7, 2023. In the updated search, similar search terms were used to search Google Scholar with a reference search software tool called Publish or Perish (Harzing, 2007) to identify relevant potential preprint publications and grey literature. Google Scholar was limited to the first 200 relevant results. The search terms were then filtered using a set of inclusion criteria and a structured review process outlined in the next section.

2.2.4 Inclusion Criteria & Process

A set of inclusion criteria were established for the complete literature review. These criteria were created to constrain scope, alignment with research questions, maintain academic rigour (Snyder, 2019), and ensure that a consistent definition of AV was applied (Hopkins & Schwanen, 2021; J. Wang et al., 2020).

For a publication to be included in the literature review, it must satisfy the below criteria:

- Must be a peer-reviewed academic publication or authoritative grey literature source
- Must discuss bicycle users as a *distinct* group of VRUs
- Must describe the study as involving a bicycle user (i.e. 'cyclist') and an AV (or mock AV)¹ with a capability higher than SAE level 2
- Must concern the perspective of the bicycle user
- Where scenarios are concerned, these must not be virtual simulations (i.e. study was conducted in a real-world environment)

Publications were reviewed in a multi-step process as follows:

1. Reviewing the title and abstract of the publication for compliance with the above inclusion criteria. If the inclusion criteria were satisfied, the publication advanced to the next step. 669 publications did not satisfy the inclusion criteria.
2. The publication's full text was then reviewed in its entirety. 57 publications were included in this stage and 4 publications were excluded for one or more of the following reasons.
 - a. Inaccessible (n= 1)
 - b. Not full publication (abstract only) (n= 1)
 - c. Patent (n= 1)
 - d. Author's own work (n= 1)

53 publications were reviewed in their entirety. At this stage, 13 publications were removed because they did not discuss bicycle users as a distinct group of VRUs and 26 publications were removed because there was no AV present in the study. 14 publications were included in the final review and are summarised in Table 2.3.1.

¹ A mock AV is a stand-in 'autonomous vehicle' that, for the purpose of the study, is being driven by a human and may include physical design features on the outside of the vehicle and/or disguises the driver to make the vehicle seem like an AV from the perspective of study participants.

Literature was reviewed and categorized into nine themes to better understand what discourse exists, the methods employed, and the gaps identified. The themes identified (listed here by alphabetical order) are altruism, behaviour, comfort, negotiation, safety, separated infrastructure, subordination, and trust. Some publications raised more than one theme which resulted in the numbers below adding to more than the total number of articles (14) included in the review.

Publications that were categorised into the altruism theme (n= 2) engaged with hierarchical structures in the transportation system and how the needs of other road users added nuance to this hierarchy. This was particularly prevalent with authors that drew on perspectives from more than one mode of transportation such as those who ride a bicycle sometimes and drive a car in other instances. Nixon (2014, p. 97) explains that that individuals “who used more than one mode inferred or explicated a potential ‘remedy’ for the negative social impacts and alienation associated with the intensive mobility technologies” such as AVs, in this case. The types of AVs that this study engages with are quite sensitive and were observed to have exaggerated reactions that were more abrupt than what a human-operated vehicle would expectedly demonstrate. The altruism theme discussed in literature broadly pertains to the concern that other road users have for other road users and is discussed in further detail in section 2.3.6 under the *experiential* umbrella theme.

Secondly, literature that was classified into the behaviour theme (n=6) was identified when authors engaged with bicycle user behaviour. This was broadly defined when an AV would influence the behaviour of other road users, particularly bicycle users. The studies identified in the systematic review examined how bicycle users adapt their behaviour when interacting with AVs compared to when they interact with conventionally operated vehicles. Situations that arose in the literature are behaviour changes related to speed and distance, uncertainty/hesitation, and the disruption of bicycle user mobility. These situations are expanded on in section 2.3.6 under the *experiential* umbrella theme.

Next, the comfort theme (n=1) explores how this theme relates to situations where bicycle users share street space with AVs. In the systematically identified literature, bicycle users report feeling uncomfortable due to unpredictability and a lack of trust in AVs. However,

literature also acknowledges potential variation in comfort levels, with some bicycle users expressing fear due to unfamiliarity with the technology, while others might have a higher understanding and potentially less discomfort. This is expanded further with direct references in section 2.3.6 under the *experiential* umbrella theme.

The fourth theme, negotiation (n=7), was used to classify literature that discussed and empirically assessed the act of AVs and bicycle users needing to interpret, predict, and understand each other's actions in mixed traffic or controlled environments. This theme also includes communication between road users and the umbrella situations that a bicycle user would need to establish confirmatory interaction (i.e. eye contact, gestures) with a vehicle operated by a human. Several areas of future work were identified related to the theme of negotiation. Al-Taie et al. (2023) highlight the need for observing scenarios with different settings for assessing different variables that could impact negotiation with AVs. Given the complexity of traffic negotiation, there was also a strong voice highlighting that more real-world studies are needed with AVs and bicycle users (Boersma et al., 2018; De Ceunynck et al., 2022; Pelikan, 2021) and specifically in other countries and/or regions (Al-Taie et al., 2023; De Ceunynck et al., 2022). The negotiation theme is expanded on in section 2.3.5 under the *environmental* umbrella theme.

Fifth, where a study dealt with aspects relating to safety (n=3) such as safety perception, it was classified under the safety theme. Due to issues with language semantics between living lab sites that were used in the empirical section of the present study, the safety theme also encompasses papers that deal with comfort. More detail pertaining to this 'comfort' and 'safety' grouping is available in Section 4.3.1.2. The safety theme is expanded on, including with direct reference to the literature, in section 2.3.6 as part of the *experiential* umbrella theme.

Sixth, studies that involve roadway infrastructure design and the degree of separation between AVs and bicycle users were classified into the theme of separated infrastructure (n=3). Where a study's interpreted primary purpose or major finding fit this description it was assigned this thematic category. Literature identified as part of this theme explores contrasting views on how bicycle users and AVs should share the road. Some authors believe AV technology will improve safety and allow for more integrated use of existing

infrastructure. Studies that included experienced cyclists as participants supported this view, suggesting that increased perceived safety was co-determinant with AV exposure. Not all cyclists are comfortable with current traffic conditions, and relying solely on exposure might exclude them from feeling safe. Some studies address this theme as a sub-theme; three studies were deemed to be categorised under this theme as their primary theme and is more fulsomely discussed in section 2.3.5 as part of the *environmental* umbrella theme.

The seventh theme in literature is subordination (n=1). This theme explores the concept of cyclists being subordinate to AVs. While the term *subordination* is not explicitly used, bicycle users are described as unpredictable or disruptive to the current traffic system dominated by cars. Authors highlight how AV manufacturers express concerns that plainly communicating AV operation modes might encourage bicycle users to exploit predictable AV behaviour. This perspective cements the existing power dynamic where cars hold dominance over bicycle users and other VRUs. This theme is expanded on further in section 2.3.6 in the *experiential* umbrella theme.

Eighth, when a study presents concepts that deal with blended AV and conventional vehicle traffic when interacting with bicycle users, they were grouped under the theme of transition period (n=2). A transition period can be broadly referred to as the stage of AV adoption where both conventionally operated vehicles and AVs co-exist on public roadways. While there remain many unknowns, these studies have analyzed empirical data from bicycle users that have interacted with AVs to present a comparative analysis of both types of vehicles and the implications for road user interaction. Al-Taie et al. (2023) frame this as part of their problem statement in writing that they position themselves among researchers that recognise the need for “AVs to compensate for the disappearance of human drivers” and note that “AV-cyclist interaction remains largely unexplored” (p. 3). They also conclude by reflecting on interactions observed in their real-world study of diverse scenarios that AVs’ differing “implicit cues to human drivers would disrupt the current traffic paradigm and other road users’ expectations” (p. 15) in a transition period. Others write that, despite these changes and unknowns, as more AVs begin to operate and share the road with bicycle users, they are more likely “to believe that AVs will reduce

traffic injuries and fatalities” (Imanishimwe & Kumar, 2023, p. 8). This theme is further elaborated on in section 2.3.5 as part of the *environmental* umbrella theme.

Finally, the theme of trust (n= 6) has been predominantly studied together with acceptance applying “‘Unified theory of acceptance and use of technology’ or the ‘Technology Acceptance Model’” (De Ceunynck et al., 2022, p. 3). Framing AVs as something to be accepted could be problematic as outlined in section 2.4.1 and intentionally focus on trust independently. Most authors engage with the theme of trust by explaining a certain behaviour that is exhibited by the AV. Oskina et al. (2023) found that “the factors having most influence on the cyclists’ trust levels are the vehicle’s speed and distance” (p. 1147). This supports one of the first concepts raised in the Section 1.1 around how speed influences comfort and safety. Others cite an inability to predict AV behaviour as a reason for feeling uncomfortable or unsafe (Rahman et al., 2021). Furthermore, another area impacting trust is the individual attributes of a bicycle user such as experience level, age group, and AV familiarity (Rahman et al., 2021). Pokorny et al. (2021) describe situations where the AV shuttle and bicycle user yielded to one another or came to a complete stop in what they describe as a “stalemate situation” (p. 8) which may suggest that there is a “lack of trust from the perspective of the cyclists, possibly because of experiences with the shuttles” (De Ceunynck et al., 2022, p. 16). Trust is engaged with further in section 2.3.6 under the *experiential* umbrella theme.

2.2.5 Results

The PRISMA method was used to conduct this systematic literature review (Page et al., 2021). In line with the PRISMA method, a flowchart outlining the number of publications and the review process is outlined in Figure 2.2.1.

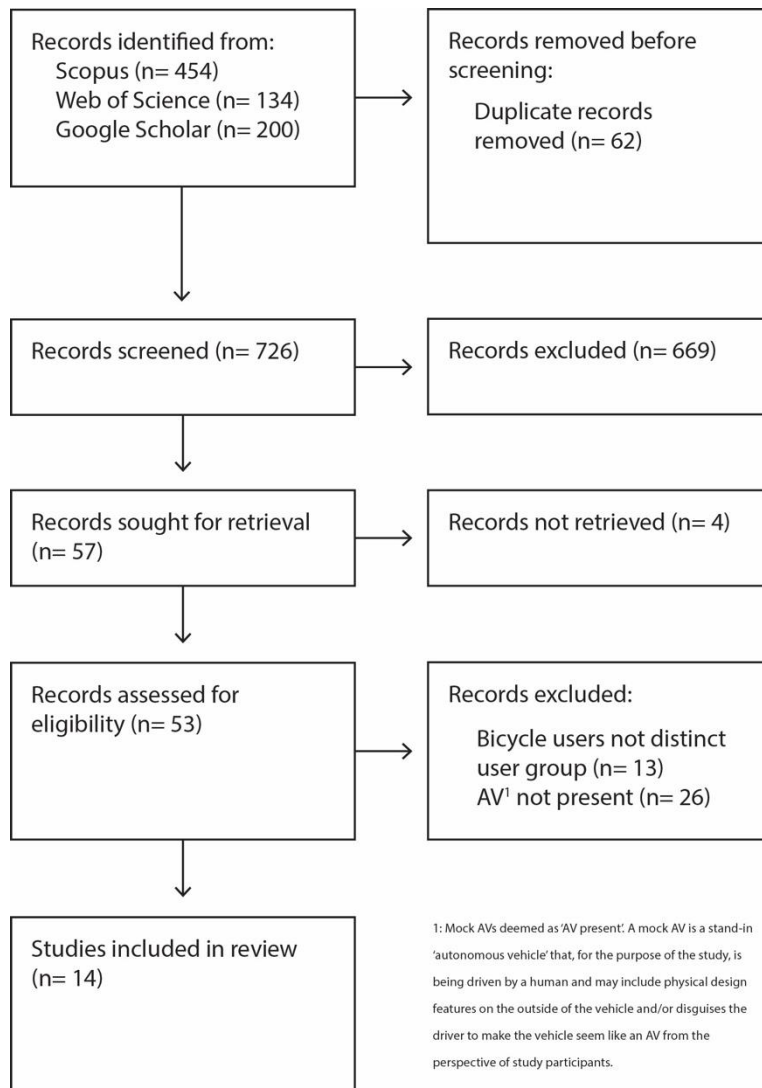


Figure 2.2.1 PRISMA screening process

The principle of this review is to understand the current discourse surrounding AV-bicycle user interaction from the perspective of the bicycle user. Literature that has a primary premise of describing detection, computer vision, algorithmic computations, or similar areas of research from a technological standpoint is not included in the scope of this review.

2.3 Discussion

2.3.1 Vulnerable Road Users and Vulnerable Transport Planning

Many studies identified in this literature review use the umbrella term of ‘vulnerable road users’ (VRUs) to group pedestrians and bicycle users together when describing the impact of AVs on other road users. As previously highlighted in section 0, auto-oriented determinism is somewhat problematic. This perspective of “vulnerable transport planning” (p. 1) that *creates* road user vulnerability as a product of systemic car-centric planning (Khayesi, 2020) should be re-emphasised. In saying this, however, the VRU is commonly referred to in literature and is a regularly used concept used to describe these types of equity-deserving transport users.

In the most basic terms, a road user is anyone that is using the public right-of-way designated for transportation. In urban areas, this is usually what lies between property lines on opposing sides of the street and in denser settings is the area between building facades that includes (but is not limited to) sidewalks, street trees, curbs, lighting, parking lanes, bike lanes, and driving lanes.

VRU is a term that is used to describe the most at-risk participants in traffic. These participants are not protected by an external shield and make up a significant proportion of road traffic deaths in many countries. Pedestrians, bicycle users, motorcycle users, are accordingly categorised as VRUs because they fit this description and do not benefit from any protective device that would absorb the kinetic energy in a crash. While these are broad VRU categories, many attributes such as the presence of a stroller, wheelchair, or walker would create unique needs and behaviours that cannot be generalised when attempting to research the impact of AVs on a particular subset of road users. In almost all cases, a VRU would be adversely impacted as the weaker participant in a collision (Constant & Lagarde, 2010).

Generalised study of VRUs and AVs will result in unspecific findings that will not address many of the core needs of subsets of VRUs. The safety and comfort of each participant in traffic varies depending on factors such as their speed, proximity to other vehicles, age, level of experience, and surrounding mobility culture. For example, an individual using a

wheelchair or walker may require a two-stage crossing and infrastructure such as ramp curb cuts with refuge islands in the middle of the street to allow for extra time to cross. Conversely, a bicycle user may prefer a shorter, more direct route with fewer interruptions as well as level ground to improve comfort and reduce starting and stopping (the latter of which many people find difficult to do, particularly on high-stress urban streets). In this sense, by applying a general approach, while attempting to address the needs and concerns of all VRUs, none of the highest priority concerns facing each subset of VRU are addressed.

At a minimum, VRUs should be classified as bicycle users and pedestrians. If this minimum distinction threshold is not made, it negates the different behaviour and infrastructure needs of these two distinct groups and diminishes the value of any findings. Within these two VRU groups, there are several factors that further impact the diverse subset needs that can be attributed to each group. In addition to the previously mentioned attributes, variables such as age and physical fitness all impact a pedestrian's speed, infrastructure needs, route choice, and communication for example. All of these variables apply to bicycle users in a way that is different from pedestrians but can be further expanded to include bicycle user variables such as level of confidence, and bicycle type. While this description is not meant to be exhaustive, it is important to recognise that bicycle users play an important role in the transportation system and must be afforded a level of attention instead of being grouped in with other VRUs. In doing so, grouping all VRUs does a disservice to all VRUs because findings cannot be generalised and the needs of each group cannot be adequately considered. In a similar vein, classifying road users more generally into vehicular and non-vehicular is also a useful distinction for the work in this dissertation when dealing with AVs and VRUs (respectively). A proposed way of distinguishing these groups follows in the next section.

2.3.2 Occupants and Non-occupants: Bicycle Users in Focus

Discourse in the space of AV research has focussed primarily on occupant travel behaviour (Bazilinskyy et al., 2015; Deb et al., 2017; Kassens-Noor et al., 2020; Kyriakidis et al., 2015; Li et al., 2023; Nordhoff et al., 2019; Pelikan, 2021; Rahimi et al., 2020). Occupants experience mobility entirely differently from VRUs. Other research broadly addresses the

opinions and preferences (Cugurullo et al., 2021), or the moral challenges around AI morals for decision making (Awad et al., 2018). Other themes concern addressing the novelty, instead of considering the impact of the technology on the perspective of road users that have been systematically oppressed through previous novel transport technology. There is a notable gap in focus on bicycle users as a distinct group of non-occupant VRUs.

This gap is further pronounced when considering real-world AV-VRU interaction research. A review by Berge (2023) identifies only six studies which investigated real-world AV-bicycle user interaction among a total of 16 publications. Study of AVs in real-world settings is a missing link in understanding the technology in a potential transition period when conventional vehicles, AVs, and other road users coexist on roads (Cugurullo et al., 2021; De Ceunynck et al., 2022). Furthermore, little emphasis is placed on the cyclist's attitude, behaviour, or infrastructure needs as cycling continues to make a larger share of transport (Reid, 2017) both before and during the COVID-19 pandemic (Buehler & Pucher, 2021) and with more net positives than automobility in cities (Brand et al., 2021).

Even when considering AV interaction technology solutions and AV interaction research, the majority target pedestrians and not bicycle users (Dey et al., 2020; Rasouli & Tsotsos, 2020). Bicycle users must be considered a distinct group among VRUs because of their unique interaction with other road users and their tendency to communicate in unique ways. This is demonstrated in findings by Trefzger et al. (2018) where it was observed that they have a greater emphasis on the road and perform fewer shoulder check compared to other VRUs. Al-Taie et al. (2023) also highlight bicycle users' "more complex needs" (p. 3) in that they move faster, situate themselves in different locations around vehicles, and have encounters that are not limited to crossings only (Holländer et al., 2021). Popan (2020) also highlights the "visceral nature of cycling senses" (p. 298) which starkly contrasts the numbing effect of encapsulated mobility (Nixon, 2014). This distinction is of particular importance because of all VRUs, bicycles are, historically, least likely to be afforded dedicated infrastructure (Szell et al., 2022) and are more likely to share the road with AVs than other vulnerable modes (Berge et al., 2022).

More broadly, considering those who are impacted by the arrival of AVs, the present study has identified two groups: *occupants* and *non-occupants* (Borenstein et al., 2020).

Occupants are those who use vehicles as passengers and ride inside the AV. Non-occupants are other road users such as pedestrians and bicycle users that can interact with AVs outside of the vehicle. The key difference between these two groups is that the former group uses an AV as a means of transport, and the latter group constitutes those who are VRUs. These two groups have different needs and experiences in the public realm because of the mode of transportation that they use. Non-occupant bicycle users (in particular) experience urban environments in unique ways as outlined in the literature. The themes related to this experience are important to understand when engaging with prevailing discourse but also to draw connections to the empirical results. The umbrella themes used to describe these experiences follow below.

2.3.3 Identifying Umbrella Themes in Literature

In considering factors that influence an individual's urban bicycle experience, there are varying tolerance levels for traffic stress. Traffic stress is the cumulative sensory experience of a bicycle user as imposed by perceived danger and other stressors such as noise, relative velocity, vehicle volume, size differential, and exhaust fumes (Furth et al., 2016). Most bicycle users cannot tolerate traffic stress to a level that they are comfortable sharing the road with faster, larger, and louder vehicles. While some effort has been in recent years to lessen this stress by providing bicycle-specific infrastructure, some types of this have been more successful than others. The overwhelming majority of urban bicycle users are "traffic-intolerant" and can only tolerate a minimal amount of traffic stress. (Furth et al., 2016; Winters et al., 2011)

In some less successful cases, 'bicycle-specific infrastructure' will involve little more than painting a mark on a street with mixed traffic (referred to as a 'sharrow') or delineating a narrow lane with a painted line. This kind of infrastructure does not provide a significant enough stress reduction to meet the threshold tolerated by most bicycle users. In other more successful cases, bicycle-specific infrastructure has involved providing physical barriers such as concrete jersey barriers, grade separation with curbs, planters and/or green medians, or flexible plastic bollards called 'flexiposts'. Physical barriers are widely applied as best-practice in many applications of high quality, low-stress urban bicycle networks such as those cited by participants in the empirical chapters (NACTO, 2025). For

example, Montréal's Réseau Express Vélo (REV) employs physical separation on its network. World leaders in urban bicycle use such as Denmark and the Netherlands also employ grade separation, or bicycle first streets where cars are guests. In the Dutch example, an entire manual for bicycle traffic outlines the importance of safe, separated bicycle infrastructure ad nauseum (Groot, 2016). These more successful instances create a lower threshold of traffic stress that a measurably greater proportion of the bicycle user population considers tolerable (McNeil et al., 2015; Winters et al., 2011). However, there are many different kinds of environments and bicycle infrastructure types that all contribute to a street or a city being suitably low stress that people choose the bicycle as a viable everyday transportation option. A more fulsome discussion of bicycle user classifications and infrastructure follow in sections 3.3.2 and 3.3.3 respectively.

A small minority of bicycle users can tolerate high-stress environments, however the majority of 'bicycle-specific infrastructure' is only usable by a small minority of bicycle users. There is generally an understanding that bicycles can provide solutions to lifestyle stagnation, particulate air pollution, carbon emissions, and transportation system capacity constraints. Bicycles are particularly well-suited to address this suite of challenges in urban centres. If these benefits are so keenly sought after, then how have cities been advancing a misguided understanding of tolerable levels of traffic stress thereby creating environments that discourage bicycle use? How can traffic stress be better understood and built-in to the design of urban bicycle infrastructure?

Several traffic stress and bicycle user classification systems have been devised to provide a systematic and more thorough understanding of how the bicycle user experience is influenced by a wide variety of environmental factors (Winters et al., 2011), many of which are directly related to traffic stress. These systems are a useful tool to understand traffic stress and the phsyco/demographic characteristics of a (potential) bicycle user population.

All things considered, until recently, all understanding of traffic stress and bicycle infrastructure design has been based on conventional vehicles driven by humans. As AVs begin to operate in some cities and are rapidly becoming a viable prospect in a growing number of other cities, there may be a change in how VRUs (particularly bicycle users) behave and feel around these vehicles (Botello et al., 2019). Given the strong connection

of traffic stress to travel behaviour and bicycle user comfort and safety, their real-world empirical approaches are vitally important. These are discussed below and in section 2.3.7.

To provide a structured approach for synthesising this information and interpreting subsequent empirical results, these nine themes are further organized under two overarching 'Umbrella Themes': Environmental and Experiential. The Environmental themes encompass external, extrinsic factors in a bicycle user's surroundings that influence their experience, such as the dynamics of negotiation with AVs, the need for separated infrastructure, and considerations during the transition period when AVs and conventional vehicles coexist. Conversely, the Experiential themes delve into the intrinsic, individual accounts of riding a bicycle, covering aspects like perceived safety, trust in AV technology, comfort levels, feelings of subordination, altruistic considerations, and observed behavioural changes. This comprehensive framework allows for a nuanced understanding of the complex interplay between AVs and urban cycling, setting the stage for a detailed examination of each of these nine themes in the following section and in both sections 2.3.6 and 2.3.7.

2.3.4 Highlighting Real-world Empirics in the Literature

Another aim of this literature review is to synthesise the current discourse on the interface between bicycle users and AVs in real-world scenarios and extends this by drawing on relevant literature for context and completeness. Based on the existing body of literature, themes related to AV and bicycle user interaction can be grouped into two umbrella categories. These categories are defined as environmental and experiential. Environmental themes relate to external factors in a bicycle user's surroundings that influence their experience. Firstly, environmental themes in literature relate to the transition period when AVs and conventional vehicles co-exist, negotiation between VRUs and AVs, and separated infrastructure for bicycle users. Environmental factors are extrinsic and influence the experiential factors of bicycle users. Fraser & Lock (2011) and Winters et al. (2011) describe that environmental factors impact bicycle use. Secondly, experiential themes relate to the experience of riding a bicycle (Dunlap et al., 2021). These themes are intrinsic and relate to how a bicycle user's individual accounts are described or felt (Lim et al., 2022). Experiential themes in literature include comfort of riding a bicycle, sense of safety,

subordination by other modes, sense of altruism for other road users, trust in AV technology, and behavioural influence. Experiential themes are individual and vary between bicycle users.

The bicycle user-AV experience combination of intrinsic and extrinsic factors is corroborated by Pyrialakou et al. (2020) in a study on sharing road space with AVs. These themes are described and discussed in this section. The results of the systematic literature review are summarised in Table 2.3.1 using a method adapted from (Berge et al., 2023). It should also be highlighted that while there are 14 studies included in Table 2.3.1, some of the studies analyze the same source data. In the *Source Data* column there are 8 unique data sources.

Table 2.3.1 Literature review summary table

Reference	Situation	n (bicycle)	Scenario	AV type	Source Data	Method
(Al-Taie et al., 2023)	Driver-cyclist interaction in real-world traffic.	12	Bicycle user eye tracking in live traffic.	Mock	Project-specific	Field test
(Bjørnskau et al., 2023)	Spot video recordings across two AV shuttle pilots.	522 ²	Bicycle users interacting with AV shuttle on public roads.	Shuttle	Autobus Project	Survey
(Boersma et al., 2018)	AV shuttle on bike path.	Unspecified	Bicycles sharing space with AV and attempting to overtake.	Shuttle	STAD Project	Survey
(Das et al., 2023)	Uncontrolled; everyday bicycle use.	477 ³	Bicycle user interacting with AV in public roads.	Free-floating	BikePGH 2019	Third-party survey data
(De Ceunynck et al., 2022)	Spot video recordings at five locations on an AV shuttle route.	Unspecified	Bicycles catching up or overtaking AV shuttle.	Shuttle	Autobus Project	Video recordings
(Imanishimwe & Kumar, 2023)	Uncontrolled; everyday bicycle use.	477 ³	Bicycle user interacting with AV in public roads.	Free-floating	BikePGH 2019	Third-party survey data
(Madigan et al., 2019)	Video recordings from AV-mounted cameras.	132 ⁴	Bicycle users interacting with AV shuttle on public roads.	Shuttle	CityMobil 2 Project	Video recordings
(Oskina et al., 2023)	Controlled field experiment with interaction scenarios on minor campus street.	29	Vehicle approaching bicycle user from behind.	Mock	Project-specific	Field test

² Combined sum of both bicycle user samples in Kongsberg (115) and Oslo (407)

³ 60% of n=795 shared the road at least once with an AV as a bicycle user (Bike PGH 2019)

⁴ Sum of cyclist observations in both test sites as reported by authors in Table 4 of the article

Reference	Situation	n (bicycle)	Scenario	AV type	Source Data	Method
(Parkin et al., 2023)	Controlled environment; temporarily closed university roads.	33	Cyclists pushing bicycle on pre-determined walking route. ⁵	Pre-determined self-driving route	Project-specific	Field test
(Pelikan, 2021)	Video recordings from inside AV on mixed use road/pathways on university campus.	Unspecified	Study participants biking with AV shuttle.	Shuttle	Project-specific	Video recordings
(Penmetsa et al., 2019)	Uncontrolled; everyday bicycle use.	277 ⁶	Bicycle user interacting with AV in public roads.	Free-floating	BikePGH 2017	Third-party survey data
(Pokorny et al., 2021)	Spot video recordings at T-intersection with bicycle lanes.	35	Bicycles interacting with AV from bicycle lane.	Shuttle	Autobus Project	Video recordings
(Rahman et al., 2021)	Uncontrolled; everyday bicycle use.	477 ⁷	Bicycle user interacting with AV in public roads.	Free-floating	BikePGH 2019	Third-party survey data
(Rahman et al., 2023)	Uncontrolled; everyday bicycle use.	409 ⁸	Bicycle user interacting with AV in public roads.	Free-floating	BikePGH 2017	Third-party survey data

⁵ On-road bicycle trials were affected by technical errors and insurance requirements however data removal did not affect mean scores in data analysis and was therefore not removed

⁶ This number is different from other BikePGH data sources because the authors directly specify the sample size

⁷ 60% of n=795 shared the road at least once with an AV as a bicycle user (Bike PGH 2019)

⁸ 36.5% of n=1120 shared the road with at least once with an AV as a bicycle user (Bike PGH 2017)

2.3.5 Environmental Themes in Literature

As earlier outlined in section 2.3.3, one of the two umbrella themes that literature discusses is environmental factors. The environmental factors arising in literature have been identified as negotiation, separated infrastructure, and transition period.

Firstly, Madigan et al. (2019) draw on multiple scholars' work highlighting the delicate negotiation that is required between AVs and bicycle users. They note that current AV shuttles (in particular) rely on collision avoidance principles instead of actively interpreting other road users and reacting accordingly (Eden et al., 2017). Any further adoption of AVs will largely depend on their ability to operate in mixed traffic safely and predictably, particularly during a transition period. Findings suggest that the "interaction requirements of road users are unlikely to change dramatically" (Madigan et al., 2019, p. 211). A study of an AV shuttle in Greece, Switzerland, and France that operated in a shared space found that pedestrians and bicycle users expected to have priority over the shuttle. AVs need to understand the context and mode prioritization in the context where they operate to avoid conflicts and to improve AV-bicycle user negotiation (Merat et al., 2018). This is especially important where there is not any separated infrastructure for bicycle users and AVs.

Secondly, other interview-based research with specialist knowledge highlighted certain divisions in the need for separated infrastructure for bicycles and a AVs. Participants in a study by Pettigrew et al. (2020) had contrasting views and postulated that "AVs would enable greater mixing of road users or strengthen the case for separate lanes for different users" (p. 3). The group that favoured integration pointed to a sensor suite that is more capable of detecting bicycle users and the group that favoured separation stressed this scenario would allow travelling at "optimal speeds without endangering or inconveniencing others" (p. 3). In a similar vein, when bicycle users and AVs share the same infrastructure, this integration was expanded on in a study of BikePGH survey data on bicycle user stated preference. Imanishimwe & Kumar (2023) found that among those who have experience sharing the road with AVs and are familiar with AV technology that "AVs' safety potential to reduce injuries and fatalities [...] is 75%" (p. 7) and among those unfamiliar with AVs the safety potential falls to 55%. This finding is consistent with findings by Rahman et al. (2023) where increased exposure correlated with higher perceived safety.

However, this is not entirely consistent with what Pyrialakou et al. (2020) found where they contrast this suggesting there is not a uniform increase in perceived safety associated with more AV exposure and awareness. It was also found that “road users who feel unsafe sharing the road with human-driven cars are 17.3% more likely to believe that AVs will reduce traffic injuries and fatalities” (Imanishimwe & Kumar, 2023, p. 8). Taken together, this may suggest that as bicycle users share the road with AVs in a transition period that they will have a greater sense of perceived safety. However, studies have cited that a weakness in their approach is their use of experienced bicycle users (Oskina et al., 2023), and if it is to be assumed that increased exposure will lead to greater perceived safety that only those who deem current conditions to be a low enough traffic stress threshold will achieve a greater level of perceived safety. All other bicycle users with a different level of traffic stress tolerance stand to be excluded in perpetuity if their needs are not met through other infrastructure interventions, as recommended in findings by Das et al. (2023). Their findings recommend that “policymakers should prioritise the design and implementation of infrastructure that supports safe interactions between AVs and non-motorists” which “may involve creating dedicated bike lanes” (Das et al., 2023, p. 14).

Thirdly, understanding environmental themes through the lens of the concept of a transition period was somewhat less prevalent in the literature. However, the period when both conventionally-operated vehicles and AVs coexist could be described as having unsettling potential because of how bicycle users will need to process additional information and make additional calculations for how to behave and interact with a vehicle depending on how a vehicle is controlled. Imanishimwe & Kumar (2023) analyzed survey data from BikePGH, where bicycle users interacted with free-floating AVs. The authors describe a “proving ground” (p. 8) with mixed vehicle control methods and find that “as more people feel safe sharing the road with AVs, the more likely they are to believe that AVs will reduce traffic injuries and fatalities” (p. 8). They expand by explaining that those who currently feel “unsafe sharing the road with human-driven cars are 17.3% more likely to believe that AVs will reduce traffic injuries and fatalities” (Imanishimwe & Kumar, 2023, p. 8).

2.3.6 Experiential Themes in Literature

Similarly, the second of the two umbrella themes (also outlined in section 2.3.3) that literature discusses is experiential factors. The experiential factors arising as part of the PRISMA process have been identified as safety, trust, comfort, subordination, altruism, and behaviour. These are discussed below.

Safety and trust were often connected themes in the literature. In many cases, overcoming barriers related to safety and trust were found to be broadly important in AV acceptance (Cugurullo et al., 2021; Howard & Dai, 2014; Luger-Bazinger et al., 2021) and specifically for bicycle users (Pettigrew et al., 2020). Furthermore, research suggests that the more AV exposure that a bicycle user has, the more likely they are to adopt an ‘accepting’ attitude towards AVs (Penmetsa et al., 2019; Pyrialakou et al., 2020) and have “higher perceived safety on sharing roadways with AVs” (Rahman et al., 2023, p. 275). While the Penmetsa et al. study of early real-world AV-bicycle user interaction surveys is useful, they explain that “few respondents [...] have directly interacted with AVs” (2019, p. 10).

First, PRISMA-identified literature that discussed trust with bicycle users and AVs on calm streets yielded results that had a distinction between a male/female gender binary. Oskina et al. (2023) note that male bicycle users have lower subjective (perceived) risk levels than females. This corresponded to higher objective risk for male bicycle users because of their higher sense of trust in AVs. This trust was demonstrated by male bicycle users’ tendency to ride faster and closer to the AV with less caution. Broadly, bicycle users in this study felt less safe when they were being overtaken by the AV. Oskina and colleagues also found that there was no difference in bicycle user behaviour and risk perception between AVs and COVs when they were being followed. The biggest factors that influenced bicycle users’ trust in this study were the speed and distance of the AV. However, this study limited participants to experienced bicycle users and the authors identify this as a weakness of the study.

Second, with regard to safety, in studies that surveyed bicycle users who interacted with AVs in uncontrolled environments, Das et al. (2023) found that the majority of participants “felt safe around AVs and felt neutral around cars” (p. 6). A modest majority (53.7%) of

participants who were also bicycle users had interacted with an AV in this study. It was also found that negative press around AVs did not impact bicycle users' perceptions toward AVs. Das and colleagues also used counterfactual analysis to understand casual relationships between survey variables. They adjusted desirable AV characteristics (injury reduction) up and down to see how it would affect the original survey results. In performing this analysis, the improved or reduced ability to prevent injury resulted in a relative change in variables around safety and opinion towards AVs.

Furthermore, some reasons that research participants cite as factors that impact their perception and sense of safety include awareness of crashes and safety incidents, familiarity with AVs, and whether they are a driver, bicycle user or pedestrian. Bicycle users feel the least safe sharing the road with AVs and drivers feel the most safe (Pyrialakou et al., 2020). Additionally, those that have a "lack of concern regarding threats from hackers, terrorists, or other such parties and attitudinal factors pertaining to subjective norms and the perceived relative advantage of AVs" (Pyrialakou et al., 2020, p. 256) which corroborates sentiment around broader urban AI and AV applications outlined by Cugurullo & Acheampong (2023). Awareness can impact perceived AV safety potential significantly. Imanishimwe & Kumar (2023) found that those that are aware of AV technology predict the probability of AVs to reduce injuries and fatalities is 75% whereas those unfamiliar predict the injury and fatality prevention falls to 55%.

Third, in a similar vein to perceptions of safety, comfort is a closely related theme that arose in the literature. Although less prevalent than safety in the literature identified in the PRISMA process, it is an important theme to engage with due to broad recognition in cycling literature outside of AV/AI transport systems (Cabral & Kim, 2020; Dill & McNeil, 2016; Heinen et al., 2010; Winters et al., 2011). Rahman et al. (2021) found that respondents, in their assessment of BikePGH data, felt "uncomfortable/unsafe around AVs, did not trust AVs and were not able to predict their behaviours while sharing the roads" (p. 439). While this is supported in findings by Reig et al. (2018) in a study concerning pedestrians and AVs, Rahman et al. (2021) provide evidence of conflicting concerns from respondents in their data where some are afraid because they either lacked confidence in the technology which could be summarised as fear of AVs and, in the other being a higher degree of understanding of AVs respectively. It should also be noted that the Rahman et

al. (2021) study did include respondents that had only interacted with an AV as a pedestrian and not as a bicycle user. In the case of the respondent that lacked confidence/was fearful of AVs, this individual was labelled as only having interacted with an AV as a pedestrian. In empirical chapters 5 to 7 of this dissertation, similar conflicting concerns with respondents in the research conducted for this project are also highlighted.

Fourth, while a dominant theme in AV-VRU discourse, subordination is not directly addressed by name but is written about in the way that VRUs are described as behaving in an “unexpected manner” (Pokorny et al., 2021, p. 6) or “disrupting the current traffic paradigm” (Al-Taie et al., 2023, p. 15). Of all the literature identified and reviewed, the most compelling discussion of the concept of subordination is in a paper by Madigan et al. (2019) where they outline concern from vehicle manufacturers that if an AV were to more clearly communicate its operating mode (either manual or AI-driven) it could incite “‘bullying’ or ‘malicious’ behaviour by other road users” (p. 5) that do not yield. They further explain that this could lead to an impact on safety and “traffic flow” (p. 5). This is an interesting, although biased, position to take because these manufacturers have benefitted from the “current traffic paradigm” (Al-Taie et al., 2023, p. 15) and the System of Automobility (Urry, 2004) that came to exist through an evolutionary process of subordinating previous generations of transport modes (Gaio & Cugurullo, 2023). Auto manufacturer concern is reiterated in saying that “road users may take advantage of easily identifiable AVs by engaging in dangerous behaviours on the assumption that the AV will always stop” (Madigan et al., 2019, p. 24). It could be argued that a rethink of road user hierarchies and visceral experience recalibration of mobilities may be necessary. This seems pertinent when auto-oriented subordination of other modes (namely bicycle users) has led to the manifestation of the current transportation landscape. Within the context of this landscape, it has led to a somewhat unfounded concern that VRUs present a threat through bullying of vehicular transportation that has exerted significant dominance in cities over all other modes (Nixon, 2014; Popan, 2020). This notion of VRU bullying could be construed as victim blaming where bicycle users are made victims of an otherwise oppressive transport system that already subordinates them (Gaio & Cugurullo, 2023; Pimentel, 2017).

Penultimately, fifth, altruism arose in two manuscripts identified in the systematic review. The altruism theme, as outlined in section 0, pertains to the concern that other road users (non-occupants) may have for those that experience such adverse exaggerated reactions such as “sharp braking” (Pelikan, 2021) as occupants. Parkin et al. (2023) does not directly address altruism between participants and the AV, but does raise the validity of “‘empathy for pain’ and vicarious somatosensory” (p. 771) in their methods to understand impacts of immersive experiences. In a real-world test of AV shuttles in Linköping, Pelikan (2021) attempts to promote more altruism/empathy from bicycle users for the sensitive AV shuttles by adding text “to the back of the bus saying ‘I can brake strongly – thank you for keeping the distance :)’ in Swedish” (p. 4) but this was not successful in preventing sharp braking.

Ultimately, sixth, it could be argued that all the literature arising from the PRISMA review process deals with the behaviour theme. AVs have highlighted how pioneering physical manifestations of AI disrupt transportation systems and behaviours in different ways (Gaio & Cugurullo, 2024). However, there two authors that engage with behaviour the most through the design of their research. Oskina et al. (2023) designed their study specifically to assess “behaviour of participants who were riding an instrumented bicycle while they were followed or passed by a vehicle” (p. 1139) in both a mode that operated as an AV and as a conventionally-operated vehicle. They further explain that the design of their study “aimed to investigate the behavioural adaptation of cyclists when interacting with an AV compared with interacting with a conventional vehicle” (p. 1140). In another study by Pokorny et al. (2021) in a more naturalistic setting, 35 bicycle users’ behaviours were observed in video recordings with an AV shuttle similar to those examined in the present project’s research. They explain that in situations where bicycle users ride close to the shuttles and that the shuttle is not programmed to deal with these situations, resulting in “hard stops” (p. 10) which is similar to the situations that Pelikan (2021) describes as “sharp braking” (p. 5). Oskina et al. (2023) found that the most significant behaviour changes for bicycle users with AVs were caused by the “the vehicle’s speed and distance” (p. 1147). Pokorny et al. (2021) describe some situations as “stalemate” (p. 8) situations where a VRU and the AV are not sure about the others’ intentions. These two examples of behaviour

are influenced by the AVs disrupting a bicycle user's mobility that could have been mitigated by better communication to establish trust.

2.3.7 Summary of Recommendations for Future Study from Real-world Empirical Research

Most of the studies included in the review (listed in Table 2.3.1) made recommendations for future research which were taken into consideration when designing the methods chosen for this research project. Details related to the methods and approached chosen based on recommendations are more broadly engaged with in Chapter 4. The recommendations are to gather more data from real-world studies, expand understanding of public perception, investigate specific safety aspects, and refine research methods.

By and large, the most prevalent recommendation was that of conducting more real-world studies (Boersma et al., 2018; De Ceunynck et al., 2022; Oskina et al., 2023; Pelikan, 2021; Penmetsa et al., 2019; Pokorny et al., 2021) with specific attention given to different locations (Al-Taie et al., 2023; De Ceunynck et al., 2022; Rahman et al., 2023), traffic conditions, and larger/more diverse participant groups (Das et al., 2023; Oskina et al., 2023; Rahman et al., 2021, 2023). In terms of participant groups, Das et al. (2021, p. 15) explain that it is "crucial for future studies to include larger and more diverse samples of non-motorists from different socio-demographic backgrounds, such as age, gender, and ability level" which is echoed by Oskina et al. (2023, p. 1148) in writing that "future research should recruit participants with different ages and experience levels". Rahman et al. (2021, 2023) also state, similarly, that future studies need to engage more diverse socioeconomic and demographic participants including those with varying levels of AV familiarity.

There were also recommendations for future study that explore how people from different backgrounds perceive AV safety and regulations. Imanishimwe & Kumar (2023, p. 10) write that "future research can extend [their] study by considering the impact of unexpected events, such as fatalities caused by AVs, on public trust in the technology". Longitudinal studies were also recommended to track how perceptions change over time, especially after major events (Rahman et al., 2023).

Methodological approaches were also the subject of scholars' recommendations. Several authors suggested that using more representative samples using different recruitment methods to engage larger sample sizes (Das et al., 2023; Imanishimwe & Kumar, 2023; Parkin et al., 2023; Rahman et al., 2023), considering different data collection methods (Bjørnskau et al., 2023; Oskina et al., 2023), and using methods that minimise participant behaviour being influenced by the study itself explaining that it would be beneficial "not to inform cyclists in advance about the vehicle's driving mode (automated/manual) but to ask cyclists at the end of the ride what the vehicle's driving mode was" (Oskina et al., 2023, p. 1148).

2.3.8 Critical Reflections from the Identified Studies

The design and approach of this thesis are directly and significantly informed by a critical reflection on the methods and limitations of existing studies identified through this literature review. This critical analysis revealed several key approach gaps in the current discourse on AVs and urban cycling, which this research explicitly aims to address.

Critical reflections on previous studies include, firstly, an over-reliance on hypothetical and simulation-based research. Many existing studies investigate a *hypothetical* future with AVs, often relying on virtual reality simulations or stated preference surveys. This approach fails to capture the nuances of real-world immersive environments and the situational traffic stress experienced by road users.

Secondly, there is a limited focus on non-occupants, specifically bicycle users. A significant portion of AV research primarily focuses on occupant travel behaviour, often overlooking or broadly grouping VRUs such as pedestrians and bicycle users, thus failing to distinguish the unique needs, behaviours, and interaction patterns of bicycle users.

Thirdly, there is an inadequate understanding of communication challenges. Existing literature highlights that communication between AVs and cyclists is underdeveloped, with AVs struggling to interpret subtle human signals such as eye contact, gestures, or changes in pace, rendering nonverbal communication "useless" (Hagenzieker et al., 2020, p. 97).

Fourth, there is a problematic framing of acceptance. Some scholarly work frames the adoption of AVs in terms of public uptake or acceptance (Stilgoe & Cohen, 2021), which this thesis identifies as a techno-centric and potentially misguided approach that positions society as a barrier to technological adoption.

Fifth, existing literature reflects on an insufficiency of real-world data. There was a notable scarcity of data understanding bicycle user attitudes, behaviours, and infrastructure preferences in real-world AV contexts.

Sixth, there were limitations in participant sampling and diversity. Previous studies sometimes struggled with small sample sizes or unrepresentative sample sizes, particularly regarding gender and experience levels, making generalizations difficult.

Seventh, there was a lack of contextual and geographical variation. Much existing research tended to be localized in a few prevalent research hubs, limiting the generalizability of findings across different urban morphologies and cycling cultures.

This thesis directly responds to as many of these identified gaps and limitations as practically possible through its design and approach in six ways. Firstly, it employs a real-world living lab approach, conducting mixed-methods studies (surveys, interviews, and focus groups) in operational AV pilot sites where participants daily interact with AVs in uncontrolled environments, providing empirical observation of lived experiences.

Second, this thesis exclusively focuses on urban bicycle users as a distinct group of non-occupant VRUs, acknowledging their unique needs and experiences.

Third, the research directly interrogates the impact of AVs on communication and negotiation tactics for bicycle users, finding that the loss of human communication is a major concern influencing cyclists' comfort and trust.

Fourth, it challenges the techno-centric view of acceptance by prioritizing the lived experiences and concerns of bicycle users, emphasizing mobility justice and ensuring AV integration without compromising active transportation.

Fifth, the study systematically investigates attitudes, behaviours, and infrastructure preferences through a mixed-methods approach to provide empirical data.

Sixth, the study was conducted across four diverse "Living Lab" sites (Aalborg, Denmark; Montréal, Canada; Linköping, Sweden; and Stavanger, Norway) chosen for their variations in bicycle urbanism maturity and Levels of Traffic Stress (LTS), providing a more comprehensive understanding of AV-bicycle user interactions in varied urban contexts.

By intentionally building upon the identified gaps and limitations of previous research, this thesis offers a robust and pioneering study that moves beyond hypothetical scenarios to provide real-world empirical insights into the complex interplay between autonomous vehicles and urban cycling, critically informing policy and planning for an AI-mediated transportation future.

2.4 Adjacent Subject-matter

2.4.1 Addressing 'Acceptance' of AVs

As introduced in Chapter 1, it is important to highlight again that as AVs and other novel technology are thrust on society, it should incite pause as to the role-relationship between society and technology. While many scholars address acceptance to some extent (usually after a period of exposure), this may imply that the techno-centric view that there is no argument to adoption of technology. Instead of the technology being the problem, the problem is that of public uptake (Stilgoe & Cohen, 2021).

2.4.2 Simulation-based Research

Many studies have investigated a *hypothetical* future with AVs through virtual reality simulations or stated preference surveys (Botello et al., 2019; Comeau et al., 2021; Hagenzieker et al., 2020). While valuable for establishing a preliminary baseline understanding, many variables that would otherwise be present in a real-life scenario, such as speed, were missing for participants to take into consideration (Hagenzieker et al., 2020). Additionally, situational traffic stress and broader immersive environments add a comprehensive sensory experience for better understanding of the real-world impacts.

Scholars recommend that these baseline studies should be expanded upon and similar methods be applied to real-world scenarios (Hagenzieker et al., 2020).

In the present study, real-world living lab neighbourhoods are used to conduct travel behaviour research with participants who are likely to interact with AVs in their daily life. In doing so, this builds on the body of knowledge that was established in earlier studies.

2.4.3 Mobility Justice

Considering the impacts of automobility through a perspective of mobility justice, and extrapolating the externalities that will likely be exacerbated through the increasing prevalence of AVs, Sheller aptly writes how the current regime of automobility was predicated on “dominant forms of white, male, elite automobility” (2018, p. 106). Unravelling the structures and regimes through a transitional state as AVs become more pervasive will involve a “[recalibration of] planning and cityscapes to prioritise place and people rather than (motorised) mobility and traffic flow” (2018, p. 74). Sheller further writes that there is a challenge in pitting ‘mobility’ against ‘place’ and that if society were to shift *beyond* mobility then there would be difficulties in advocating for *better, fairer, and more just* mobilities. This shift could be better described as moving ‘beyond automobility’ to encompass mobility that favours active and green mobility. However, the delicate nature of suggesting the reduction of automobility often stalls progress given that it is so deeply ingrained and politicised as ‘us’ vs ‘them’ debates in public forums.

Notwithstanding the social structures, subjective norms, and inertia of automobility systems, advocating for human-centred public approaches are often cast aside in favour of new technology such as AVs (Sheller, 2018). In any case, the National Association of City Transportation Officials (NACTO) argues that AVs need to be regulated in ways that promote health, safety, equity, and access. The only way that the benefits of AVs will be felt is if the freed-up public space is redeveloped at a human-scale. Furthermore, in addition to redeveloping public space, AV regulation will be essential to prevent an oversaturation of curb-space not dissimilar to how parking under conventionally operated vehicles oversaturate open space. Sheller further explains that NACTO argues that ‘coding the curb’ (pricing curb space) will be important to avoid a ‘tragedy of the commons’

(Sheller, 2018). In a similar vein, and citing an inadequate regulatory framework, a 2017 study found that app-based ride services added 50,000 additional vehicles and 36% more vehicle miles travelled (VMT) and a 15% increase in passenger trips by for-hire vehicles (Schaller, 2017).

2.4.4 Socio-technical Imaginaries

The future of urban mobility will not organically occur without being intentionally shaped. Socio-technical imaginaries are shared visions of the future that incorporate both society and technology. These types of imaginaries guide how people think about what is possible in the future. Similarly, ‘futuring’ or the process of futuring refers to the ways people, institutions, and systems imagine, plan and work toward futures. Future visions are manifested in the present. Without planning, visioning, and goal setting— and using policy tools to shape the trajectory of society— the future is set into motion in the present. The visions of the future are often set by governments, large corporations, and powerful institutions while marginalised groups struggle to have their voices heard and this may also be the case for future AV usage (Kassens-Noor et al., 2021). For example, tech companies' visions of AI influence policies, while community-driven concerns about AI ethics may be sidelined.

Building upon this understanding, the concept of sociotechnical imaginaries has been further explored across various domains. For instance, Sismondo (2020) highlights how these imaginaries represent collectively envisioned forms of social life intertwined with technological advancements, influencing national scientific and technological projects. This perspective underscores that the future of urban mobility is not just a result of technological innovation but is also deeply rooted in shared societal visions and institutional frameworks. Therefore, achieving equitable and inclusive mobility solutions necessitates the active participation of diverse communities in shaping these future narratives, ensuring that the benefits of technological progress are broadly and fairly distributed. The research presented herein attempts to bring a valuable perspective forward to shape future narratives.

2.4.5 Bicycle User Behaviour

Early research suggests that bicycle users may trust AVs more than human drivers. Only 5% of the respondents involved in a study by Pammer et al. (2021) were identified as only cyclists and it is difficult to generalise findings from a small sample size. Cavoli et al. (2017) have also written that cyclists and pedestrians trust AVs more than human drivers when they are programmed to operate safely, but only law-abiding pedestrians and cyclists have more trust than those that do not obey traffic laws. In a paper by Hagenzieker et al. it was found that cyclists may have “incorrect or over-reliant expectations of automated driven cars” (2020, p. 110) which may impact mutual trust if AVs are programmed to operate safely, but subsequently programmed to operate more aggressively to assert their place in the road. This may lead to erratic cyclist behaviour and is difficult to predict using hypothetical scenarios without empirical real-world research outside of simulations, therefore, real-world deployments are extremely important to evaluate and study carefully (Susilo et al., 2021).

Further to Hagenzieker et al. (2020), the gap in research intersecting the topics of AVs and cyclists was a demonstrable omission that needed to be resolved in order to better understand the implications of AVs on cycling (Ahmed et al., 2019a, 2019b; Botello et al., 2019; Coelho & Guarnaccia, 2020; Eldesokey et al., 2017; Kress et al., 2018; Penmetsa et al., 2019; K. Wang & Akar, 2019; M. Zhang et al., 2020). Of note is the fact that, while there is research on AVs, the primary research focus is either on hypothetical future users or is too thematically broad to draw adequate conclusions for bicycle users. These broad conclusions are frequently grouped into a universal codification of ‘vulnerable road users’ (VRU). A VRU is defined as a “non-motorised road users such as pedestrians and cyclists as well as motor-cyclists and persons with disabilities or reduced mobility and orientation” (European Union, 2009, p. np). This codification is not specific enough to adequately distinguish cyclist characteristics from those of other vulnerable road users.

Other recent studies have found that, related to trust, communication between AVs and bicycle users remains underdeveloped. Communication gaps are likely a major contributor to a lack of trust between road users. In a paper by Botello et al., “[n]early half of the interview respondents raised the issue of communication between C/AVs and cyclists and

pedestrians” (2019, p. 4). Some respondents suggested that, while more explicit communication from AVs may be helpful, their ability to detect subtle signals, hints, or even no signals was a weakness in the technology’s functionality in real-world traffic scenarios involving cyclists and pedestrians (Botello et al., 2019). Subtle signals such as waves and direct eye contact are important for establishing trust and understanding between road users in high-pressure or high-stakes interactions. De Ceunynck et al. corroborate that “[h]uman road users typically communicate their intentions in traffic through lights (e.g. direction indicators), sounds (e.g. horn), eye contact and direction of gaze, bodily orientation, (change of) pace, gestures, etc. Some of these ways of communication can neither be generated nor easily interpreted by autonomous vehicles.” (2022, p. 3). When a cyclist’s hands and feet are engaged, the only effective form of communication they can use is eye contact. This emphasised in a study by Hagenzeiker et al. on AV-bicycle user interaction where “[n]onverbal communication between road users will become more or less useless” (2020, p. 97) when communicating with AVs.

2.5 Urban AI

Due to the rapidly evolving nature of the field of AI urbanism, there were few instances discussing this concept in the systematically reviewed literature. However, as one of the first physical manifestations of Urban AI that people can interact with in a tangible sense, it is important to acknowledge AVs in this context and discuss some implications that have been raised by several preeminent scholars. In this section Influence of AVs on cycling infrastructure preference give a high-level overview of the web of Urban AI and how AVs are situated in this web.

AVs form one of the four pillars of Urban AI alongside urban robots, city brains, and urban software agents (Cugurullo et al., 2023). As first introduced in Chapter 2, AI is a dominant force that is shaping our everyday lives in different spheres. Despite its increasing dominance, there are few physical manifestations or concrete meanings that are readily accessible to form an understanding of thereby further exacerbating Urban AI’s elusiveness (Crawford, 2021; Cugurullo et al., 2023).

Cugurullo et al. (2023) explain that AI should not be referred to as singular. There are a wide variety of different artificial intelligences that cannot be generalised into a singular form. Although AIs are heterogenous, there are unifying characteristics that are shared among them. These are: “(a) the quality of being artificial, (b) the capacity for learning, (c) the ability to extract concepts, (d) the power to manage uncertainty and (e) the capability to act rationally and (f) autonomously” (Cugurullo et al., 2023, p. 4). AI is being physically applied, most commonly, in the urban realm. Cugurullo et al. (2023) explain that AI is “intrinsically linked to urbanity” (p. 5) because there are several interrelated conditions that must be true for AI to function. First, AI needs physical environments (i.e. AVs operating on public streets). Second, AI is an agent in and of itself in that it *acts* and *engages* in a wide variety of situations and scenarios (Russell & Norvig, 2016) (i.e. city brains mitigating adverse weather effects by dispatching crews (see Xu et al., 2024)). Third, AI development and urban development are interdependent (i.e. urban environments fabricate granular *real-life* data that is invaluable to train machine learning).

A summary of these Urban AI pillars, their characteristics, and dependencies are shown in a Web of Urban AI in Figure 2.5.1 below.

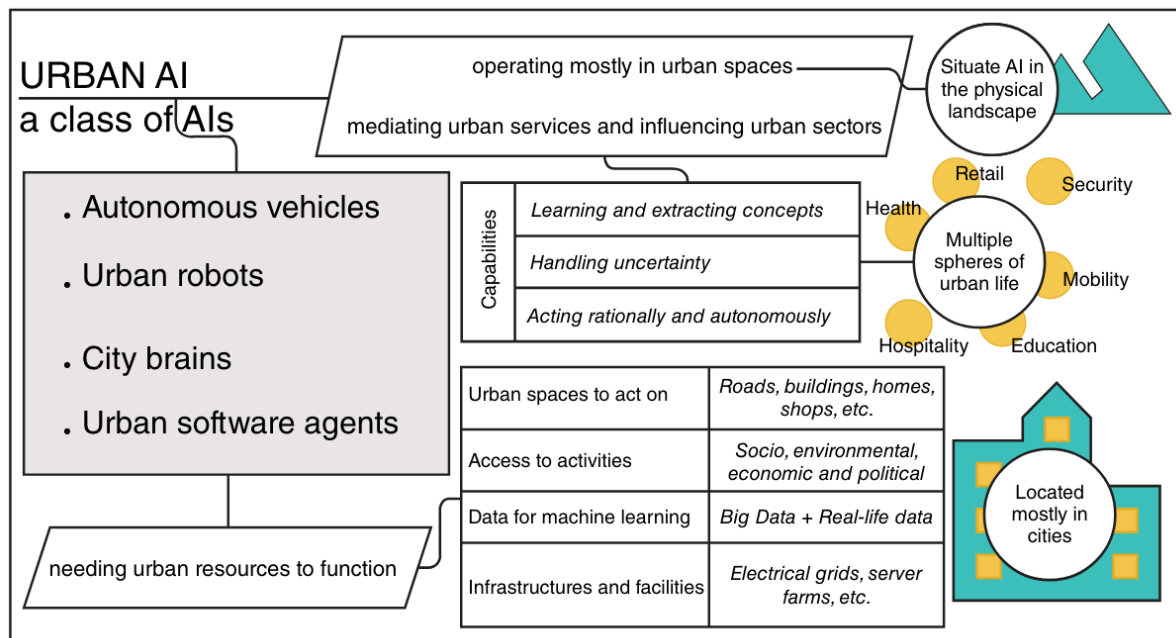


Figure 2.5.1 The Web of Urban AI (Cugurullo et al., 2023, p. 11)

Taken together, it is important to acknowledge the evolving nature of Urban AI. Urban AI remains immature, experimental, and iterative. While there is an ongoing “transition to AI

urbanism” (Cugurullo et al., 2023, p. 14) there remain many unanswered questions and its manifestations— both empirically and theoretically remain undefined and unknown. Pre-empting Urban AI with an understanding of its increasing ubiquity and capability as well as fostering critical discourse and curiosity will equip future generations with the readiness skills in an age with Urban AI. While fear may be an important evolutionary trait to maintain Urban AI skepticism (Cugurullo & Acheampong, 2023), it is undeniable that “a more-than-human component that is redefining the urban experience, as artificial and biological intelligences collide and collude in the making and governance of cities” (Cugurullo et al., 2023, p. 14).

As this work should make clear, AVs are a rapidly developing and consequential form of Urban AI that will implicate cities and non-occupants in particular. Understanding the behavioural implications of AV-bicycle interaction is just the tip of the iceberg in understanding how Urban AI can fundamentally reshape our understanding of urban life.

2.6 Conclusion

This rapid development and shift in understanding of how urban life is understood is emphasised through several research gaps identified in this chapter which will be explored in-depth. One of these research gaps is a predominant focus on occupant travel behaviour. A substantial proportion of literature that engages with AVs devotes its attention to occupant travel behaviour and discounts the external urban environment and active transport users which are made vulnerable by design. A second gap in discourse is limited real-world empirics. Much existing research relies on simulations or presenting hypotheticals to research participants which, consequently, means there is a scarcity of real-world interaction empirics; further, many of these studies also do not sufficiently contemplate the impacts of a transition period where AVs and COVs exist simultaneously. The need for research in uncontrolled, everyday settings would help to alleviate this gap. Third, there is insufficient data on understanding bicycle user attitudes, behaviours, and infrastructure preferences. The presence of AVs presents a new way of communication among transportation actors which necessitates new ways of communication and negotiation which impacts attitudes, behaviours, and infrastructure preferences which is understudied. The uncertainty that this new communication may usher in— especially

how AVs interpret subtle signals (such as eye contact and gestures) remains a concern. Fourth, there is a divide on the trajectory of infrastructure needs where some posit that AV technology will enhance safety in shared spaces while others advocate for increased separation. More research is needed to further inform how each approach would affect a diverse active transport user base with different confidence levels.

Some recommendations that have emerged from the literature are to take AV-other road user research to the real-world that involve everyday scenarios with bicycle users and operational AVs. Research recommendations also focus on how there is a need to better understand public perception specifically focussing on attitudes (impacted by trust and safety concerns) of bicycle users towards AVs. Efforts should also be made to recruit more representative and larger sample sizes through a variety of recruitment methods. There are also needs to conduct more longitudinal studies to investigate impact and changes over time as AVs evolve. The need to also recognise and embody the diversity of vulnerable other road users and how bicycle users' distinct characteristics influence their unique interaction patterns.

Ultimately, some key areas that will be outlined and discussed based on the gaps existing research as well as their recommendations are a focus on bicycle users and real-world studies; investigating attitudes, behaviours and infrastructure preferences; exploring communication challenges; addressing infrastructure needs; trialling methodological approaches to better base AV and non-occupant research in real-world empirics, as well as introduce new approaches for cross-sectional sampling across geographies, urban morphologies, and cultures.

By explicitly focusing on bicycle users in real-world settings and investigating their attitudes, behaviours, and infrastructure preferences through a mixed-methods approach across multiple urban environments, this dissertation directly addresses many of the key research gaps and takes into consideration several important recommendations highlighted in this systematic literature review. The basis of this approach, informed by sound theory, is outlined in the following chapter.

3. Background & Theory

3.1 Introduction

This chapter provides contextual background information surrounding the state of urban bicycle use. It is designed to give a high-level overview of the power dynamics that bicycle users as vulnerable road users are deposited into. It furthermore aims to explain the sensory experience of using a bicycle in a system that prioritises automobility. In recognising the challenges presented to bicycle users in cities, this chapter also draws from other bicycle user behaviour studies to explain how using planned behaviour theory, bicycle user classification, and traffic stress together to formulate a comprehensive theoretical frame to design and advance the research explained in the methodological and empirical chapters.

3.2 Background

To date, discourse in the space of AV research has focussed primarily on occupant travel behaviour (Bazilinsky et al., 2015; Behrendt, 2020; Deb et al., 2017; Li et al., 2023; Nordhoff et al., 2019; Pelikan, 2021; Rahimi et al., 2020). Given the underrepresentation of nonoccupants, and the need to make bicycle use more attractive in urban settings, AVs' impacts on their environments must be interrogated. Emerging work on AVs with VRUs suggest that they "can create a challenge [...] because [pedestrians and bicycle users are] ascribed greater responsibility to be cautious, aware, and predictable in interactions with [AVs] versus [conventionally operated vehicles], which may reduce the attractiveness of walking" (Bardutz et al., 2023, p. 14), and the same can be said for cycling. Additionally, there is a notable gap in focus on bicycle users as a distinct group of non-occupant vulnerable road users (VRU). This gap is further pronounced when considering real-world AV-VRU interaction research. The review by Berge et al. (2023) identified in the literature review highlights only six studies which investigated real-world AV-bicycle user interaction among a total of 16 publications. The present study aims to contribute to this emerging body of literature. Bicycle users must be considered a distinct group among VRUs because of their unique interaction with other road users and their tendency to communicate in unique ways. This is demonstrated in findings by Trefzger et al. (2018) where it was

observed that they have a greater emphasis on the road and perform fewer shoulder checks compared to other VRUs. This is of particular importance because, of all VRUs, bicycles are least likely to be afforded dedicated infrastructure and are more likely to share the road with AVs than other vulnerable modes.

The mode of the living lab was selected as a practical and real-world manifestation urban experimentation that operationalize AVs in everyday urban environments. As introduced in Section 1.3, living labs are increasingly recognised as key instruments of urban experimentation within the broader context of smart city development. They serve as real-world test environments where novel technologies, infrastructures, and regulatory frameworks are trialed in-situ. In direct connection to the research carried out in this thesis, living labs facilitate experimentation with the interactions of AVs and emerging technologies with urban infrastructures (e.g., streets, buildings, sensors), socio-natures (e.g., people, animals, terrain), and regulatory systems (e.g., licensing, liability) (Dowling & McGuirk, 2022). Importantly, this includes interactions with people that ride bicycles, whose presence complicates techno-centric visions of urban mobility. Building on scholarship by Evans et al. (2016) and Bulkeley et al. (2016), this research approaches living labs as spaces of socio-technical experimentation that test new technologies and also iterate configurations of urban governance, spatial politics, and citizenship practices.

By foregrounding the everyday accounts of residents and road users who engage with AVs, this study critically assesses how living labs serve as pilot zones that can either reinforce or disrupt dominant, car-centric mobility paradigms (Behrendt, 2020). As such, the research contributes to ongoing debates about smart cities and urban futures, extending the concept of auto-oriented policy inertia where living labs—while often framed as neutral, evidence-based testing grounds—are political sites where specific futures are enacted and normalized (Joss et al., 2019; Shelton et al., 2015). This critical lens positions the study within a broader interdisciplinary literature on urban experimentation and living labs, with implications that extend across contextual, empirical, and concluding chapters.

3.3 Theory

By reflecting on the context that bicycle users are thrust into, the design of this research is rooted in three foundational theories that provide a good approach cross-section and frame of mind for assessing the state of bicycle interaction with AVs in cities. There are challenges to bicycle use in cities that most people face because of how bicycles are treated on streets and are subordinate to other motorised road users (Gaio & Cugurullo, 2023). Most people perceive using a bicycle on streets with mixed traffic as dangerous and stressful (Furth et al., 2016; Winters et al., 2011). The vast majority of spaces available ride a bicycle in cities are shared with fast moving vehicles thereby actively discouraging bicycle use as an everyday form of transportation. This discouragement contributes to individual decisions to not ride a bicycle. The decisions and inputs that lead to an individual weighing the factors that contribute to a transportation mode choice can be framed by the first theory that this PhD work is structured around.

3.3.1 Theory of Planned Behaviour

The first theory used to frame the work in this dissertation is Ajzen's Theory of Planned Behaviour (TPB) (1985, 1991) which is a behavioural psychology theory that is commonly used in transportation planning and travel behaviour research to determine variables that impact an individual's behavioural determinants. In the original theory, this is determined by factoring attitude, subjective norms, and perceived behavioural control. While the basis of TPB is useful for thinking about this research, it has been criticised and adapted by scholars because of what that the original theory does not consider. In itself, TBP is an extension of the Theory of Reasoned Action (Ajzen & Fishbein, 1975). Early criticism of TPB has highlighted its failure to encompass the impact of external factors such as beliefs, past behaviours, and habits (Donald et al., 2014), design and structure of perceived behavioural control (PBC), moral norms, and self-identity (Conner & Armitage, 1998). TPB forms the core of the theoretical framework.

This first theoretical framing, Ajzen's TPB, is a theory that proposes model for understanding and predicting human behaviour (Ajzen, 1985). The theory, based on the Theory of Reasoned Action (Ajzen & Fishbein, 1975), proposes that human behaviour is

determined by three factors. The three factors are: attitude, subjective norms, and PBC. These factors are all present in an individual's decision to choose to ride a bicycle, and when presented with the added variable of an AV, add a new layer of complexity that TPB alone may not be adequately able to suitably capture. While the three factors are a good starting point, the aforementioned shortcomings are augmented by the additional two theoretical frames discussed below.

The layer of complexity that an AV introduces that TPB may not be suitably able to capture independently stems from the fundamental disruption AVs pose to established human-human and human-environment interactions on roads. While TPB effectively models behaviour through attitude, subjective norms, and PBC, AVs significantly alter these components. For instance, attitudes are critically impacted by the complete elimination of nonverbal communication like eye contact and gestures, which bicycle users heavily rely on for trust and negotiation with human drivers. This absence, coupled with the observed unpredictability and sharp braking or hard stops (Pelikan, 2021; Pokorny et al., 2021) of AVs, directly influences a bicycle user's perceived safety and comfort, and consequently their decision to cycle. The impact on subjective norms arises from unestablished interaction rules in a mixed traffic environment where AVs and human-operated vehicles coexist, leaving bicycle users uncertain about expected behaviours and negotiation tactics. Furthermore, PBC is challenged by an increased cognitive load and situational traffic stress because bicycle users must discern vehicle type and adapt, along with new technology-specific trust issues related to AV reliability and detection capabilities.

Attitudes are formed by an individual based on their appraisal of a behaviour they are deciding to do. It may include an assessment of consequences and a determination if they are positive or negative. When applying this to AV-bicycle interaction, an individual may weigh the consequences of a discrete choice and consider things like utility or satisfaction through perceptions of hostility from other modes, exposure, trip distance, and physical effort (Gutiérrez et al., 2020). For example, the utility of riding a bicycle in a space with an AV may be a more direct route than taking a more circuitous bicycle priority route with dedicated bicycle-only facilities there by increasing the satisfaction through shorter trip duration. Considering the AV-bicycle interaction itself, the AV may behave more cautiously and afford more space to a bicycle user when compared to conventional human-operated

vehicles also improving bicycle user satisfaction. These are only two examples of how attitudes can be influenced by AVs and, as discussed in the empirical chapters, there are many more influences that study participants consider in making their decision to ride a bicycle with an AV.

Subjective norms are the societal or social influences that surround a given behaviour. This can include normative beliefs which is what others think an individual *should* do and an individual's motivation to comply with that normative belief. Depending on the magnitude of the normative pressure, an individual could be more or less likely to conform and comply with social pressure. When applying this to urban bicycle use and AV interaction, there may be pressures to ride a bicycle for environmental and sustainability reasons, these could be considered subjective norms that encourage bicycle use for everyday purposes. Conversely, things like negative media coverage of the risks and dangers of AV bicycle user detection may foster subjective norms that discourage bicycle use (Das, 2021).

PBC describes an individual's interpretation of the simplicity or complexity (difficulty) of performing a behaviour. This can include intrinsic or extrinsic factors that would make behaviour easier or more difficult. When applied to urban bicycle use with AVs, this could be adapted to an individual's perception of safety and/or comfort. The empirical research approach is applied in exclusively living labs where study participants can interact with AVs in their daily lives. The safety/comfort PBC of interacting with a novel transportation option that is driven by artificial intelligence (AI) is a useful proxy for understanding the level of 'difficulty' or if any barriers exist to using a bicycle in ways that participants otherwise would in a city with conventionally operated vehicles.

All these inputs are designed to form the basis of the research design and are discussed in section 4.3.1 *Survey Design & Questions* explaining how they are woven into the research tools, and specifically, the survey questions.

The TPB is a method of determining an individual's *intention*. The theory argues that intention is likely to result in a corresponding behaviour. This thereby serves as a useful way to understand and predict behaviour. In writing this, however, habits are one major factor that is missing from TPB. Shaping an individuals' intention may be better suited to

re-establishing habits than looking at the perceived behavioural control factor, for example (Donald et al., 2014; Gaio, 2020). Individuals who consider choosing a bicycle for urban everyday urban transportation cite their unwillingness to break their habit of using other means of transportation which is usually the private car (Passafaro et al., 2014).

Another missing piece in the TPB is the lack of consideration for *external factors*. For instance, in the context of researching cycling in urban environments, built form and urban morphology can play a significant role in the formation of habits and behavioural intention. The density of buildings, design of rights-of-ways, provision of bike lanes, and availability of sidewalks can all have significant impact (Gaio, 2020; Gutiérrez et al., 2020; Stojanovski, 2019). Actual intention for an individual to make a mode choice can be determined by individual preference which has been referred to as ‘market segments’ or ‘mobility classes’ (Anable, 2005; Barr & Prillwitz, 2012a).

Emotion has also been cited as a factor that impacts behaviour that is not present in the intention-behaviour decision framework of the TPB. Similarly, TPB also overemphasises *rationality*. Several studies have suggested seemingly contrasting qualities of bicycle use such as urban bicycle use being simultaneously healthy and dangerous. Qualitative studies have also found that people describe cycling as evoking both positive and negative emotions (Passafaro et al., 2014). In a qualitative study by Rimano et al. (2012), participants identified emotional feelings of joy, happiness, freedom. They also identified fear-based emotions such as the risk of accidents, and health problems (from air pollution). This study also acknowledged that an individual’s willingness to use a bicycle in urban settings is determined by a combination of practical/utilitarian considerations as well as emotional considerations (Passafaro et al., 2014). While the former consideration may be considered in the TPB, the lack of consideration of emotion (i.e from traffic stress) for urban bicycle use needs to be augmented with supplementary theoretical framing.

A substantial and growing body of research on AV-bicycle user interaction is based on this foundational theory (Passafaro et al., 2014). While many extend the original theory to understand how AVs contribute to an individual’s ultimate behaviour, the TPB approach is common (Fu et al., 2023; Pyrialakou et al., 2020). In acknowledging the gaps in the TPB

theory, this expanded theory and the complementary theories augment the theoretical frame to provide a more complete and nuanced research design.

This dissertation tackles some of the limitations of TPB by integrating it with complementary theoretical frameworks (detailed in the following section) to better understand how AVs impact urban cycling behaviour. The traditional TPB framework, which focuses on attitudes, subjective norms, and perceived behavioral control. As discussed above, TPB has been criticized for overlooking crucial factors like habits, external environmental influences, emotions, and self-identity. To address these gaps, the research incorporates three additional theories: Bicycle User Classification theory (to capture habits and self-identity by categorizing cyclists as 'Interested but concerned,' 'Enthusied and confident,' or 'Strong and fearless'), Traffic Stress Theory (to account for external environmental stressors and emotional responses to different levels of traffic stress), and Fear of AI Theory (to directly address the emotional component, particularly fear of both injury and technology adoption).

The dissertation's methodology is designed to overcome another major limitation in existing AV research: the predominant focus on vehicle occupants rather than vulnerable road users, and the reliance on hypothetical scenarios rather than real-world data. The study exclusively examines bicycle users as non-occupant vulnerable road users through real-world living labs where participants interact with AVs in their daily lives. Using a mixed-methods approach that combines surveys, interviews, and focus groups, along with geospatially calibrated data collection that maps participants' residential proximity to AV routes, the research ensures that findings are based on actual lived experiences rather than theoretical scenarios. This approach aims to provide a more complete understanding of how AVs influence urban cycling behavior by accounting for the complex interplay of psychological, emotional, environmental, and habitual factors that the TPB alone cannot capture.

3.3.2 Bicycle User Classification

The second theory used is to gain a holistic view of bicycle users and to ensure that differing needs of people are represented in urban bicycle use. This second theory is that of bicycle

user classification. Many scholars have contributed different ways to better understand a diverse population of bicycle users. In 2006, the bicycle coordinator at the City of Portland proposed a way of classifying cyclists according to their level of comfort. This classification system has been influential in cycling research and policymaking (Dill & McNeil, 2013). Others have used classification systems that are based on frequency of cycling (Heinen et al., 2010; Winters et al., 2011), seasonality (Bergström & Magnusson, 2003), and cycling stereotype (Gatersleben & Haddad, 2010). While these classification systems that academics have developed are useful for classifying cyclists, they are somewhat inward-looking and do not encompass a perspective of the population that may fit into categories if they consider themselves a 'cyclist' or not (Dill & McNeil, 2013).

In acknowledging that the TPB does not adequately capture individual habits, classifying bicycle user behaviour into commonalities such as habitual infrastructure choices, sense of comfort/safety, and self-identity helps to add a layer of completeness to the inputs of TPB. Therefore, this helps to compensate for weaknesses in TBP: namely habits (Donald et al., 2014) and self-identity (Conner & Armitage, 1998). While the research tools outlined in 4.5 *Data Preparation* do not rely on self-reported self-identity, this self-identity is inferred based on self-reported preferences to elicit a more reliable participant response (Brenner, 2011). The methods for stratifying participants into Geller classifications are also detailed in section 4.5.

The Geller classifications are split into four categories that describe different types of bicycle users (Geller, 2006). The classifications are: 1) 'No way no how' and will not use a bicycle under any circumstances. This study excluded any respondent who indicated that they did not know how to ride a bicycle or were physically unable to ride a bicycle, therefore the Geller classification of 'no way no how' does not apply to the study participants who completed the survey and is not included in the traffic stress scenario matching. This exclusion resulted in three groups that closely resemble those in an empirical reappraisal of bicycle user classifications by Cabral & Kim (2020). The second group is 2) 'Interested but concerned' and will use a bicycle if high quality bicycle facilities are available and are most suited to riding in low levels of traffic stress (i.e. bike trails or multi-use paths through parks and green space or a quiet residential street). The third class is 3) 'Enthused and confident' and will ride a bicycle if there are some bicycle facilities in

place. They are most suited to higher levels of traffic stress than the ‘interested but concerned’ group such as major roads with painted bicycle lanes or cycle tracks. Fourth, 4) ‘Strong and fearless’ bicycle users are a group that will ride a bicycle in nearly all situations even with no bicycle-specific facilities. They can tolerate the highest levels of traffic stress (i.e. major roads without bike lanes/cycle tracks). These groups will be impacted differently according to their *self-identity* and their bicycle use *habits* thereby uncovering a cross-section of *attitudes* towards AVs in the living labs this study examined.

3.3.3 Traffic Stress

The third theory used to frame this research is that of Levels of Traffic Stress (LTS). Traffic stress is a measure determined by risk (also described as safety) and comfort when bicycling with and among motor traffic (Furth et al., 2016). Furth et al. (2016) acknowledge earlier attempts to classify roadways by (perceived) comfort and resulting works such as the bicycle level of service model for road segments (Landis et al., 1997) and the bicycle compatibility index (Harkey et al., 1998). In acknowledging the weaknesses of these earlier attempts that rely on elusive data availability (traffic volumes, lane widths), confusing and complex calculations that are difficult to understand therefore having reduced utility, and assuming that all bicycle users are ‘average’ thereby assuming all bicycle user needs are identical.

LTS bases its bicycle user group distinction on the Geller classification segments but reclassifies the least confident ‘No way no how’ segment as a bicycle user group that represents children. The four levels of traffic stress are outlined in Table 3.3.1 below.

Table 3.3.1 Levels of Traffic Stress (Furth et al., 2016)

LTS Level	Description
1	Demands little attention to traffic from cyclists and attractive for a relaxing bike ride. Suitable for almost all cyclists, including children trained to safely cross intersections. On road sections, cyclists are either physically separated from traffic or are in an exclusive bicycling zone next to a slow traffic stream with no more than one lane per direction, or are in mixed traffic with a low-speed differential and demanding only occasional interactions with motor vehicles. Next to a parking lane, cyclists have ample operating space outside the zone into which car doors are opened. Intersections are easy to approach and cross.
2	Presents little traffic stress but demands more attention than might be expected from children. On road sections, cyclists are either physically separated from traffic or are in an exclusive bicycling zone next to a well-confined traffic stream with adequate clearance from a parking lane, or are on a shared road where they interact with only occasional motor vehicles with a low-speed differential. Where a bike lane lies between a through lane and a right-turn lane, it is configured to give cyclists unambiguous priority where cars cross the bike lane and to keep car speed in the right-turn lane comparable to bicycling speeds. Crossings are not difficult for most adults.
3	Offers cyclists an exclusive cycling zone (e.g., bike lane) requiring little negotiation with motor traffic, but in close proximity to moderately-highspeed traffic or mixed traffic requiring regular negotiation with traffic with a low speed differential. Crossings may be stressful but are still considered acceptably safe by most adult pedestrians.
4	Requires riding near to high-speed traffic, or regularly negotiating with moderate-speed traffic, or making dangerous crossings.

The living lab sites for this study were selected based on their traffic stress situations. The classification and site selection for each of the four living labs included in this study are outlined in section 0.

3.3.4 Other Theories Considered

While the core theory of TPB was used, layered in with LTS and Bicycle User Classifications, there were other theories considered but ultimately ruled out from being used as the core theoretical frame. Two additional theories were contemplated: the Technology Acceptance Model (TAM) (Davis, 1993) and Diffusion of Innovations (DOI) Theory (Rogers et al., 2008). While aspects of the TAM and Diffusion of Innovations Theory were considered and even utilized within specific components of this research, they were not selected as the primary socio-psychological theoretical framing because they did not directly address the core behavioural determinants and critical societal implications of AVs on urban bicycle users as suitably as the augmented TPB could.

While the TAM and DOI Theory were acknowledged and partially applied within the research, they were ultimately not selected as the central socio-psychological theoretical

framework due to their limitations in addressing the core behavioural and societal dimensions of how AVs affect urban bicycle users. TAM was set aside because of its technocentric focus on *acceptance*, which is critiqued as implicitly framing the technology as inherently beneficial and placing the burden of adaptation on society. This perspective was seen as incompatible with the study's commitment to mobility justice and its goal to critically examine how AVs might reshape attitudes, power dynamics, and infrastructure for urban bicycling. Similarly, DOI was only used as a background variable to assess general technology adoption tendencies but was not suited to explain the specific psychological processes behind individual behavioural intentions in response to AVs.

Instead, TPB was selected as the primary theoretical framing because of its established relevance in transportation behaviour research and its direct alignment with the study's objectives. TPB's focus on attitudes, subjective norms, and perceived behavioural control offered a robust framework for understanding bicycle users' behavioural intentions in environments shared with AVs. To overcome TPB's limitations, the model was augmented with complementary theories—such as Bicycle User Typologies (for self-identity and habit), Level of Traffic Stress (for environmental comfort and safety), and, to a lesser extent, Fear of AI theory (to account for emotional responses). This blended approach allowed for a more nuanced, human-centred analysis of how AVs impact active transportation users beyond what TAM or DOI could provide.

3.3.5 Other Contemporary Theoretical Influence

An additional theory that is woven throughout the research design is the concept of fear of AI theory. Fear of AI theory is based in what psychology describes as a basic emotion which is understood as an “innate psychological [state] that universally characterize[s] human beings” (Cugurullo & Acheampong, 2023, p. 1). Fear (more broadly) is present, most obviously, through two aspects that this study interrogates.

The first is the fear of injury or death when riding a bicycle in a risky, high stress environment that is often synonymous with inadequate cycling infrastructure in cities. The above-mentioned levels of traffic stress aim to describe and stratify into a set of ordinal classifications. Bicycle users fear that their vulnerability on streets where they are expected

to share the road with multi-tonne, fast moving metal projectiles is a high-risk activity. And without safe, separated, all ages and abilities bicycle infrastructure it *is* high risk and justifiably incites fear. The second fear is one that of technology that is dealt with in AI adoption theory. Although not an exclusive fear of bicycle users, the fear of AI described through AI adoption theory (Cugurullo & Acheampong, 2023) is a reasonable apprehension that many people experience. Particularly when walking and biking next to a vehicle that, when driven by a human, is already sufficiently intimidating to a VRU. When reflecting on AI-mediated transport systems and the application of AI to vehicles such as AVs interacting or sharing space with bicycle users, there are several plausible scenarios where the “risks and dangers connected to AI as something that we should not underestimate, but rather be afraid of” (Cugurullo & Acheampong, 2023, p. 2).

A visual overview of the input structure and theoretical framework is shown in Figure 3.3.1 is presented below. This figure illustrates the augmented theoretical framework, which combines the TPB with Geller Bicycle User Classifications and LTS Tolerance to comprehensively understand how AVs will impact urban cycling.

A major component of the framework is TPB, which models how attitude, subjective norms, and PBC shape a person’s intention to perform a behaviour—in this case, urban cycling in the presence of AVs. To address known limitations of TPB—such as its minimal attention to identity, habit, emotional responses, and environmental constraints—the model is enhanced by two complementary components. The Geller Bicycle User Classifications contribute to understanding cyclist self-identity and habit, which influence their attitudes toward cycling. The LTS Tolerance framework captures external factors and emotional responses, particularly safety perceptions and fear of AV-related risks, and feeds into the PBC construct.

Together, these added lenses enrich TPB’s explanatory power. The resulting framework, as visualized in Figure 3.3.1, provides a holistic view of how behavioural intentions and actions are shaped not just by rational assessments, but also by identity, environment, and emotion—enabling a more grounded analysis of how AVs might alter the cycling experience in real-world urban contexts.

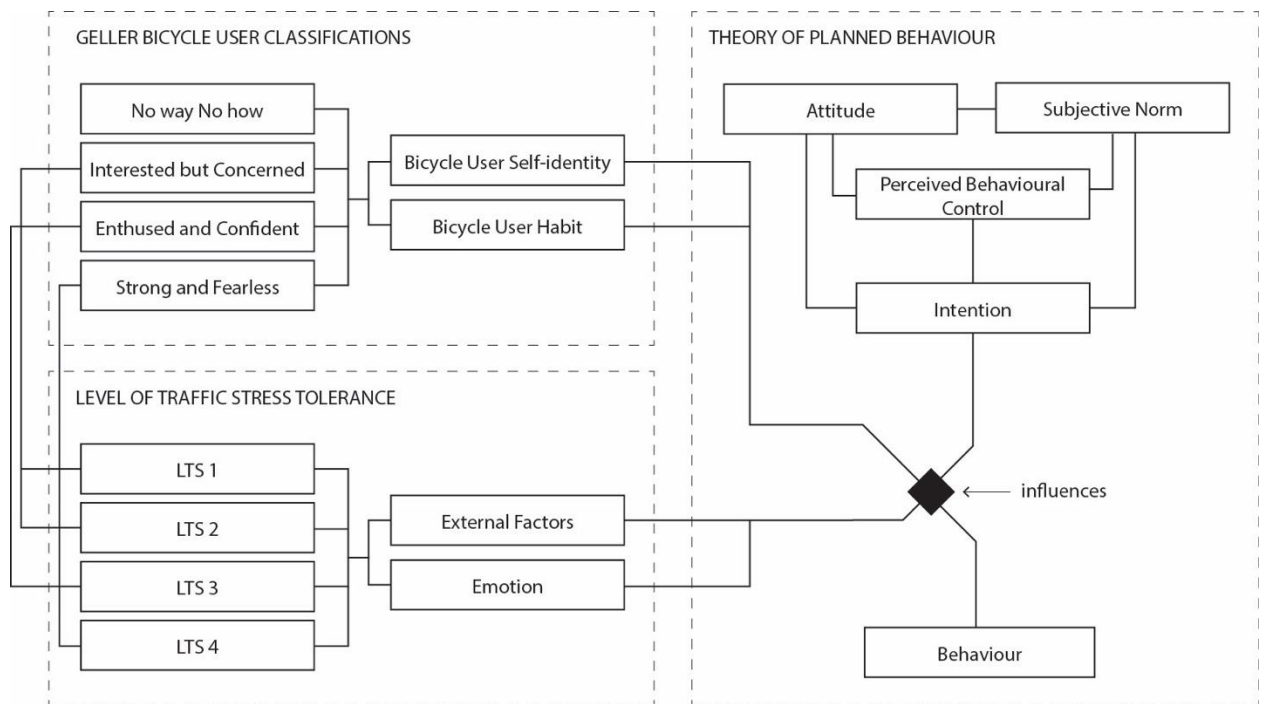


Figure 3.3.1 Theoretical framework structure

3.4 Linking Theory to Research Questions

3.4.1 Question 1: To what extent will the introduction of self-driving vehicles impact attitudes towards cycling in self-driving 'living labs'?

Question 1 is designed to glean data related to the 'attitude' input to the TPB. It is also influenced by the 'bicycle user self-identity' and 'bicycle user habit' factors that impact an individual's decision-making process that are drawn from the Geller bicycle user classifications. Attitude is closely related to trust and perception in determining bicycle use near autonomous vehicles (Penmetsa et al., 2019; Pyrialakou et al., 2020). Therefore, understanding the impact from bicycle users who identify as more or less confident will have differing attitudes that impact their propensity to bike in a streetscape that also hosts AVs.

Posing attitudinal questions to participants in AV living labs as outlined in the empirical chapters is the method for gaining an understanding to answer this question.

3.4.2 Question 2: How is the introduction of self-driving pilots influencing cycling trips?

This question is a normative question that assesses how the subjective norms component of TPB influences cycling trips regarding AV-bicycle interaction. It asks how bicycle users that interact with AVs in the selected living lab sites will ultimately behave in a streetscape with AVs. The methodological approach to collecting data for this question discussed in Chapter 6 asks participants to both quantitatively and qualitatively describe how their normative perception of AVs and the perceptions among other bicycle users and those in their peer groups will impact their ultimate decision to take a bicycle trip and for what purpose as well as what factors impact their decision. This question is designed to understand the 'subjective norm' component of the TPB.

3.4.3 Question 3: How can streets be designed to be conducive to cycling with self-driving vehicles from a non-occupant perspective?

As discussed throughout this dissertation, one of the biggest barriers to riding a bicycle in cities is the lack of safe, separated bicycle infrastructure. This creates a perception of difficulty for a majority of individuals who are 'interested but concerned' to ride a bicycle. In directly attributing safety and comfort to the level of difficulty of an urban bicycle user, this question is designed to solicit input to the 'perceived behavioural control' variable of the TPB. It is also influenced by the LTS framework input.

The identified living lab sites represent a complete cross-section of four types of street design scenarios as defined by the LTS framework. Participants who experience an AV in each of the traffic stress environments inform the desirable street design qualities for each level of traffic stress.

Collectively, all three research questions aim to collect information on the factors that lead to an intention and an ultimate behavioural decision on whether to ride a bicycle in a future with AVs. The factors are augmented by supplementary theory to better understand relevant influences for bicycle users that aims to address weaknesses of using TPB on its own.

4. Methods

4.1 Introduction

This chapter explains, in detail, the methodological approach used for this project. It provides a practical application of the theories discussed in Chapter 3 as well as several approaches to address background concerns and research gaps raised in Chapter 2. In the most basic terms, a mixed-methods approach was used that relied on three different methods. These methods are surveys, interviews, and focus groups. The places where these methods were used were also determined using a site selection method that is also outlined.

The sites chosen are a set of living labs that are real-world environments that can facilitate everyday interactions with smart city technology, including AVs, where residents can encounter AVs in an uncontrolled environment (Dowling & McGuirk, 2022). This chapter is laid out in 8 subsections following the introduction. In Section 0 the living lab approach is outlined, how the sites were selected, including some of their characteristics that were applied to the traffic stress theory as described above in Section 3.3.3. In Section 4.3, there is an explanation of the survey design, participant selection, and recruitment approach. Thereafter, in Section 4.4, the design and format of interviews and focus groups and how they were carried out is outlined. Section 4.5 and 4.6, outline data preparation and analysis methods from each collection tool. Following, in Section 4.7, the consent and privacy measures taken to preserve personal data integrity and maintain participant trust are described. In section 4.8, contributions that this methodological approach and design can offer for the field of transportation geography, travel behaviour, and transportation planning research are highlighted. Finally, conclusions regarding methods are drawn in section 4.9.

4.2 Living Lab Approach and Site Selection

This project employs the use of living labs to apply theory to empirical observation. These experimental neighbourhoods, often called ‘living labs’, are being created that facilitate everyday interactions with smart city technology including AVs (Cugurullo et al., 2023; Dowling & McGuirk, 2022). This section outlines how the accounts of residents of living labs who can use and interact with AVs in their daily lives are engaged for this study. This approach was chosen to engage participants who have lived experience with AVs which is an identified research gap (Berge et al., 2023) (see Section 2.3.2). Living labs with AVs are a pioneering example of how urban mobility innovation policy may materialise which requires further study. These living lab ‘utopias’ could be an embodiment of policies that focus more on vehicles than other mobility (Behrendt, 2020) and this could have an unknown impact on other road users, namely bicycle users, which are the focus of this study.

4.2.1 Selection Criteria

Living lab sites were selected systematically based on several factors. These were informed by the theoretical framing and selected for pragmatic reasons. The data collection for the present study necessitated that AV living labs were active during the data collection phase of the project (2021-2022). Living lab sites were selected to represent a range of bicycle urbanism maturities (McLeod et al., 2020), levels of traffic stress (Furth et al., 2016), and feature similar types of AVs (appearance, speed, capacity) operating in them. To be considered for the study, the living lab’s AV operating capability must have met the description for SAE level 2 or higher. This means that, at a minimum, the AV shuttles must be capable of partial automation: “automated steering and acceleration capabilities” (Dyble, 2020, para. 11), however, all AVs included in this study satisfied SAE level 3 which can be described as conditional automation: “environment detection” (Dyble, 2020, para. 13). All AV shuttles had a safety operator onboard for when the conditional automation failed or in the event of an emergency.

The methods described in this chapter were replicated at each location. In consideration of the AV capabilities across all sites, study sites were chosen based on the following criteria:

1. AVs with SAE level 3 (SAE International, 2018) capability (i.e. the AV features are driving the vehicle unless the feature required operator intervention) were operating in public rights-of-way;
2. AVs were available for the public to use and/or interact with;
3. AVs share the right-of-way with bicycle users; and,
4. The traffic situation corresponded to one of the levels of the Mineta Transportation Institute's levels of traffic stress (Furth et al., 2016).

The selected locations used as living labs for the study that answered that was designed to answer the three research questions outlined in Section 3.4 are fourfold. Each site met the four selection criteria presented above. The first living lab site was an AV shuttle test-site in a suburb (Aalborg Øst) of Aalborg, Denmark and served as the pilot location for the study. The second living lab site was a commercial street with an AV shuttle circuit in an inner-city neighbourhood (Rosemont–La Petite-Patrie) of Montréal, Canada. The third living lab site was a university campus and neighbouring residential area (Vallastaden) in Linköping, Sweden where four AV shuttle vehicles from two vendors were operating a fixed-route circuit. The fourth and final living lab site was a fixed route AV public bus route in Stavanger, Norway that connected the main railway station with the main concert hall. The Stavanger AV bus was integrated into the regular transit system where passengers could pay with their regular transit fare card. All AV shuttles at the living lab sites were operated by third parties not involved with this study and had onboard attendants as required by local laws. There were two additional Greater Toronto Area sites (Rouge Hill and Whitby) initially planned. The latter of the two sites contributed some survey results; however, both sites had further data collection aborted due to technical problems and subsequent cancellation by the operating agencies as described in section 4.3.1 and alluded to in section 4.5.2.5.

Living lab sites were also selected to represent a range of bicycle urbanism maturities. McLeod et al. (2020) provide a rubric called the 'Maturity Model' for adjudicating planning

for cycling. This model is a tool to extrapolate a city's bicycle urbanism maturity in a systematic way. The model has 6 maturity stages ranging from 0 – 5. Cycling maturity stage 0 is 'marginalised/ignored' and stage 6 is 'culture'. Each maturity level is scored in 14 categories: planning attitudes, 'who are cyclists in the eyes of decisionmakers?', commitment for coordinated investment/network development, integration with land use planning, integration with public transport, policy consistency/longevity, vulnerability of cycling projects/implementation, safety management approach, safety enforcement, health promotion, infrastructure design standards, use of network planning tools, incentives/competitive with private vehicle travel, and typical source of leadership.

Each living lab was scored on this model. Aalborg scored 3.23, Linköping scored 2.87, Montréal scored 2.62, and Stavanger scored 4.03. This range of bicycle urbanism maturities is shown on the spectrum in Figure 4.2.1 below. It should be noted that this scoring method is subjective and bias was reduced by averaging the score from the author and at least one third party adjudicator that is also a local resident in each living lab city. Cities were scored on the cycling maturity model and awarded points in each thematic category on a point scale (0-5). An average score was determined for each person performing the assessment by totalling all the point values and dividing by the total number of thematic categories (14). The two averages from both evaluators were then averaged to assign a bicycle urbanism maturity score. A summary of the third party adjudicators qualifications is included in Table 4.2.1 below.

Table 4.2.1 Third party adjudicators

living lab City	Adjudicator Qualification(s)
Aalborg	President of Aalborg Chapter and Board Member of Danish Cycling Federation
Montréal	Local Cycling Advocate
Linköping	AV-ORU Interaction Researcher
Stavanger	Local Planning Official

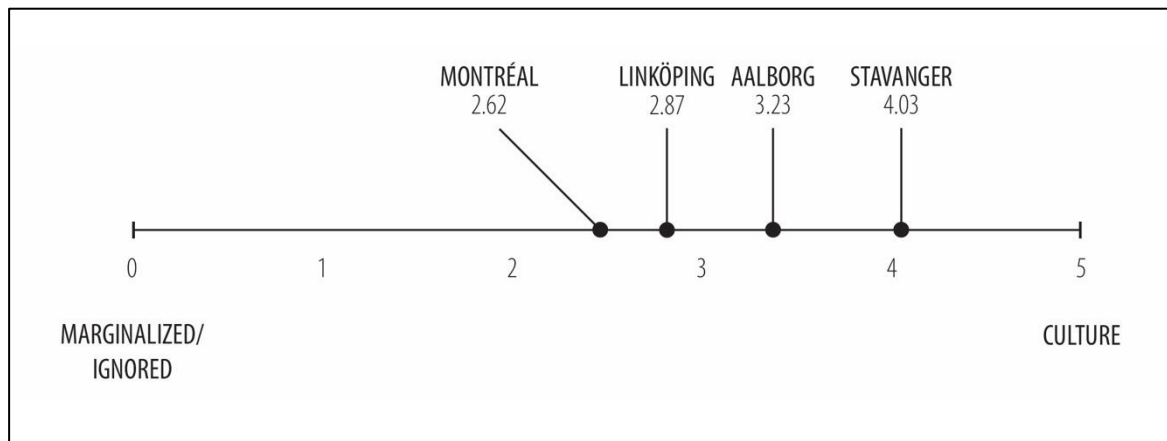


Figure 4.2.1 Bicycle urbanism maturity scores (author's original)

In addition to bicycle urbanism maturity, living labs were also assessed against the LTS classification system (Furth et al., 2016). These classifications were determined by using the relevant traffic stress classification tables from a paper titled *Network Connectivity for Low-Stress Bicycling* (Furth et al., 2016). The tables require a systematic assessment of the street design and traffic scenario in each segment of the Av's operating environment. Each segment was classified into a type of infrastructure that could be evaluated with one of the tables in the LTS classification system. The tables in the LTS traffic system used were:

- Table 2: Criteria for Bike Lanes Alongside a Parking Lane
- Table 3: Criteria for Bike Lanes Not Alongside a Parking Lane
- Table 4: Criteria for Level of Traffic Stress in Mixed Traffic

The LTS scoring for the living lab sites was systematically conducted using the Mineta Transportation Institute's LTS framework (Furth et al., 2016). This framework classifies the safety and comfort of bicycle infrastructure based on factors like traffic speed and separation.

The assessment for each living lab site involved a segment-by-segment evaluation of the AV operating environment. Specifically, the study consulted three relevant LTS classification tables from the paper *Network Connectivity for Low-Stress Bicycling* (Furth et al., 2016):

The "weakest link logic" (Furth et al., 2016, p. 46) was then applied to determine the overall LTS for each site. This means that the entire route was assigned the LTS level of its "most stressful link" (Furth et al., 2016, p. 46).

Tables 5 and 6 for intersection approaches were not used because there were either no intersection approaches that matched the LTS description in the living lab sites or there was no effect on LTS. The sites were scored against these tables and the results were determined using "weakest link logic" (Furth et al., 2016, p. 46) which assigned a level of traffic stress according to "the most stressful link" (2016, p. 46). The results of the LTS assessment are shown with the requisite table scoring tools along with photos and descriptions in Sections 0 to 4.2.5 below.

4.2.2 Aalborg



Figure 4.2.2 Typical streetscape of autonomous shuttle in Aalborg living lab site (author's original)

AV Shuttle Info At-a-glance:

Typical operating speed: 20 km/h

Make/model: Navya AUTONOM® Shuttle

Number of vehicles at site: 2

Approximate route distance: 1.8 km

The shuttles in Aalborg operated separate from vehicular traffic on a mixed-use pedestrian and bicycle pathway. The shuttle had designated pick-up and drop-off stops at designated points along the route approximately every 400 metres. These stops were only on one side of the pathway and because of the bidirectional design of the shuttle with a door only on one side, it did not turn around and served the stops on the one side of the pathway. Stops were only installed on one side of the pathway to save infrastructure costs. It should be noted that while the stops were on the 'correct' side for only one direction of the shuttle's

operation. When the shuttle travelled in the opposite direction, it served the stops on the 'incorrect' side by veering onto the side of the pathway that would normally be for oncoming pathway users travelling counter to the direction of the shuttle. This was confusing for other pathway users and was somewhat disruptive.

Two Navya shuttle vehicles operated at speeds of no more than 20km/h at SAE level 4, but usually only one was in service at any given time, either due to technical issues or labour disputes from the safety operators caused by discontent with the shuttle service's imminent termination leading to their inevitable redundancy. The route was approximately 1.8km and took 15mins to complete one direction, making several stops along the route between the neighbourhoods of Mjel and Nørre Tranders. Navya has positioned itself as a pioneer in the AVs shuttle space, deploying their AUTONOM® shuttle vehicles in various urban environments such as university campuses, business parks, and airports around the world.

The nature of the urban morphology along the route in East Aalborg is suburban. There are single family homes, multiplexes, and walk-up apartment blocks. In the centre of the route, there is a community centre with a library, café, playground, and supermarket. The demographics around the shuttle route are new immigrants, young professionals, young families, and seniors.

Due to the shuttle's operating environment of a mixed-use pathway separated from other vehicular traffic, no LTS assessment tables were required for the Aalborg living lab site because "cycle tracks and shared use paths, which offer a physically separate cycling zone, are classified as LTS 1" (Furth et al., 2016, p. 42) which describes the environment of the Aalborg living lab.

Aalborg was pilot location and served as the initial test location for the study's methodological approach. The primary objective of this pilot was to evaluate the practicality and usability of the data collection tools.

This pilot critically informed and shaped the study design, particularly regarding the online survey platform. Initially, the EUSurvey platform was used for data collection in Aalborg. However, it was found to lack overall usability and an intuitive design, which likely impacted response rates. This observation led to a significant adjustment in the study's methodology where the survey questions were ported to a different, more user-friendly and GDPR-compliant platform called Tripetto, which subsequently resulted in improved response numbers at later sites. While Aalborg served as the pilot survey location, no focus groups were conducted at this site.

4.2.3 Linköping



Figure 4.2.3 Typical streetscape of autonomous shuttle in Linköping living lab site (author's original)

AV Shuttle Info At-a-glance:

Typical operating speed: 20 km/h

Make/model: Navya Autonomous Shuttle DL4, EasyMile WZ10 gen2

Number of vehicles at site: 4 (two of each shuttle)

Approximate route distance: 2.1km

In Linköping, two types of shuttles were used. There were two Navya shuttles and two EasyMile shuttles operating at SAE level 4 with a safety operator. At the time of data collection, these buses operated in a fixed-route pattern of speeds of no more than 20 km/h. In the fixed route pattern, there are designated stops for riders to board and alight along the route to serve popular destinations on the University of Linköping (LiU) campus and surrounding science park and neighbourhood. Unlike the Aalborg example, and owing

to the one-way circuit pattern of the route, the shuttle busses always served stops on the ‘correct’ side of the street which aided in the behavioural legibility of the shuttles.

The nature of the urban morphology where the Linköping shuttles operated was varied. They drove on both mixed-use slow-speed woonerf style streets, and regular streets with clear curb edges where pedestrians, bicycles, and vehicle traffic were delineated. The route served portions of a university campus main pedestrian and cycling mall, a science park with industrial office buildings, and a residential neighbourhood.

Owing to the varied operating environment of the Linköping shuttles, more than one LTS scoring table was required to assess the overall LTS for this living lab.

Table 4.2.2 AV/bicycle route sections in Linköping

Section(s)	Limit	LTS Scoring Table
Main pedestrian/bike mall with AVs	N/A	Table 4: Criteria for Level of Traffic Stress in Mixed Traffic
Hans Meijers väg, Olaus Magnus väg, Paradisgatan, Lärdomsgatan, Johannes Magnus väg	30 km/h	No table: Physically separated bike ways – LTS 1
Kunskapslänken	50 km/h	No table: Physically separated bike ways – LTS 1

Noted in Table 4.2.3 below, where the Linköping site could be considered either a LTS 1 or 2 environment based on the “weakest link” (Mekuria et al., 2012, p. 7) logic given that the only section eligible to be scored on an LTS table is the main pedestrian and bike mall which is shared by the AV shuttles and other working vehicles. Understanding that the most stressful section of the operating environment, there are a few considerations to be made. While the space is mixed traffic and has a de facto low speed limit with no centerlines, it is not a residential street and often has high volumes of people walking and cycling at the same time. Volumes of other bicycle users and people walking are not determined as factors for traffic stress under the LTS scoring tables, in considering this, given the complexities through a high volume of simultaneous movement, and using weakest link logic, Linköping is deemed to be LTS 2. This builds on a recommendation by De Ceunynck et al. where “future research could focus more strongly on specific situations in which

other road users can have a stronger gain from taking advantage of the way automated shuttles behave, such as locations where many VRU are in a hurry” (2022, p. 18). This is broadly an example of what the LiU campus environment exemplifies.

Table 4.2.3 Criteria for Mixed Traffic at Linköping living lab site, adapted from (Mekuria et al., 2012, p. 21)

Speed Limit or Prevailing Speed	2-3 lanes	4-5 lanes	6+ lanes
Up to 40 km/h	LTS 1 ^a or 2 ^a	LTS 3	LTS 4
50 km/h	LTS 2 ^a or 3 ^a	LTS 4	LTS 4
55+ km/h	LTS 4	LTS 4	LTS 4
^a Use lower value for streets without marked centerlines or classified as residential and with ADT ≤ 3000; use higher value otherwise. Conversion to metric rounded to nearest 5 km/h			

4.2.4 Montréal



Figure 4.2.4 Typical streetscape of autonomous shuttle in Montréal living lab site (author's original)

AV Shuttle Info At-a-glance:

Typical operating speed: 20 km/h

Make/model: Navya AUTONOM® Shuttle

Number of vehicles at site: 2

Approximate route distance: 2.0 km

The shuttles in Montréal operate on a commercial street in the neighbourhood of Rosemont. The shuttle circuit proceeds one direction on St-Hubert Street then returns the other direction on St-Denis Street turning at Beaubien and Jean-Talon. Two Navya shuttle vehicles operated as SEA level 4 with a safety operator at speeds of no more than 20km/h, but usually only one was in service at any given time. The circuit was 1.2km and took 30mins to complete, making several stops along the route.

The nature of the urban morphology along the route is urban, with a commercial plaza on St-Hubert including mixed traffic zones where the sidewalk blended with the roadway. St-Denis was more residential and is lined with two-to-three story multiplexes and apartments.

St-Hubert Street was the primary focus of the study and had no separate bike lanes or other infrastructure. The street operated as one way and has on-street-parking on one side. The streets running parallel (Boyer St and Av de Chateaubriand) have designated bike lanes.

Table 4.2.4 AV/bicycle route sections in Montréal

Section(s)	Limit	LTS Scoring Table
St-Hubert	20 km/h	Table 4: Criteria for Level of Traffic Stress in Mixed Traffic
St-Denis	30 km/h	Table 2: Criteria for Bike Lanes Alongside a Parking Lane

The maximum speed on St-Hubert is 20km/h and 30km/h on St-Denis. The LTS tables for both 'Bike Lanes Alongside Parking Lane' and 'Mixed Traffic' were consulted to determine a level of traffic stress for this site based on the available LTS criteria, the physical manifestation of the infrastructure because neither neatly fit the description of the conditions of St-Hubert Street. This was also balanced with how participants described

usage in practice. The Bike Lanes Alongside Parking Lane table resulted in LTS 3 and the Mixed Traffic table resulted in LTS 2. In using weakest link logic, and the primary observation from fieldwork, this site is deemed to have LTS 3 as shown in Table 4.2.5 and Table 4.2.6 below.

Table 4.2.5 Criteria for Bike Lanes Alongside a Parking Lane at Montréal living lab site; adapted from (Mekuria et al., 2012, p. 18)

	LTS ≥ 1	LTS ≥ 2	LTS ≥ 3	LTS ≥ 4
Street width (thru lanes per direction)	1	(n.a.)	2 or more	(n.a.)
Sum of bike lane and parking lane width	15 ft or more	14 or 14.5 ft ^a	13.5 ft or less	(n.a.)
Speed limit or prevailing speed	40 km/h or less	50 km/h	55 km/h	60 km/h or more
Bike lane blockage	rare	(n.a.)	frequent	(n.a.)
^a If speed limit < 25 mph, or land use is residential with little parking turnover, then any width is acceptable for LTS 2. Conversion to metric rounded to nearest meter or 5 km/h				

Table 4.2.6 Criteria for Mixed Traffic at Montréal living lab site, adapted from (Mekuria et al., 2012, p. 21)

Speed Limit or Prevailing Speed	2-3 lanes	4-5 lanes	6+ lanes
Up to 40 km/h	LTS 1 ^a or 2 ^a	LTS 3	LTS 4
50 km/h	LTS 2 ^a or 3 ^a	LTS 4	LTS 4
55+ km/h	LTS 4	LTS 4	LTS 4
^a Use lower value for streets without marked centerlines or classified as residential and with ADT ≤ 3000; use higher value otherwise. Conversion to metric rounded to nearest 5 km/h			

4.2.5 Stavanger



Figure 4.2.5 Typical streetscape of autonomous shuttle in Stavanger living lab site (author's original)

AV Shuttle Info At-a-glance:

Typical operating speed: 50 km/h

Make/model: Karsan Autonomous e-ATAK

Number of vehicles at site: 1

Approximate route distance: 1.3km

The Stavanger living lab site was unique in comparison to the other living lab sites. In Stavanger, the autonomous bus was a different kind of vehicle that resembled a traditional city bus. The bus operated at normal speed limits up to 50 km/h along bus route 18. This was a bus route that was integrated into the regular Kolombus public transport network and accepted paying customers. The vehicle used is an 8.3m Karsan Autonomous e-ATAK bus that operates as SAE level 4 with a safety operator onboard.

The route was approximately 1.3km long and busses operated bidirectionally. Along the route, there were advisory bike lanes that designated space for bicycles to share the space with vehicular traffic. The urban morphology along the route was varied. The route began in the city centre at the main bus exchange near the central train station next to a park. The route continued through a shopping plaza (Kongsgårdbakken) and along the harbour quay (Strandkaien transitioning to Nedre Strandgate) with shops, businesses, and housing on one side of the street, and a parking lot on the other side of the street. The bus route continued to the main concert house and turned around to do the return trip. On many occasions, large cruise ships were docked alongside the bus route and there was ample cruise ship tourism activity along the bus route. Table 4.2.7 (below) outlines the three different LTS tables that were used to define the overall LTS for the Stavanger living lab.

Table 4.2.7 AV/bicycle route sections in Stavanger

Section(s)	Limit	LTS Scoring Table
Kongsgårdbakken	30 km/h	Table 4: Criteria for Level of Traffic Stress in Mixed Traffic
Strandkaien	40 km/h	Table 2: Criteria for Bike Lanes Alongside a Parking Lane
Nedre Strandgate	40 km/h	Table 3: Criteria for Bike Lanes Not Alongside a Parking Lane

Following the evaluation of the living lab operating conditions and street design for Stavanger in Table 4.2.8 to Table 4.2.10 the LTS score is LTS 3, based on the weakest link logic for the results for a bike lane alongside a parking lane. This score is the same as the Montréal score, however the difference in cycling maturity and the type of AV that is used differs which also adds to the diversity of traffic stress scenarios investigated.

Table 4.2.8 Criteria for Bike Lanes Alongside a Parking Lane at Stavanger living lab site; adapted from (Mekuria et al., 2012, p. 18)

	LTS ≥ 1	LTS ≥ 2	LTS ≥ 3	LTS ≥ 4
Street width (thru lanes per direction)	1	(n.a.)	2 or more	(n.a.)
Sum of bike lane and parking lane width	15 ft or more	14 or 14.5 ft ^a	13.5 ft or less	(n.a.)
Speed limit or prevailing speed	40 km/h or less	50 km/h	55 km/h	60 km/h or more
Bike lane blockage	rare	(n.a.)	frequent	(n.a.)
^a If speed limit < 25 mph, or land use is residential with little parking turnover, then any width is acceptable for LTS 2. Conversion to metric rounded to nearest meter or 5 km/h				

Table 4.2.9 Criteria for Bike Lanes Not Alongside a Parking Lane at Stavanger living lab site; adapted from (Mekuria et al., 2012, p. 18)

	LTS ≥ 1	LTS ≥ 2	LTS ≥ 3	LTS ≥ 4
Street width (thru lanes per direction)	1	2, if directions are separated by a raised median	more than 2, or 2 without ^a separating median	(n.a.)
Bike lane width (includes marked buffer and paved gutter)	6 ft or more	5.5 ft or less	(n.a.)	(n.a.)
Speed limit or prevailing speed	50 km/h or less	(n.a.)	55 km/h	60 km/h or more
Bike lane blockage	rare	(n.a.)	frequent	(n.a.)
Conversion to metric rounded to nearest meter or 5 km/h				

Table 4.2.10 Criteria for Mixed Traffic at Stavanger living lab site, adapted from (Mekuria et al., 2012, p. 21)

Speed Limit or Prevailing Speed	2-3 lanes	4-5 lanes	6+ lanes
Up to 40 km/h	LTS 1 ^a or 2 ^a	LTS 3	LTS 4
50 km/h	LTS 2 ^a or 3 ^a	LTS 4	LTS 4
55+ km/h	LTS 4	LTS 4	LTS 4
Conversion to metric rounded to nearest 5 km/h			

4.2.6 Contextual Background of Living Lab Sites

4.2.6.1 *Aalborg, Denmark*

Aalborg's emergence as a living lab reflects Denmark's position as a global leader in cycling culture and sustainable mobility policy. The Danish national context is characterised by comprehensive cycling infrastructure, supportive regulatory frameworks, and a cultural norm that positions cycling as a legitimate mode of transport across all demographic groups. At the regional level, North Denmark has actively pursued smart city initiatives and autonomous vehicle pilots as part of broader innovation strategies.

The specific living lab location in Aalborg, a suburban neighborhood featuring mixed housing typologies and a community centre, was selected for its dedicated pedestrian and bicycle pathway infrastructure. This physically separated cycling environment provides an ideal setting for observing AV-bicycle interactions in low-stress conditions, where the potential for conflict is minimized by design. The site's characteristics enable examination of how AVs navigate spaces where cyclists have protected priority.

4.2.6.2 *Linköping, Sweden*

Sweden's national commitment to smart city innovation and sustainable urban mobility creates a supportive environment for AV testing and cycling integration. The Swedish approach emphasises technological solutions to urban challenges while maintaining strong environmental and social sustainability goals. Linköping, as a university city with significant technology sector presence, exemplifies this national approach at the local level.

The living lab at Vallastaden encompasses a mixed-use area incorporating university campus facilities, science park developments, and residential zones connected by slow-speed streets. This urban fabric was crucial for the site's selection, as it enables observation of AV-bicycle interactions across varying contexts—from segregated paths to shared spaces with mixed traffic conditions. The level of cycling maturity in Linköping provides insights into how AVs perform in environments where cycling infrastructure is present but not yet fully integrated into the urban system.

4.2.6.3 Montréal, Canada

Montréal's inclusion represents the North American context, where cycling infrastructure development varies significantly from European approaches. While Canada increasingly supports cycling and AV initiatives at the national level, implementation varies considerably across urban centers. Montréal's leadership in cycling infrastructure development within the Canadian context made it an essential case study for understanding how AVs interact with cyclists in North American urban environments.

The living lab focuses on urban commercial and residential streets characterized by mixed traffic conditions and varying cycling facility types. This higher-stress environment, where cyclists must navigate alongside conventional vehicles and emerging AV technology, provides critical insights into the challenges of AV-bicycle integration in cities with evolving cycling infrastructure. The site's selection enables examination of how AVs perform in environments where cycling facilities are present but may lack the deep, comprehensive integration found in more mature cycling cities.

4.2.6.4 Stavanger, Norway

Norway's substantial investment in sustainable transport and AV technology, supported by both national policy and regional innovation initiatives, creates an ideal environment for living lab research. The Norwegian context combines strong environmental commitments with technological innovation capabilities, particularly in the transportation sector.

Stavanger's city center location, encompassing shopping areas and waterfront area with advisory bike lanes and shared spaces, was selected for its high cycling maturity and the integration of AVs into regular public transport operations. This complex, high-activity urban setting enables observation of AV-bicycle interactions in environments where both modes of transport are well-established and must coexist within limited urban space. The site provides insights into how AVs navigate complex urban environments where cycling is normalised and infrastructure is mature.

4.2.7 Identified Strengths & Weaknesses

The living lab approach used in this research design is beneficial for understanding the current state of accessible AVs in real-world environments. The selection of case study locations is a diverse representative sample of the current transition to AI-mediated transport systems and autonomous transportation in particular. The four living lab site locations are a carefully selected group of neighbourhood-scale AV deployments that are an ideal example of the technology's application in Western cities. The learnings gleaned from study of these living labs are a useful baseline and can serve as a proxy for other, more progressed implementation of AVs in other urban settings.

It must be noted that a weakness of the LTS framework and the above tables were designed in and for traffic stress environments in the United States. The LTS framework was developed in San Jose, California at San Jose State University. This may preclude the full range of the LTS scoring spectrum from being used in a European setting because, in many cases, the street designs and traffic stress environments are typically lower. There may be cases that the LTS framework may need to be calibrated for different locales. This became apparent when scoring the LTS for Stavanger vs Montréal where the Stavanger living lab site had relatively higher LTS than Montréal (i.e. higher prevailing vehicle speeds, dotted paint advisory bike lanes) but was scored the same level based on the LTS framework. While this is noted in the above evaluation (4.2.5), it is important to acknowledge that there is no 'right way' to conduct LTS analysis, but that it is difficult to systematically assess street environments objectively especially noting that traffic stress is experienced differently by everyone and is *relative* to the individual's experience. Importantly, by using a mixed-methods approach, taking user input into account avoids oversimplifying LTS analysis and overgeneralization.

The study acknowledges that the LTS framework, while useful, has limitations, particularly given its origin in the United States. It was developed in San Jose, California, and may not perfectly capture the nuances of European street designs, potentially leading to subjective assessments of traffic stress. The framework may need to be calibrated for different locales.

To overcome some of these limitations and enhance future stress evaluation, several additional or alternative approaches could be implemented:

- **Develop a Bicycle-Specific LTS Framework:** The existing LTS framework, while comprehensive, was not specifically designed for the detailed assessment of *bicycle-only* traffic stress. Future research could assess more granular variability in infrastructure quality, perhaps through a Bicycle LTS framework. This would allow for a more precise evaluation of bicycle infrastructure where the current LTS did not provide "sufficient opportunity to assess, in detail, some specific instances".
- **Incorporate AV-Specific Variables into LTS:** The current LTS framework relies on data from conventionally operated vehicles. To make it more universal and account for the unique dynamics introduced by autonomous vehicles, there is an opportunity to expand the framework to make it more universal for more cities and urban morphologies. This could include factors such as:
 - **Mode split of AVs:** The proportion of AVs within the traffic stream in a specific city could be a useful factor for consideration in the LTS framework.
 - **Characteristics of AI-mediated transport systems:** Incorporating how new mobility and AI-mediated transport systems influence stress levels would be pertinent.
- **Enhance Subjectivity and Lived Experience Capture:** The study recognized that traffic stress is experienced differently by everyone and is *relative* to the individual's experience. While the mixed-methods approach of this study (surveys, interviews, focus groups) aimed to capture user input and avoid oversimplifying LTS analysis, future studies could:
 - **Utilize more extensive qualitative methods:** Going beyond the methods employed in this research to explore the underlying mechanisms of perceived stress in greater depth.

- Collect more granular contextual data: This would allow for a more nuanced understanding of how specific environmental and social factors contribute to perceived stress.
- Longitudinal Studies for Exposure-Based Stress Changes: The current study acknowledges its time constraints for conducting a truly longitudinal study. Future research could implement longitudinal designs to track how individual perceptions of stress change over time with prolonged exposure to AVs, as initial trips might be more stressful, but comfort could increase with familiarization.
- Focus on Different Geographical and Cultural Contexts: Since the LTS framework was developed in the US and may not perfectly fit European contexts, replicating and building on this research in other parts of the world beyond the Global North and Western cultures would be pertinent. This would help interrogate how underlying cultural or infrastructural factors drive differences in perceived stress and inform targeted interventions.
- Assess Broader AV Types: The study focused on fixed-route AV shuttles operating at slower speeds. Future research could include free-floating and privately operated AVs that represent a more progressed version of AV technology. This broader scope could reveal different stress factors associated with varying AV speeds, routes, and interaction patterns.

By integrating these recommendations, future research can build on the foundational understanding provided by this study to develop more adaptable and precise methods for evaluating traffic stress in an evolving urban mobility landscape that includes AVs.

Additionally, the bicycle urbanism maturity index (McLeod et al., 2020) was found to be a useful assessment tool for high-level bicycle urbanism using a basis of peer-reviewed metrics. However, third party adjudicators found it to be somewhat inflexible to fully capture the most accurate state of cycling maturity in the cities in question. As with any attempt to standardise assessment, this is a weakness of fully capturing the most minute nuances of each bicycle culture. While it was not the intent to create a perfect representation of the 'on-the-ground' bicycle urbanism culture, it was used to ensure that

a reader could have a baseline understanding of the variations in bicycle urbanism situations at each of the living lab sites. This assessment was completed to systematically demonstrate that there are a variety of situations that bicycle users encounter when cycling with AVs and that it is important to factor these different situations into a study for it to be as comprehensive as possible. Future studies that aim to ensure broad representation from a variety of bicycle urbanism situations should seek out other rubrics as discourse evolves in this space. They should also acknowledge that it is an imprecise and imperfect process that may not necessarily be 100% representative but gives a useful indication of bicycle urbanism *relative* to other sites when applied consistently. The key in this study is the *relative* representation across living lab sites.

4.3 Surveys

Likert-scale surveys were used to understand behavioural and attitudinal preferences for cycling among AV shuttle vehicles. Five-point Likert Scale questions were used to determine agreement or disagreement with 15 statements concerning comfort, trust, and behaviour. The survey was localised across the living lab sites to allow participants the option for completing the survey in the local language as well as English. The full list of questions is available in the appendices under 10.5 Survey Questions.

4.3.1 Survey Design & Questions

The surveys were designed to solicit responses from a sample of participants and to understand their threshold of traffic stress tolerance (Mekuria et al., 2012), attitudes towards AVs, perceived behavioural control, and effects of subjective norms (Ajzen, 1985, 2006)—all directly connected to the theoretical design of the study.

Questions that were designed to collect information that could be used to classify a participant's level of traffic stress threshold are labelled *STRESS* for traffic stress. Similarly, *ATTITUDE*, *PBC*, *NORMS*, and *INTENT* were used to label collected information for attitudes towards AVs, perceived behavioural control, effects of subjective norms, and intent respectively.

The survey used screening questions as part of the online survey methodology to ensure that participants met the specific criteria for inclusion in the research. These questions were designed to identify individuals who were physically able to ride a bicycle and knew how to do so. Furthermore, screening questions ascertained participants' prior interactions with autonomous shuttles, including whether they had experienced the shuttle while biking, as a passenger, as a pedestrian, as a driver, or observed it from a distance. The survey also included a question about the environments in which participants would ride a bicycle, which was later used to classify their LTS tolerance and bicycle user classification. The full question set, including screening questions, is available in Appendix 10.5 in section 10.5.1.

Table 4.3.1 outlines the Likert scale questions that are used to help understand the inputs to these theoretical variables and breaks them down into input categories. The basis column provides the background source for where and how this question was derived from prevailing discourse. Questions that are not evaluated on the Likert scale do not appear in this table and a complete list of survey questions is available in the Appendices. Additional detail on the sampling approach follows in Section 4.3.2.

Table 4.3.1 Question and theory connections

Q #	Question wording	Label	Basis
4	Which environments will you ride a bicycle?	STRESS	(Mekuria et al., 2012)
7	Before the shuttle started, I felt comfortable knowing I would bike in an area with an autonomous shuttle	PBC	(Ajzen, 1985; Botello et al., 2019; Luger-Bazinger et al., 2023; Wallén Warner et al., 2021)
8	The first time I encountered the autonomous shuttle I felt comfortable biking in the same area	PBC	
9	After encountering the autonomous shuttle many times, I feel comfortable biking in the same area	PBC	
10	I generally have a favourable impression of cycling with the autonomous shuttle	ATTITUDE	(Ajzen, 2006)
11	Most people like me are comfortable cycling in an area with an autonomous shuttle	NORMS	
12	Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle	NORMS	(Ajzen, 1985; Luger-Bazinger et al., 2023; Wallén Warner et al., 2021)
14	Before cycling with the autonomous shuttle I felt the technology was trustworthy	PBC	
15	After cycling with the autonomous shuttle I feel that the technology is trustworthy	PBC	
17	Autonomous vehicles on roads without separate bike space would make me feel comfortable while cycling.	STRESS	(Al-Taie et al., 2023; Botello et al., 2019; Luger-Bazinger et al., 2023; Mekuria et al., 2012)
18	Autonomous vehicles on roads without separate bike space would make me...	INTENT	(Ajzen, 1985, 2006)
19	Sharing the same street space with an autonomous vehicle would benefit cycling	STRESS	(Luger-Bazinger et al., 2023; Mekuria et al., 2012; Wallén Warner et al., 2021)
20	Autonomous vehicles on roads with separate bike space would make me feel comfortable while cycling.	STRESS	
21	Autonomous vehicles on roads with separate bike space would make me...	INTENT	(Ajzen, 1985, 2006)
22	Separating space between autonomous vehicles and bicycles would benefit cycling	STRESS	(Luger-Bazinger et al., 2023; Mekuria et al., 2012; Wallén Warner et al., 2021)
23	Human-operated vehicles on roads without separate bike space makes me feel comfortable while cycling.	STRESS	
24	Human-operated vehicles on roads with separate bike space makes me feel comfortable while cycling.	STRESS	

Surveys were conducted exclusively online so that they could be adequately localised and use alternative delivery methods given general apprehension around the risk of COVID-19. At the time of fieldwork, the severity of the pandemic was subsiding however general apprehension remained making in-person research somewhat difficult.

Two different platforms were used for the online survey (EUSurvey and Tripetto). The first platform used during the pilot fieldwork at Aalborg was the EUSurvey platform from the European Union. While the platform was feature-rich and publicly sponsored, it lacked overall usability and an intuitive design. This may have impacted response rates for the Aalborg site. After the Aalborg site, the same EUSurvey platform was used for the aborted Whitby site in the Toronto area, however, this reinforced that the platform's usability may be impacting response rates. It has been found that the design of the survey plays a major role in response rates. In a literature review in Sammut et al. (2021), factors that increased response rates were found to be design simplicity such as black text on a white background, reducing effort through a visually appealing design, and limiting overall length. These best practices were used to take the same questions from the first platform (EUSurvey) and port them over to another GDPR-compliant platform called Tripetto. After porting to the new platform, response numbers improved.

4.3.1.1 Likert Scale

Five-point Likert scale questions formed the basis of the survey and were used to understand attitudes towards 16 variables. Participants could respond strongly disagree (1), somewhat disagree (2), neither agree nor disagree (3), somewhat agree (4), or strongly agree (5).

The decision was made to use a five-point Likert scale when designing the survey for several reasons, despite a seven-point scale being beneficial in some situations (Finstad, 2010). Firstly, data reliability between five-, seven-, and ten-point Likert scales was found to have similar means in Dawes' (2008) study which is suitably reliable for the purposes of this study and was corroborated in a more recent study by Revilla et al. (2014) which also supported five-point scales over seven or eleven. Second, importantly, five-point scales were used to improve simplicity and shorten response time (Preston & Colman, 2000). This

was particularly important to fit the entire Likert scale on a mobile screen because the survey was primarily delivered online and promoted using a quick response (QR) code. Furthermore, an odd-numbered scale was chosen to allow participants to indicate a neutral option so that more participants could progress and participate to a greater extent even if they had no opinion, however including this option is debated (Croasmun & Ostrom, 2011). It was important to reduce friction for participants, so the trade-off was deemed suitable for this study given that participation was voluntary and involved no benefits or incentives.

4.3.1.2 *Language*

The living labs selected through the methods described in section 0 each had a different local language. This necessitated survey localisation to maximise participation and reduce user friction. In doing so, there was a limitation that arose through the translation process when the survey was localised for the different living lab sites. The primary research tools (online surveys) were designed to be accessible to participants in the language they are most comfortable with as much as possible.

While most translation was unproblematic, there were some concepts that were ambiguous when translated. Namely, the concept of *safety* was a point of concern during survey localisation. Pyrialakou et al. (2020) note that “subjective safety is a very broad concept” (p.250) and is impacted by a variety of factors as discussed in section 2.3.6, the localisation and language used was important to ensure that participants could universally understand the questions that concerned safety.

For example, when translating the survey from the source language of English, certain nuances may not be sufficiently captured in the localised survey versions, however, efforts were made to ensure that equivalencies were used as much as possible. The use of comfort and safety have particularly unique nuances in some Scandinavian languages. Of note is the translation of the term ‘comfort’ into Danish.

In close consultation with living lab host institution advisors, for the Danish version of the survey in the section that collects responses on participants’ *sense* of comfort (the first survey section named ‘comfort’), the term was translated to “tryghed” which means

comfortable in the way that "I don't feel unsafe or out of my comfort zone" by sharing roads with a bus - essentially "I feel safe when sharing the road".

In the section that attempts to collect *general level* of comfort, the Danish term "komfortabel" was used because that is a more approachable way of articulating "I would not mind/pay any attention to this" or "this does not bother me".

In recognition of this, some localisation elements were determined to be the most suitable to capture accurate results. They were chosen using the collective best judgement of the researcher and translator with knowledge of both Danish and English.

This distinction also applies to the Swedish and Norwegian translations. In Swedish the word to capture sense of comfort was 'trygg' instead of 'bekväm'. In the case of Norwegian, the word to capture sense of comfort was 'trygg' instead of 'komfortabel' or 'bekvem'.

4.3.2 Sampling

For this study, there was an effort made to engage participants whose perspectives are missing in prevailing discourse. This missing perspective, specifically from non-occupants, was solicited for the study. These non-occupant participants could readily interact with an AV shuttle while riding a bicycle given their proximity to AV shuttles. See the map diagrams in the following section (4.3.3) for more detail on invited participants' proximity.

Non-probability sampling was used to recruit participants to respond to the survey (Vehovar et al., 2016). These individuals were selected in a stratified sampling approach that targeted residents of living labs that had characteristics and knowledge relevant to the study (Acharya et al., 2013). Living lab residents were targeted based on their proximity to the AV shuttles as informed by open data. Residential address information was obtained from local authorities through their respective open data portals. The use of open data was instrumental to the methodology and is outlined in the following section.

4.3.3 Geospatially Calibrated Data Collection

The stratified sampling approach was operationalised through authoritative open data sources. The living lab sites were mapped with Geographical Information Systems (GIS)

software (QGIS) using authoritative address point layers from local authorities and the official AV shuttle routes either traced from an official route map or provided by the operating agency. The mapping and catchment definition helped to clearly define the focus recruitment area and reduce context ambiguity (Kwan, 2012). A 150m buffer was then applied to the shuttle routes to identify eligible participants. This 150m buffer is within the commonly accepted 5-min (400m) walkshed of a transit stop's service area (Foda & Osman, 2010) accounting for actual active transportation/pedestrian network conditions and ensuring that the area could be sufficiently targeted and managed by an independent researcher. Identified participants had study invitation slips deposited in their mailboxes to complete the online Likert scale survey. In addition to residential addresses, local civic buildings such as libraries, community centres, schools, neighbourhood associations, and seniors' homes were also contacted through social media channels and via email to ensure the study's maximum reach. Screening questions were used to ensure all participants met the requirements to participate in the study. An example participation slip is included in the appendices.

The maps shown in Figure 4.3.1 through Figure 4.3.4 below show the mapped addresses in the 150m catchment buffer that were used to promote and recruit for the study.



Figure 4.3.1 Aalborg shuttle route and catchment addresses

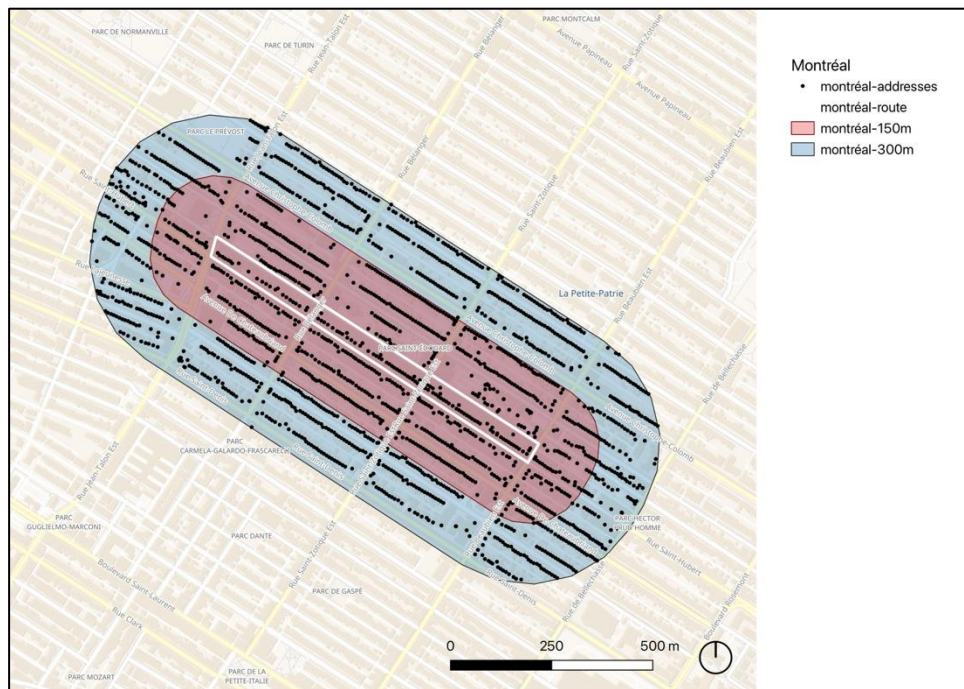


Figure 4.3.2 Montréal shuttle route and catchment addresses

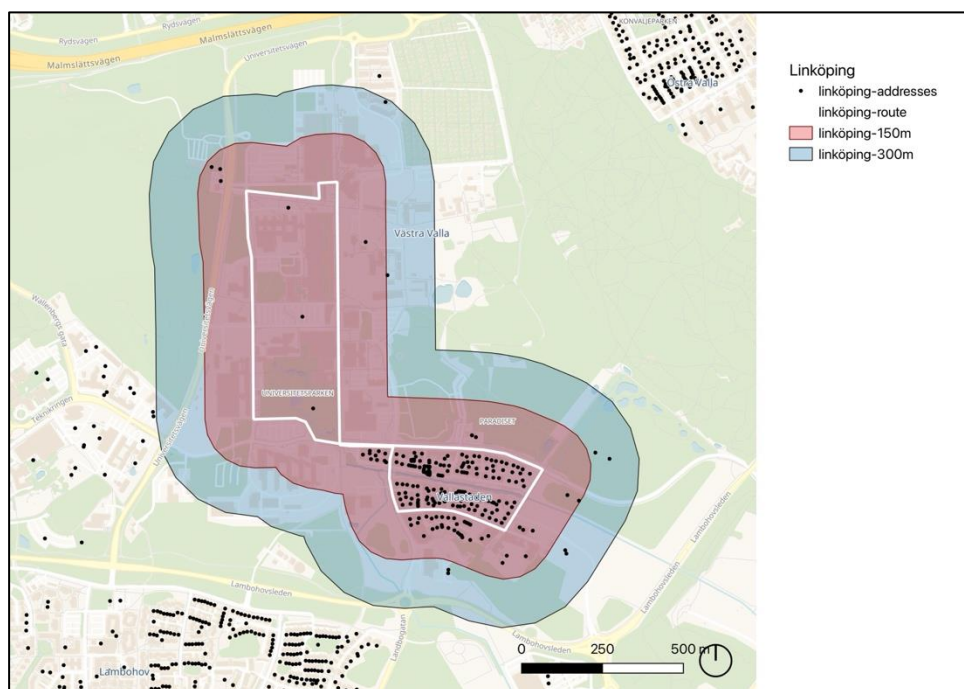


Figure 4.3.3 Linköping shuttle route and catchment addresses

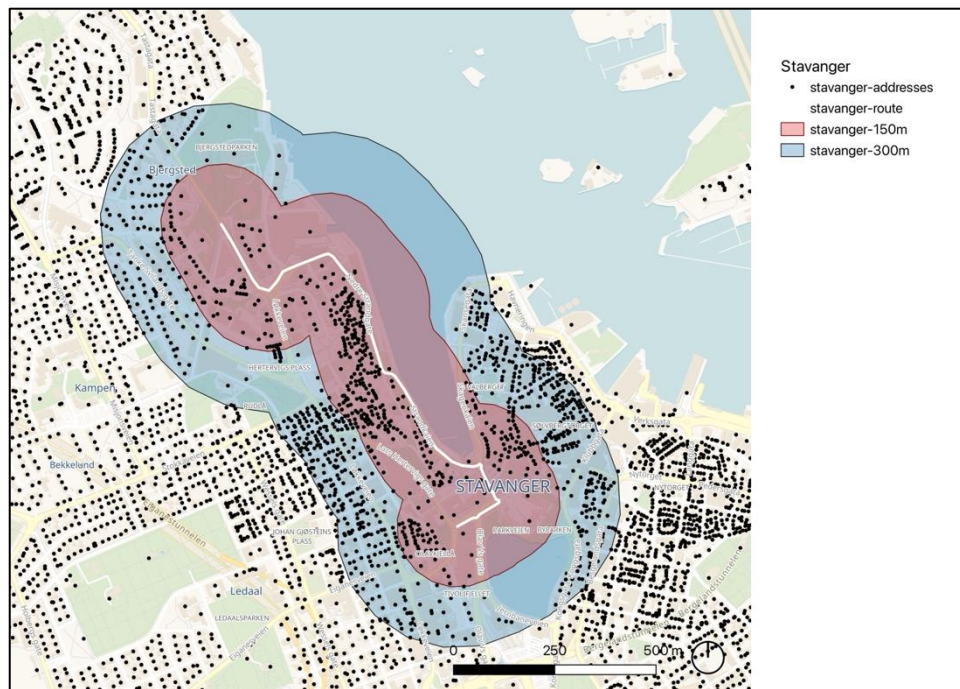


Figure 4.3.4 Stavanger shuttle route and catchment addresses

The use of open data through authoritative civic information enabled the dissemination approach for recruiting study participants at each living lab. This approach is outlined below in the next section.

4.3.4 Dissemination Approach

At each living lab, open data provided insight into the number of residential addresses within a proximal distance to each AV shuttle operating route. For those addresses that lay in the buffer zone explained in section 4.3.3 above, each point had a participation invitation flyer printed and delivered to their letterbox. Where letterboxes were inaccessible, invitations were sent through a condominium board or strata association electronically or by advertising on-screen in shared spaces of apartment buildings such as on screens in the lobby. Below is an example of on-screen advertising the study at a residential building where letterboxes were inaccessible. Examples of the printed flyers are included in the appendices.



Figure 4.3.5 Example of electronic study invitation in Stavanger (photo by Mikal Fuglestein)

The dissemination approach was chosen to directly target individuals who had the most experience interacting with the AV shuttles in their neighbourhoods.

A non-probability, stratified sampling approach was used to recruit study participants from residents of living labs who had relevant characteristics and knowledge pertaining to AV exposure. This targeted recruitment strategy focused specifically on individuals with pre-existing, real-life exposure and proximity to operational autonomous vehicles, ensuring participants had meaningful experience.

The recruitment process commenced with geospatial calibration of data collection sites. As outlined above, living lab locations were systematically mapped using GIS software (QGIS), with authoritative address point layers obtained from local municipal authorities.

Participation invitation flyers were systematically distributed to all residential addresses identified within the 150-meter buffer zones. Where direct letterbox access was unavailable, invitations were disseminated electronically through condominium boards, strata associations, or via on-screen advertising in shared spaces of apartment buildings. To maximize recruitment reach, local civic buildings including libraries, community centers, schools, neighborhood associations, and seniors' homes were contacted through social media channels and email correspondence.

The scope of recruitment efforts can be quantified through the number of civic address points identified within each living lab's catchment area. Distribution encompassed 1,466 civic address points in Aalborg, Denmark; 927 civic address points in Montréal, Canada; 1,696 civic address points in Linköping, Sweden; and 478 civic address points in Stavanger, Norway. These figures represent the total number of stratified participants eligible to participate.

The actual number of participant invitation slips distributed that successfully resulted in a participant engaging with the study cannot be precisely determined because some participant invitations slips were left at public places such as libraries, or posted on community bulletin board, as well as electronically distributed using neighbourhood group pages on social media. The number of address points is the most accurate way to represent the number of participants invited to participate.

4.3.5 Identified Weaknesses

It must be acknowledged that the breadth and depth of data set out to be collected as part of this study is novel and unprecedented. The importance of understanding bicycle users with AVs is important, as outlined in Chapter 3. Without empirical research at early stages of AV uptake there is a risk that no study will be undertaken until AV uptake is much higher. If empirical research is delayed until a late stage, there is a risk that little can and would be done to moderate AVs' impact on the urban realm and other road users. Therefore, while weaknesses exist, the importance and novelty of the empirics from this study should be used as a baseline to broaden collective understanding. In saying this, several identified weaknesses were identified that should be minimised in future studies.

Firstly, the nature of non-probability sampling used in this research means that findings cannot be generalised (Acharya et al., 2013). Therein lies an inherent weakness of studying AV and bicycle user interaction because the overall population does not have any consistent exposure to AVs in real-world scenarios. In studying this stratified participant data, a baseline study design and preliminary findings can be made. However, for more representative study and similarly representative generalizable results, a probability sample of study participants should be drawn to make broader conclusions.

Secondly, from a practical standpoint, when the dissemination of participation invitations was being carried out some difficulties were encountered. The most noticeable of which was that of access to private mailboxes in apartment buildings. While efforts were made to reach as many residents as possible, there is no way in knowing for sure if all those who lived within the defined buffer for study recruitment were reached. This impacted the ability to accurately determine sample sizes which added to the difficulty of estimating catchment population. Additional details relating to the challenges associated with this weakness are outlined in the Section 4.5.

4.4 Interviews and Focus Groups

Semi-structured interviews and focus groups were blended with the survey methods to gain deeper insight and to add nuance to the survey data. The interview and focus groups were structured and executed using the focus group/interview guide in Appendix 10.4. They were also used together to help mitigate weaknesses in the survey method and understand cognitive and social processes more in-depth (Kitzinger, 2005; Wolff et al., 1993). Interviews and focus groups were selected due to their adaptable, modular, and straightforward implementation for this study. The flexible interview and focus group methods, both structured around the same semi-structured discussion guide was adaptable to different situations. The interchangeable methods are used in other transportation behaviour research (Ayala & Elder, 2011). These two methods are also adaptable, complementary and extensively used in geographical, transportation, and behavioural research (Longhurst, 2003).

Focus group participants were selected from the survey respondents ensuring that they were able to interact with the AV shuttle in their daily lives and that they knew how to ride a bicycle. These participants, like the survey respondents, were selected from a strata of the population for their specific experience (Cameron, 2000). Participants were stratified based on their individual bicycle typological classification that explained their level of comfort and confidence riding a bicycle in urban settings. While some focus groups were composed of one bicycle typology, the number of volunteer participants was usually too small to convene one entire group of participants with one bicycle typology. In this case, and for practical reasons, focus groups drew from all bicycle user typologies and the individual open-ended questions and survey responses were used to provide deeper insight into any specific effect of AVs on the disaggregated stratifications of bicycle users. However, each focus group was drawn from one specific living lab location thereby producing deep local insight to specific bicycle culture and how it is impacted by AVs.

Focus groups took place in a central location such as a meeting room, or online depending on the availability and comfort of the participants in a setting that was as neutral as possible to not influence or bias participants' contributions (Longhurst, 2003). Hybrid options were available. On some occasions, only one participant was able to attend and the format was changed to a semi-structured interview using the same guide as used for focus groups. Groups of 2-6 participants were convened over seven meetings lasting 45-90 mins and asked a series of questions from a discussion guide about:

- Factors impacting biking in cities as impacted by the presence of AVs
- Levels of stress and comfort on different types of streets
- Social acceptability of AVs
- How participants feel about AVs now and how that might change in the future

Participant dynamics were generally consistent and engaged across all Focus Group participants where the facilitator took a strictly guiding role and enabled all participants to contribute equally. Some participants did not contribute as readily as others and facilitation encouraged them to contribute their perspective. Participants sometimes had contrasting views, especially about how they understood and felt respected by AVs and these contrasts led to lively and engaged debate where participants built off each other. It

was particularly useful to convene participants from the same living lab locations because they were able to cite specific locations (i.e. a corner, or a bicycle lane) where they had an experience that could be re-hashed in-depth by several participants who may have had different experiences. This multiple-account perspective was an excellent opportunity for dialogue and probing questions.

These guiding discussion points were integrated into a series of questions for facilitated discussion in focus groups and interviews as described in the following section. Guiding points and questions were used instead of a rigid script because focus groups are ultimately “a social interaction and there are no hard and fast rules one can follow” (Longhurst, 2003, p. 106; Valentine, 2005). The guide was adapted for each interview and focus group in acknowledgement of the social and informal nature of conducting them.

While some focus groups were designed to include participants from the same typology, logistical constraints often led to mixed-typology groups. Nevertheless, all sessions were conducted with participants from the same geographic living lab to preserve local context and insight.

The decision to include interviews alongside focus groups arose from practical recruitment challenges. Focus groups ideally required 2–6 participants, but difficulties in gathering sufficient numbers, compounded by the lingering effects of the COVID-19 pandemic, meant that some planned sessions could only be attended by a single participant. In these cases, the format was shifted to a one-on-one semi-structured interview using the same discussion guide. This methodological flexibility ensured consistency in data collection while enhancing the study's adaptability, ultimately strengthening the research design.

4.4.1 Discussion Questions

The questions posed to interview and focus group participants were designed supplement the inputs from the Likert based survey questions. Each question was designed to be open-ended so that it would spark a discussion beyond simple binary responses. The discussion was facilitated to ensure all participants could contribute and that probing questions were posed when appropriate and to extract additional information. Questions in the discussion

guide used during focus groups and interviews is included in Appendix 10.4 Focus Group/Interview Discussion Guide.

4.5 Data Preparation

Data collection for this study was conducted between Fall 2021 and Fall 2022, following ethical approval granted on November 19, 2021, and within the overall project timeline (August 1, 2020 – August 31, 2024). Pilot survey fieldwork began in Fall 2021 at the Aalborg site in Denmark. The full data collection for Montréal, Canada (including surveys, interviews, and focus groups) took place in Summer 2022. For both Linköping, Sweden, and Stavanger, Norway, data collection occurred in Fall 2022. These phases collectively align with the broader research project's data collection period.

The data collected through the mixed methods in this study were systematically prepared and processed. In this section, the data preparation process is presented. There are four main categories of data which were all prepared for processing. The data types processed are: Likert-scale survey data, demographic survey data, interview/focus group transcripts, and open-ended survey data. For all data types, Microsoft Excel was used to organise and prepare the data. All data were also cleaned by removing incomplete responses that did not have enough data for practical use.

All localised versions of survey responses in language other than English were matched to the equivalent English responses for coding and mapping.

4.5.1 Likert-scale Survey Data

All Likert-scale survey data were prepared using a similar process. All responses were coded in a 1-5 ordinal scale (Meyers et al., 2013). The ordinal scale reflected the strength of agreement or disagreement with the statement in the survey, or in cases where respondents were asked to indicate behaviour change, they were coded to represent the strength or weakness of the behaviour change. For example, these two kinds of ordinal Likert-scale variables were coded as follows (with the coded value in parentheses):

- Agree-Disagree Likert scale
 - Strongly agree (5)

- Somewhat agree (4)
- Neither agree nor disagree (3)
- Somewhat disagree (2)
- Strongly disagree (1)
- Behaviour change magnitude scale
 - Cycle much more (5)
 - Cycle more (4)
 - Cycle the same amount (3)
 - Cycle less (2)
 - Cycle much less (1)

As a rule, the most affirming response was coded with the highest numerical value and the most dissenting response was coded with the lowest numerical value. In all cases, if the question included a 'prefer not to say' response, it was assigned a *null* value and was invalidated in the results processing. A complete list of Likert-scale questions used in the questionnaire is included in the appendices.

4.5.2 Demographic Survey Data

4.5.2.1 Age & Gender

Age is an ordinal variable and was grouped into four categories plus a 'prefer not to say' (5) option. The categories a respondent could select were 0-17 (1), 18-34 (2), 35-54 (3), and 55+ (4). The coded values for SPSS appear in parentheses.

Gender is a categorical variable which also included an optional open-ended text field to ensure maximum inclusion and participation which allowed participants to self-identify. This aligns with best-practice and an adapted "expanded format" (Broussard et al., 2018, p. 606) that had more than a simple male/female binary for this question was shown to be the preferred. Each variable was assigned a value for analysis in SPSS. The options were classed with numerical value in parentheses as Female (1), Male (2), and Other (3). Additionally, for respondents who indicated 'prefer not to say' the response for this question was coded as *undisclosed* (4).

4.5.2.2 *Education Level*

The education categorical variable was subject to cultural incongruencies due to the structure of learning levels in the living lab countries. The levels of education in each living lab country varied slightly and local knowledge was needed to determine suitable equivalencies to draw comparisons across all sites. These equivalencies and their survey codes are summarised in Table 4.5.1 below.

Table 4.5.1 Education level equivalency table

Code	Canada	Denmark	Sweden	Norway
1	Bachelor's degree	Bachelorgrad	Kandidatexamen	Bachelor grad
2	High School	Gymnasium	Gymnasieexamen	Videregående skole
3	Master's Degree	Kandidatgrad	Magisterexamen	Mastergrad
4	PhD or higher	Ph.d. eller højere	Doktorsexamen eller högre	Doktorgrad eller høyere
5	Prefer not to say	Jeg foretrækker ikke at svare	Föredrar att inte svara	Foretrekker å ikke svare
6	Some high school	En videreuddannelse efter folkeskolen (fx erhvervsuddannelse e.l.)	Någon gymnasieskola	Ufullstendig Videregående skole
7	Trade School/College Diploma	Handelshøjskole	Högskola eller motsvarande	Fagbrev/Svennebrev (eller tilsvarende)

4.5.2.3 Employment Status

Employment was a categorical variable used in analysis to determine if there was a correlation to any other studied variable. The responses and codes in the survey were as follows:

- Student (1)
- Working part-time (2)
- Working full-time (3)
- Looking for work (4)
- Retired (5)
- Prefer not to say (6)

4.5.2.4 Household Composition (Children)

Only one household composition question was asked. This question concerned number of children under the age of 12 in a respondent's household. The question asked a binary question first, a positive response to the binary prompted the respondent to indicate the number of children in the household. The responses were coded as no children under 12 (0) and children under 12 (1). The coded value for analysis in SPSS appears in parentheses. For respondents who indicated there were children under the age of 12 in their care, a

follow-up question was presented using survey logic. The responses to this follow-up question had five ordinal choices to choose from:

- None (1)
- 1 (2)
- 2-4 (3)
- More than 4 (4)
- Prefer not to say (9999)

4.5.2.5 *Ethnic Origin*

Ethnic origin is a categorical variable used to understand if certain ethnic origin groups may be more impacted by AV shuttles than others. The categories used for the ethnic origin question are ninefold including a 'prefer not to say' option. The coded values and categories prepared for analysis are as follows:

- African origins (1)
- Asian origins (2)
- Caribbean origins (3)
- European origins (4)
- Latin, Central, and South American origins (5)
- North American Aboriginal origins (6)
- Oceania origins (7)
- Other North American origins (8)
- Prefer not to say (9)

It should be noted that this question was originally designed to be used at the two living lab sites in Canada in the Toronto Area both at Whitby (Toronto) and Rouge Hill (Toronto) AV shuttle pilot locations. However, these sites were cancelled after the pilot AV projects in these locations were cancelled. The categories used for this question are the standard categories used by Statistics Canada as the '*list of ethnic origins 2016*' standard. To maintain dataset consistency the same categories were used for all living lab sites.

4.5.2.6 Income Levels

Income levels collected were classified into five categories for correlation analysis. The income level variable is an ordinal variable. The categories were assigned a classification and a value for analysis in SPSS. The categories were lowest (1), low (2), med (3), high (4), and highest (5). The value for SPSS analysis is in parentheses. A summary of the income level data and a cross-section of deemed equivalents across all living lab sites appear in Table 4.5.2 below.

Table 4.5.2 Income classifications

Classification	Canada (CAD)	Denmark (DKK)	Sweden (SEK)	Norway (NOK)
Lowest (1)	≤ 19,999	≤ 200 000	≤ 199 999	≤ 199 999
Low (2)	20,000 - 49,999	200 000 - 500 000	200 000 - 499 999	200 000 - 499 999
Med (3)	50,000 - 99,999	500 000 - 1 000 000	500 000 - 999 999	500 000 - 999 999
High (4)	100,000 - 199,999	1 000 000 - 2 000 000	1 000 000 - 1 999 999	1 000 000 - 1 999 999
Highest (5)	≥ 200,000	≥ 2 000 000	≥ 2 000 000	≥ 2 000 000

4.5.2.7 Bicycle User Classification (Geller Classifications)

In this study design, study participants were classified into Geller bicycle classifications to gain an understanding if their confidence level had any correlation with their responses to the questions in the survey portion of the study. The design of the study was based on different urban geographies with different levels of traffic stress, and due to the theoretical framing that required a slightly modified version of the Geller classification system that aligned with the LTS framework, participants were not directly asked to self-report their Geller classification (Hosford et al., 2020). Instead, participants were classified according to a bespoke approach that was based on other classification approaches in literature so it could be structured around the triangulated theoretical framework in this study.

The study was designed to treat cyclist class is an ordinal variable used to classify bicycle users' level of confidence or comfort with different types of traffic stress scenarios and bicycle facilities. As outlined in section 3.3.2, the classification used for this study was based on the Geller (2006) classification system using four levels of bicycle users (Dill &

McNeil, 2016) these classifications were also matched to one of four levels of traffic stress best suited to the cyclist classification in question (Furth et al., 2016).

The four types of bicycle users are: 1) 'No way no how' and will not use a bicycle under any circumstances. The survey excluded any respondent who indicated that they did not know how to ride a bicycle or were physically unable to ride a bicycle, therefore the Geller classification of 'no way no how' does not apply to the study participants who completed the survey and is not included in the traffic stress scenario matching. By eliminating the 'no way no how' classification, the classifications closely resemble a statistically validated version of the Geller classifications as presented by Cabral and Kim (2020). The second, is 2) 'Interested but concerned' and will use a bicycle if high quality bicycle facilities are available and are most suited to riding in low levels of traffic stress (i.e. bike trails or multi-use paths through parks and green space or a quiet residential street). The third class is 3) 'Enthusied and confident' and will ride a bicycle if there are some bicycle facilities in place. They are most suited to higher levels of traffic stress than the 'interested but concerned' group such as major roads with painted bicycle lanes or cycle tracks. Fourth, 4) 'Strong and fearless' bicycle users are a group that will ride a bicycle in nearly all situations even with no bicycle-specific facilities. They can tolerate the highest levels of traffic stress (i.e. major roads without bike lanes/cycle tracks). The classification logic follows below.

The survey prompted participants to indicate the highest level of traffic stress environment that they would tolerate. The answer to this question (Figure 4.5.1) was used to classify a participant's bicycle user classification for 'cyclist-class'.

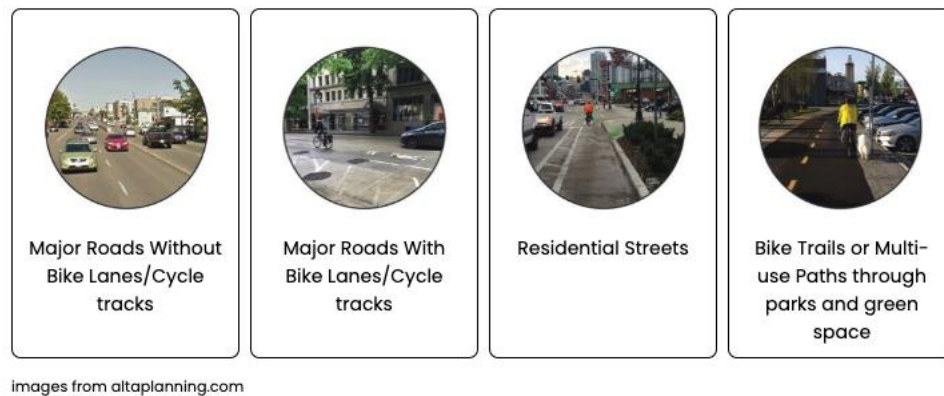


Figure 4.5.1 Bicycle user classification question

The bicycle user classification logic used was as follows:

- IF a respondent marked LTS 4 as their highest level of traffic stress, Geller classification 'Strong and fearless' (4) was assigned regardless of how they responded to other LTS situations
- IF a respondent marked LTS 3 as their highest level of traffic stress, Geller classification 'Enthusied and confident' (3) was assigned regardless of how they responded to other LTS situations
- IF a respondent marked LTS 2 OR LTS 1 as their highest level of traffic stress, Geller classification 'Interested but concerned' (2) was assigned
- IF a respondent marked FALSE for all levels of traffic stress, they were assigned Geller classification 'no way no how' and have been omitted from the results.

By eliminating the 'no way no how' classification, the classifications closely resemble a statistically validated version of the Geller classifications as presented by Cabral and Kim (2020).

Additionally, a supplementary ordinal variable called 'Bike Regularity' classified how often a bicycle user would ride a bicycle. These classes ranged from the most frequent daily riders (assigned the value of 6) and the least frequent rider who rode less than once per year (assigned the value of 1). The bicycle use frequencies are: less than once per year (1); at least once per year (2); at least once every six months (3); at least once per month (4); at least once per week (5), and; daily (6). These data were analyzed to understand if frequency impacted findings for the relevant research questions outlined in Chapters 5 - 0.

Other bicycle user data was collected and used to inform participant invitation for interviews and focus groups. These data were not analyzed and were used for participant selection only. These data are bicycle user purpose(s), acceptable bicycle use weather conditions, bicycle use frequency, and AV-induced bicycle use avoidance.

4.5.2.8 *Driver's License Possession*

Possession of a driver's license is a binary categorical variable. This binary variable was coded for analysis in SPSS. Yes was coded as 1 and no was coded as 0.

4.5.2.9 *Innovation Diffusion*

The survey aimed to assess how respondents view their comfort and trust for AVs through a proxy: their willingness to adopt new technology products. This was assessed using a Likert-style scale from "I am generally the last to try a new technology product" (1) to "I am generally the first to try a new technology product" (5). There was also an option for those who prefer not to answer.

The options on the survey were:

- a. I am generally the last to try a new technology product (1)
- b. I am generally among the last to try a new technology product (2)
- c. I am generally in the middle when it comes to trying a new technology product (3)
- d. I am generally among the first to try a new technology product (4)
- e. I am generally the first to try a new technology product f. Prefer not to say (5)
- f. Prefer not to say (9999)

This self-assessment scale was designed based on Everett Rogers' *Diffusion of Innovations* (2008) which categorises individuals as innovators, early adopters, early majority, late majority, or laggards. Responses indicating early adoption (options d and e) suggest a proactive approach to new technologies, while responses reflecting late adoption (options a and b) show a more cautious stance. The middle response (option c) represents those who wait until others have tried a product before adopting it. Understanding where individuals see themselves in this spectrum helps in developing effective strategies for

understanding the impact of AVs for bicycle users in recognizing that innovations are adopted at different rates (Rogers et al., 2008).

4.5.3 Interview/Focus Group Transcripts

The interviews and focus groups carried out were recorded and transcribed with the permission of participants. For in-person focus groups, an array of microphones on several smartphones connected to a Google Meeting equipped with recording. Live transcription was used. Where interviews were 1-on-1, a single smartphone voice recorder was used and transcribed asynchronously. Virtual interview or focus groups were carried out over Google Meeting and were live transcribed and recorded.

A multi-step process was used that produced a final focus group summary report. In the recording and transcription step, recordings were transcribed using WhisperAI's small model which transcribes recordings and removes filler words (Wollin-Giering et al., 2023). The transcripts were then exported to comma-separated value (CSV) tabular files with timestamps and were manually reviewed and corrected where transcription inaccuracies were detected. The outputs of the transcription process were fed into a thematic categorization process which follows in section 4.6.1.

4.5.4 Open-ended survey responses

Open ended survey questions were received in four languages: English, Swedish, French, and Norwegian. These data were translated with machine translation using large language models (LLM) which has been found to produce "operationally workable English versions" (Balk et al., 2013, p. 4). This finding was for academic applications when using a 2013 version of Google Translate. However, capabilities have significantly improved, and with introduction of LLMs and generative pre-trained transformer (GPT) applications, machine translation is even more viable. In recent studies, GPT translation performance was found to be "extremely good" (Akshat et al., 2024, p. 6) was similarly found to perform well in translating European languages (Huang & Wei Liu, 2024), which is exclusively what the source survey data is in.

4.6 Data analysis process

Two primary analyses processes were used to interpret the data. The study design is primarily qualitative and relied on qualitative analysis methods as primary. Statistical methods were used to understand potential correlations between demographics and behaviour. This was especially relevant for interpreting results for understanding the impact of AVs on cycling trips in Chapter 6. Qualitative data was sourced from interview/focus group transcripts and open-ended survey data. Quantitative data was sourced from Likert-scale and demographic survey data.

4.6.1 Qualitative Analysis Processes

4.6.1.1 *Interview/Focus Group Transcript Analysis*

An adapted Constant Comparison Analysis (CCA) and approach influenced by Grounded Theory (B. G. Glaser, 1965; B. Glaser & Strauss, 1967) were used to group and sort the focus group data into themes. Glaser's approach to grounded theory relies on data itself to induce theory to reach saturation and Strauss allows for more flexibility to deduce theory from data as informed by discourse in literature. This inductive process enabled simultaneous iteration and codification which Glaser describes as blending two approaches. The data were coded and grouped into as many categories as possible in a column on a Microsoft Excel spreadsheet. Themes were drawn by combining similar categories and their properties (B. G. Glaser, 1965). Compared to pure Grounded Theory, 'in-vivo' themes were not used. In lieu, paraphrased theme titling was used to improve clarity and simplify the number of thematic categories.

4.6.1.2 *Open-ended survey data analysis*

Braun & Clarke's (2006) six-step approach was used for analyzing open-ended survey data and was selected for its flexibility and accessible approach (Braun & Clarke, 2006; Byrne, 2022). It was also chosen due to the applicability in similar studies that work with bicycle use and AVs (Al-Taie et al., 2024; Berge et al., 2022). The process undertaken to assess and analyze the open-ended data involved the following steps which are adapted from Braun & Clarke (2006).

Following data preparation explained in section 4.5, data was organised in Excel to complete a comprehensive review and familiarization. Familiarization involved reading through the responses multiple times and highlighting recurring words, segments of text, and data features that could be coded. Following several read-throughs, codes were generated from these data elements that identified key features of the data such as 'AV acted as obstruction', 'unestablished norms', 'unpredictability', and 'requires extra attention'. The codes were then reviewed and cross-examined to identify where they could be combined into overarching themes that could adequately capture the patterns in the data. Themes were refined, split, and combined to ensure that they were distinct and highlighted important parts of respondents' input.

The themes were then reviewed and named. This analysis is primarily discussed in Chapter 7 alongside other supplemental data. In brief, the analysis process for identifying themes from the open-ended survey input was as follows (Braun & Clarke, 2006; Byrne, 2022):

1. Data familiarization
2. Initial code generation
3. Searching for themes from recurring words, segments of text, and data features
4. Reviewing themes
5. Defining and naming themes
6. Reporting back

4.6.2 Quantitative analysis processes

Two analyses were used to analyse quantitative data from the survey. These analyses were used for a variety of ordinal variables to best understand how they were correlated with each other, the coefficients for which combination of variables contribute to certain bicycle user behaviour outcomes, and descriptive statistics to provide contextual information for the datasets.

4.6.2.1 Descriptive statistics

Descriptive statistics were used to analyze and contextualise the data, especially to determine the point values for each degree of affirmative or dissenting answers in Likert-

scale data. Descriptive statistics were analysed in SPSS to show the number of responses, response minimum, maximum, mean, and standard deviation per question (variable).

For all Likert-scale data, as explained in section 0, strongly disagree was assigned the point value of 1 and strongly agree was assigned the point value of 5. In equally distributing the point ranges across the Likert-scale intervals where each interval is 0.8 points, the point ranges mean the following:

- 1 – 1.80 is strongly disagree (dissenting opinion/decrease bicycle use);
- 1.80 – 2.60 is somewhat disagree;
- 2.60 – 3.40 is neither agree nor disagree (neutral opinion/no change to bicycle use);
- 3.40 – 4.20 is somewhat agree; and,
- 4.20 – 5 is strongly agree (affirming opinion/increase bicycle use).

All other analyzed data, where necessary, are presented as a frequency table showing the number of survey responses for each variable. Frequency tables also include columns showing the percent, valid percent, and cumulative percent of responses per variable.

4.6.2.2 Wilcoxon tests

Wilcoxon tests were used to best interpret the ordinal nature of the Likert scale data, which is not necessarily normally distributed making non-parametric tests more appropriate. The design involved repeated measures, examining pre- and post-interaction Likert-scale ratings for trust and comfort. Recall bias was a consideration in the analysis. The tests helped assess differences while accounting for these factors effectively. The Wilcoxon signed-rank test was used to analyze differences in responses based on Likert-scale survey data. The Likert-scale ranges from 1 to 5, with the test focusing on responses for trust and comfort before and after interactions. Recall bias may have affected self-reported responses.

This test was ultimately chosen due to the ordinal nature of the data and the non-normal distribution concerns (as well as potential recall bias). The test evaluated changes in participants' trust and comfort levels before and after interactions with AVs, including comparisons between pre- and post-interaction measures and first vs. subsequent

interactions. Effect sizes (r) were also calculated to provide insight into the magnitude of the observed differences.

4.6.2.3 Ordinal logistic regression

Ordinal logistic regression analysis was conducted to examine the relationship between the four dependent variables against several independent variables. These four dependent variables form the basis of discussion and findings in Chapter 6. Due to the ordinal nature of the data, an ordered logistic regression nonparametric analysis was chosen to assess the data. This approach has been shown to be functional in interpreting other travel behaviour studies, specifically cycling frequency, which has posed similar questions using other independent variables with similar affect (Damant-Sirois & El-Geneidy, 2015; Giacomantonio et al., 2024).

This approach was furthermore chosen to analyze latent, multi-dimensional variables (such as attitude, subjective norms, and PBC) because these constructs, while theoretically continuous and complex, were operationalized using ordinal Likert-scale items. This type of regression is specifically designed to model relationships where the dependent variable is ordinal, making it well-suited for outcomes measured on scales like "strongly disagree" to "strongly agree" or "cycle much less" to "cycle much more."

Latent constructs from TPB were measured using multiple Likert-scale questions that served as proxies for participants' underlying cognitive and social dispositions. Although these constructs are multidimensional and theoretically continuous, the responses themselves do not meet the assumptions required for parametric analysis (e.g., normal distribution or equal intervals between categories). Ordinal logistic regression does not assume interval-level measurement, making it a methodologically sound choice for analyzing such data.

Additionally, ordinal logistic regression allows researchers to explore the predictive relationships between these ordinal dependent variables and a range of independent variables (e.g., bicycle typology, living lab site, demographics), without violating statistical assumptions. As described above, this approach has been validated in similar studies of

travel behaviour, reinforcing its suitability for examining structured, theory-driven constructs through non-parametric ordinal data.

As explained in sections 0 and 4.6.2.1, the dependent variables were measured on a 5-point Likert scale, ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree'). The independent variables were similarly measured using Likert scales to capture comfort, trust, stress, intent, and norms. Certain variables were used as the dependent variable to answer research question 2 and another set of variables were used as the dependent variable to answer research question three. In some cases, the dependent and independent variables are swapped for each research question.

Ordinal logistic regression analysis was carried out in SPSS. For the ordinal logistic regression interpretation, a low p-value of ≤ 0.05 was interpreted to have a statistically significant relationship between the independent variable and the ordered dependent variable. Any values that had a sufficiently low p-value were found to significantly contribute to predicting outcomes in the dependent variable(s) and were further assessed/discussed. Insignificant relationships were reported but were not further discussed.

4.6.2.4 Multivariate correlation

A multivariate correlation analysis was performed to explore the relationships between multiple variables. This correlation analysis was used to answer research question 3 and it was selected because it allows for analysis of how variables are associated with one another, providing insights into the strength and direction of relationships. Spearman's rank-order correlation was employed to capture monotonic relationships and was a more appropriate application over Pearson due to the ordinal/continuous nature of the Likert-scale response data (de Winter et al., 2016). Multivariate correlation analysis was performed using SPSS which calculated the correlation matrix and the associated p-values to assess significance.

The correlation matrix was used to succinctly display Corr. Coeff.s between all variable pairs. The values in the matrix range from -1 to +1. Values that are close to +1 indicate a strong positive correlation. Conversely, values close to -1 indicate a strong negative

correlation. Values near zero indicate no strong linear relationship. The results of the matrix table (Table 7.5.5) was reviewed for any notably strong or weak correlations that should be highlighted.

4.7 Consent and privacy

In line with research ethics requirements, all participants were required to acknowledge the informed consent information at the start of the questionnaire portion. When participants were invited for additional research participation, they were prompted to reconfirm their consent to participate verbally over voice recording. Informed consent forms were made available at the interview and focus group sessions. The consent and privacy information provided to study participants is included in the appendices.

4.8 Methodological contributions

Through this project, there are three primary contributions to methodological approaches that can be reapplied and refined for future AV interaction research. The first contribution is the interdisciplinary approach that blends theory from urban geography, behavioural psychology, and cycling research. These three theories applied together establish a new synthesis to more comprehensively understand travel behaviour with some of the most referenced and trusted frameworks. These frameworks are ideally suited to more comprehensively triangulate the motivations and deterrents of bicycle use when presented with a new environmental variable such as an autonomous vehicle. The triangulation of theories is a constructive methodological contribution because they all form inextricable components of an individual's decision to ride a bicycle and, when studied independently, obfuscate the complete picture of factors that impact bicycle use in cities.

The second contribution is the concentrated targeting of individuals that interact with AVs on a regular basis *outside* of the United States (i.e. the San Francisco Bay Area). Due to these regions often presenting themselves as a hotbed for AV deployment, significant research is carried out on their residents. Importantly, the methods used in this research present a viable multi-city data collection methodology that can be rapidly deployed to regions where AV interaction is understudied. This is particularly useful in places where

AVs may be introduced on short-notice given the rapidly evolving and potentially rapidly accelerating field of AI-mediated mobility systems. While this method is constructive, it should be refined and expanded on, especially where local partners are able to network as part of a larger project to conduct more comprehensive longitudinal studies such as those in continental Europe under the CityMobil2 project and, more recently, EVRA in France.

The third contribution is a thorough cross-section of sampling the concentrated targeted groups across multiple countries and cultures. While this approach was constrained by the availability of AV shuttle operations that aligned with the data collection phase of this project, the potential to expand a broader base over a more protracted period with a larger sample of asynchronous data collection is merited. The method used in this project was successful at a small scale and should be expanded, particularly as the availability of AV technology progresses.

4.9 Conclusion

The methods discussed above present a uniquely tailored methodological approach that emphasises a practical application of theories and approaches to address research gaps outlined in Chapters 2 and 3. The mixed methods approach combines surveys, interviews, and focus groups with technical geographical data overlays to triangulate the impact of AVs on bicycle users in urban living labs. There are four key aspects of this methodology and its contributions.

Firstly, the living lab approach and site selection employed living labs as real-world environments to observe everyday interactions with AVs. The sites were selected based on bicycle urbanism maturities, traffic stress levels, and AV capabilities. The selected locations included Aalborg (Denmark), Montréal (Canada), Linköping (Sweden), and Stavanger (Norway). These sites were chosen to represent a range of bicycle urbanism maturities, as measured by a rubric called the 'Bicycle Urbanism Maturity Model' as established in literature (McLeod et al., 2020). Each individual site was geospatially mapped, analyzed, and referenced against mailing address and cadastral data to determine an estimate of population size and suitable sample sizes.

Secondly, the survey design used online Likert-scale surveys to understand behavioural and attitudinal preferences for cycling near AVs. The survey method is designed to measure traffic stress tolerance, attitudes towards AVs, perceived behavioural control, and subjective norms rooted in TPB. Questions were designed to gather information on participants' comfort, trust, and behaviour related to cycling with AVs.

Thirdly, semi-structured interviews and focus groups were conducted to gain deeper insights and add nuance to the survey data which is an established approach of blending qualitative methods (Wolff et al., 1993). Participants were selected from survey respondent pool and stratified based on their bicycle typological classification. The discussions covered factors impacting biking in cities due to AVs, stress levels, social acceptability of AVs, and future perceptions.

Fourth, data from surveys, interviews, and focus groups were systematically prepared and processed. Statistical methods and qualitative analysis were employed to interpret the data. Qualitative analysis involved approaches adapted and informed by Constant Comparison Analysis (CCA) and Grounded Theory to group focus group data into themes. Quantitative analysis included descriptive statistics, Wilcoxon tests, ordinal logistic regression, and multivariate correlation to identify relationships between variables.

Note that each empirical chapter contained herein will also have its own methodology section recalling what is introduced in this chapter. These methodology subsections of each empirical chapter will provide added details on the methods employed as they apply to each specific research question.

Overall, this research project employs a robust methodological framework that combines urban geography, behavioural psychology, and cycling research to provide unique insights into bicycle-AV interactions. By specifically targeting individuals in urban living labs and implementing cross-sectional sampling across diverse geographical and cultural contexts, the study offers a comprehensive perspective on this emerging field. While it is acknowledged that methodological limitations including non-probability sampling challenges and access constraints, these limitations do not diminish the study's meaningful contribution as a foundational baseline for understanding bicycle user-AV interactions. The

findings, beginning with those centred on attitudes in the following chapter, establish a valuable platform for future research initiatives in this increasingly important area of urban mobility.

5. Attitudes of ‘living lab’ Bicycle Users Towards AVs

“The most important communication signal from an automated vehicle [...] is the message ‘I have seen you’.”

—Babak Zandi et al. (2020)

This chapter outlines the results from the mixed-methods study that evaluated the impact of AVs on urban bicycle use and behaviour. As outlined in Chapter 3, the theoretical framing blended behavioural psychology theory with traffic stress and bicycle user classifications to understand how AVs operating in urban areas affect the decision to ride a bicycle as informed by perceptions of *safety* and *comfort*. The subject matter in this chapter centres around how AVs would impact bicycle users’ mobility in urban settings. More specifically, this chapter engages with the question: *to what extent will the introduction of AVs impact attitudes towards cycling in urban AV ‘living labs’?*

This chapter is broken into seven subsections. First, the chapter begins with an introduction in section 5.1. Following, in section 5.2, the research question is presented and discussed. In section 5.3, a brief link back to theory is made to situate the connection in the broader monograph. In section 5.4, methods are outlined followed by results in section 5.5. Penultimately results are discussed in 5.6 and, finally, conclusions are drawn in section 5.7.

5.1 Introduction

Street dynamics for bicycle users are predicated on prevailing dominant modes of transportation that subordinate other transport modes (Gaio & Cugurullo, 2023). Bicycle users are largely thrust into a world of automobility (Urry, 2004) and are expected to behave like vehicles when the visceral cycling experience is incompatible with this expectation (Green et al., 2012; Popan, 2020). Riding a bicycle must be understood as a ‘multisensory’ experience which contrasts the fragmented perception that automobility affords through “windscreens, visor helmets, and mirrors” (Popan, 2020, p. 293). This idea of fragmentation is also discussed as “alientation” from the surrounding environment leading to a disconnect from others (Nixon, 2014, p. 93). In contrast to automobility, bicycle

users are vulnerable, exposed, and acutely alert of their surroundings (Popan, 2020). Given the differing sensory experiences and the power imbalance between bicycles and automobiles, despite the former having the conditions of the latter imposed on it, “[decisionmakers] must eliminate regulatory discourse that frames the modes as equal, and instead acknowledge differences and current inequalities” (Nixon, 2014, p. 100).

In this chapter, AVs are described as ‘forthcoming’ and in a ‘transition period’ when AVs will coexist with conventionally-operated vehicles (COV) is discussed. This acknowledges current transport policy inertia and the pace of technology deployment. As introduced in Section 0, this is a deterministic view that is approached with a degree of skepticism. While many scholars address acceptance to some extent (usually after a period of exposure), this may impose the techno-centric view which dismisses opposition to technology adoption. This positions *technology* as an unequivocal solution and *public uptake* (or lack thereof) as a problem. It should be acknowledged again, and as previously highlighted, that by framing AVs in this way, current societal practices are a problem requiring a prescriptive technological solution, which is a problematic way of adopting novel technology (Stilgoe & Cohen, 2021).

Auto-oriented determinism is problematic. The very concept of a vulnerable road user accepts a degree of power imbalance and inequality where the idea of seamless movement is the overarching motive. The infrastructure, policies, and planning approaches that have birthed this concept are fundamentally rooted in car-centric planning which has subsequently systematically limited options for bicycle users and people walking. To this end, Khayesi (2020) explains how the road users themselves may not necessarily be vulnerable (car-inflicted injury and death, for instance), but that auto-oriented planning neglects the needs of people walking and cycling thereby fabricating their vulnerability through what Khayesi coins as “vulnerable transport planning” (2020, p. 1). In this vein, the research question that this chapter is based on flips the script from this techno-centric determinism and asks, based on empirical observation, how bicycle users’ attitudes are impacted. The design and framing of the research question that this chapter is based on follows in section 5.2 below.

5.2 Research question 1

First outlined in section 3.4.1, the first research question investigated is: *to what extent will the introduction of AVs impact attitudes towards cycling in urban AV ‘living labs’?* This research question was specifically designed to measure one of the inputs of TPB, attitude, as outlined in Section 3.3.1. This question is also framed with Geller bicycle classifications in mind, which is outlined later in this chapter by extrapolating survey responses to understand and classify the types of respondents in the study.

The data collection tools used to collect data to answer this question are twofold: the Likert scale survey questions marked with *ATTITUDE* and *STRESS* in Table 4.3.1 and the interviews/focus groups with participants from living labs.

5.3 Attitude influence on bicycle use and urban mode choice (Theory: Planned Behaviour)

The subject-matter in this chapter is informed and influenced by TPB as outlined and described in section 3.3.1. As introduced in Chapter 3, TPB’s emphasis on attitudes, subjective norms, and perceived behavioural control (PBC) provides a foundational model for understanding the behavioural determinants influencing decisions to ride a bicycle in environments where AVs are present. However, acknowledging its limitations—such as the underrepresentation of external factors, habits, emotions, and built environment influences—this chapter elaborates on how TPB is augmented with complementary perspectives and primary input.

Attitude is one of the primary inputs to TPB and plays a significant role in influencing mode choice. The research design for this chapter aims to understand what influences attitudes and how these influences can be used to achieve transport mode distribution in urban areas. Naturally, the focus is on bicycle users, however the influences on attitudes may influence other active transportation users and the findings could have broader implications than only for bicycle users. The blended approach put forward aims to capture the complexity of safety and comfort as participants navigate AV ‘living labs,’ linking empirical findings to the broader discourse on cycling behaviour in urban spaces.

5.4 Methods

As is the case for all empirical chapters, the blend of applied theories informed the study design as explained in chapters 3 and 4. To this end, the living lab approach was intentionally designed to empirically observe AV-bicycle interaction in real-world applications. This is a direct response to a critical gap in discourse that focuses on a *hypothetical* future with AVs with research on simulations and theoretical scenarios (outlined in chapter 2). The methods used to answer research question 1 are primarily qualitative in nature. Although the survey portion was used as a recruitment tool to identify participants, the quantitative methods used to answer other research questions were not used to answer this research question. In recognition of this, the qualitative methods used to answer research question 1 were interviews and focus groups. The specifics of this methods application are explained above in section 4.4.

Owing to the qualitative nature of the study, only a small number of participants were needed to examine this research question in-depth via focus groups (Daley & Rissel, 2011). Participants were recruited based on characteristics indicated in the survey that was the precursor to the focus groups in acknowledgement that cycling is not equally experienced (Jahanshahi et al., 2023). Focus groups were conducted across three living-lab test sites using a multi-city approach applying the same focus group/interview approach (Woods & Masthoff, 2017). These sites are outlined in Table 5.4.1 below.

Table 5.4.1 Living-lab sites

Location	Date	Focus Group participants	Interview participants
Montréal, Canada	Summer 2022	8	1
Linköping, Sweden	Fall 2022	2	1
Stavanger, Norway	Fall 2022	0	2
Subtotal		10	4
Total engaged		14	
Note: Each participant is unique. There was no overlap of focus group or interview participants.			

The participants identified in Table 5.4.1 above were selected using convenience sampling. To identify participants for the survey portion of this study, a systematic process that specifically targeted individuals with unique AV experience was carried out. This systematic

process is described in detail in section 4.3.3. In brief, that process involved using geographic information system (GIS) point files for municipal addresses for each of the data collection sites that were obtained from authoritative municipal open data sources (local government website or national address registry) to identify all addresses around the operating AV shuttle. The fixed-route AV shuttle routes were buffered within 300m to identify all the civic address points within the catchment. This 300m buffer is within the commonly accepted 5-min (400m) walkshed of a transit stop's service area (Ammons, 2014; Foda & Osman, 2010).

Participants in this catchment were invited to participate in a survey. Those within a 150m radius had a leaflet delivered in their mailbox. Participants were screened using an online survey to ensure that they were able to interact with the AV shuttle in their daily lives and that they knew how to ride a bicycle. Considering vaccination rates and social hesitancy at the time, it was difficult to recruit participants for in-person activities due to the prevailing COVID-19 pandemic. A total of fourteen participants were engaged for qualitative data collection in either a guided focus group or semi-structured interview conducted in English. Not all participants spoke English as a first language, but all participants consented to participating in English and were given information to give informed consent in line with university research ethics standards. Participants under the age of 18 were not eligible to participate.

As detailed in section 3.3.2 and 3.3.3, two related classification systems are used to interpret the results of this study. Both participants and living lab sites are classified. Participants are classified according to their highest tolerance of traffic stress which is mapped to a modified Geller classification (Geller, 2006) developed by Cabral and Kim (2020). The modified Geller classification system is referred to more generally as *bicycle user classification* throughout. Additionally, each living lab site is also classified according to a level of traffic stress (LTS) as developed and discussed by Mekuria et al. (2012).

The two classification systems employed are: (i) participant classification using the modified Geller classification which is referred to as bicycle user classification; and, (ii) site LTS classification which was used to determine the type of living lab settings to adequately represent a variety of traffic stress scenarios. The variety of traffic stress scenarios is

important to better understand how the added variable of an AV would impact individuals across all bicycle user classifications.

In accordance with the above, participants were classified into four groups that summarised their bicycle user classification. The classifications were adapted from the Geller (2006) classification system using four levels of bicycle users which was tested by Dill & McNeil (2016) and widely used as a bicycle user classification standard (Dill & McNeil, 2013; Félix et al., 2017). These classifications were also matched to one of four levels of traffic stress best suited to the cyclist classification in question (Furth et al., 2016) using a method adapted from a study by Cabral et al. (2019). Participants were assigned a bicycle user classification level using this approach which is outlined in greater detail in section 4.5.2.7.

The study screening process had prospective participants indicate the highest level of traffic stress environment that they would tolerate to assign them a bicycle user classification. Traffic stress scenarios were illustrated and described in order from highest traffic stress on the left to lowest on the right. The answer to this question was used to classify a participant's bicycle user classification for 'cyclist-class' in a modified approach to that used by Cabral and Kim (2020).

5.4.1 Focus Groups and Interviews

Focus groups of 2-6 participants or 1-on-1 interviews were held over seven meetings lasting 45-90 minutes. Participants were asked a series of questions from a semi-structured interview guide about attitudes toward AVs. A multi-step process was used that produced a final focus group summary report. Recordings were transcribed using WhisperAI's small model which transcribes recordings and removes filler words (Wollin-Giering et al., 2023). The transcripts were then exported to comma-separated value (CSV) tabular files with timestamps and were manually reviewed and corrected where transcription inaccuracies were detected.

Thereafter, an adapted Constant Comparison Analysis (CCA) and approach influenced by Grounded Theory (B. G. Glaser, 1965; B. Glaser & Strauss, 1967) were used to group and sort the focus group data into themes. Glaser's approach to grounded theory relies on data

itself to induce theory to reach saturation and Strauss allows for more flexibility to deduce theory from data as informed by discourse in literature. This inductive process enabled simultaneous iteration and codification which Glaser describes as blending two approaches. The data were coded and grouped into as many categories as possible in a column on a Microsoft Excel spreadsheet and then categories and their properties were combined where similarities could be drawn into themes (B. G. Glaser, 1965). Compared to pure Grounded Theory, ‘in-vivo’ themes were not used and paraphrased theme titling was used instead to improve clarity and minimise the number of thematic categories.

By using this approach, the themes were delimited into theoretical groups: environmental (extrinsic factors that impact cycling) or experiential (intrinsic individual accounts described or felt) groups ultimately resulting in 9 themes (three experiential, six environmental). The themes induced from data are discussed in section 5.5.1.1 and 5.5.1.2. The thematic categorization process is outlined in Table 5.4.2 below.

Table 5.4.2 Data analysis and interpretation process

Phase	Step	Action	CCA Step
Collection	1	Interview/focus group recordings	
	2	WhisperAI transcription	
	3	Transcripts to CSV	
Analysis	4	Manual review/correction in Excel	
	5	Transcripts punctuated/segmented	
	6	Sentences/segments assigned codes in code column on Excel spreadsheet	Comparing incidents applicable to each category (1): <i>coding into as many categories of analysis as possible</i>
Interpretation	7	Codes delimited into theoretical groups: <i>environmental/experiential</i>	Integrating categories and their properties (2): <i>analyst makes related theoretical sense of each comparison</i>
	8	Theoretical groups broken into nine theme column labels in Excel: <i>communication & cues, infrastructure, transition period, trust, behaviour, comfort, safety, subordination, altruism</i>	Delimiting the theory (3): <i>solidifying theory and list of categories</i>
Dissemination	9	Publication process (<i>current step</i>)	Writing theory (4): <i>paper and memo writing</i>

5.4.2 Likert-scale Attitude and Stress Survey Variables

The Likert scale data were analyzed solely through descriptive statistics to address this research question #1. This was used to establish a baseline understanding of participants' attitudes and stress towards cycling with AVs and with COVs. These Likert variables are analyzed more in-depth in subsequent chapters through different statistical analysis methods. The variables concerned several areas. The first of these variables is the level of bicycle user confidence which was subject to a classification and data processing method that systematically drew on participant responses to assign a Geller classification. The process of this classification is outlined in detail in section 4.5.2.7. On average, participants were slightly more confident than 'enthused and confident' (3.15/4 where 4 = strong and fearless).

Several other prompts related to attitude and stress were posed to participants as follows (the coding in the table is indented below each prompt):

1. I generally have a favourable impression of cycling with the autonomous shuttle
 - Coded as 'comfortgeneral favourable'; labelled *ATTITUDE*
2. Autonomous vehicles on roads without separate bike space would make me feel comfortable while cycling.
 - Coded as 'avsharedcomfort'; labelled *STRESS*
3. Sharing the same street space with an autonomous vehicle would benefit cycling
 - Coded as 'avsharedbenefit'; labelled *STRESS*
4. Autonomous vehicles on roads with separate bike space would make me feel comfortable while cycling.
 - Coded as 'avseparatecomfort'; labelled *STRESS*
5. Separating space between autonomous vehicles and bicycles would benefit cycling
 - Coded as 'avseparatebenefit'; labelled *STRESS*
6. Human-operated vehicles on roads without separate bike space makes me feel comfortable while cycling.
 - Coded as 'convsharedcomfort'; labelled *STRESS*
7. Human-operated vehicles on roads with separate bike space makes me feel comfortable while cycling.

- Coded as 'convseparatecomfort'; labelled *STRESS*

The responses to these survey questions are summarised in Table 5.4.3 below and are discussed in section 5.5.2.

Table 5.4.3 Descriptive statistics of Likert-scale attitude and stress responses

		Bicycle User Classification	1. comfortgeneral favourable	2. avshared comfort	3. avshared benefit	4. avseparate comfort	5. avseparate benefit	6. convshared comfort	7. convseparate comfort
N	Valid	415	335	415	415	415	415	415	415
	Missing	1	81	1	1	1	1	1	1
Mean		3.15	3.93	3.25	2.66	4.51	4.13	2.37	4.40
Median		3.00	4.00	4.00	3.00	5.00	4.00	2.00	5.00
Std. Deviation		.774	1.130	1.296	1.081	.932	1.130	1.126	.932

Note that in the table above, the variable *comfortgeneral favourable* was added following the pilot data collection phase when the survey was determined to not have sufficient representation from the subjective norms component of TPB. The missing responses represent this pilot location strata subset not having this variable to respond to. While all questions were optional, responses that are missing are omitted from further analysis.

5.5 Results

5.5.1 Interviews and Focus Groups

Based on the transcripts and thematic classification, nine recurring themes emerged from the focus groups and interviews during analysis (Figure 5.5.1). The most prevalent theme, *communication & cues*, arose 23 times. Separated infrastructure, with 19 occurrences, highlighted the importance of separated bicycle infrastructure for safety and comfort cycling. Concerning *trust* (15 occurrences), participants had varying levels of familiarity and concerns about AI which was inextricably linked to the topic of AVs. The *behaviour* theme

(with 13 occurrences) had participants sharing how some exercise caution and others see AVs as approachable and potentially beneficial to cycling. In terms of *comfort* (12 occurrences), particularly with the AVs involved in the present study, discussions revealed that AVs' slower speeds and reduced road rage increase comfort for cyclists. Participants mentioned the *transition period* 7 times and highlighted that as conventional vehicles and AVs coexist, bicycle users face challenges, including adjusting their defensive tactics. *Safety* was raised 7 times as well. Participants' primary concerns were audibility, vehicle size, blind spots, and speed. Penultimately, *subordination* (4 mentions), had discussions on power dynamics and modal hierarchy. Finally, *altruism* came up 3 times which outlined how participants considered their impact on the transportation system, adjusting their behaviour in response to AV shuttle shortcomings.

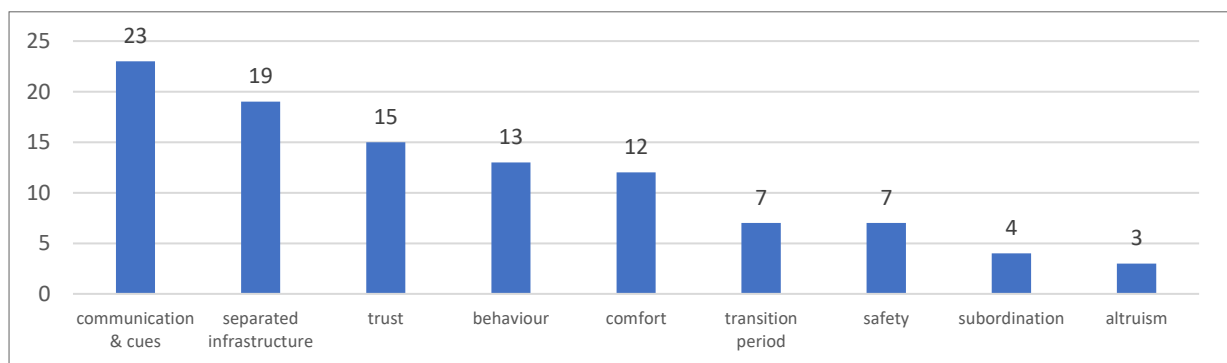


Figure 5.5.1 Theme frequency in focus groups

The direct quotes in the following sections are presented verbatim with minimal editing to preserve the original tone and delivery by the individual participant(s).

5.5.1.1 Environmental themes

5.5.1.1.1 Negotiation Attitudes

Current urban bicycle use depends largely on subtle cues and nonverbal communication from motorists who share streets with other road users. These include waves, eye contact, flashing headlights, pointing, and/or sounding the horn. As unarmoured active transport users, bicycle users rely heavily on confirmatory messaging from motorists to ensure that they have been seen, acknowledged, and have granted them priority in a roadway negotiation at an intersection, crossing, or other point of conflict. This theme also arose in

open-ended survey responses and is highlighted and discussed in section 0 in the chapter that deals more directly with safety, comfort, and infrastructure preferences.

For the Negotiation theme, participants explained their attitudes towards negotiating and communicating with AVs and applicable traffic scenarios. Negotiation was the most frequently mentioned theme in participant comments. Participants engaged for this study cited many concerns around how to communicate and receive confirmatory messages from AVs. Discussion items pertaining to 'negotiation' involved interpreting, responding, executing, and overall power dynamics between AVs and bicycle use on public streets.

"One of the first things I say out of the gate to them is it's all about communication I think that's one of the soft spots of it. You no longer have that interaction [with AVs]. [...] At any intersection, sure you're making eye contact with the driver at least see them slowing down. That's where I might fall off 'the autonomous vehicle might be safer' [bandwagon]. That interaction will not exist. So that's the weight of the be predictable. So versus not being able to, not being able to tell for yourself by looking at the eyes and you're riding along." (Montréal, 55+, Strong and fearless)

"Communication can go both ways. People can go ahead, or they can wave. If they don't have that part of the communication then maybe it's not that bad. I feel like there's always pros and cons and I guess I wouldn't mind that much and it wouldn't change the way I drive my bike, which is maybe change how I learn to act around for anything in general. I think at the end, I don't know what the role is in this, because I'd say there will be people in the car and I contact with them, they can do nothing." (Montréal, 18-34, Strong and fearless)

"Honestly, you're making me even more scared. because communication is such a big thing when I'm on my bicycle. I'm always making sure, okay, this person sees me." (Montréal, 18-34, Strong and fearless)

Other participants noted that the interpretation of traffic rules is subject to a degree of flexibility in practice. While a bicycle user may not have the absolute right-of-way, a human driver may grant them the courtesy by waving them through. While bicycle users may become accustomed to this courtesy and pre-empt it in certain circumstances, AVs will

likely not be flexible in interpreting traffic law nor will they be in a position to 'wave' through a bicycle user.

"Sometimes I arrive at a stop, like, let's say three seconds after the car that's another side will arrive, and normally I'll be like, 'Okay, he was there first, so I'll let him go,' but he does a little [wave] like, 'Okay, go ahead.' So, 'Okay, I know I can go.'" (Montréal, 18-34, Strong and fearless)

Several other participants from other sessions and sites echoed this sentiment.

"but comes down to when you're at a stop, like an intersection, and there's no light, a lot of drivers will give you priority." (Montréal, 35-54, Strong and fearless)

"They are going to stop and you are going to proceed and you're never, when you get really comfortable, you're never going to even pause. So you, you get to the crosswalk, you immediately make your 90 degree turn, you're crossing." (Stavanger, 35-54, Interested but concerned)

"Cars are extremely polite, they always stop, regular cars, they stop when they're not meant to stop. They don't obey the traffic rules in that they stop for you as a cyclist when they're meant to be carrying on." (Stavanger, no age provided, bicycle class not available)

Many participants clearly stated the importance of eye contact in negotiating with human-operated vehicles. Most participants across all living lab sites stressed that they regularly found interpreting communication challenging from the shuttles.

"[...] we don't have this communication, we don't have to this feedback emotions that we can have with humans." (Montréal, 18-34, Strong and fearless)

"The autonomous car? Like will they just because they won't be able to do eye contact." (Montréal, 35-54, Strong and fearless)

"So if there is a driver that I cannot establish eye contact with, it's much less trustworthy" (Linköping, 35-54, Enthused and confident)

“I would probably change [my riding behaviour] a bit, since I wouldn't exactly know where to look for eye contact” (Linköping, 35-54, Enthused and confident)

If AVs become more common, one of the biggest concerns for their deployment among non-occupants is the issue of communication (Botello et al., 2019). The findings in this study corroborate these findings noting that the most common theme of negotiation raises identical concerns to that of communication between VRUs (bicycle users) and AVs. Any nonverbal communication may be rendered completely useless in the age of driverless vehicles (Hagenzieker et al., 2020) and this could be a major negative drawback when considering the comfort and confidence of bicycle users and other VRUs.

5.5.1.1.2 Attitudes towards Separated Infrastructure

The second most discussed theme among participants was the importance of high-quality, separated bicycle infrastructure. While this theme does not directly relate to attitudes, it should be noted that this theme was a substantial component of focus group subject-matter. The data related to this theme is more readily applicable, and is discussed exhaustively, in Chapter 7. Participants widely agreed that greater separation from traffic enhances comfort and provides more legible, safe, and comfortable space for cycling. This is evidenced by the survey and interview-focus group responses compiled in Chapter 7 where there was a drastically different comfort level for cycling among AVs and COVs in shared infrastructure (37%) vs. separated infrastructure (2.5%). This is further outlined and discussed in Chapter 7 also highlighting findings which support and corroborate this both with COVs (Heinen et al., 2010; Whannell et al., 2012) and AVs (Botello et al., 2019).

5.5.1.1.3 Attitudes towards the ‘Transition Period’

During the period when both conventional and autonomous vehicles exist on roadways simultaneously, there will be challenges that bicycle users will face. Much of these challenges have to do with identifying how a vehicle is being driven, then determining how to interact with it.

“People will have to change if there are ways of cycling and so they can be safer with autonomous vehicles. So that maybe could take time to adapt so maybe in the

transition time it could be a little bit harder for people and more at risk. But I feel like over time when people are used to it, improve the safety.” (Montréal, 18-34, Strong and fearless)

One situation identified by participants was if a bicycle user should be more or less willing to compromise their defensive driving tactics (taking the whole lane).

“I feel if it was an autonomous vehicle, like I would be maybe more comfortable if it was like maybe only autonomous vehicle because I could say, okay, I'll stay in the middle of the lane and the car which has a radar I guess will know that I'm there and if they want to pass me they'll just change lane but they won't be impatient. It's not a driver who has emotion and like oh that stupid bike.” (Montréal, 18-34, Strong and fearless)

It was raised that there could be a generational divide as people are introduced to AV technology. Different age groups will likely handle the transition differently.

“I think that the pacing [of AV technology deployment], I think that's kind of a critical element to an introduction to people that are less comfortable with technology, et cetera, et cetera. Older people are going to be like [more impacted].” (Stavanger, 35-54, Interested but concerned)

“I think the average cyclist would, I think the average cyclist once they got used to understanding what it meant would be okay with it, a bit like electricity.” (Stavanger, no age provided, bicycle class not available)

5.5.1.2 Experiential descriptors

5.5.1.2.1 Attitudes around trust

Focus group participants were prompted to share their level of trust with AV technology. Participants discussed trust with AVs as a technology package and artificial intelligence (AI) as a component of the AV technology package. Different participants came with different levels of understanding and experience with AVs and AI.

“I don't feel like I trust more the AI than you. I'm not at this level yet. Sounds strange but if you ask me this question a few years ago I would have told you ‘Oh the AI is the way of the future’. I just finished my Master in AI and now I'm a bit scared because I know how it works” (Montréal, 18-34, Strong and fearless)

Other participants spoke more broadly about AVs and their trustworthiness and how favourably they view the driverless shuttle and the benefits that the trajectory of its underlying technology will take on urban bicycle users.

“I sort of figured, again, I think I am more favourable of this program as opposed” (Montréal, 55+, Strong and fearless)

“I think there's a lot of people who don't like technology and they prefer to stay away from it. But for bicycle, I think for the person who likes to bike, I think it would prefer autonomous.” (Montréal, 18-34, Strong and fearless)

“If it's on the street, I would say, okay, you have been through the battery of tests, it's safe enough. If you have a street, my first reaction would be to trust people. Until proven otherwise” (Montréal, 18-34, Strong and fearless)

“The autonomous car makes less accidents after tests, I think the perception that there's somebody that you can like last resort ask or I think that people feel safer with people than machines.” (Montréal, 35-54, Strong and fearless)

“Well in Stavanger, I think people don't care [...] Setting aside the incredible infrastructure, which is what makes me feel good. Yeah, they are trusting.” (Stavanger, 35-54, Interested but concerned)

There were specific accounts that some participants recounted that impacted their level of trust around suspicious actions that the shuttle took. However, it was not clear if the shuttle was operating under autonomous driving during the time that these accounts were recorded.

“So it was like a bit of a weird situation where it felt like the environment was not that well understood by the shuttle. So I'd be a bit careful around that because of that past experience, I guess.” (Montréal, 18-34, Strong and fearless)

“Like okay it's not moving so I guess I can go ahead but if it's a long distance you cross then maybe it can be a little I would be a bit more hesitant like okay does it know that I'm going and I have time to cross before it” (Montréal, 18-34, Strong and fearless)

“I guess I've made it stop. I feel it's difficult to know how far away it could be before it senses me and stops.” (Linköping, 18-34, Strong and fearless)

“When I was in a separate bike lane it didn't... I didn't think about it too much. Yes [I was able to block it out and ride normally] more so than with cars because I know cars can take turns and cross my path to go into the [side] streets. But I know the route of the autonomous vehicle, it would never turn that way or if it did so, it would never so abruptly. I don't think it's able to. So I can rely on it, it stays on its path, whereas with the car, no.” (Linköping, 35-54, Enthused and confident)

5.5.1.2.2 Behaviour-based attitudes

The behaviour theme encompasses daily bicycle use behaviour, behavioural changes that are made while riding, route choice, and the ability to change mode choice behaviour. This theme concerns adaptations that bicycle users have or plan to make to accommodate AVs. Many participants highlighted they exercise a greater degree of caution around the shuttles, which was evident in their directly quoted remarks.

“I quite frankly, am more conscious of the autonomous vehicle, than of your average person behind the wheel.” (Montréal, 55+, Strong and fearless)

“I was thinking if I could treat the situation any differently. I don't think that I necessarily would; I might give it a wide turn maybe but maybe a little bit more caution” (Montréal, 55+, Strong and fearless)

“How it will impact cycling, I guess I would be more, as a person who bikes, I think I would be more cautious around the shuttle. [...] It still sounds like it's experimental in a way. It also adds to the cautiousness, I guess.” (Montréal, 18-34, Strong and fearless)

“So I leave it some more space, then I probably would leave a driver before I have eye contact.” (Linköping, 35-54, Enthused and confident)

“[If I knew it was an AV I would be] less patient. Yeah, because it's more predictable.” (Stavanger, no age provided, bicycle class not available)

Other participants outlined that they did not foresee any change in their behaviour.

“So I feel like yeah if there's a lot of people [onboard] or not I think it wouldn't change the way I act.” (Montréal, 18-34, Strong and fearless)

“I don't think it would make me want to change my route or something, but [the AV is] definitely not something that I would avoid.” (Linköping, 35-54, Enthused and confident)

Participants elaborated that the AV shuttles may be a more approachable vehicle. Less confident bicycle users such as the ‘interested but concerned’ and the ‘no way no how’ individuals could be more inclined to cycle.

“[...] if there's less cars it will be I think safer so if people know that street over time as okay this street is slow because of that shuttle and it's something there then I will take another way and therefore there'll be less cars” (Montréal, 18-34, Strong and fearless)

Conversely, one participant explained that their colleagues have found the AVs a deterrent to their choosing to ride a bicycle for their daily travel needs.

“Yeah, I can't really understand why, but I've heard some of my colleagues talking about them that they are really not comfortable with biking besides that they stop biking to work.” (Linköping, 18-34, Strong and fearless)

5.5.1.2.3 Attitudes around comfort

Bicycle user behaviour is determined by safety and comfort (Winters et al., 2020; Broach et al., 2012; Sener et al., 2009; Imani et al., 2019). Comfort is a key determinant of bicycle user behaviour that will be influenced by AVs and it is the fifth-most discussed theme during focus groups. The most common discussion related to comfort was when participants drew comparisons to conventionally operated vehicles.

“But say, I would feel like it's more stable [than conventionally operated vehicles], because I feel like I would trust more than any other perspective.” (Montréal, 18-34, Strong and fearless)

“What's most stressful is the total unpredictability of people.” (Montréal, 55+, Strong and fearless)

“I'm pretty confident that there is one of these shuttles behind me, and you feel the stress, and it's been more confident that it wouldn't pass” (Montréal, 55+, Strong and fearless)

“What's most stressful is the total unpredictability of people.” (Montréal, 55+, Strong and fearless)

Many participants noted that the shuttles they experienced operated at unusually slow speeds which made them feel much safer.

“I feel that maybe if it's slower, I'll be more comfortable because even if there's some cars behind that are waiting, like especially on the St-Hubert it's not wide enough that a car can pass another car but it's wide enough that when you're biking even if there's traffic because it's 5pm and there's a red light and the cars are accumulating you can still go on the side and it's like, ‘woohoo, I'm on my bike so I can go faster.’ So when the cars are not moving very fast, I feel more safe because I can just go on the side and pass them easily.” (Montréal, 18-34, Strong and fearless)

“I would expect the whole, overall the whole traffic to be slower, which makes me feel more comfortable because if it's slower, even if it's almost slower, it means that we all have more time to react if something goes wrong. I would expect less accidents that way.” (Montréal, 18-34, Strong and fearless)

Topics of road rage were raised in that AVs would eliminate the anger, adversarial interaction, and verbal abuse that some urban bicycle users face for simply moving around by bike.

“I feel like again when there's no driver then there's no road rage so I feel maybe they would be more comfortable if there's more autonomous vehicles and less people can be angry at people for just using their bikes.” (Montréal, 18-34, Strong and fearless)

5.5.1.2.4 Attitudes around safety aspects

Safety concerns were not necessarily exclusively attributable to AVs and AV technology. Sub-themes that emerged were: audibility, vehicle size and mass, visibility/blind spots, and speed. One participant also commented on the comparative safety of an AV.

“Actually, the fact that [the shuttle is] electric brings up another element; it's quiet [...] to think that silence could actually be a bad thing.” (Montréal, 55+, Strong and fearless)

“Normally I always only go on the left of the car if I don't have enough space. In that case, I was like, it's not a bus, but it's big enough to do a lot of damage.” (Montréal, 35-54, Strong and fearless)

“Say the autonomous car comes to its stop and their pedestrians crossing, like the [bicycle user] will have less visibility if they're next to it.” (Montréal, 35-54, Strong and fearless)

When prompted about sense of safety as AVs operate at faster speeds, participants made the following remarks:

“[When vehicles travel 50-70 km/h] I feel I need a little less [speed with paint markings alone], like a more more speed limit.” (Linköping, 18-34, Strong and fearless)

“Eventually an autonomous vehicle is safer than a human driver. That's how I perceive it.” (Stavanger, 35-54, Interested but concerned)

5.5.1.2.5 Attitudes on subordination

Power dynamics through the form of prevailing modal hierarchy was discussed during sessions. Contributions related to the subordination or marginalisation of bicycle users are grouped under the subordination theme. Participants discussed sub themes related to usage rights, privilege, and established ‘superiority’.

A participant raised a point about who has the right to use public streets which is similar in concept to the ‘Right to the City’ (Purcell, 2002). The Right to the City is a concept that purports that urban space should be inclusive, accessible, and embody democratic principles.

“I think this is something here in terms of who has the right to be a disturber. Your average driver in your situation always says that cyclist has no business in my lane on my street. I'm a car. You're a car, we're okay. You can do whatever you want.” (Montréal, 55+, Strong and fearless)

Another participant highlighted that they have little ability to exert dominance over the streetscape because of established systemic transport mode hierarchies and their inferior size.

“And if I'm getting hit by the shuttle, it's a bit more than just if I was in the car. Like, I'm more-- as a rider on the bike, I'm more-- I'm weaker than other vehicles.” (Montréal, 18-34, Strong and fearless)

5.5.1.2.6 Attitudes towards aspects of altruism

This theme grouped sentiment that participants explained about their place in the transportation system and how they were considering the needs of other road users. Many

responses were a result of some of the AV shuttle's shortcomings. Participants would continue their defensive bicycle behaviour (i.e. taking an entire road) or being courteous by moving to the side when there is sufficient shoulder space or an unused parking lane and moving back into the travel lane when there is insufficient shoulder space or parking spaces are used. The AVs that participants interacted reacted abruptly to what participants felt was normal and justified bicycle behaviour.

"I feel bad for like taking up the lane and like cars can't go past me. Like, 'cause sometimes I do that, I'll take the whole street." (Montréal, 18-34, Strong and fearless)

Another participant shared an account of the collective psyche around impacting movement of buses.

"They'd say, 'You would never cut off a bus like the collective guilt would be [high]'" (Stavanger, 35-54, Interested but concerned)

In a similar vein, another participant from the Stavanger living lab highlighted that they would not want to be the cause of sudden or abrupt movements for the individuals onboard the shuttle.

"Yes, for sure, 'cause I wouldn't want to purposefully put ill at ease the people that were inside that vehicle." (Stavanger, no age provided, bicycle class not available)

This sense of concern for occupant well-being and other road users is interesting, especially because the abrupt or sudden movements for AV shuttle occupants are more often the result of the AV shuttle's sensor suite 'overreacting' in situations that conventionally operated vehicles would react less abruptly. It could be said that these participants are internalizing guilt that is not necessarily the result of their actions.

5.5.2 Likert-scale Attitude and Stress Survey Variables

All participants indicated their position on a five-point Likert scale for each of the statements outlined in section 5.4.2 resulting in distributions shown in Table 5.5.1 and Figure 5.5.2. There are clear attitude distinctions that show respondents' affirming or

dissenting positions depending on the different variables posed in the statements. Each of the statements centered on the position of a bicycle user on the street. Statements asked participants, firstly, to give an overall impression of cycling with an AV (1. I generally have a favourable impression of cycling with the autonomous shuttle). A majority of respondents (~67%) either agreed or strongly agreed with this statement. Participants likely had this attitude toward cycling with an AV due to their regular experience, prolonged exposure, and understanding of how the AV shuttles operated in their neighbourhoods (Li et al., 2023; Pyrialakou et al., 2020).

Respondents were asked to respond to a statement about how comfortable they individually feel riding a bicycle with AVs on streets that they share space with an AV (statement #2) and another statement about how comfortable they feel riding a bicycle where there is separate space for bicycles and AVs (statement #4). The data show a clear division in the attitude toward each of these scenarios. The data suggest that respondents feel significantly more comfortable when separated from AVs (~51% responded positively). The data also suggest that respondents feel uncomfortable sharing street space with an AV while bicycling (~43% responded negatively).

Two statements related to cycling benefit more generally were posed to participants. Like the above statements, there was both a statement about separating or combining road users. The statement on sharing space benefitting cycling more broadly (statement #3) skewed more negative than individual comfort (~43% somewhat disagree/strongly disagree). The statement on separating space for AVs and bicycles (statement #5) skewed noticeably more positive than for individual comfort (~76% somewhat agree/strongly agree).

Human-operated statements were also used as a comparison to benchmark and understand if AVs would further polarise comfort attitudes on shared or separated bicycle/auto street configurations. Statements #6 and #7 were worded as: human-operated vehicles on roads with/without separate bike space makes me feel comfortable while cycling. Compared to the AV statement (#2), statement #6 about shared space, skewed more negative. Of particular note, compared to the AV statement on separated space (#4), statement #7 had nearly identical sentiment to that for human-operated

vehicles. This suggests that attitudes of comfort are universally higher with separated-mode streetscapes and that well-designed infrastructure may nullify any technological change. AVs may only marginally improve comfort attitudes for cycling in shared space with AVs. Importantly, these attitude towards comfort findings must to be further analyzed with independent demographic variables to better understand the impact for specific groups of bicycle users. This finding will be further expanded and analyzed in Chapter 6.

Table 5.5.1 Likert-scale response summary

	STRONG DISAGREE	SOMEWH DISAGREE	NEUTRAL	SOMEWH AGREE	STRONG AGREE	Total
1. I generally have a favourable impression of cycling with the autonomous shuttle	2.7%	10.1%	20.6%	24.2%	42.4%	335
2. Autonomous vehicles on roads without separate bike space would make me feel comfortable while cycling.	9.2%	24.8%	13.3%	34.2%	17.8%	415
3. Sharing the same street space with an autonomous vehicle would benefit cycling	13.0%	30.1%	37.3%	12.3%	6.3%	415
4. Autonomous vehicles on roads with separate bike space would make me feel comfortable while cycling.	1.4%	1.7%	5.1%	22.2%	68.4%	415
5. Separating space between autonomous vehicles and bicycles would benefit cycling	1.9%	2.7%	16.9%	26.7%	49.6%	415
6. Human-operated vehicles on roads without separate bike space makes me feel comfortable while cycling.	22.9%	40.5%	13.7%	20.0%	2.4%	415
7. Human-operated vehicles on roads with separate bike space makes me feel comfortable while cycling.	1.2%	3.1%	5.1%	31.1%	58.6%	415

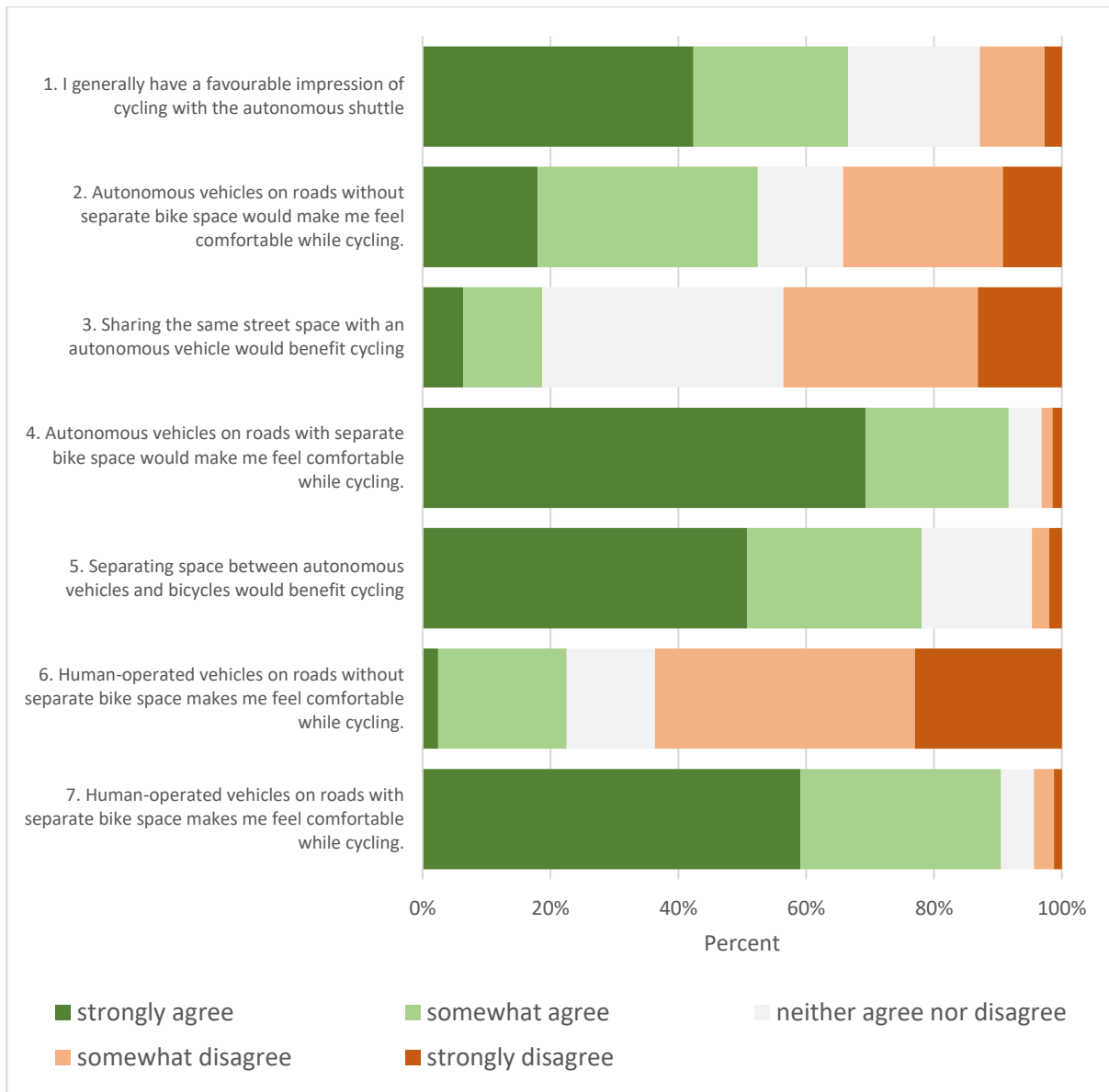


Figure 5.5.2 Likert-scale response summary chart

The above Likert-scale responses should be interpreted together with an understanding of the bicycle user classifications of the respondents shown in Figure 5.5.3 below. A more comprehensive regression analysis is conducted in Chapter 6 to understand the magnitude of influence for the most pertinent AV preference datapoints against bicycle user classifications. This figure is presented here to provide some context for the Likert-scale responses.

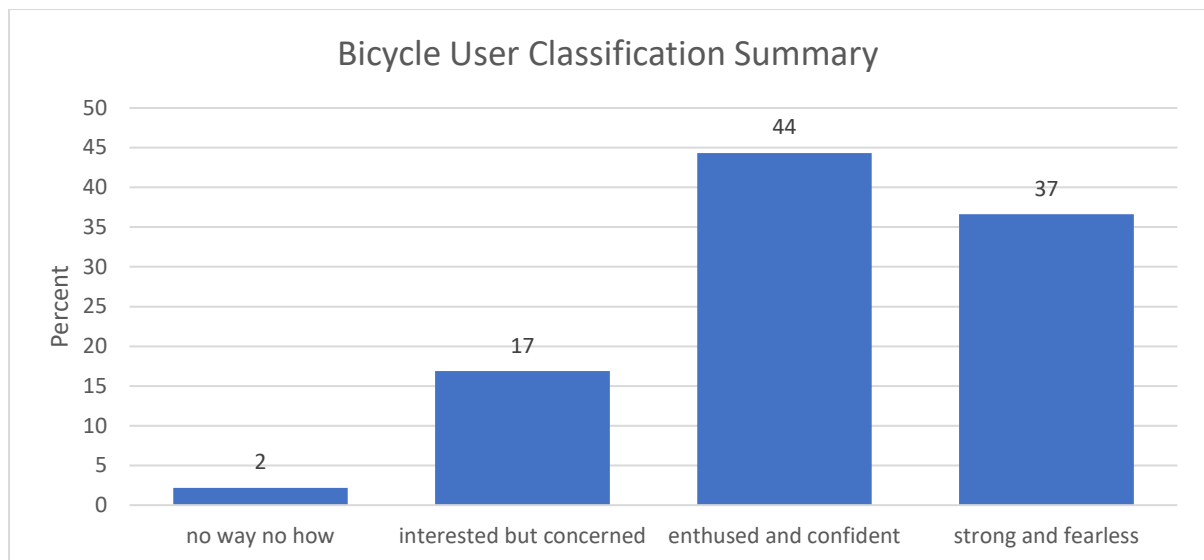


Figure 5.5.3 Bicycle user classification summary chart

5.6 Discussion

Qualitative results discussed a wide range of themes that impacted *environment* and *experience*. Holistically, attitudes of those that use a bicycle in the urban realm where an AV is introduced highlight several overarching themes from study participants. Findings across living lab sites primarily highlight several major concerns that are reflected in the literature but are strengthened by the empirical findings of this research. At its core, the empirical findings in this chapter can be summarised in the two thematic categories (environmental and experiential).

Environmental themes which are factors that impact cycling (Fraser & Lock, 2011; Winters et al., 2011) emphasise, firstly, concern around the loss of nonverbal communication which is echoed in research by Pelikan (2021) and by Al-Taie (2023) especially at uncontrolled intersections and roundabouts through gestures and speed changes, or when there is confusion around overtaking (Boersma et al., 2018) and its associated risks (Oskina et al., 2023). Other studies emphasise that clear communication through the form of “assurance” (p. 772) is a requirement for bicycle users (Parkin et al., 2023) and that AVs struggle to “coordinate their movements with other people who are normally present in regular traffic” (Pelikan, 2021, p. 5). Other recurring themes showed a strong preference for physically separated bicycle infrastructure which is reinforced by several scholars (Das et al., 2023; Madigan et al., 2019; Oskina et al., 2023). Furthermore, both participants in

the study and literature cite a degree of unease over a transition period when vehicles have varying levels of automation and how a mixed AV/conventional vehicle environment will materialise. Other scholars also report unease, however that it varies depending on how positively perceived AVs are (Imanishimwe & Kumar, 2023).

Experiential themes that participants highlighted included varying levels of trust in AI and AV technology. As similarly outlined in a study by Bjørnskau et al. (2023), it was found that bicycle users change their behaviour when interacting with AVs which the data in this study support in that AVs lead to an increase in caution from bicycle users. Other changes to behaviour from other road users were also noted in other studies that deal with ‘bullying’ AVs (Liu et al., 2022), which is a concern cited by auto manufacturers (Madigan et al., 2019), and behaving differently than expected (Haué & Merlhiot, 2024; Pokorny et al., 2021).

Findings from this study also align in that some participants cite potential positive changes to comfort through AV shuttle slower operating speeds and the potential to eliminate road rage which is corroborated in a study by Haué & Merlhiot (2024). Participants also discussed concerns about safety where AVs may change vehicle audibility, the size delta between bicycle users and AVs, and blind spots. These findings, particularly around audibility, align with results in other studies (Pelikan & Jung, 2023). There were also discussions around *affective* interaction such as themes that deal with subordination and power dynamics between modes of transportation as well as elements of empathy through expressions of altruism that participants expressed towards AVs and other road users more broadly.

Aspects that were more quantitatively measured through Likert-scale sentiment showed that a modest majority of respondents had a favourable impression of riding a bicycle in a streetscape with AVs. In studies that co-opt this with understanding the technology, they also find that a majority of participants have a favourable impression so long as they have a “positive perception toward AVs” (Imanishimwe & Kumar, 2023, p. 10). There is a strong preference for dedicated bicycle space in urban environments with AVs and findings suggest that infrastructure separation may be more important than vehicle type for fostering a healthy mode split to balance the transportation system as AVs mature. This

finding is shared by Botello et al. (2019) in their research which found that infrastructure neutralises the effect of vehicle type on comfort (one of the largest behavioural determinants of urban cycling as explained in contextual chapters 1 - 3).

5.7 Conclusion

This chapter and its associated research question aimed to understand attitudes of bicycle users with autonomous vehicles. The question that was posed to participants (research question #1) directly addressed this by asking: *to what extent will the introduction of AVs impact attitudes towards cycling in urban AV 'living labs'?* The extent of impact on attitudes was measured using qualitative surveys and focus groups primarily as well as quantitatively using ordinal-scale survey responses that asked participants to rank their agreement or disagreement. These Likert-scale questions posed seven statements used as proxies to assess attitudes either directly, or by using traffic stress to frame the impact on a bicycle user's attitude.

The attitudes that form the basis of the interpretation in this chapter show that there is a clear hierarchy of importance for fostering constructive attitudes. There are several conclusions that can be drawn from the results presented.

1. Well-designed, high quality, separated infrastructure may be more important for cyclist comfort than the extent of vehicle automation
2. The removal of human communication/negotiation is a major concern
3. A forthcoming transition period where mixed AVs and conventional vehicles presents unique challenges
4. Slower AV shuttle operating speeds and an absence of road rage were seen as positive aspects
5. Inter- and intra- street participant power dynamics between modes remain a concern

The conclusions directly translate to attitude impact of bicycle users in living labs. They can be summarised in a hierarchy of bicycle user needs in AV environments (Figure 5.7.1). The base of the hierarchy has is the most important need for bicycle users in a streetscape. It must be underscored that the findings from this research and the conclusions presented suggest that, while AVs may offer some benefits for bicycle users, infrastructure design remains crucial for bicycle user comfort and safety.

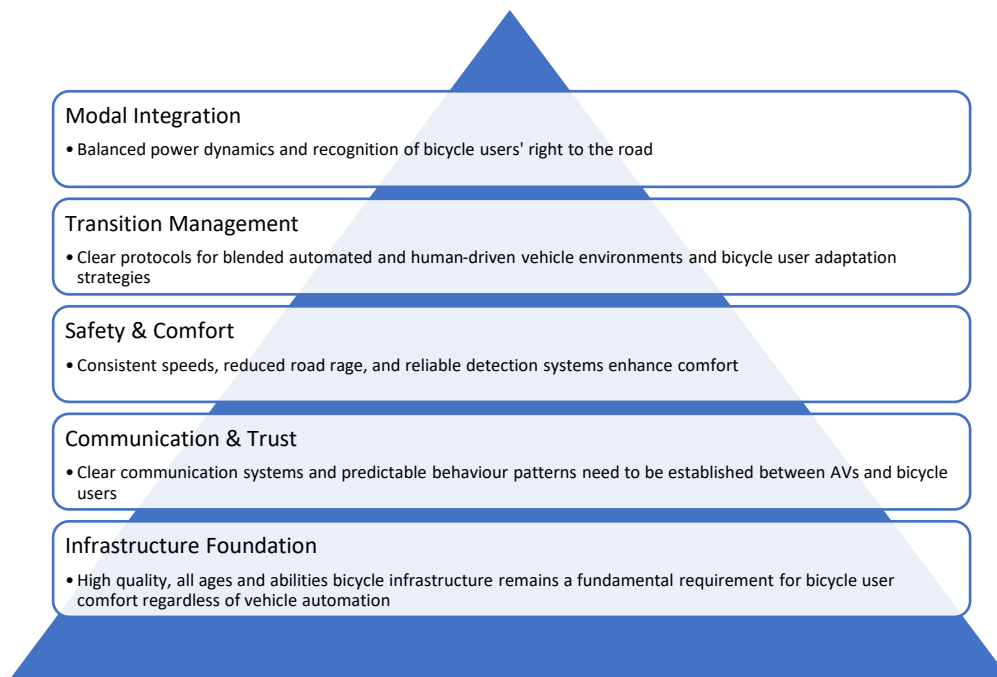


Figure 5.7.1 Hierarchy of bicycle user needs in AV environments

Results show that participants' top three concerns which impacted their attitudes towards AV living labs were predicated on their ability to communicate with AVs, the importance of separating bicycles from traffic, and how trust impacts their way of thinking through deeply held trust intuitions. Through these three core concerns, they form the base-level needs on a hierarchy of bicycle user needs in AV environments (Figure 5.7.1).

To succinctly present what most affects the attitudes of bicycle users, a Hierarchy of Bicycle User Needs was devised to highlight the biggest concerns and the top-priority areas that need to be addressed in urban environments. Foundationally, for bicycle use to be encouraged, a strong presence of bicycle-focussed infrastructure that is low-stress and high quality must be the core priority to simultaneously advance urban bicycle and AV readiness. Participants were also concerned about how they would communicate with and

interpret cues from AVs which impacted their trust levels and, ultimately, attitude towards the AV shuttles in operation in each of the living lab sites. Provided the foundation is established, safety and comfort through rules, regulations, and policy need to consider the importance of AV speed consistency, the need to reduce negative/anti-social behaviour towards bicycle users, and as other scholars have echoed: the importance of reliable detection and prediction systems (Pelikan, 2021; Pokorny et al., 2021; Rahman et al., 2021). As the core needs are met, transition management and modal integration will be important but subject to more extensive testing and broader interaction between bicycle users and AVs that should be collaboratively, iteratively, and democratically designed to reflect societal values for how the future of cities should look many generations into the future. Further study will be necessary to better understand attitudes and bicycle user needs both as AVs become more readily available and as the public increases their level of understanding. This study may provide a useful blueprint for where to begin, but the rapidly evolving nature will require a responsive effort to ensure the needs of bicycle users and the understanding of AVs is kept current.

In our current level of understanding and through the types of AVs that are presently operating in living labs, the series of bicycle user needs can be further nuanced with current behavioural impact on cycling trips. While attitudes lay part of the foundation of behavioural intent according to TPB, the ultimate decision and behaviour is vitally important to understand to gain a more complete picture. In the next chapter, the impacts of AVs on bicycle user behaviour are explored through empirical data which aim to further lay a foundational understanding of AV impact to be built and expanded upon.

6. AV Impact on cycling trips and behaviour

“A city with a lot of bicyclists is indeed a city with a lot of life. A city with a lot of cars is a city with a lot of cars, metal, and speed.”

—Jan Gehl

This Chapter builds on the attitudes of bicycle users from Chapter 5 and continues to investigate two other components of an adapted TPB which asked participants to respond to survey questions that served as proxies. The questions were designed as proxies to target both behavioural intent (that ask how behaviour may change with AVs) and subjective norms (that ask how generally acceptable and comfortable AVs are from the respondent's point of view). This chapter is laid out in 7 subsections beginning with an introduction in section 6.1, followed by a connection to the research question that this chapter specifically addresses in section 6.2. In section 6.3, a link back to the framing theories of bicycle user classification and the components of an adapted theory of planned behaviour are reiterated. In section 6.4, the methods used in this Chapter are outlined and connected to the overarching theory, including an overview of how results were found to be valid for further discussion. 0 presents the discussions and results that the research question set to answer. Penultimately, in section 6.6, key contributions from the results of this chapter are discussed along with any pertinent limitations for consideration. Finally, in section 6.7, concluding remarks and takeaways are presented in response to research question 2 as presented in section 6.2.

6.1 Introduction

In Chapter 5, attitudes were presented as a major factor that contribute to Ajzen's TPB. In this Chapter, the second research question explores how behaviours may be impacted. As introduced in section 1.8, mobility systems are intricate systems that are influenced by power dynamics.

The integration of AVs into urban transportation systems presents a novel challenge, particularly for bicycle users (Botello et al., 2019; Pelikan, 2021). It is crucial to understand how the existing systems of automobility and power dynamics, such as subordination cycles and the balance of mobility systems, will interact with the introduction of AVs and subsequently impact bicycle users (Gaio & Cugurullo, 2023). Currently, AI is rapidly evolving, often with limited tangible manifestations for the general public (Cugurullo et al., 2023). While AI is predominantly experienced in the digital sphere through generative models, AVs offer a unique and physical representation of AI's influence on urban environments. Early studies of AI-mediated transport with non-occupants have often been conducted in virtual settings (see section 2.2), which may not fully capture the responses of individuals interacting with AVs in real-world conditions.

Research question 2 seeks to explore this dynamic. The investigation aims to understand how bicycle users that interact with AVs in selected living lab sites will ultimately behave in a streetscape with AVs. This involves blending both quantitative and qualitative data to understand a bicycle user's perception of AVs and their perceptions impact their decision to ride a bicycle. This question is designed to understand the 'subjective norm' (noted as *NORMS* herein) component of the Theory of Planned Behaviour (TPB) as well as subsequent *INTENT* which considers the social influences on a given behaviour.

6.2 Research question 2

As first introduced in section 3.4.2, research question two is: "How is the introduction of self-driving pilots influencing cycling trips?". This question is designed to interpret a participant's intentions to ride a bicycle in an urban setting with an AV and if there is a general consensus around how cycling with an AV is interpreted from respondents' subjective norm (i.e. their frame of view). These interpretations source their data from the Likert questionnaire that are labelled *INTENT* and *NORMS*.

6.3 Bicycle user typology behaviour and tolerance (Theory: Bicycle User Classification)

This chapter is informed by the Bicycle User Classification Theory which was initially outlined in section 3.3.2. This theory provides a sufficiently holistic understanding of urban

bicycle users, a general understanding of their tolerance interacting with AVs in stratified groups based on their characteristics. A prominent example is the classification system introduced in 2006 by the City of Portland's bicycle coordinator which categorises cyclists according to their comfort levels and has since become a foundational tool in cycling research and policymaking (Dill & McNeil, 2013; Félix et al., 2017). Complementary approaches have classified cyclists using other methods, however, they often adopt an inward-looking perspective, failing to account for individuals who may not self-identify as 'cyclists' (Dill & McNeil, 2013). In taking an inward-looking view, this may create a research design that excludes valuable perspectives of people who do not consider themselves 'cyclists', which is also highlighted in section 1.9.

Core to this chapter, and alongside the bicycle user classification framing, variables that represent two components of TPB that were not captured in *ATTITUDE* discussed in Chapter 5 make up most of the data interpretation in this chapter. The questions and data points that represent the TPB components are outlined in Table 4.3.1 and the variables used as a proxy for behaviour and tolerance are *INTENT* and *NORMS*.

Each bicycle user group exhibits distinct behaviours related to cycling and tolerances for traffic stress. For instance, Interested but Concerned bicycle users prioritise low-stress environments such as multi-use paths or quiet residential streets, while Enthused and Confident bicycle users tolerate moderate traffic stress and are comfortable using bike lanes on major roads. Strong and Fearless bicycle users, in contrast, are willing to ride in nearly any condition, including high-stress environments without dedicated cycling facilities. These distinctions allow the study to explore how self-identity and habitual cycling behaviour influence participants' behaviour in the form of influence on their bicycle use and trip habits. The methods used to understand and interpret these data are outlined in the following section.

6.4 Methods

Data collection was carried out using online surveys to those who lived within 300m of an AV shuttle route with participation invitations that were deposited into mailboxes of residents who lived within 150m. These invitations encouraged residents to visit and

complete the online survey portion of the study. A detailed overview of the data collection methods is outlined in Chapter 4.

Two nonparametric statistical analyses were used to interpret the data to answer research question two. Ordinal logistic regression analysis is used to determine the magnitude that different independent variable predictors have on several dependent *INTENT* and *NORMS* variables. The Wilcoxon rank-sum test was used to compare paired data that are related and concern study participant's comfort and trust before and after an intervention, in this case the intervention is the introduction of an AV shuttle. Both trust and comfort are categorised as *PBC* variables.

Firstly, for the ordinal logistic regression, the included dependent variables are as follows:

1. **General comfort level:** "Most people like me are comfortable cycling in an area with an autonomous shuttle"
(Subnorm most comfortable - *NORMS*)
2. **General acceptability:** "Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle"
(Subnorm general acceptable - *NORMS*)
3. **Behaviour change with shared space:** "Autonomous vehicles on roads without separate bike space would make me..."
(AV shared cycle more - *INTENT*)
4. **Behaviour change with separate space:** "Autonomous vehicles on roads with separate bike space would make me..."
(AV separate cycle more - *INTENT*)

To clarify the specification of the logistic regression models used in this study: only models that demonstrated a good statistical fit were selected for detailed analysis, while others were excluded due to poor fit or lack of statistically significant results. This decision was based on a series of three preliminary statistical checks used to assess the validity and reliability of each model before interpretation. These checks included: (1) Model Fitting Information, which compared each full model against an intercept-only model using a significance threshold of $p \leq 0.05$; (2) the Pearson Goodness of Fit Test, where a p -value

greater than 0.05 ($p > 0.05$) indicated an acceptable model fit; and (3) the Nagelkerke R-square, used to assess the model's explanatory power, primarily for relative comparison across models within the same dataset.

Models that failed to meet these criteria—particularly those that did not significantly improve over the baseline or showed poor goodness-of-fit (denoted with a hollow circle o in Table 6.4.1)—were not analyzed further, as their results were not considered statistically robust or meaningful for interpretation. In contrast, models that passed all three checks (denoted by a solid circle ●) were deemed to have a "good fit" and were included in the main analysis. Limiting the analysis to these better-fitting models enhanced the overall reliability and interpretability of the findings, ensuring that conclusions were based on statistically sound relationships between variables. A summary of the results presented and discussed are summarised in Table 6.4.1.

To validate the logistic regression model and identify statistically significant input variables, three preliminary statistical checks were conducted. First, model fitting information was used to compare each logit model with an intercept-only model, using a 95% confidence interval ($p \leq 0.05$) as the significance threshold. A model was considered to have a good fit if it demonstrated a statistically significant improvement over the baseline intercept-only model. Second, the Pearson goodness of fit test was applied to assess the model's ability to accurately represent the underlying data. For this test, a p-value greater than 0.05 ($p > 0.05$) indicated an acceptable fit, suggesting that the model's predicted outcomes were not significantly different from the observed data. Finally, the Nagelkerke R-square was calculated to determine the model's explanatory power. This measure provides insight into the proportion of variance in the dependent variable that can be explained by the independent variables in the model, helping to evaluate the overall predictive strength of the logistic regression.

In the case of the Nagelkerke pseudo R-squared values, while these may give relative insight compared against the same dataset, they cannot be interpreted independently. Baguley writes “comparisons between pseudo-R² must be restricted to the same measure within the same data set to be at all meaningful” (2012, p. 44). This is also shared by the UCLA: Statistical Consulting Group and they expand to explain that without broader

contextual information, pseudo R-squared values have little meaning (2011). Furthermore, noting that the field of social science deals with complex and unpredictable human behaviour that is difficult to capture in a statistical model, any interpretation must factor the emerging and novel behavioural influence that AVs inflict on human behaviour. Until there is a larger pool of data and more reliable data to draw comparisons from, this value may only be useful in comparing results within this dataset and should not be interpreted in absolute terms. All considered, these results are interpreted with caution.

Table 6.4.1 Variable reliability and significance crosstabs (Author's original)

	NORMS 1. Most people like me are comfortable cycling in an area with an autonomous shuttle	NORMS 2. Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle	INTENT 3. Autonomous vehicles on roads without separate bike space would make me...	INTENT 4. Autonomous vehicles on roads with separate bike space would make me...
Bicycle user classification	○ Fit ● Pearson Nagelkerke (0.025)	○ Fit ● Pearson Nagelkerke (0.012)	● Fit ● Pearson Nagelkerke (0.040)	○ Fit ○ Pearson Nagelkerke (0.004)
living lab site/bicycle urbanism maturity	● Fit ● Pearson Nagelkerke (0.060)	● Fit ● Pearson Nagelkerke (0.082)	● Fit ● Pearson Nagelkerke (0.058)	● Fit ● Pearson Nagelkerke (0.050)
Age	○ Fit ● Pearson Nagelkerke (0.014)	● Fit ● Pearson Nagelkerke (0.041)	● Fit ● Pearson Nagelkerke (0.045)	○ Fit ● Pearson Nagelkerke (0.005)
Gender	○ Fit ● Pearson Nagelkerke (0.008)	○ Fit ● Pearson Nagelkerke (0.011)	● Fit ● Pearson Nagelkerke (0.026)	○ Fit ● Pearson Nagelkerke (0.012)
Education Level	○ Fit ● Pearson Nagelkerke (0.014)	○ Fit ● Pearson Nagelkerke (0.030)	○ Fit ● Pearson Nagelkerke (0.028)	○ Fit ● Pearson Nagelkerke (0.018)
Employment Status	○ Fit ● Pearson Nagelkerke (0.014)	● Fit ● Pearson Nagelkerke (0.077)	○ Fit ○ Pearson Nagelkerke (0.023)	○ Fit ○ Pearson Nagelkerke (0.022)
Ethnic origin	● Fit ● Pearson Nagelkerke (0.082)	○ Fit ● Pearson Nagelkerke (0.052)	○ Fit ○ Pearson Nagelkerke (0.018)	○ Fit ● Pearson Nagelkerke (0.047)
Income level	○ Fit ● Pearson Nagelkerke (0.022)	● Fit ● Pearson Nagelkerke (0.033)	○ Fit ● Pearson Nagelkerke (0.020)	○ Fit ● Pearson Nagelkerke (0.014)
Innovation diffusion	○ Fit ● Pearson Nagelkerke (0.012)	○ Fit ● Pearson Nagelkerke (0.024)	○ Fit ○ Pearson Nagelkerke (0.012)	● Fit ● Pearson Nagelkerke (0.039)
Model fit significance: ○ None ($p > 0.05$) ● Strong ($p \leq 0.05$) Pearson chi-square goodness-of-fit: ○ Data does not fit model ($p \leq 0.05$) ● Data fits model ($p > 0.05$)				

The results of the logistic regression model shown in Table 6.4.1 resulted in certain input variables having significant influence over dependent variables. Table 6.4.1 is a summary of all the logistic regression tests performed on each of the independent and dependent variables. The dependent variables are listed on the x-axis and the independent variables are listed on the y-axis. Each cell contains the results of the logistic regression test which includes three items to determine how reliable the model fit and, therefore, the strength of the statistical relationship to use to draw conclusions.

There are three results in each cell. First, the model fit is listed where the threshold used to determine significance was $p \leq 0.05$, if the test met this threshold, a solid circle indicates a significant result (●) and a hollow circle indicates non-significant (○). If a model does not significantly improve prediction, it suggests that the independent variables do not strongly explain variations in the dependent variable. Second, a Pearson chi-square goodness-of-fit test threshold of $p > 0.05$ is used to determine model fit, where the threshold was met, similarly, a solid circle indicates good model fit (●) and hollow represents poor model fit (○). Thirdly, Nagelkerke pseudo r-squares values are included for comparison within the dataset only. As described above, no further analysis relied on these pseudo r-squared values.

The independent variables that were shown to have more statistically significant influence over dependent variables are highlighted in green in the above table. These relationships are listed below and will form the basis of the discussion and results section and how certain groups' cycling trips may be more impacted over others. In the case of relationships that were not statistically significant, there will also be a discussion on why this may be the case and recommendations to better understand these relationships in future studies that focus specifically on them.

1. **General comfort level:** "Most people like me are comfortable cycling in an area with an autonomous shuttle"
(Subnorm most comfortable - *NORMS*)
 - a. living lab site/bicycle urbanism maturity
 - b. Ethnic origin

2. **General acceptability:** “Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle”

(Subnorm general acceptable - *NORMS*)

- a. living lab site/bicycle urbanism maturity
- b. Age
- c. Employment Status
- d. Income level

3. **Behaviour change with shared space:** “Autonomous vehicles on roads without separate bike space would make me...”

(AV shared cycle more - *INTENT*)

- a. Bicycle user classification
- b. living lab site/bicycle urbanism maturity
- c. Age
- d. Gender

4. **Behaviour change with separate space:** “Autonomous vehicles on roads with separate bike space would make me...”

(AV separate cycle more - *INTENT*)

- a. living lab site/bicycle urbanism maturity
- b. Innovation diffusion

Secondly, for the Wilcoxon tests, there are two sets of related variables. One set is for trust before and after cycling with the AV shuttle and the other set is for pre-encounter, first encounter, and several encounters. Each of these have a before/after paired sample which is ideally suited to this type of statistical test. Before and after intervention assessments are commonly used in the medical field (Pirelli et al., 2010), however, this analysis method can easily be applied to cycling behaviour (Ciccone et al., 2021). These variables that are available to be paired are listed in Table 6.4.2 below.

Table 6.4.2 Trust and comfort variables for pairing

Trust variables	Comfort variables
T1. Before cycling with the autonomous shuttle I felt the technology was trustworthy (<i>trust-pre</i>)	C1. Before the shuttle started, I felt comfortable knowing I would bike in an area with an autonomous shuttle
T2. After cycling with the autonomous shuttle I feel that the technology is trustworthy (<i>trust-post</i>)	C2. The first time I encountered the autonomous shuttle I felt comfortable biking in the same area
	C3. After encountering the autonomous shuttle many times, I feel comfortable biking in the same area

Each of the variables were tested against the other(s) in their set to determine statistical significance. The results of these tests of statistical tests in shown in Table 6.4.3 below.

Table 6.4.3 Paired variable significance and test statistics

Set	Variable A	Variable B	Significance	Test Statistic
Trust	T1	T2	p = <.001	4765.500
Comfort	C1	C2	p = .385	2426.500
	C1	C3	p = <.001	3918.000
	C2	C3	p = <.001	3067.500

All trust and comfort pairs tested except one were statistically significant. Trust was tested before and after exposure which yielded a p-value of <.001. Comfort was tested before exposure to the first exposure which resulted in a p-value of 0.385 which was not statistically significant. This could be due to a negligible change in understanding of AV interaction or too few opportunities for a bicycle user to adequately assess how their comfort level would be impacted. Comfort was also tested between pre-exposure and many exposures as well as between first exposure and many exposures—both resulting in p-values of <.001. The comparisons between paired variables that yielded statistically significant results will form the basis of the discussion and results section for trust and comfort impacts on cycling behaviour.

6.5 Results

The results from this study show that different types of people experience AVs in different ways. The above statistical analysis demonstrated that different attributes are factors of how comfortable and accepting people are. Independently, comfort and safety are useful predictors of how individuals choice to use a bicycle and, thereby, their cycling trips are impacted (Cabral et al., 2018; Heinen et al., 2010; Whannell et al., 2012). The subject of these factors is briefly discussed as a predictor in this section but is more specifically addressed in Chapters 1 and 2. A more pointed question specifically designed to address the research question posed for this chapter prompted participants to directly respond to whether they would ride a bicycle more or less often. These prompts (#3 and #4 in section 6.4) asked if an AV in shared or segregated street space would lead a participant to ride a bicycle more or less often.

In the following sections, each of the statistically significant independent variables (attributes) impact on the dependent variables (trip predictors) are discussed. The headings are structured so that the independent (attribute) variable is the third-level heading and dependent (predictor) variables are nested under each independent variable as fourth-level headings. Only the dependent variables that had *both* a good model fit and were statistically significant (indicated in Table 6.4.1 with cells highlighted) with the dependent variables are outlined and discussed in this section. Table 6.5.1 below summarises key demographic information about the survey participants by living lab site.

Table 6.5.1 Selected key demographics of study participants

DEMOGRAPHIC		% OF SAMPLE					
		Aalborg	Linköping	Montréal	Stavanger	Whitby	Overall
CYCLIST CLASS	No way no how	10.0	0.0	0.0	1.1	2.3	2.2
	Interested but concerned	11.4	12.3	5.9	18.1	59.1	16.9
	Enthused and confident	45.7	64.2	32.7	42.6	25.0	44.3
	Strong and fearless	32.9	23.6	61.4	38.3	13.6	36.6
GENDER	Male	35.7	40.6	55.4	78.7	54.5	53.5
	Female	60.0	57.5	40.6	18.1	40.9	43.1
	Other	0.0	0.0	2.0	0.0	0.0	0.5
	Undisclosed	4.3	1.9	2.0	3.2	4.5	2.9
AGE (YEARS)	0-17	0.0	0.9	0.0	0.0	0.0	0.2
	18-34	48.6	67.0	43.6	51.1	9.1	48.4
	35-54	31.4	24.5	40.6	36.2	22.7	32.0
	55+	17.1	7.5	14.9	11.7	65.9	18.1
	prefer not to say	2.9	0.0	1.0	1.1	2.3	1.2
ETHNICITY	African origins	1.4	1.9	1.0	0.0	0.0	1.0
	Asian origins	1.4	5.7	1.0	6.4	0.0	3.4
	Caribbean origins	0.0	0.0	1.0	0.0	2.3	0.5
	European origins	87.1	88.7	53.5	84.0	52.3	74.9
	Latin, Central, and South American origins	1.4	0.0	2.0	1.1	0.0	1.0
	North American Aboriginal origins	0.0	0.0	3.0	0.0	4.5	1.2
	Oceania origins	0.0	0.9	0.0	0.0	0.0	0.2
	Other North American origins	1.4	0.0	24.8	1.1	25.0	9.2
	Prefer not to say	7.1	0.0	12.9	7.4	13.6	7.5
	Unspecified	0.0	2.8	1.0	0.0	2.3	1.2

6.5.1.1 *Bicycle user classification attribute*

Bicycle user classification was used as an independent variable to measure impact on cycling trips in a potential future with AVs. Bicycle user classifications were made using the process described in section 4.5.2.7 and were compared against all statistically significant and sufficiently good-model-fit variable relationships. The only subsection for this chapter that yielded results with significance is the following section, 6.5.1.2, which looks at how AVs will influence behaviour based on self-reported tendency to ride a bicycle in shared street space.

6.5.1.2 *Behaviour change with shared space*

Statement #3: *“Autonomous vehicles on roads without separate bike space would make me...”*

Only one independent variable had a statistically valid relationship with statement #3 (Autonomous vehicles on roads without separate bike space would make me...). To explore the relationship between bicycle user classifications and changes in cycling behaviour in response to sharing space with an AV shuttle, an ordinal regression analysis was conducted. The dependent variable, change in cycling behaviour (avsharedcyclemore; variable #3), was measured on a Likert-scale, ranging from "cycle much less" to "cycle much more." The independent variable, bicycle user classification (cyclistclass), classified respondents into four categories: "no way no how," "interested but concerned," "enthused and confident," and "strong and fearless."

The analysis showed that the model provided a significantly better fit ($p = 0.002$) than a baseline model with no predictors. Measures of model fit indicated that the model aligned well with the data. The model results highlighted significant differences between bicycle user typologies. People in the "no way no how" (coded 1) group were much less likely to report increased cycling ($\beta = -1.987$) compared to those in the "strong and fearless" group (coded 4). Similarly, those categorised as "interested but concerned" (coded 2) were less likely to increase cycling, though the effect was smaller ($\beta = -.594$). On the other hand, individuals in the "enthused and confident" (coded 3) group showed no meaningful

difference from the "strong and fearless" group in their likelihood of increasing cycling. These results are shown in Table 6.5.2 below.

These findings suggest that psychological and experiential factors significantly influence how individuals respond to cycling infrastructure. Efforts to encourage more cycling should focus on addressing the barriers faced by groups like "interested but concerned" cyclists, who may be more open to change but still face challenges about how safe and comfortable they deem AVs.

Summary:

- **What is being modelled:** This analysis models the relationship between a bicycle user's classification (an independent variable representing their inherent comfort and confidence riding a bicycle) and their intended change in cycling behaviour when sharing road space with AVs.
- **Dependent Variable:** The dependent variable is "Behaviour change with shared space" (coded as *avsharedcyclemore*), which measures participants' self-reported intention to change their cycling frequency on roads *without* separate bike space due to the presence of AVs. This variable is measured on a Likert scale ranging from "cycle much less" to "cycle much more". It serves as a proxy for INTENT in the Theory of Planned Behaviour.
- **Underpinning Hypotheses:** The implicit hypothesis is that different bicycle user classifications will exhibit varying intentions to change their cycling behaviour in shared AV spaces. More specifically, less confident bicycle users ("no way no how," "interested but concerned") are hypothesized to be less likely to increase cycling (or more likely to decrease) compared to more confident users ("strong and fearless," "enthused and confident") when sharing space with AVs. This aligns with the general understanding that less confident users are often deterred by high-stress traffic environments.

Table 6.5.2 Parameter estimates for bicycle user classification and behaviour change

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[avsharedcyclemore = 0]	-4.416	.439	1	<.001	-5.277	-3.554
	[avsharedcyclemore = 1]	-2.680	.239	1	<.001	-3.150	-2.211
	[avsharedcyclemore = 2]	-1.204	.182	1	<.001	-1.561	-.847
	[avsharedcyclemore = 3]	2.738	.252	1	<.001	2.244	3.231
	[avsharedcyclemore = 4]	3.554	.335	1	<.001	2.896	4.211
Location	[cyclistclass=1]	-1.987	.637	1	.002	-3.234	-.739
	[cyclistclass=2]	-.594	.298	1	.046	-1.178	-.011
	[cyclistclass=3]	.105	.239	1	.661	-.364	.573
	[cyclistclass=4] (ref)	0	.	0	.	.	.

Link function: Logit.

6.5.2 living lab site/bicycle urbanism maturity attribute

living lab sites were also classified based bicycle urbanism maturity which could be used to understand if there is any impact that could be attributed to the individual locale. Notably, each of these living lab sites embody different types of bicycle urbanism maturity, as outlined in section 4.2.1 Selection Criteria. It should be noted that the Aalborg site is missing from some of these results because its pilot location survey questions did not include the same questions/statements that made up the independent variables for the following analyses in this section. Some data from the cancelled site, Whitby (Toronto), are available for these questions/statements and are analyzed.

6.5.2.1 General comfort levels

Statement #1: “Most people like me are comfortable cycling in an area with an autonomous shuttle”

Ordinal regression analysis was repeated to explore the relationship between respondents’ locations and their comfort with cycling, measured on a five-point Likert-scale scale from "strongly disagree" to "strongly agree." Four locations were included in the analysis: Linköping (lkpg), Montreal (mtl), Stavanger (svg), and Whitby (whb), with Whitby serving

as the reference category. The analysis included 335 valid responses, with 80 missing cases owing to participants electing not to respond to optional survey questions.

The model significantly improved upon the baseline, suggesting that location influences general comfort levels with cycling. While model fit statistics indicated reasonable alignment between the model and the data, there were some discrepancies.

Examining specific locations, respondents from Linköping reported slightly higher comfort levels compared to those in Whitby ($\beta = .450$), though this difference was not statistically significant. Similarly, respondents from Montreal were less likely to express high comfort ($\beta = -.625$), with results nearing significance. No meaningful differences were observed between Stavanger ($\beta = -.419$) and Whitby (ref category).

Summary:

- **What is being modelled:** This analysis models the relationship between the living lab site/location (an independent variable, which also reflects varying levels of bicycle urbanism maturity) and the respondents' perceived general comfort level related to cycling in an area with an autonomous shuttle.
- **Dependent Variable:** The dependent variable is "General comfort level" (coded as `comfortgeneralfavourable`), which captures how comfortable respondents perceive the statement "most people like me are comfortable cycling in an area with an autonomous shuttle". This is measured on a five-point Likert scale from "strongly disagree" (1) to "strongly agree" (5). It serves as a proxy for NORMS.
- **Underpinning Hypotheses:** The implicit hypothesis is that the geographical context (living lab site and its associated bicycle urbanism maturity) will influence respondents' perceptions of general comfort regarding cycling with AVs. The study aimed to identify if locations with different cycling cultures and infrastructure conditions would show varying levels of perceived comfort when interacting with AVs.

Table 6.5.3 Parameter estimates for general comfort and location

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[comfortgeneralfavourable = 1]	-3.839	.433	1	<.001	-4.688	-2.991
	[comfortgeneralfavourable = 2]	-2.158	.314	1	<.001	-2.774	-1.542
	[comfortgeneralfavourable = 3]	-.891	.289	1	.002	-1.458	-.324
	[comfortgeneralfavourable = 4]	.161	.285	1	.571	-.397	.720
Location	[loc=lkpg]	.450	.340	1	.186	-.217	1.117
	[loc=mtl]	-.625	.336	1	.063	-1.283	.034
	[loc=svg]	-.419	.340	1	.217	-1.085	.246
	[loc=whb] (ref)	0	.	0	.	.	.

Link function: Logit.

These findings highlight modest geographic variation in perceived comfort with cycling. Future research could explore additional factors, such as granular variability in infrastructure quality or broader cultural attitudes, to better understand these differences.

6.5.2.2 General acceptability

Statement #2: “Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle”

The relationship between location and perceptions of the social norm acceptability of cycling with an AV was also assessed. Similarly, this was also measured on a five-point scale from "strongly disagree" to "strongly agree." Five locations were included: Aalborg (albg), Linköping (lkpg), Montréal (mtl), Stavanger (svg), and Whitby (whb), with Whitby serving as the reference category. The analysis was based on 389 valid responses, with 26 missing cases.

The model significantly improved upon the baseline ($p = <.001$), indicating that location influences perceptions of the social acceptability of cycling with an AV. The model explained a modest but meaningful portion of the variance. Goodness-of-fit results suggested a reasonable overall fit, though some discrepancies were noted.

On a location-by-location basis the following conclusions can be made:

- Respondents from Linköping were significantly more likely ($\beta = .659$) to view cycling with an AV as socially acceptable compared to those from Whitby, reflecting a positive perception in this location.
- Conversely, respondents from Stavanger were significantly less likely ($\beta = -.714$) to express agreement, suggesting less favourable perceptions.
- No significant differences were observed for respondents in Aalborg ($\beta = .166$) or Montreal ($\beta = -.420$) compared to Whitby (ref).

Table 6.5.4 Parameter estimates for general acceptability and site location

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[subnormgeneralacceptable = 1]	-4.202	.465	1	<.001	-5.113	-3.290
	[subnormgeneralacceptable = 2]	-2.785	.331	1	<.001	-3.434	-2.136
	[subnormgeneralacceptable = 3]	-.590	.279	1	.035	-1.137	-.042
	[subnormgeneralacceptable = 4]	.777	.281	1	.006	.227	1.328
Location	[loc=albg]	.166	.373	1	.657	-.566	.897
	[loc=lkpg]	.659	.331	1	.046	.011	1.307
	[loc=mtl]	-.420	.331	1	.204	-1.068	.228
	[loc=svg]	-.714	.336	1	.034	-1.373	-.055
	[loc=whb] (ref)	0	.	0	.	.	.

Link function: Logit.

These findings summarised in Table 6.5.4 show that there is geographic variability in perceptions of bicycle use acceptability in shared space with AVs. Future research should explore the underlying cultural or infrastructural factors driving these differences, which could inform targeted interventions to promote cycling.

6.5.2.3 Behaviour change with shared space

Statement #3: “Autonomous vehicles on roads without separate bike space would make me...”

Site location influences on comfort with shared cycling paths was investigated in a similar way. Comfort was measured on a six-point scale ranging from "0" (unspecified) to "strongly agree," with the majority of respondents expressing "somewhat agree" (34.2%). Locations included Aalborg (albg), Linköping (lkpg), Montreal (mtl), Stavanger (svg), and Whitby (whb), with Whitby serving as the reference category. A total of 415 responses were included, with no missing data.

The model significantly improved upon the intercept-only model ($p = .003$), indicating that location is a significant predictor of comfort levels. Goodness-of-fit tests confirmed the model fit well with the observed data.

Location-specific findings revealed that respondents from Linköping were significantly more likely ($\beta = .914$) to report higher comfort levels with shared space when cycling with an AV compared to those from Whitby. Aalborg showed a positive ($\beta = .584$) but non-significant association, while Montreal ($\beta = .206$; $p = .524$) and Stavanger ($\beta = .065$; $p = .841$) did not differ meaningfully from the reference category.

Table 6.5.5 Parameter estimates for shared infrastructure behaviour and site location

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[avsharedcomfort = 0]	-4.583	.630	1	<.001	-5.818	-3.348
	[avsharedcomfort = 1]	-1.864	.299	1	<.001	-2.450	-1.279
	[avsharedcomfort = 2]	-.256	.274	1	.349	-.793	.280
	[avsharedcomfort = 3]	.314	.274	1	.251	-.222	.851
	[avsharedcomfort = 4]	1.972	.292	1	<.001	1.400	2.543
Location	[loc=albg]	.584	.346	1	.091	-.094	1.261
	[loc=lkpg]	.914	.324	1	.005	.279	1.549
	[loc=mtl]	.206	.323	1	.524	-.427	.839
	[loc=svg]	.065	.327	1	.841	-.575	.706
	[loc=whb] (ref)	0	.	0	.	.	.

Link function: Logit.

These findings suggest that while comfort with shared cycling paths varies by site location, Linköping stands out as particularly comfortable ($\beta = .914$). Similar to section 6.5.2.2,

further research could explore infrastructure differences, cultural attitudes, or cycling policies in these locations to better understand the observed patterns.

6.5.2.4 Behaviour change with separate space

Statement #4: *“Behaviour change with separate space: “Autonomous vehicles on roads with separate bike space would make me...”*

The same analysis for shared space was applied to understand the relationship between location and comfort with bicycle use with AVs where separated infrastructure was present. Comfort was measured on a five-point scale ranging from “strongly disagree” to “strongly agree,” with most respondents expressing “strongly agree” (68.4%). The analysis included five locations as above: Aalborg (albg), Linköping (lkpg), Montréal (mtl), Stavanger (svg), and Whitby (whb), with Whitby serving as the reference category. A total of 415 valid responses were included, with no missing data.

The model significantly improved upon the intercept-only model, suggesting that location influences comfort levels. Goodness-of-fit tests indicated strong alignment between the model and the data.

Specifically, the following results could be attributed to each location:

- Respondents from Linköping were significantly more likely ($\beta = 1.470$) to report high comfort levels compared to those from Whitby, indicating strong support for separate bike paths in this location.
- Positive, though not statistically significant, associations were observed for respondents in Montreal ($\beta = .588$) and Stavanger ($\beta = .624$), suggesting these groups may also perceive separate bike paths favourably. The lack of statistical significance means this result should be interpreted cautiously.
- No meaningful (statistically significant) differences were found between Aalborg and Whitby.

Table 6.5.6 Parameter estimates for separate infrastructure behaviour and site location

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[avseparatecomfort = 0]	-3.819	.519	1	<.001	-4.837	-2.801
	[avseparatecomfort = 1]	-3.011	.401	1	<.001	-3.797	-2.226
	[avseparatecomfort = 2]	-2.495	.354	1	<.001	-3.190	-1.801
	[avseparatecomfort = 3]	-1.657	.311	1	<.001	-2.268	-1.047
	[avseparatecomfort = 4]	-.122	.291	1	.675	-.691	.448
Location	[loc=albg]	.221	.372	1	.552	-.508	.950
	[loc=lkpg]	1.470	.388	1	<.001	.709	2.230
	[loc=mtl]	.588	.356	1	.099	-.110	1.285
	[loc=svg]	.624	.361	1	.084	-.084	1.333
	[loc=whb] (ref)	0	.	0	.	.	.

Link function: Logit.

These findings summarised in Table 6.5.6 above suggest geographic variability in comfort for bicycle use when AVs are separated through infrastructure design, with Linköping emerging as the most supportive. Similar to section 6.5.2.2, future research could, again, explore the role of local cycling infrastructure or cultural factors to further explain these differences.

6.5.3 Age attribute

6.5.3.1 General acceptability

Statement #2: “Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle”

Analysis examined the relationship between age classification groups and perceptions of subjective norm acceptability of cycling with AVs (subnormgeneralacceptable). The dependent variable (predictor) had five levels, ranging from "strongly disagree" to "strongly agree." The independent variable included four age groups: "18–34," "35–54," "55+," and "prefer not to say" (reference group). Data from 389 valid responses were analyzed with 26 missing who elected not to complete the optional question.

The model significantly improved over the intercept-only model ($p = .002$), and goodness-of-fit tests indicated a good fit to the data. Threshold parameters showed clear distinctions at the lowest and highest levels of the dependent variable (acceptability of cycling with AVs) – $p = 0.021$ and $p = 0.005$ respectively. Among the age categories, respondents aged 18–34 showed significantly higher perceptions of subjective norm acceptability compared to those who "preferred not to say" ($p = .024$). Although the older age groups (35–54 and 55+) showed positive trends, these were not statistically significant.

Summary:

- **What is being modelled:** This model assesses how age classification influences participants' perceptions of the social acceptability of cycling in an area with an autonomous shuttle.
- **Dependent Variable:** The dependent variable is "Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle" (coded as `subnormgeneralacceptable`). This variable measures general perceived social acceptability on a five-point Likert scale from "strongly disagree" (1) to "strongly agree" (5). This serves as a proxy for NORMS within the TPB framework.
- **Underpinning Hypothesis:** The implicit hypothesis is that different age groups will have varying perceptions of the social acceptability of cycling in areas with autonomous shuttles. For example, younger adults (e.g., 18-34) were hypothesized to be more likely to view cycling with AVs as socially acceptable compared to older age groups.

Table 6.5.7 Parameter estimates for general acceptance and age classifications

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[subnormgeneralacceptable = 1]	-2.261	.979	1	.021	-4.179	-.342
	[subnormgeneralacceptable = 2]	-.843	.932	1	.366	-2.671	.984
	[subnormgeneralacceptable = 3]	1.325	.936	1	.157	-.509	3.160
	[subnormgeneralacceptable = 4]	2.645	.941	1	.005	.802	4.489
Location	[classagesimple=2]	2.130	.945	1	.024	.278	3.983
	[classagesimple=3]	1.421	.947	1	.134	-.436	3.277
	[classagesimple=4]	1.742	.958	1	.069	-.136	3.621
	[classagesimple=5] (ref)	0	.	0	.	.	.

Link function: Logit.

These results summarised in Table 6.5.7 above indicate that younger respondents (18–34) may perceive subjective norms more favourably than other groups. Further investigation into the underlying reasons could provide valuable insights for targeted interventions or communication strategies.

6.5.3.2 Behaviour change with shared space

Statement #3: “Autonomous vehicles on roads without separate bike space would make me...”

The dependent variable had six levels ranging from “cycle much less” to “cycle much more.” The independent variable included five age categories as per those described in section 6.5.3.1, with “prefer not to say” serving as the reference group.

The model significantly improved upon the intercept-only model ($p = .002$) and demonstrated an excellent fit to the data. Threshold parameters revealed significant differentiation at the levels “cycle much less”, “cycle more”, and “cycle much more” ($p < .05$), suggesting these categories are well delineated in the data. However, the location parameters showed no statistically significant effects for any age category compared to the reference group ($p > .05$).

Summary:

- **What is being modelled:** This model assesses how age classification influences participants' perceptions of the social acceptability of cycling in an area with an autonomous shuttle.
- **Dependent Variable:** The dependent variable is "Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle" (coded as `subnormgeneralacceptable`). This variable measures general perceived social acceptability on a five-point Likert scale from "strongly disagree" (1) to "strongly agree" (5). This serves as a proxy for NORMS within the TPB framework.
- **Underpinning Hypothesis:** The implicit hypothesis is that different age groups will have varying perceptions of the social acceptability of cycling in areas with autonomous shuttles. For example, younger adults (e.g., 18-34) were hypothesized to be more likely to view cycling with AVs as socially acceptable compared to older age groups.

Table 6.5.8 Parameter estimates for shared infrastructure behaviour change and age classifications

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[avsharedcyclomore = 0]	-3.599	.956	1	<.001	-5.473	-1.724
	[avsharedcyclomore = 1]	-1.731	.867	1	.046	-3.430	-.033
	[avsharedcyclomore = 2]	-.254	.857	1	.767	-1.934	1.425
	[avsharedcyclomore = 3]	3.672	.883	1	<.001	1.941	5.403
	[avsharedcyclomore = 4]	4.487	.911	1	<.001	2.701	6.272
Location	[classagesimple=1]	-22.693	.000	1	.	-22.693	-22.693
	[classagesimple=2]	.962	.871	1	.269	-.744	2.669
	[classagesimple=3]	1.034	.878	1	.239	-.687	2.755
	[classagesimple=4]	.287	.886	1	.746	-1.449	2.024
	[classagesimple=5] (ref)	0 ^a	.	0	.	.	.

Link function: Logit.

These findings suggest that while the overall model captures variability in cycling behaviour changes, age does not significantly predict these changes in this dataset. This may suggest that cycling behaviour changes in this dataset may be influenced more by

factors other than age, such as infrastructure, weather, or personal preferences, which were not captured in the model. Future research might explore other demographic or contextual factors that could better explain variations in cycling behaviour.

6.5.4 Gender attribute

Only one model relationship between an independent and dependent variable had a good enough fit and was statistically significant.

6.5.4.1 Behaviour change with shared space

Statement #3: *“Autonomous vehicles on roads without separate bike space would make me...”*

The findings of this ordinal regression analysis explore the relationship between gender and self-reported changes in cycling behaviour. There were 415 valid responses, with 53.5% identifying as male, 43.1% as female, 0.5% as other, and 2.9% as undisclosed. Most respondents (68.9%) reported cycling the same amount as before, while 17.8% reported cycling less, and 5.8% reported cycling more. A smaller number indicated cycling "much less" (6.0%) or "much more" (2.7%).

In this analysis, the gender variable was coded into four categories: 1 (male), 2 (female), 3 (other), and 4 (undisclosed), with "undisclosed" serving as the reference category for regression analysis (results summarised in Table 6.5.9). The cycling behaviour variable, "avsharedcyclemore," was ordinal and coded into six levels representing changes in cycling activity: 0 (no response), 1 (cycle much less), 2 (cycle less), 3 (cycle the same amount), 4 (cycle more), and 5 (cycle much more). These ordinal levels were treated as ranked outcomes, reflecting varying degrees of change in cycling habits.

The model was statistically significant, indicating that gender influenced cycling behaviour in shared space with an AV shuttle. Goodness-of-fit tests demonstrated that the model adequately fit the data, though its explanatory power was modest. Threshold parameters distinguishing cycling categories were also statistically significant, confirming that the responses reflected meaningful and distinct changes in behaviour.

The analysis revealed several trends in how gender relates to cycling behaviour and how it impacts cycling trips. For male respondents, there was no significant difference from the baseline category (undisclosed), indicating that their cycling patterns were comparable to this reference group. Female respondents showed a trend toward reduced likelihood of increasing cycling ($\beta = -1.257$) compared to the baseline, although this difference was not statistically significant. This finding aligns with existing literature suggesting that women face unique barriers to cycling, such as safety concerns and infrastructural limitations (Damant-Sirois & El-Geneidy, 2015; Garrard et al., 2008; Jahanshahi et al., 2023). Due to the small sample size of respondents identifying as "other," no meaningful interpretations could be made for this group.

Table 6.5.9 Parameter estimates for shared infrastructure behaviour change and gender

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[avsharedcyclemore = 0]	-5.183	.783	1	<.001	-6.718	-3.647
	[avsharedcyclemore = 1]	-3.466	.692	1	<.001	-4.822	-2.110
	[avsharedcyclemore = 2]	-2.011	.674	1	.003	-3.331	-.690
	[avsharedcyclemore = 3]	1.929	.672	1	.004	.611	3.247
	[avsharedcyclemore = 4]	2.742	.706	1	<.001	1.358	4.127
Location	[classgender=1]	-.693	.682	1	.310	-2.030	.645
	[classgender=2]	-1.257	.687	1	.067	-2.604	.089
	[classgender=3]	-.041	1.755	1	.981	-3.481	3.399
	[classgender=4] (ref)	0	.	0	.	.	.

Link function: Logit.

The results suggest that women may face distinct challenges in increasing cycling activity when sharing space with AVs, reflecting broader issues such as limited access to infrastructure, safety concerns, and cultural perceptions of vulnerability in shared public spaces. While there was a good model fit, the results were not statistically significant and should be interpreted with caution.

A limitation of this analysis is the small representation of gender-diverse individuals, restricting the generalizability of findings to these groups. Future research should aim to include larger, more diverse samples to capture a broader range of experiences.

Overall, the findings underscore the importance of incorporating gender considerations into understanding the impact of cycling trips in a future with AVs. While gender alone does not fully explain bicycle use and behaviour, it interacts with other factors to shape participation in sustainable transportation. Addressing these disparities can contribute to more inclusive and equitable cycling as AVs are deployed more widely, fostering broader adoption of active transportation modes. To address barriers, policy measures could focus on enhancing cycling infrastructure, such as adding protected bike lanes and improving lighting and surveillance on cycling routes. Noting the gender-based disparity uncovered

in these results, programs specifically tailored to women, such as women-led cycling workshops, may also encourage greater participation.

6.5.5 Education level attribute

There were no statistically significant relationships nor was there any sufficiently reliable model fit between the independent variable *education level* and any of the dependent variables (statements 1-4). This finding is summarised in Table 6.4.1 and, consequently, is not discussed further due to insufficient model fit and poor statistical significance. In acknowledgement of this, it was determined that the results for these comparisons are not sufficiently authoritative to make any constructive conclusions for these relationships.

6.5.6 Employment status attribute

6.5.6.1 General acceptability

Statement #2: *“Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle”*

The relationship between employment status and the perceived general acceptability of riding a bicycle with AVs was analyzed through ordinal regression. The dependent variable, *subnormgeneralacceptable*, was coded into five ordinal categories: 1 (strongly disagree), 2 (somewhat disagree), 3 (neither agree nor disagree), 4 (somewhat agree), and 5 (strongly agree). The independent variable, *classemploymentsimple*, represented employment status and included six categories: 1 (full-time employed), 2 (part-time employed), 3 (self-employed), 4 (unemployed), 5 (retired), and 6 (other). Category 6 ("other") was used as the reference group for the analysis.

The model fitting information indicated a statistically significant improvement over the null model ($p < .001$) suggesting the predictors contribute meaningfully to explaining variations in the dependent variable. The goodness-of-fit statistics showed no evidence of poor model fit.

The location parameters showed how each employment category influenced the likelihood of respondents agreeing with the general acceptability of cycling with AVs relative to the

reference group (category 6, "other"). Full-time employment (category 1) had a significant positive effect ($\beta = 2.191$, $p < .001$), indicating that full-time employed respondents were significantly more likely to perceive riding a bicycle with AVs as acceptable compared to the reference group. Similarly, self-employed respondents (category 3) showed a significant positive effect ($\beta = 1.202$, $p = .025$), as did retired respondents (category 5; $\beta = 1.539$, $p = .009$). However, the effects for part-time employment (category 2) and unemployment (category 4) did not reach statistical significance.

Table 6.5.10 Parameter estimates for general acceptance and employment

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
Threshold	[subnormgeneralacceptable = 1]	-2.682	.615	1	<.001	-3.887	-1.478
	[subnormgeneralacceptable = 2]	-1.266	.528	1	.017	-2.302	-.230
	[subnormgeneralacceptable = 3]	.929	.524	1	.076	-.098	1.955
	[subnormgeneralacceptable = 4]	2.292	.532	1	<.001	1.249	3.335
Location	[classemploymentsimple=1]	2.191	.558	1	<.001	1.096	3.285
	[classemploymentsimple=2]	1.020	.612	1	.095	-.179	2.219
	[classemploymentsimple=3]	1.202	.538	1	.025	.148	2.255
	[classemploymentsimple=4]	1.193	.799	1	.135	-.373	2.759
	[classemploymentsimple=5]	1.539	.590	1	.009	.382	2.697
	[classemploymentsimple=6] (ref)	0	.	0	.	.	.

Link function: Logit.

Overall, employment status significantly influenced perceptions of general acceptability of using a bicycle with AVs, with full-time employed, self-employed, and retired individuals showing higher levels of agreement with general acceptability riding a bicycle with AVs compared to those classified as "other." These findings highlight the potential impact of occupational roles and circumstances on normative evaluations.

6.5.7 Ethnic origin attribute

6.5.7.1 General comfort levels

Statement #1: “Most people like me are comfortable cycling in an area with an autonomous shuttle”

The relationship between ethnicity and perceptions of general comfort using a bicycle with AVs was analyzed. This dependent variable was coded into five ordinal categories: 1 (strongly disagree), 2 (somewhat disagree), 3 (neither agree nor disagree), 4 (somewhat agree), and 5 (strongly agree). The independent variable, classethnicity, included the following categories: African origins, Asian origins, Caribbean origins, European origins, Latin, Central, and South American origins, North American Aboriginal origins, Oceania origins, Other North American origins, Prefer not to say, and unspecified. The category unspecified was treated as the reference group in the analysis.

The model fitting results indicated that the predictors significantly improved the model over the intercept-only baseline. The goodness-of-fit statistics suggested that the model adequately fit the data. Significant thresholds were identified for "strongly disagree" ($\beta = -2.003$, $p = .017$) and "strongly agree" ($\beta = 1.980$, $p = .015$), suggesting meaningful distinctions at these levels of agreement.

The attribute independent variables (location) examined the effects of ethnicity categories relative to the reference group as shown in Table 6.5.11. Respondents identifying as Asian origins ($\beta = 3.220$, $p = .002$) and North American Aboriginal origins ($\beta = 2.419$, $p = .044$) showed significantly higher odds of stronger agreement with general levels of comfort cycling with AVs compared to the unspecified group. Respondents identifying as having European origins also showed a significant positive association ($\beta = 1.690$, $p = .038$). While the category “Other North American origins” approached significance ($\beta = 1.647$, $p = .055$), other ethnicity categories did not yield significant effects. The exceptionally high estimate for Oceania origins ($\beta = 20.872$) was likely due to sparse data in this category, rendering the result unreliable.

Table 6.5.11 Parameter estimates for general comfort and ethnic origin

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Threshold	[comfortgeneralfavourable = 1]	-2.003	.843	1	.017	-3.655	-.351
	[comfortgeneralfavourable = 2]	-.309	.803	1	.700	-1.883	1.265
	[comfortgeneralfavourable = 3]	.941	.806	1	.243	-.638	2.520
	[comfortgeneralfavourable = 4]	1.980	.810	1	.015	.392	3.567
Location	[classethnicity=African origins]	2.371	1.607	1	.140	-.780	5.522
	[classethnicity=Asian origins]	3.220	1.043	1	.002	1.175	5.265
	[classethnicity=Caribbean origins]	1.461	1.510	1	.333	-1.499	4.420
	[classethnicity=European origins]	1.690	.813	1	.038	.096	3.284
	[classethnicity=Latin, Central, and South American origins]	1.093	1.308	1	.403	-1.470	3.656
	[classethnicity=North American Aboriginal origins]	2.419	1.199	1	.044	.070	4.768
	[classethnicity=Oceania origins]	20.872	.000	1	.	20.872	20.872
	[classethnicity=Other North American origins]	1.647	.860	1	.055	-.038	3.333
	[classethnicity=Prefer not to say]	.916	.875	1	.295	-.799	2.630
	[classethnicity=unspecified] (ref)	0	.	0	.	.	.

Link function: Logit.

The results highlight significant differences in comfort perceptions by ethnicity, particularly for respondents identifying as Asian origins, North American Aboriginal origins, and European origins. These findings suggest cultural or experiential factors associated with ethnicity may shape comfort levels when riding a bicycle with AVs. Future research could further explore these relationships in more diverse and balanced samples or specifically target AV-bicycle user interaction in the origin locations where these ethnicities can interact with AVs to design a study that would yield larger sample sizes and more reliable and significant results.

6.5.8 Income level attribute

6.5.8.1 General acceptability

Statement #2: *“Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle”*

This section presents the penultimate interpretation of the logistic regression analysis for the factors influencing attitudes towards societal norms related to general comfort and acceptability of cycling with AVs. The analysis used an ordered logistic regression model with the dependent variable `subnormgeneralacceptable`, which represents the level of agreement towards societal norms, ranging from strongly disagree (1) to strongly agree (5). Independent variables included `classincomesimple`, which captures self-reported income categories.

The model fitting information indicates a statistically significant improvement in the model fit when including the income variable. The parameter estimates for the thresholds indicate that there are significant distinctions between the levels of agreement with general acceptability to ride a bicycle with AVs.

The negative estimates for the lower thresholds of `subnormgeneralacceptable = 1` ($\beta = -3.817$) and `subnormgeneralacceptable = 2` ($\beta = -2.408$) suggest that individuals are less likely to strongly disagree or somewhat disagree with general acceptability to ride a bicycle with AVs. In contrast, the positive estimate for `subnormgeneralacceptable = 4` ($\beta = 1.065$) indicates a higher likelihood of somewhat agreeing with general acceptability to ride a bicycle with AVs.

For the independent variable, lowest income (`classincomesimple = 1`) showed a significant positive coefficient ($\beta = 0.863$, $p = .009$), indicating that individuals in this income category are more likely to agree that there is general acceptability to ride a bicycle with AVs compared to those who prefer not to disclose their income. The coding for this variable was as follows:

- 1 = Lowest income
- 2 = Low income

- 3 = Middle income
- 4 = High income
- 5 = Highest income
- 6 = Prefer not to say (reference category).

Detail pertaining to the income levels for the living lab sites is summarised in Table 6.5.12. Other income categories, including low, middle, high, and highest, did not show a significant relationship with agreement towards societal norms. “Prefer not to say” (classincomesimple = 6) was the reference category for this analysis, meaning there was no comparison made for this group in the model's parameter estimates.

Table 6.5.12 Parameter estimates for general acceptability and income category

		Estimate (β)	Std. Error	df	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Threshold	[subnormgeneralacceptable = 1]	-3.817	.447	1	<.001	-4.693	-2.941
	[subnormgeneralacceptable = 2]	-2.408	.307	1	<.001	-3.009	-1.806
	[subnormgeneralacceptable = 3]	-.251	.258	1	.332	-.757	.255
	[subnormgeneralacceptable = 4]	1.065	.264	1	<.001	.547	1.582
Location	[classincomesimple=1]	.863	.332	1	.009	.213	1.513
	[classincomesimple=2]	.010	.335	1	.977	-.648	.667
	[classincomesimple=3]	.044	.314	1	.889	-.572	.659
	[classincomesimple=4]	.166	.327	1	.613	-.476	.807
	[classincomesimple=5]	.182	.520	1	.727	-.838	1.202
	[classincomesimple=6] (ref)	0	.	0	.	.	.

Link function: Logit.

The results suggest that income significantly influences acceptability to ride a bicycle with AVs. Specifically, individuals in the lowest income category are more likely agree that there is general acceptability to ride a bicycle with AVs compared to those who prefer not to disclose their income. This effect diminishes for higher income categories, which do not show a significant relationship with agreement towards acceptability to ride a bicycle with AVs. This result underscores the importance of considering socioeconomic factors in understanding societal attitudes and norms. It provides valuable insights into how income

influences social perceptions and supports the development of policies that address these disparities.

6.5.9 Innovation diffusion (technology acceptance) attribute

6.5.9.1 Behaviour change with separate space

Statement #4: *“Behaviour change with separate space: “Autonomous vehicles on roads with separate bike space would make me...”*

The final logistic regression analysis conducted compared innovation diffusion (technology acceptance) with AV-induced bicycle behaviour change in separate infrastructure configurations. The dependent variable (trip predictor), *avseparatecyclomore*, was treated as an ordinal variable, with categories reflecting varying levels of cycling frequency. These categories included: 0 for "no response" (representing 0.7% of the sample), 1 for "Cycle less" (1.3% of the sample), 2 for "Cycle the same amount" (73.2% of the sample), 3 for "Cycle more" (11.7% of the sample), and 4 for "Cycle much more" (13.1% of the sample). The sample included 298 valid responses, with 117 cases missing. This question was optional and was not included in the pilot (Aalborg) living lab questionnaire.

For the independent variable (attribute), *classtechnologyacceptancesimple*, a categorical scale was used that classified respondents into how they self-reported technology uptake in comparison with the general public. The categories were: 1 for "First" (5.0% of the sample), 2 for "Among first" (24.8% of the sample), 3 for "Middle" (53.0% of the sample), 4 for "Among last" (14.8% of the sample), and 5 for "Last" (2.3% of the sample).

The regression model demonstrated a statistically significant improvement over the intercept-only model. Pearson chi-square (12.623, $p = .397$) and deviance (17.147, $p = .144$) tests, both suggest that the model fits the data well.

Participants categorised as "Among first" technology adopters (category 2) exhibited a significant negative effect on their likelihood to cycle more frequently ($\beta = -1.717$; $p = .023$). Similarly, "Middle" technology adopters (category 3) showed a significant negative effect ($\beta = -2.000$; $p = .007$). "Among last" technology adopters (category 4) also demonstrated a significant negative effect ($\beta = -2.349$; $p = .004$). These findings indicate that individuals in

these technology acceptance categories are less likely to increase their cycling frequency compared to those in the "Last" category (reference group). This result may suggest that the separated infrastructure has a greater impact on behaviour for late adopters considering using a bicycle with AVs.

Table 6.5.13 Parameter estimates for separated infrastructure behaviour change and technology acceptance

		Estimate (β)	Std. Error	df	Sig.	95% Interval Lower Bound	Confidence Upper Bound
Threshold	[avseparatecyclemore = 0]	-6.946	1.013	1	<.001	-8.931	-4.961
	[avseparatecyclemore = 2]	-5.834	.832	1	<.001	-7.465	-4.202
	[avseparatecyclemore = 3]	-.770	.717	1	.283	-2.175	.635
	[avseparatecyclemore = 4]	.042	.714	1	.953	-1.358	1.442
Location	[classtechnologyacceptancesimple=1]	-1.190	.876	1	.175	-2.907	.528
	[classtechnologyacceptancesimple=2]	-1.717	.758	1	.023	-3.202	-.232
	[classtechnologyacceptancesimple=3]	-2.000	.739	1	.007	-3.448	-.552
	[classtechnologyacceptancesimple=4]	-2.349	.810	1	.004	-3.936	-.762
	[classtechnologyacceptancesimple=5] (ref)	0	.	0	.	.	.

Link function: Logit.

The majority of the sample (73.2%) reported cycling the same amount, regardless of their technology acceptance class. This suggests that while there is a statistically significant relationship between technology acceptance and cycling frequency, its practical impact may be limited, implying that other influencing factors are at play.

Further study should seek to include additional variables such as:

- Investigating interaction effects;
- Gathering more granular contextual data; and,
- Using more extensive qualitative methods than those in this research to explore the underlying mechanisms further.

These findings underscore the complexity of factors influencing cycling behaviour and the need for a more comprehensive, multi-faceted approach to understanding transportation choices.

6.5.10 Wilcoxon Tests

The following Wilcoxon tests for related samples are based on the Likert-scale survey responses. It should be noted that these responses could be subject to recall bias because respondents were asked to recount their levels of trust and comfort for their self-reported comfort and trust for each of the questions. For all tests, r was calculated by dividing the Z value by the square root of the total number of observations (N). This calculation is shown in Equation 1 below.

Equation 1 Formula for calculating Wilcoxon test r -value

$$r = \frac{Z}{\sqrt{N}}$$

All results of the Wilcoxon tests were based on coded responses where 1 represented “strongly disagree”, 2 represented “somewhat disagree”, 3 represented “neither agree nor disagree”, 4 represented “somewhat agree”, 5 represented “strongly agree”. The 50th percentile median can be interpreted to represent the coded response on the Likert scale.

6.5.10.1 Trust pre- and post-interaction

Table 6.5.14 Trust pre- and post-interaction descriptive statistics

	N	25th	Percentiles 50th (Median)	75th
trustpre	351	3.00	4.00	4.00
trustpost	306	3.00	4.00	5.00

A Wilcoxon signed rank test was performed for trust pre- and post-interaction with an AV for participants who could ride a bicycle. The test revealed that trust scores were identical before (Md = 4.00, n = 351) and after (Md = 4.00, n = 306) the interaction, $z = -4.152$, $p = <.001$, with a small effect size, $r = 0.16$ (Cohen, 2013).

There may have not been any significant change in the before and after situations due to participants' understanding of AV technology and how there may not have been sufficient change in understanding how AVs operate or detect active transport users. Furthermore, trust is a complex psychological construct influenced underlying dispositions, intergroup processes, and cognitive expectations (Bierhoff & Vornefeld, 2004; Kwasnicka et al., 2016; Rehak et al., 2006). These complexities may make altering trust difficult through simple interventions.

6.5.10.2 Comfort pre-interaction and after first interaction

The test for these related samples did not yield statistically significant results ($p = 0.385$) and is, therefore, not exhaustively discussed. As explained in section 6.4, this could be due to a negligible change in understanding of AV interaction, or too few opportunities for a bicycle user to adequately assess how their comfort level would be impacted. More data, either through a larger sample size or by increasing the time between interactions. The other related samples in this section address the latter concern and may better address the change in trust and comfort of bicycle users which is important for determining the impact of cycling trips (i.e. the likelihood of an individual to choose to ride a bicycle in a transportation system that includes AVs).

6.5.10.3 Comfort pre-interaction and after several interactions

N	Percentiles

		25th	50th (Median)	75th
comfortpreshare	331	3.00	4.00	5.00
comfortpostshare	286	4.00	5.00	5.00

The same Wilcoxon signed rank test was performed for comfort pre- and post-interaction with an AV for participants who could interact with it. The test revealed that comfort scores increased from pre-interaction comfort (Md = 4.00, n = 331) to post-interaction comfort (Md = 5.00, n = 286) scenarios, $z = -3.348$, $p = <.001$, with a small effect size, $r = 0.13$ (Cohen, 2013).

6.5.10.4 Comfort first interaction and after several interactions

	N	25th	Percentiles 50th (Median)	75th
comfortfirstshare	299	3.00	4.00	5.00
comfortpostshare	286	4.00	5.00	5.00

Finally, the Wilcoxon signed rank test was once again performed for comfort during the first interaction with an AV and after many interactions. The test revealed that comfort scores similarly increased from the first interaction comfort (Md = 4.00, n = 299) to post-interaction comfort (Md = 5.00, n = 286) scenarios, $z = -5.111$, $p = <.001$, with a small effect size, $r = 0.21$ (Cohen, 2013).

6.6 Discussion

The findings in on cycling trip impact, as extrapolated from several likert-scale statements, lay the foundation for understanding impact on cycling trips. The empirical findings align with existing research on vehicle-bicycle user interaction showing that the level of autonomy does not significantly affect behaviour when compared to existing vehicle technology. However, there are some findings that emerged which reinforce the underlying theory and others that extend the interpretation of other scholars' findings (through preliminary validation) for if/when AVs increase in prevalence.

Firstly, the qualities and behaviours of bicycle user classifications aligned with the expected behaviour of each class of bicycle user. This reinforces the Geller (2006) classification generalizations and builds on the validation that other scholars carried out (Cabral & Kim,

2020; Hosford et al., 2020). Specifically, the results above highlight that *strong and fearless* bicycle users were most likely to maintain or increase cycling with AVs in shared spaces. Conversely, and in concurrence with other scholars' findings with COVs, *interested but concerned* bicycle users showed a moderate decrease in the likelihood to ride a bicycle with AVs. *No way no how* bicycle users were least likely to increase cycling. These findings validate concerns of negative effects of AVs, particularly for less confident bicycle users, by exacerbating "safety concerns during the transitional period" (Botello et al., 2019, p. 4) which was quantified by Rahman et al. stating that "60% of the respondents regarding road sharing with AVs as pedestrians and bicyclists" (2023, p. 267) reported safety concerns.

As introduced in the literature review chapter, only a small minority of bicycle users can tolerate high-stress environments. This was measured through a cycling maturity index method that looked at the cycling culture of each living lab site (McLeod et al., 2020). Each lab site ranked differently in terms of cycling maturity, and this was reflected in the quality of cycling environment that each group of participants expected for riding a bicycle. While the living lab host cities were evaluated on a macro-scale, some parts of the living lab sites deviated from the host city's overall cycling experience and sometimes contrasted with participants' expectations. The different living lab sites showed geographic variation in comfort levels and perceived acceptability of AVs. Linköping was consistently more positive where Stavanger participants showed significantly lower perceptions of acceptability for cycling with AVs. The delta between bicycle culture is reinforced by Berge et al. (2022) explaining that culture also has a role to play in AV-bicycle interaction. Acceptability and data from ethnic origin and AV acceptability further corroborate this finding in section 6.5.7.

By introducing geographic variation, it is noteworthy to acknowledge that there are urban and human geography implications brought by discrete attributes of each living lab site. Commonly discussed in urban geographical literature is the influence of urban morphology on a wide range of behaviours and attitudes (Barr & Prillwitz, 2012b; P. Zhang et al., 2023). In recognition of this influence, the variation in urban living lab locations presented an interesting urban form cross section through their different "street network, building-plot characteristics, land use, natural features and greenspace" (P. Zhang et al., 2023, p. 1). Further, the urban geographical context can impact and predispose inhabitants to certain

modes of transportation. This predisposition is a function of each mode's accessibility and stressfulness which can be attributed to building density, design of streets, provision of bike lanes, and availability of sidewalks (Gaio, 2020; Stojanovski, 2019). To ensure that there was a suitably diverse representative sample of urban morphologies for this study, the living labs selected were chosen to ensure variations of these urban geographical contexts.

Each context's unique urban morphology, tied with its traffic stress level are both factors that influence mode choice and travel behaviour. Certain places which are more conducive to riding bicycle or walking where it is difficult to find parking or there are street-oriented businesses in cities may predispose an inhabitant to choose a bicycle as their primary mode of transportation. Conversely, a place that is low density and provides only wide and high-speed streets with no sidewalks may predispose someone to choose to drive as their first choice. This type of modal predisposition is dependent on individual's preferences and attitudes as influenced by urban morphology has been referred to as 'market segments' or 'mobility classes' as influenced by their urban geographical contexts (Anable, 2005; Barr & Prillwitz, 2012a). The site selection of urban living labs was intentionally chosen to provide a diverse sample of morphologies and urban geographies for the study.

Layering on top of environmental stress and urban geographical context, the existing body of literature is reinforced by the empirics from this study. "Vulnerable transport planning" (Khayesi, 2020, p. 1) persists in that behaviour of bicycle users remain to be influenced by AVs as they are retrofitted into a system of automobility (Urry, 2004). This system of automobility emphasises the importance of occupant transport systems (Bazilinskyy et al., 2015; Deb et al., 2017; Kyriakidis et al., 2015; Li et al., 2023; Nordhoff et al., 2019; Pelikan, 2021; Rahimi et al., 2020). Madigan et al. (2019) highlights the delicate negotiation that is required between AVs and bicycle users which was presented in the results from this study. Specifically, it was found that trust through exposure to AVs over time did not significantly change, which aligns with other observation of AV shuttles in an Oslo study that posits "there is no tendency that cyclists or pedestrians become more convinced over time that the AV shuttle will stop" (Bjørnskau et al., 2023, p. 13) as well as with other scholars which corroborate this stating "vulnerable road users' perceived safety of AVs increased, but their receptivity toward AVs did not change" (Das et al., 2023, p. 3).

While certain bicycle user groups remain fearlessly unaffected by AVs, more sensitive and already marginalised interested but concerned (potential) bicycle users will be further ostracised by AI-enabled transport systems, thereby negatively impacting mode share in urban areas. Fear and uncertainty that bicycle users experience is well documented (Cugurullo & Acheampong, 2023; Furth et al., 2016) and poorly addressed in this early stage of transition while vehicles increase their level of autonomy. Without deliberate action to mitigate the effects of further mode marginalization there will be a greater polarization of bicycle users (Gaio & Cugurullo, 2023). This polarization, where strong and fearless bicycle users continue to experience the city largely unaffected, would, conversely, represent a further subordination of those who deem the city too stressful or unsafe to ride a bicycle in an exaggeration of current urban bicycle theory that already articulates the divide between ‘have’ and ‘have not’ bicycle users based on their level of stress tolerance (Geller, 2006; Hosford et al., 2020; McLeod et al., 2020; Winters et al., 2011).

6.7 Conclusion

The complexities of diverse bicycle user trip habits and individual visceral experiences make it difficult to coherently draw blanket conclusions for all types of trips and bicycle users. Street dynamics with AVs will undoubtedly impact trips broadly, but perhaps more specifically impact trip generation and trip purposes more closely. By saying this, certain trips that are more vulnerable or carried out by more vulnerable bicycle users may well be impacted to a greater degree.

This chapter has explained that individual attributes and characteristics significantly influence how people perceive and interact with autonomous vehicles in different urban contexts. Several key findings have emerged from this chapter. Infrastructure preferences and cycling confidence levels are crucial determinants, with more experienced bicycle users (such as those identified as ‘strong and fearless’) showing greater adaptability to shared spaces with AVs, while less confident bicycle users require more supportive infrastructure. Geographic and cultural contexts across AV living lab sites matter too, as demonstrated by the consistent positive results from Linköping compared to other living lab sites, suggesting that local bicycle culture and infrastructure conditions influence AV tolerance.

There are also patterns in demographic factors that affect AV acceptability and comfort. Younger adults show higher acceptance levels, while women express more hesitation about using a bicycle with an AV. Full-time employed participants demonstrate greater acceptance, while lower-income groups show higher acceptance levels. Additionally, certain ethnic groups report significantly different comfort levels, indicating the importance of cultural factors in AV acceptance. What could be said about higher levels of acceptability, particularly for low-income participants, is that their higher acceptance of bicycle use with AVs may be tied to their hopes for increased accessibility, affordability, and potential benefits from these technologies.

Urban geography and morphology play an important role in the impact of cycling trips both presently without widespread AV adoption and will remain a major factor as AV adoption increases. The urban living labs used to investigate bicycle user trips are a small sample of a range of geographical contexts with unique attributes that influence mode choice, attitude, and preference. The variety of study sites— from a low stress pedestrian and bicycle pathway in the Aalborg pilot site, to a bustling shopping street in Montréal, a residential/university campus in Linköping, and a city centre/harbourfront promenade in Stavanger all have important variations that have different implications and learnings to be applied for AV/bicycle user readiness. As outlined briefly in this chapter’s discussion section, urban morphology can predispose inhabitants to certain modes of transportation thereby influencing their preferences and trip characteristics (Anable, 2005; Barr & Prillwitz, 2012b; Gaio, 2020; Stojanovski, 2019). The geographic diversity of living lab sites is critical to ensure there is sufficient representation of as many different factors as feasible to paint a complete picture as possible of early AV impacts on urban bicycle use.

In addition to urban geographical factors, the relationship between technology acceptance and cycling behaviour is complex, with proxy indicators from the Technology Acceptance Model showing late technology adopters having more positive responses to separated infrastructure, challenging assumptions about early adopters being more accepting of AV integration. Trust levels remain relatively stable before and after AV interaction, but comfort levels increase significantly with repeated exposure, suggesting that familiarization with AVs can positively influence cycling behaviour.

As articulated in the discussion section of this chapter (6.6) and summarised above, AVs represent a new frontier in urban street negotiation and could disrupt or marginalise the ability for large proportions of bicycle users to experience their city in ways that they are *interested but concerned* to do. To understand and mitigate these negative trip impacts, a factor-impact-consideration table (Table 6.7.1) has been created to help bolster AV/bicycle user readiness that can be used a tool for policymakers and transportation planners.

Table 6.7.1 AV/Bicycle User Readiness Recommendations

Theme	Factor	Impact	Planning Recommendation
Bicycle User Typologies and Behaviour	Strong & Fearless	Baseline group - most adaptable to AV integration	Can be early adopters for testing AV-cycling interaction
	Enthusied & Confident	Similar to Strong & Fearless	Focus on clear communication of AV behaviour patterns
	Interested but Concerned	Less likely to increase cycling ($\beta = -.594$)	Prioritise separated infrastructure and education programs
	No Way No How	Significantly less likely to cycle ($\beta = -1.987$)	May require completely separated facilities or alternative solutions
Key Demographic Considerations	Gender	Women trend toward reduced cycling likelihood	Implement women-focussed programs and enhanced safety measures
	Age	Younger users (18-34) more accepting	Develop targeted outreach for older populations
	Income	Lower income groups show higher acceptance	Ensure equitable access to AV-cycling infrastructure
	Employment	Full-time workers most accepting ($\beta = 2.191$)	Consider commuter-focussed infrastructure improvements
Infrastructure Impact	Separated Facilities	Increases comfort across all groups	Prioritise protected bike lanes at every opportunity
	Shared Space	Lower comfort levels, especially among cautious cyclists	Use only in low-speed, low-volume areas
	Signage & Markings	Can improve user understanding and comfort (negotiation)	Implement clear wayfinding and interaction zones meant for heightened awareness
	Integration Points	Critical for user confidence	Design clear crossing points and interaction areas
Implementation Strategy	User Experience	Comfort increases with exposure over time	Plan gradual rollout with community engagement
	Technology Adoption	Late adopters more influenced by infrastructure	Focus on infrastructure before technology
	Geographic Context	Varies by location (e.g., Linköping more positive)	Adapt strategies to local cycling culture

The findings from this chapter and this study indicate that thoughtful integration of AVs with urban bicycle use will require tailored approaches that consider diverse user groups' needs, preferences, and concerns, rather than a one-size-fits-all solution. These insights contribute to an understanding of how different population segments' bicycle trips will respond to AVs in urban environments, providing valuable guidance for policymakers and urban planners in developing inclusive, equitable transportation systems.

7. Influence of AVs on cycling infrastructure preference

“If you make more streets better for cars you get more traffic. If you make more bicycle infrastructure you get more bicycles. If you invite people to walk more and use public spaces more, you get more life in the city. You get what you invite.”

—Jan Gehl

Chapter 7 further builds on the impact on cycling trips from Chapter 6 and draws connection from behaviour while linking it to infrastructure preferences. The infrastructure preferences were extracted from both close-ended Likert-scale survey questions and supplemented with remarks participants indicated in the relevant open-ended survey responses. The answer to research question 3 that concerns the subject-matter of this chapter is laid out in the following seven subsections. In section 7.1, the chapter is introduced with contextual information and links to discourse on cycling infrastructure research. In section 7.2, research question three and its design intent, including foundational theory, are explained. In section 7.3 the link to theory is reiterated for contextual reference. Following, in section 7.4, methods used to answer research question three are outlined. Section 7.5 discusses the results based on the empirics collected through research question 3 and are discussed in relation to broader research in section 7.6. Finally, conclusions and policy implications are drawn out in section 7.7.

7.1 Introduction

Active transport and bicycle user safety involves several interconnected systems and frameworks in the physical and policy realm. Infrastructure, planning, and regulations can make active transport users feel safe, impacting safety and comfort, by providing dedicated lanes, traffic calming, and enforcement. This, in turn, encourages more people to choose active transport (Caulfield et al., 2012; Pucher & Buehler, 2008; Winters et al., 2011). Conversely, feeling unsafe due to poor design or dangerous road user behaviour discourages active transport and creates car dependence, putting further strain on the very infrastructure active transport users need (Cabral & Kim, 2020; Dill & McNeil, 2013).

Automobility isolates its occupants from their surroundings and discounts the hostile environment it has created to the detriment of all other mobilities. De Cauter describes that much of the modern world uses “transport capsules from one enclave or capsule (home, for example), to another (campus, office, airport, all-in hotel, shopping mall and so on)” (De Cauter, 2004, pp. 45–46) and synonyms that corroborate this idea of encapsulated mobility are common in literature (Nixon, 2014). If automobility estranges occupants and desensitises them from the “spaces and beings” they impact, thereby leading them to discount the welfare of others, then advancing AV mobility without regard for non-occupants would be a catastrophic misstep (Burns & Brown, 2006; Hoffman et al., 1996; Nixon, 2014, p. 92).

Vehicular mobility will likely remain part of mainstream mobility for the foreseeable future, however, sharing, autonomous driving, and electrification will all significantly impact the urban mobility sensory experience (Popan, 2020). During a period of transition to AVs, bicycle users are only one group of people that will be impacted by cities and societies managed by AI where the risks and benefits are uncertain (Cugurullo & Acheampong, 2023). While many cities are advancing an investment program in walking and cycling, the reallocation of street space ushered in by an increase in AV prevalence. There may be a divide in urban design trajectories based on the current policy directions already in motion in each locality. Cugurullo et al. explain this divergence of space reallocation approaches in urban environments positing that “cities which have traditionally invested in spaces for walking and cycling are likely to maintain the same agenda and use autonomous vehicles as an opportunity to reduce spaces for cars, while local governments supporting automobile-oriented cities will tend to keep a business-as-usual approach, thereby exacerbating commuting and urban sprawl” (2021, p. 28).

It will be important to acknowledge the broad transformative implications AI will have on our collective ability to communicate with AI-mediated mobilities unencumbered by the likes of human-machine interface (HMI) devices (Berge et al., 2022). While the simple presence of AVs stands to impact bicycle user wellbeing, a major component of this is an (in)ability to communicate in the analog sphere with humans (Pelikan & Jung, 2023). The findings from the present study contribute to a foundational level of understanding of the impacts that AI-mediated mobilities will have on urban bicycle use as embodied by

everyday interactions with AVs that have little ability to communicate with bicycle users in similar ways to human drivers.

Outlined above, in section 1.1, safety and comfort were introduced to impact infrastructure choice. Both safety and comfort can be influenced by how a city is designed and what types of transportation are afforded space and priority. Wide streets and high speed limits foster a prohibitively stressful and unsafe environment to ride a bicycle (Khayesi, 2020). Providing bicycle-oriented infrastructure that is cohesive, direct, safe, comfortable, and attractive increases the viability of cycling as a practical option for daily transport needs (Groot, 2016). Careful attention must be afforded to the type of environments that are created and the safety and comfort that they extend to bicycle users. This section centres the mixed methods results on data that can aid in understanding safety and comfort that lead to infrastructure choices. The results of these qualitative and quantitative data can inform infrastructure design choices for creating a transportation system that is approachable for a wider array of bicycle user typologies.

7.2 Research question 3

The third research question this project set out to better understand is “How can streets be designed to be conducive to cycling with self-driving vehicles from a non-occupant perspective?”. This question was expressly designed to interpret the *perceived behavioural control* component of TPB as the barriers presented by traffic stress induced by infrastructure design which has a strong link to comfort and safety (Buehler & Dill, 2016). In line with this research design and theoretical framework design interpretation, the primary data sources for this question are the open-ended survey questions, along with the interview and focus group responses. Special attention was made to zero-in on the themes of negotiation (survey and focus groups), environment and infrastructure (survey), and attitudes towards infrastructure configurations (focus groups). These data are supplemented with the Likert questionnaire results interpreted using multivariate correlation analysis from the questions labelled with *STRESS* and *PBC* in Table 4.3.1 which are used as input variables that directly impact comfort and safety of bicycle users (Lowry et al., 2012; Sorton & Walsh, 1994; K. Wang & Akar, 2019). As first explained in section

3.4.3, this question is also largely framed and influenced in the context of the LTS framework, which is explained in section 3.3.3.

7.3 Factors influencing safety and comfort (Theory: Traffic Stress)

This chapter is informed by the Traffic Stress theory as first outlined in section 3.3.3 which is abbreviated throughout this dissertation as LTS for the Mineta Transportation Institute's Level of Traffic Stress. The theoretical approach to LTS is that roadways can be classified based on several attributes and grouped together in a system to form a level of traffic stress based on the weakest link (i.e. the most stressful roadway segment) (Mekuria et al., 2012). The concept is that LTS provides a set of classification tables that provide a user-friendly and manageable systematic method to assign a level of traffic stress to urban environments which is a key determinant of urban cycling behaviour (Cabral et al., 2019). This approach was useful to apply to the living lab context.

Closely linked, and due to the LTS playing a significant role in the perceived level of difficulty (or PBC) component of TPB to ride a bicycle in an AV environment, traffic stress denoted as *STRESS* in Table 7.4.2 is accompanied and supplemented with *PBC* variables from the survey questions that participants answered. In addition to the survey data, open-ended responses were coded and the results were used to augment traffic stress, PBC, and statistical analysis.

7.4 Methods

7.4.1 Open-ended survey questions

In the survey results, two open-ended questions allowed for respondents to freely input text to respond to prompts about comfort and trust. While these were intended to specifically target subject-matter of each respective question, respondents addressed safety and comfort in both text fields in an unstructured manner. In the coding and analysis process, it was determined that the responses from both fields could be grouped together to provide insight on both safety and comfort to answer the research question for this chapter.

The prompts in the survey for the localised English version are shown in Table 7.4.1 below.

Table 7.4.1 Open-ended survey subject and prompts

Subject	Survey prompt (EN)
Comfort	Additional comments about your sense of comfort (optional)
Trust	Comments about your sense of trust (optional)

The methods involved a coding and thematic classification process identical to that described in section 4.6.1.2 based on the Braun & Clarke (2006) process as operationalised and tested by Byrne (2022). The process, introduced in section 4.6.1.2 involved the below multi-step process:

1. Data familiarization
2. Initial code generation
3. Searching for themes from recurring words, segments of text, and data features
4. Reviewing themes
5. Defining and naming themes
6. Reporting back

In addition to the coding and thematic classification process, general sentiment was inferred from the comment to understand a cursory-level opinion of the AV shuttle from the respondent's perspective. "Sentiment analysis, or opinion mining, is a type of natural language processing (NLP) that helps determine the summarised view or emotional tone behind a text" (Dake & Gyimah, 2023, p. 4631). This emotional tone was assessed for polarity—either positive, negative, or neutral using an approach adapted from Wankhade et al. (2022).

7.4.2 Survey data multivariate correlation analysis

Multivariate correlation analysis was carried out to determine correlation between *STRESS* and *PBC* variables that represent infrastructure preferences. These variables are compared against a set of demographic attributes. The *STRESS* and *PBC* variables were correlated with the same variables used as independent variables (attributes) in Chapter 6 that are summarised in

. The variables used as proxies for infrastructure preferences in this multivariate correlation analysis are listed in Table 7.4.2 below. This analysis was carried out using SPSS. Spearman's

correlation was favoured over Pearson due to the ordinal/continuous nature of the data (de Winter et al., 2016).

Table 7.4.2 Infrastructure preference proxy variables

Q #	Question wording	Label
4	In which environments will you ride a bicycle?	STRESS
17	Autonomous vehicles on roads without separate bike space would make me feel comfortable while cycling.	STRESS
19	Sharing the same street space with an autonomous vehicle would benefit cycling	STRESS
20	Autonomous vehicles on roads with separate bike space would make me feel comfortable while cycling.	STRESS
22	Separating space between autonomous vehicles and bicycles would benefit cycling	STRESS
23	Human-operated vehicles on roads without separate bike space makes me feel comfortable while cycling.	STRESS
24	Human-operated vehicles on roads with separate bike space makes me feel comfortable while cycling.	STRESS
7	Before the shuttle started, I felt comfortable knowing I would bike in an area with an autonomous shuttle	PBC
8	The first time I encountered the autonomous shuttle I felt comfortable biking in the same area	PBC
9	After encountering the autonomous shuttle many times, I feel comfortable biking in the same area	PBC
14	Before cycling with the autonomous shuttle I felt the technology was trustworthy	PBC
15	After cycling with the autonomous shuttle I feel that the technology is trustworthy	PBC

7.5 Results

7.5.1 Themes and frequencies of open-ended survey input

To systematically analyze the open-ended survey responses, the following steps were carried out: first data familiarization was conducted by reviewing all of the open-ended responses. Next, initial codes were created by clustering recurring words, segments of text, and data features that captured the overarching data trends. The frequency of each code within these themes was then reviewed and tallied to provide a quantitative dimension to the qualitative insights. Finally, the results were defined, named, and summarised in Table 7.5.1 which provides an overview of the results.

Table 7.5.1 Open-ended survey theme summary

Theme	Definition	Frequency
Trust in Technology	Perceptions about reliability and safety	54
Negotiation	AV-cyclist interaction in shared spaces	50
Environment and Infrastructure	Impact of space, conditions, and design	21
Safety and Perceived Risk	Concerns around operational behaviour	34
Skepticism and Resistance	Resistance or doubts about AVs	9
Irrelevant (IRR)	Irrelevant or unusable comments	22

In the following subsections, each theme outlined above is defined and the constituent codes are listed. This section also includes relevant direct quotes which are anonymised to protect participant identity. The quotes are identified with location, age range, and bicycle user classification in parentheses following the quote. If the source language was not English, an indication that the quote was translated also appears.

7.5.1.1 Trust in Technology (54 instances)

Trust in technology is defined as concerns and perceptions about the reliability, safety, and behaviour of AV shuttles. The following codes were grouped under this theme:

Fear of unknown (8)

Untrustworthy (3)

Technological determinism skeptic/supporter (2)

AI technology not inspiring confidence (1)

Trust through eye contact (2)

Trust other AV technology (3)

Trust in regulators (1)

Safety operator diminishes trust in tech (2)

Greater exposure increases trust (2)

Trust until trust is broken (1)

Poor reaction time; skeptical (1)

Witnessed crash; diminished trust (1)

Trust technology (2)

Need more interaction (2)

Performs better than expected (1)

Took rides to build trust (1)

Trustworthy, needs dedicated lane (1)

Human backup increases trust (2)

Confident AV won't hit bicycle (1)

Nervous about other AV tech (1)

Reaction distance; unpredictable (1)

7.5.1.2 *Negotiation (50 instances)*

Negotiation is defined as ways that AVs and cyclists interact, including predictability, shared space, and behaviour patterns. This theme included the following codes:

Norms unestablished (5)

Human presence (4)

Rule-abiding (2)

Cyclists skirting safety rules (1)

Limited detection ability (1)

Slow but comfortable (4)

Obstruction (10)

Extra attention needed (4)

Erratic cycling behaviour (2)

Difficult to overtake (2)

Stressful interaction (2)

Abrupt stopping (1)

Stop interfaces (2)

Predictable (2)

Traffic calming tendency (1)

Not fluid; predictable (1)

Perceived as safer than humans (3)

“It feels unnecessary that we vulnerable road users (VRUs) have to adapt to the bus so that its passengers aren't put at risk. In a VRU environment, margins are often small (without being dangerous), but the bus doesn't seem able to interact under these conditions.” (Linköping, 35-54, Strong and fearless – translated from Swedish)

“It's not so much about safety or cycling more or less. I prefer to take a detour to avoid the bus, but it's not because of safety, but rather because the bus is in the way.” (Linköping, 35-54, Strong and fearless – translated from Swedish)

“Eye contact interaction plays a major role during my cycling. Most drivers will wave me through at a four-way stop sign, some don’t, through eye contact. Cyclists generally don’t stop at a stop sign. A driverless vehicle may pose a problem.” (Montréal, 35-54, Strong and fearless)

7.5.1.3 Environment and Infrastructure (21 instances)

Environment and infrastructure encompassed codes that include influence of operating conditions, infrastructure design, and environmental factors on AV and cyclist interaction. The list of codes grouped under this theme is as follows:

Operating environment stressful (1)
Speed, space, conditions (1)
Limited space (3)
Weather challenges diminished trust (1)
Infrastructure affects trustworthiness (1)
Dedicated lane needed (1)
Mixed traffic challenging (1)
Obstacle to be avoided (2)
Hogging bike path (1)
Fears for faster operation (1)
Space intrusion (2)
Technology sensitivity to conditions (2)
Environment matters for trust (2)

“The self-driving bus constantly drives into the bike lane. I have almost been hit several times.” (Stavanger, 18-34, Strong and fearless – translated from Norwegian)

“I trust for my safety and that of my child; however, I find the transport very slow for the shuttle users: it needs a dedicated lane for the service to be smooth; otherwise, the shuttle makes many sporadic stops. We need to teach respect for sharing the road once again.” (Montréal, 35-54, Enthused and confident – translated from French)

7.5.1.4 Safety and Perceived Risk (34 instances)

The safety and perceived risk theme included concerns related to safety, risk, and operational behaviour of AVs and included the following codes:

- AV is cautious (1)
- Comfortable cycling with AV (4)
- Safe but requires attention (1)
- Sudden stops feel unsafe (1)
- Slower speeds reduce risk (3)
- Sensitivity inspires trust (1)
- AV safer/more predictable (3)
- AV does not add to 'unsafety' (1)
- Technology is unreliable (1)
- Fear of technology failure (1)
- More comfortable with AV than human (2)
- Safe but psychologically demanding (2)
- Stops interrupt traffic (1)
- Acceptable but stressful (2)
- Perception of safety culture (1)

“Even though I have a pretty good understanding of how the bus works theoretically, I think it behaves so unpredictably that it takes up a lot of psychological space, meaning it doesn't feel comfortable to be near it because I either feel a bit threatened by it or that I might cause it to brake without meaning to. Therefore, I try to avoid getting close to it, which I think means it intrudes a lot on active travelers' territory.” (Linköping, 35-54, Strong and fearless – translated from Swedish)

7.5.1.5 Skepticism and Resistance (9 instances)

Skepticism and resistance encompass reduced levels of tolerance of AVs or doubts about integration in a transition period. These are the codes grouped under this theme: Skeptical without human operator (1)

AV shuttle not useful proxy for all AVs (1)
Unfamiliarity = doubt (1)
Will always rely on human (1)
Supportive of idea but cautious (1)
ORUs annoyed by AV (1)
Technological determinism skeptic (1)
Fears complex situations (1)
Human operator negates need to trust technology (1)

“I feel uncomfortable envisioning a future that seems even more technologically determined, but perhaps I’d trust autonomous shuttles more than regular drivers in Quebec!?” (Montréal, 35-54, Strong and fearless)

7.5.1.6 Irrelevant (22 instances)

Comments marked as ‘IRR’ were either unrelated to the survey subject-matter or were not logically worded to be interpreted to have any meaning and are excluded from thematic analysis.

7.5.1.7 Attitudes towards infrastructure configurations

Highlighting the cross-cutting and intertwined nature of this study’s subject matter, a portion of the data used to answer research question three was sourced from the focus groups. In the focus groups, the second most common theme that participants discussed related to the provision of high quality, separated bicycle infrastructure. Although this was not directly related to any specific attitude, noting this was the subject matter of Chapter 5, the material was ideally suited to answer the question in the current chapter.

Existing research has presented a strong case suggesting that bicycle infrastructure impacts bicycle user behaviour (Buehler & Dill, 2016). Both are factors that contribute to an overall level of stress (Lowry et al., 2012; Sorton & Walsh, 1994; K. Wang & Akar, 2019). Sense of safety, or a lack of safety, is an often-cited deterrent to cycling (Branion-Calles et al., 2019; Sener et al., 2009; Winters et al., 2011). “The increased separation [of bicycles] from traffic is thought to improve the level of comfort” (Monsere et al., 2012, p. 22).

Many participants confirmed this saying that they preferred clear, separate space for bicycling because it was more comfortable and easier to understand.

“it's the next street, they have a line so, you know, a bit like where to go. [...] So, if I was on it, I would be like, yeah, I'd feel protected.” (Montréal, 55+, Strong and fearless)



Figure 7.5.1 Photo of St-Denis Bicycle Infrastructure Example (Author's original)

St-Denis is a nearby cycling path (Figure 7.5.1) that was often cited as a strong example of good bicycle infrastructure. It is part of Montréal's recently built Réseau Express Vélo (REV) (Express Bicycle Network).

“St-Denis would be like the perfect example. Protected, sidelined.” (Montréal, 18-34, Strong and fearless)

“Like, I feel safer if I can use some paths like St-Denis or that has like a dedicated cycling lane.” (Montréal, 18-34, Strong and fearless)

“Well, also I guess security [is a positive factor] because with the pandemic and the new REV, I feel like we see more of the vulnerable bikers.” (Montréal, 35-54, Strong and fearless)

Most participants' infrastructure preferences were that they required similar separated infrastructure to feel safe regardless of if the vehicle that they were sharing the road with was autonomous or not.

“If I'm not in a dedicated lane, if I'm neck to neck with cars, then I would be more cautious.” (Montréal, 18-34, Strong and fearless)

“So if there's some bicycle lanes, if I feel safe when I cycle, that has a big impact. Like in the last few years, there's been more and more bicycle lanes throughout the city. So it feels a lot more safe to cycle.” (Montréal, 18-34, Strong and fearless)

“but because it's not really wide, I don't feel as safe as when I'm in on my bicycle path or just another street that has a bit more space” (Montréal, 18-34, Strong and fearless)

“I feel really unsafe when I'm riding at the side, like if there's no separation between bike and cars.” (Linköping, 18-34, Strong and fearless)

“I guess I only feel unsafe biking on roads when there's no clear way for bikes.” (Linköping, 18-34, Enthused and confident)

“I think it very much depends on the setup. If it has separate lanes or same lane. Also, how fast they are allowed to drive. And here I'm thinking if it drives too slow, it feels like an obstacle.” (Linköping, 35-54, Enthused and confident)

“Availability of bike lanes. More separated the better.” (Linköping, 35-54, Enthused and confident)

However, there was one participant who felt that dedicated AV *and* cycling space would be a benefit to cycling.

“No, I don't see [the Autonomous Shuttle] as an obstacle. I'm thinking if the city gives place to the autonomous vehicles and the bikes and make them share space, that would be a gain for bikers.” (Montréal, 35-54, Strong and fearless)

This was a unique position to take when considering all other participants' comments. This participant likely made this comment because of the deployment environment for the AV in Montréal. The slow-moving nature and frequently congested traffic creates a negative experience for all road users. In particular, the AV is also susceptible to congestion and does not have any priority. Furthermore, when St-Hubert is congested, bicycle users often

weave up and down off the shared space sidewalks to leapfrog vehicles that are moving slowly or standing still on the street. In consideration of these circumstances, this participant likely saw shared separated space as a way to give priority to sustainable transportation and create a more coherent and low-stress traffic environment than on St-Hubert Street itself.

In a similar vein to the remark around dedicated space for AVs *and* cycling, participants also conceded that if AVs could be a way to accelerate the reallocation of road space then they would be more supportive of AVs being deployed more widely.

“So, I mean, if autonomous vehicles at the end of the day lead to [the elimination of the requirement for on-street parking], then we're not... That's the only way we're going to get protected bike paths, because that seems to be a lot of the pushback.” (Montréal, 55+, Strong and fearless)

Participants seemed to be more accepting of paint with AVs because they understood that AVs would be more compliant in remaining in their designated travel lanes without encroaching on bicycle space. Although difficult to measure, this could be a reason why the mean comfort increased by 0.11 from separate space with COVs to separate space with AV as shown in Table 7.5.4, which indicates alignment with Likert-scale survey results.

7.5.2 General sentiment towards AVs influencing perceived safety and comfort

In addition to the thematic categorization and analysis above, participant open-ended responses were assessed for sentiment by individually classifying 130 text-responses into sentiment that was positive, neutral, or negative based on the individual comment which can be used as a proxy to determine if an AV would inhibit a bicycle user from taking a bicycle trip. For example, a remark such as “I would feel more comfortable with the presence of one (or more) autonomous shuttles than with just drivers!” was coded as positive because the participant expressed that they would feel more comfortable, therefore, the AV did not inhibit a bicycle trip. In another example, a remark such as “the difficulty is not so much the shuttle itself, but rather the pedestrian traffic—people getting on and off the shuttle.” This was treated as neutral because the affect the participant is referring to is not an externality of the AV. Lastly, a remark such as “one doesn't really know

how it performs at high speeds without witnessing it firsthand” is coded as negative sentiment towards AVs because the participant expressed doubt or skepticism about the performance of AVs in more complex/advanced stages of technological development.

Collectively, the results shown in the histogram below (Figure 7.5.2) indicate that the sentiment that bicycle users submitted in the study are skew negative. Many of these instances expressed cautious optimism and skepticism. Among the highlights of the sentiment in this assessment is that the AV shuttles’ slow operating speed is both a strength (safety) and weakness (frustration). Sentiment also demonstrated that trust is influenced by observed incidents and personal experience—noting that much of participants’ sentiment is dictated by anecdotal interaction which is more useful in aggregate. However, all of this sentiment is impacted by the presence of a safety attendant that leads some respondents to question the technology’s maturity and reliability.

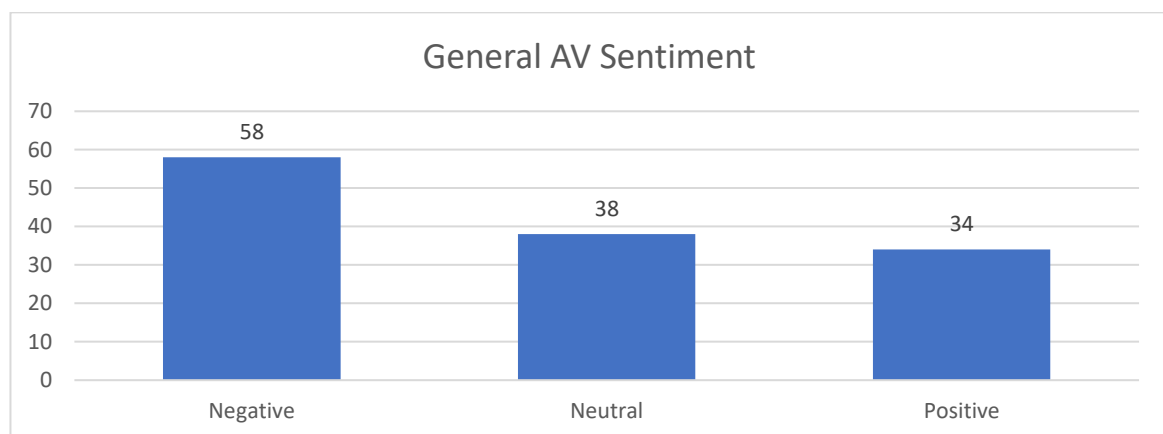


Figure 7.5.2 General AV sentiment in open-ended survey responses

While many respondents acknowledge the potential benefits of AVs, trust as a proxy variable to the impact on cycling trips, remains highly conditional on personal experience, exposure, and technological reliability. The cautious approach taken by AV shuttles increase perceived safety but also raises concerns about efficiency and unpredictability.

Addressing these concerns through improved design, better communication with other road users, and increased real-world deployment could enhance trust in the long term.

7.5.3 Multivariate correlations

7.5.3.1 *Descriptive statistics*

Table 7.5.2 below summarises the descriptive statistics for participants in the study. Each demographic category is broken down by attributes. All attributes can be interpreted on their own without additional information except for income. Due to the variation in income level between living lab site host countries, these attributes have been grouped into 5 levels as explained in in section 4.5.2.6.

Table 7.5.2 Participant descriptive statistics

	Attributes	Frequency	Percent	Valid Percent	Cumulative Percent
Bicycle Class	no way no how	9	2.2	2.2	2.2
	interested but concerned	70	16.9	16.9	19
	enthused and confident	184	44.3	44.3	63.4
	strong and fearless	152	36.6	36.6	100
	Total	415	100	100	
Gender	male	222	53.5	53.5	53.5
	female	179	43.1	43.1	96.6
	other	2	0.5	0.5	97.1
	undisclosed	12	2.9	2.9	100
	Total	415	100	100	
Age	0-17	1	0.2	0.2	0.2
	18-34	201	48.4	48.4	48.7
	35-54	133	32	32	80.7
	55+	75	18.1	18.1	98.8
	prefer not to say	5	1.2	1.2	100
	Total	415	100	100	
Education	bachelor's degree	104	25.1	25.1	25.1
	high school	84	20.2	20.2	45.3
	master's degree	109	26.3	26.3	71.6
	phd or higher	33	8	8	79.5
	prefer not to say	11	2.7	2.7	82.2
	some high school	25	6	6	88.2
	trade school/college diploma	48	11.6	11.6	99.8
	unspecified	1	0.2	0.2	100
	Total	415	100	100	
Employment	student	111	26.7	26.8	26.8
	working part-time	33	8	8	34.8
	working full-time	201	48.4	48.6	83.3
	looking for work	11	2.7	2.7	86

	Attributes	Frequency	Percent	Valid Percent	Cumulative Percent
	retired	44	10.6	10.6	96.6
	prefer not to say	14	3.4	3.4	100
	Total	414	99.8	100	
	Missing	1	0.2		
	Total	415	100		
Income ⁹	lowest	85	20.5	20.5	20.5
	low	74	17.8	17.8	38.3
	middle	103	24.8	24.8	63.1
	high	79	19	19	82.2
	highest	17	4.1	4.1	86.3
	prefer not to say	57	13.7	13.7	100
	Total	415	100	100	
Ethnic Origin	African origins	4	1	1	1
	Asian origins	14	3.4	3.4	4.3
	Caribbean origins	2	0.5	0.5	4.8
	European origins	311	74.9	74.9	79.8
	Latin, Central, and South American origins	4	1	1	80.7
	North American Aboriginal origins	5	1.2	1.2	81.9
	Oceania origins	1	0.2	0.2	82.2
	Other North American origins	38	9.2	9.2	91.3
	Prefer not to say	36	8.5	8.5	100
	Total	415	100	100	

⁹ For details on the income groupings, please see the Table 4.5.2.

7.5.3.2 Comfort Correlations

The summary of variable relationships summarised in Table 7.5.5 show several significant relationships that provide insight into infrastructure preference predicated on safety and comfort. The table's cells have been highlighted to show which relationships are most significant (with a 95% confidence interval where $p = <0.05$). Positive correlations are highlighted in green and negative correlations are highlighted in orange. Only correlations that meet the threshold of significance are discussed in this section, however, all relationships are presented in Table 7.5.5 regardless of confidence interval.

There are some key noteworthy relationships that emerged which help to understand how safety and comfort impact infrastructure preferences. Firstly, there are strong relationships between variables that interrogate participants' comfort and trust. Strong correlations are observed between comfort during the first AV interaction in shared infrastructure (comfortfirstshare), comfort post-AV interaction in shared infrastructure (comfortpostshare), and trust in AVs post-interaction (trustpost). Broadly, trust and comfort variables seem to cluster positively, particularly around scenarios that deal with shared infrastructure. While this is only an indication of how sentiment exists for shared infrastructure, it is only useful when comparing against control scenarios such as with conventionally operated vehicles (convsharedcomfort/convseparatecomfort) and separate bicycle infrastructure.

There is a clear indication that the relationships' different behaviour predictors are more reliably correlated than demographic attributes with behaviour predictors. This can be seen in the upper portion of Table 7.5.5 where there is somewhat of an upper triangle of shaded cells showing more correlation than the rest of the table. The interplay between predictor variables show that safety, trust, and comfort are deeply connected and do not affect one particular demographic more than another. This strongly suggests that all individuals will require that their safety, trust, and comfort needs are met in order to ride a bicycle as autonomously operated vehicles increase in number on public streets.

Table 7.5.3 Comparison of *r*-values between AV/COV comfort Likert responses

	Shared AV	Separate AV
Shared COV	r = 0.161 p = 0.001	r = 0.010 p = 0.847
Separate COV	r = 0.192 p < 0.001	r = 0.354 p < 0.001

Table 7.5.4 AV and COV comfort response mean values

	N	Minimum	Maximum	Mean	Std. Deviation
avsharedcomfort	415	0	5	3.25	1.296
avseparatecomfort	415	0	5	4.51	.932
convsharedcomfort	415	0	5	2.37	1.126
convseparatecomfort	415	0	5	4.40	.932
Valid N (listwise)	415				

There is a significant relationship between comfort variables across infrastructure contexts. Taking the benchmark questions around shared space and separate space with conventionally operated vehicles, there are several other variables that correlate strongly which indicates interplay between shared and separate experiences of comfort concerning different types of street layouts that either share or separate bicycles and vehicle traffic.

Table 7.5.3 above shows the correlations of participants' comfort for cycling in shared and separate spaces with both conventionally and autonomously operated vehicles. There are a few things to note with these relationships in Table 7.5.3 and the mean responses reported in Table 7.5.4. Firstly, the strongest positive correlation is that with the level of comfort with AVs and COVs and separate infrastructure. This strongly suggests that individuals feel most comfortable riding bicycles in separated infrastructure (i.e. physically separated bike lanes) with both types of vehicles. The levels of comfort are interdependent with an r-value of 0.354, which is a medium to strong effect (Cohen, 2013; Richard et al., 2003).

A notable finding emerges when comparing the comfort levels between shared and separate infrastructure across levels of vehicle autonomy (COV and AVs). While participants reported markedly different comfort levels between AVs and COVs in shared infrastructure (means of 3.25 and 2.37 respectively, representing a 37% difference), their

comfort levels in separate infrastructure were remarkably similar (means of 4.51 and 4.40, just a 2.5% difference). This pattern suggests that while the extent of vehicle automation may somewhat influence bicycle user comfort in shared infrastructure street configurations, the presence of separate infrastructure appears to largely neutralise any effect of vehicle type on perceived comfort.

Similarly, there is a medium-to-strong relationship between the sense of comfort cycling in separate infrastructure with current COVs and AVs. The mean sense of comfort from a COV to an AV only increases by 0.11 (on a 5-point Likert-scale where 1 is strongly disagree and 5 is strongly agree) which amounts to a percent change of only 2.5%. This shows that safe, separated, low-stress infrastructure is similarly necessary for bicycle users now as it will be for bicycle users at such time that AVs may become more common.

Beyond this, the correlation patterns reveal an interesting dynamic in how participants view these different scenarios. The stronger correlation for separate infrastructure comfort ($r = 0.354$, $p < 0.001$) compared to shared infrastructure comfort ($r = 0.161$, $p = 0.001$) indicates that participants' comfort levels are more consistently related when considering separated facilities. In other words, if a participant feels comfortable with separate infrastructure and conventional vehicles, they are more likely to also feel comfortable with separate infrastructure and autonomous vehicles. This relationship is notably weaker for shared infrastructure scenarios, suggesting that participants' comfort levels in shared spaces are more variable and less predictable across vehicle types. This finding further reinforces the stabilizing effect that separated infrastructure appears to have on cyclist comfort, regardless of the level of vehicle automation present.

Table 7.5.5 Correlations table

		cyclistclass	avsharedcomfort	avsharedbenefit	avseparatecomfort	avseparatebenefit	convsharedcomfort	convseparatecomfort	comfortpreshare
Spearman's rho	cyclistclass	Corr. Coeff.	--						
		Sig. (2-tailed)	.						
		N	415						
	avsharedcomfort	Corr. Coeff.	.021	--					
		Sig. (2-tailed)	.673	.					
		N	415	415					
	avsharedbenefit	Corr. Coeff.	.017	.432**	--				
		Sig. (2-tailed)	.729	<.001	.				
		N	415	415	415				
	avseparatecomfort	Corr. Coeff.	.102*	.259**	.165**	--			
		Sig. (2-tailed)	.037	<.001	<.001	.			
		N	415	415	415	415			
	avseparatebenefit	Corr. Coeff.	.054	-.134**	-.131**	.363**	--		
		Sig. (2-tailed)	.275	.006	.007	<.001	.		
		N	415	415	415	415	415		
	convsharedcomfort	Corr. Coeff.	.160**	.161**	.152**	.010	-.089	--	
		Sig. (2-tailed)	.001	.001	.002	.847	.071	.	
		N	415	415	415	415	415	415	
	convseparatecomfort	Corr. Coeff.	.088	.192**	.054	.354**	.244**	.172**	--
		Sig. (2-tailed)	.074	<.001	.274	<.001	<.001	<.001	.
		N	415	415	415	415	415	415	415
	comfortpreshare	Corr. Coeff.	.032	.521**	.344**	.351**	.047	.120*	.183**
		Sig. (2-tailed)	.560	<.001	<.001	<.001	.391	.029	<.001
		N	331	331	331	331	331	331	331
	comfortfirstshare	Corr. Coeff.	.041	.538**	.261**	.307**	.030	.083	.186**
		Sig. (2-tailed)	.481	<.001	<.001	<.001	.602	.154	.001
		N	299	299	299	299	299	299	275
	comfortpostshare	Corr. Coeff.	-.033	.580**	.288**	.389**	.019	.095	.251**
		Sig. (2-tailed)	.574	<.001	<.001	<.001	.744	.107	<.001
		N	286	286	286	286	286	286	265
	trustpre	Corr. Coeff.	-.008	.473**	.332**	.299**	.063	.150**	.206**
		Sig. (2-tailed)	.888	<.001	<.001	<.001	.241	.005	<.001
		N	351	351	351	351	351	351	308
	trustpost	Corr. Coeff.	-.125*	.530**	.322**	.405**	.104	.021	.262**
		Sig. (2-tailed)	.029	<.001	<.001	<.001	.068	.710	<.001
		N	306	306	306	306	306	306	276
	maturity	Corr. Coeff.	-.187**	-.043	.040	-.043	-.033	.184**	-.047
		Sig. (2-tailed)	<.001	.411	.442	.412	.525	<.001	.368
		N	371	371	371	371	371	371	295
	classagesimple	Corr. Coeff.	-.081	-.122*	.027	-.170**	-.082	.008	-.085
		Sig. (2-tailed)	.100	.013	.581	<.001	.096	.869	.084
		N	415	415	415	415	415	415	331
	classgender	Corr. Coeff.	-.145**	-.073	-.065	-.038	.029	-.141**	.010
		Sig. (2-tailed)	.003	.136	.184	.444	.558	.004	.833
		N	415	415	415	415	415	415	331
	classeducationsimple	Corr. Coeff.	-.044	-.016	-.020	-.027	-.050	-.106*	.004
		Sig. (2-tailed)	.374	.752	.682	.582	.305	.031	.934
		N	415	415	415	415	415	415	331
	classempleysimple	Corr. Coeff.	-.085	-.157**	.024	-.204**	-.069	-.007	-.075
		Sig. (2-tailed)	.084	.001	.630	<.001	.158	.880	.127
		N	414	414	414	414	414	414	330
	classethnicitysimple	Corr. Coeff.	.088	-.096*	-.017	-.122*	-.093	-.005	.001
		Sig. (2-tailed)	.074	.049	.727	.013	.059	.926	.981
		N	415	415	415	415	415	415	331
	classincomesimple	Corr. Coeff.	-.067	-.113*	.003	-.165**	-.033	-.005	-.033
		Sig. (2-tailed)	.175	.021	.951	<.001	.497	.924	.503
		N	415	415	415	415	415	415	331
	classtechnologyacceptancesimple	Corr. Coeff.	-.026	-.127*	-.072	.005	.028	-.034	.099
		Sig. (2-tailed)	.656	.029	.218	.934	.631	.555	.086
		N	298	298	298	298	298	298	242

*. Correlation is significant at the 0.05 level (2-tailed) **. Correlation is significant at the 0.01 level (2-tailed).

7.6 Discussion

The impact on cycling infrastructure preference can be summarised in five key findings, each with links to existing research. This section will draw on relevant literature and highlight the connections that agree or disagree and offer reasons why this may be the case.

The first key finding where AVs may impact cycling for a variety of urban bicycle users sit at the nexus of infrastructure type and level of comfort which is a major recurring finding throughout all chapters of this dissertation. As shown in the results, there is a strong statistical relationship between comfort level in separate infrastructure regardless of vehicle type (AV or COV). This is further emphasised by the difference in comfort levels between AVs and COVs that was much larger in shared infrastructure (37% difference) compared to separated infrastructure (2.5% difference). This finding suggests that separated infrastructure largely neutralises any effect of vehicle type on perceived comfort, which is supported by Botello et al. in their paper which posits “physical separation of active travelers” (2019, p. 8) is important to ensure safety, which is strongly linked with comfort (Heinen et al., 2010; Whannell et al., 2012). The impact that infrastructure configuration has on trip generation and trip decision-making barriers for bicycle users, consequently, remains substantially unchanged from the present.

Secondly, there are some specific examples which were raised that would impact bicycle user infrastructure preferences. These can be interpreted as PBC factors that make up a component of TPB, as outlined in 3.3.1. Negative sentiment towards AV shuttles often centred on their unpredictability, most notably, their sudden stops which could deter trips or lead bicycle users to change their routing. *Sudden* or *hard* stops were a regular cited erratic behaviour in literature that impacted other road users (Pelikan, 2021; Pokorny et al., 2021). Participants in this study reported actively avoiding routes with AVs, especially when they operated in shared infrastructure with bicycle, which indicated that their presence could influence route choice. Other studies contrasted this; noting in this study that while some bicycle users would avoid AVs, more confident bicycle users also had “a tendency that cyclists become less considerate towards the AV shuttle over time and yield to a smaller degree” (Bjørnskau et al., 2023, p. 14)

Thirdly, and in relation to the second key finding, there are several route choice implications that emerged which can be connected to other research. Participants expressed strong preference for routes with dedicated infrastructure, regardless of vehicle type. This is perhaps expected and is well-understood in a broad base of literature on bicycle user behaviour with COVs (Cabral & Kim, 2020; Caulfield et al., 2012; Dill & McNeil, 2013; Garrard et al., 2008; Pucher & Buehler, 2008). In fact, some participants reported taking alternative routes to avoid AVs, not necessarily due to safety concerns but due to operational inefficiencies such as those highlighted by other scholars who note AV shuttles' abruptness (Pelikan, 2021), sensitivity issues when overtaking (Bjørnskau et al., 2023; Pokorný et al., 2021), and frustration with slow operating speeds among "faster cyclists [that] got frustrated" (Boersma et al., 2018, p. 6). The latter of which was cited among participants as creating both positive effects (increased perceived safety, traffic calming) and negative effects (frustration, delay) that influence route selection.

Fourth, confidence and experience induced by infrastructure may be dictated by exposure over time. To this end, and as supported by findings from similar AV shuttle interactions in Oslo, "cyclists become less considerate" over time (Bjørnskau et al., 2023, p. 14). Other researchers have also posited that the more AV exposure that a bicycle user has, the more likely they are to adopt an 'accepting' attitude towards AVs (Penmetsa et al., 2019) and have "higher perceived safety on sharing roadways with AVs" (Rahman et al., 2023, p. 275). However, there is a diversity of opinion on this subject-matter, Pyrialakou et al. (2020) contrast this suggesting there is not a uniform increase in perceived safety associated with more AV exposure and awareness. The variety of operating environments and bicycle cultures likely influence these outcomes and, importantly, so does the quality of cycling infrastructure. All considered, participants in the present study did cite an increase in trust and comfort as they had more exposure, suggesting initial trips may be more stressful but become more comfortable over time. Participants also noted that the presence of safety operators affects trip confidence differently across users. Some feel more confident that there were safety backstops while others less so due to a perception that the AV technology was too immature to operate safely independently. In many cases, anecdotally referenced previous experience with AV incidents strongly influence future trip decisions.

Fifth, there may be long-term implications that change bicycle user infrastructure preferences. These findings are mostly rooted in the theoretical framing of traffic stress noting that the potential reallocation of road space (e.g., parking removal) for AV operations could create more opportunities for protected bike infrastructure, potentially increasing trip frequency and reducing traffic stress (Furth et al., 2016). Any improved separation from traffic could encourage more trips from a wider bicycle user base that have broader representation from the whole spectrum of bicycle user typologies (Cabral & Kim, 2020; Geller, 2006; Hosford et al., 2020). Collectively, the psychological demands of navigating infrastructure and a mobility landscape that includes AVs could have long-term impacts that should seriously interrogated through more detailed research. A summary of the takeaways for the implications on cycling trips is presented in the following section.

7.7 Conclusion

The findings presented in this chapter address how cycling infrastructure preference may be impacted as AVs become more prevalent. The findings also suggest that while AVs introduce new considerations for cycling infrastructure separation preference, the fundamental importance of infrastructure quality and physical separation remains key. The opinion of AVs on infrastructure preference seems to be most polarizing in shared spaces, where their presence can create both opportunities (potentially safer, more predictable interactions) and challenges (operational inefficiencies, psychological burden) that comfort and safety. However, these opportunities and challenges affect different typologies of bicycle users in different ways because not all bicycle users have uniform attributes and behavioural qualities.

The factors for trip generation as discussed in Chapter 6 and the barriers present for bicycle users remain largely unchanged. It is evident that prevailing understandings of bicycle user tolerance for traffic stress and integration with vehicular transport remain applicable this study which bases its findings on a sample of living lab participants. These understandings will remain valid, at a minimum, during a transition period when vehicles increase their level of autonomy and are blended with COV traffic which bicycle users would be expected to adapt to. This expectation is a further subordination that exacerbates vulnerable

transport planning (Khayesi, 2020) and transfers the transport negotiation burden on the most vulnerable road users.

A summary of the conclusions from this chapter are presented and summarised in the following two-pillar framework that present the preferences for infrastructure that can be taken into consideration when planning for AVs (Figure 7.7.1).

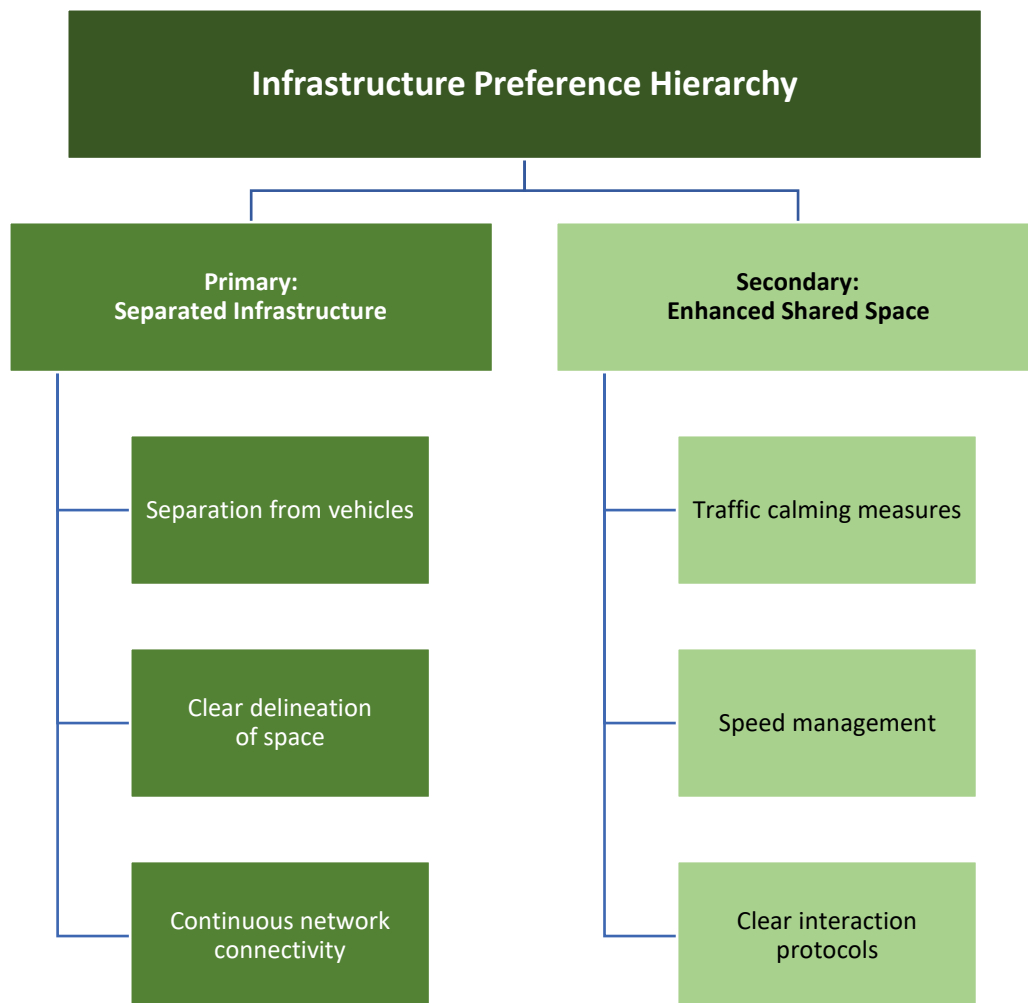


Figure 7.7.1 Infrastructure preference factors

These preference factors, which could be framed as solutions for AV-bicycle user interaction, are not particularly groundbreaking and align with existing literature on conventional understanding of how to create safer and less stressful transportation infrastructure. These preferences are both drawn from empirical data from the research for this project and are supported by an existing body of knowledge. The primary preference factors are drawn from participant input. They are presented based on an

understanding that transportation infrastructure should be designed for the least common denominator. For example, a bicycle user who is extremely traffic stress sensitive and will not ride a bicycle on a busy street sharing a lane with a fast moving car would require infrastructure intervention, however a bicycle user who is traffic stress insensitive would not require infrastructure intervention. By taking the laissez-faire approach to auto-dominant infrastructure design and continuing with current practice, we do a fundamental disservice to those who would otherwise ride a bicycle if it was safe enough to do so. Ignoring these preference factors creates inequitable access to the city and is counter to principles of mobility justice.

Taking a closer look, separation from vehicles through the provision of separated infrastructure is a proven method for reducing traffic stress and enabling more types of bicycle users across the age and ability spectrum to use a bicycle in urban settings. Participants frequently cited the “availability of bike lanes” as important; they proceeded by saying “more separated the better.” (Linköping, 35-54, Enthusiased and confident). This is widely recognised as one of the most important infrastructure design choices for urban bicycle use (Hull & O’Holleran, 2014; Winters et al., 2022). When separated infrastructure is not possible, clear space delineation is needed, recalling an earlier cited example where “the self-driving bus constantly drives into the bike lane” where the participant had “almost been hit several times.” (Stavanger, 18-34, Strong and fearless – translated from Norwegian)”. Importantly, without a network that has continuous connectivity like what drivers are afforded, bicycle users will continue to be marginalised. Participants spoke highly of high-quality networks like that of Montréal’s REV which embody the principles of continuous network connectivity and are authoritatively echoed by NACTO and CROW (Groot, 2016; NACTO, 2025).

While the primary approach is preferred both as evidenced by participant sentiment and by authoritative sources, secondarily, and in simultaneously with primary approaches shared spaces must be enhanced for more positive AV interaction— which can also improve COV-bicycle interaction during a transition period. Traffic calming which may include speed humps, raised crosswalks, chicanes, and curb extensions, which collectively help reduce vehicle speeds and enhance safety for bicycle users. These measures have been shown to improve urban bicycle conditions leading to more inclusive, low-stress and

safe environments which foster higher rates of urban bicycle use (Bellefleur, 2012; Gaio & Cugurullo, 2024; Pucher & Buehler, 2017). Similarly, speed management is both reported by participants and echoed in the literature. In one instance a participant noted that “I feel that maybe if [the AV shuttle is] slower, I’ll be more comfortable” (Montréal, 18-34, Strong and fearless) which is mirrored in discourse (Pucher & Buehler, 2016; Yannis & Michelaraki, 2025). One study in particular highlights that after 30 km/h speed limits are introduced, injuries to bicycle users were reduced by 21% (Uijtdeuwilgen et al., 2022). Finally, clear interaction protocols are existentially important when human communication is removed from the vehicle operator equation. In Chapter 5 *communication and cues* was the largest thematic area discussed and ample research stresses the importance of establishing new ways to interact, acknowledging that this remains a big challenge and is extensively discussed (Al-Taie et al., 2023; Botello et al., 2019; Hagenzieker et al., 2020; Pelikan, 2021).

In answering research question three: “How can streets be designed to be conducive to cycling with self-driving vehicles from a non-occupant perspective?”, the role of infrastructure preferences in shaping cycling behaviour as AVs become more prevalent can be better understood. The data demonstrate that bicycle users maintain a strong and consistent preference for separated infrastructure, regardless of whether they are sharing the road with AVs or COVs. This preference is quantifiably evident in the somewhat uniform comfort levels reported for separated infrastructure across both vehicle types (2.5% difference), compared to the shared infrastructure environments comfort level disparity (37% difference). Qualitative data further reinforces this finding. Participants consistently expressed a preference for clear, physically separated bicycle infrastructure that reduces psychological burden and increases interaction predictability. While AV technology stands to introduce new street dynamics, bicycle users’ infrastructure preferences remain aligned with current separation design principles. Notably, while some participants suggested that AVs could be more predictable or rule-abiding than COVs, this did not translate into a diminished preference for separated infrastructure. These findings suggest that as cities plan for a potentially a transport future that may be more AI-mediated, addressing bicycle users’ infrastructure preferences responsively through dedicated, separated facilities should remain a cornerstone of transportation infrastructure planning. Planning policy should not assume that increased vehicle autonomy will reduce the need for separated

infrastructure. These findings (summarised in Figure 7.7.1) are especially valuable for policymakers and planners working to maintain and increase cycling mode share while preparing for a transportation system that is increasingly AI-mediated.

8. Conclusion

At the early outset of this research, there was an acknowledgement that bicycle users were an understudied and poorly understood group of individuals who would stand to be most impacted by AVs. In most cases they were grouped into a general umbrella ORU user group and labelled as VRUs. The prevailing discourse, represented through the existing body of literature and discussed in the literature review, overwhelmingly focussed, nearly exclusively, on *occupant* travel behaviour who most certainly will experience extremely minimal change, if any, in their mobilities. It was also acknowledged, when it came to interaction of bicycle users and autonomous vehicles in real-world environments, that we “didn’t know what we didn’t know” (Margolin, 2014, p. 1) and that gaining an understanding of the unknowns would be a valuable contribution.

By going down this path, there was an effort to encapsulate some of the biggest concerns the bicycle users have for a future with AI-mediated transport systems in the form of AVs as echoed in the existing literature. The research outlined three research questions that worked to combine a blend of novel theory, methods, and built environment to formulate some of the most pressing issues that could impact bicycle use. This is all understanding the focus of transport systems which has continually afforded priority to vehicles with higher levels of autonomy that stand to further entrench existing norms and subordinate bicycle users by design, and perhaps with an immutable inertia. The findings in the three research questions presented in this research aim to provide measured, systematic, and thoughtful reflection for transportation decisionmakers and planners through data.

This chapter is designed to pull together all preceding chapters. It is structured as, firstly, a synopsis of the contextual chapters in section 8.1 followed by the key findings of each research question in sections 8.2 through 8.4. Following the empirical summaries, a set of theoretical contributions in relation to existing literature are outlined in section 8.5 and methodological contributions in section 8.6. Thereafter, a set of practical policy implications are presented based on the findings from empirical chapters in section 8.7. Penultimately, section 8.8 outlines limitations for consideration and, finally, recommendations for future research in section 8.10.

8.1 Synopsis of Contextual Chapters

In Chapter 1, the critical exploration of potential impacts of autonomous vehicles (AVs) on urban bicycle use was presented, situated within the broader context of transportation evolution and mobility systems. The research explained how the focus on understanding how the introduction of self-driving technologies might affect bicycle users' safety, comfort, and travel behaviour, particularly in "living labs" where AVs are being piloted. By examining the complex interactions between emerging AI-mediated transport systems and vulnerable road users, the study aimed to address significant research gaps in non-occupant perspectives on AVs. Importantly, it presented a nuanced approach that challenged techno-deterministic views, emphasizing the need to prioritise human-scale urbanism and mobility justice during this technological transition. By focusing on fixed-route autonomous vehicles in neighborhood settings, the study sought to establish a baseline understanding of how different classifications of bicycle users might perceive and experience these emerging transportation technologies.

Following, in Chapters 2 and 3, a comprehensive overview of the literature surrounding AVs and bicycle users is presented, along with the theoretical underpinnings that inform the study. Chapter 2 detailed the systematic literature review process, including search terms, inclusion criteria, and the resulting themes, such as safety, trust, comfort, and behaviour. The review highlighted the need to consider bicycle users as a distinct group of vulnerable road users (VRUs), separate from pedestrians, due to their unique interactions and infrastructure needs. The discussion further identified environmental and experiential themes that influence bicycle users' interactions with AVs. The chapter concluded by drawing a connection to Urban AI, emphasizing AVs as a key manifestation of this technology in the physical urban realm. Chapter 3 established the background and theory for the research, acknowledging the power dynamics that subordinate bicycle users and discussing the sensory experience of cycling in car-dominant systems. The chapter introduced TPB as the first theoretical frame, along with bicycle user classification systems and LTS as supplementary theories to better understand the variables influencing bicycle use in the presence of AVs. The theoretical framework is designed to address the research

questions related to attitudes, normative influences, and street design preferences for cycling with AVs, as well as the important role that fear of AI plays.

Chapter 4 outlined the study's methodology, detailing the mixed-methods approach that was employed, using surveys, interviews, and focus groups. This approach was implemented in four living lab sites, chosen for their representation of a range of bicycle urbanism maturities, levels of traffic stress, and similar types of AVs operating at SAE level 3 or higher. The living lab approach facilitated participant engagement with real-world AV experience, addressing a research gap. Sites included Aalborg, Linköping, Montréal, and Stavanger, each assessed for bicycle urbanism maturity using a model. Traffic stress levels were evaluated using the Mineta Transportation Institute's LTS classification system, which considered street design and traffic scenarios, with the "weakest link logic" assigning the overall stress level. Data collection constituted online surveys using a five-point Likert scale to understand participants' attitudes, comfort, and trust related to cycling near AVs. Qualitative data collection involved interviews and focus groups to gain more in-depth insight. The study used stratified sampling, targeting residents near AV shuttle routes, in a 150m buffer, using open data address information from local authorities. Data preparation and analysis involved coding Likert scale responses, demographic data, and using machine translation for open-ended survey responses and thematic analysis of interview transcripts.

8.2 Research Question 1: Attitudes of 'living lab' Bicycle Users Towards AVs

The first question revealed participants' attitudes towards AVs in living labs. Attitudes were overwhelmingly influenced more by the infrastructure environment. Notably, participants cited high-quality, separated infrastructure as important and noted that their sense of comfort was a key factor that influenced their attitude towards AVs. The preference for infrastructure was found to be even more important than vehicle automation. Participants also expressed concerns about the loss of human communication. The loss of such communication would lead to potential challenges in inter- and intra-street participant power dynamics. There was a particular emphasis on the challenges of a transition period with mixed vehicle types. In contrast to participants' concerns, it was noted that potential

AV benefits included their slow operating speeds and the absence of road rage, however this may not be indicative of the state-of-the-art of AV technology.

The answer to this research question identified three core concerns that shaped cyclist attitudes: communication with AVs, infrastructure separation, and trust dynamics. The findings underscored that, while AVs may offer advantages, infrastructure design remains crucial for bicycle user comfort and safety. The proposed Hierarchy of Bicycle User Needs (presented in Figure 5.7.1) highlights the importance of establishing a robust, low-stress bicycle-focussed infrastructure as the foundational priority. The results also suggest that future urban mobility design should be collaboratively and democratically developed, recognizing the need for responsive, iterative approaches to accommodate evolving AV technologies and societal expectations.

8.3 Research Question 2: AV impact on cycling trips and behaviour

Findings from the second research question revealed the tendencies of complex interactions between bicycle users and AVs across the living lab contexts. The findings from this research question revealed a nuanced set of findings on user perceptions and behaviours. Findings suggest that individual attributes influenced AV acceptance significantly, with infrastructure preferences and cycling confidence emerging as influential determinants.

Among the impact factors, demographics played a notable role. Younger adults, full-time employed participants, and lower-income groups showing higher AV acceptance, while women expressed more hesitation. Some notable insights highlighted that more experienced bicycle users (categorised as 'strong and fearless') demonstrated greater adaptability to shared spaces, whereas less confident cyclists required more supportive infrastructure. Geographic and cultural contexts also substantially influenced AV tolerance, with variations observed between living lab sites. Technological acceptance proved unpredictable, with late adopters showing more positive responses to separated infrastructure.

There are several geography-focussed reflections that can impact cycling trips and behaviour. In addition to the empirical data from participant engagement, urban

morphology likely influences observed variations. The diversity of urban living labs was intentionally structured to represent a range of bicycle urbanism maturities which may have predisposed participants to different levels of comfort and acceptance that play into their cycling trips and behaviour. The nature of urban form can predispose individuals to certain modes of transportation, especially considering the contrast between the Aalborg site which was a low stress pedestrian and bicycle pathway and the Montréal site which was a bustling shopping street. Importantly, this urban form cross-section across a variety of urban geographies allowed for the observation of a diverse range of reactions to AVs, contributing to the nuanced findings on user perceptions and behaviours. There is value in combining urban observation across morphologies and diverse user experiences to study the influence of bicycle trips and behaviour, as evidenced in the range of results presented.

Ultimately, findings underscored the importance of taking an individualised/tailored approach if/when AVs are to be further integrated into existing transportation systems that include urban bicycle users. Perhaps most importantly, the need for context-specific strategies that consider diverse user groups' needs, preferences, and concerns should be emphasised. A comprehensive factor-impact-consideration table was developed to guide policymakers and transportation planners in creating more inclusive and equitable urban mobility solutions in Table 6.7.1.

8.4 Research Question 3: Influence of AVs on cycling infrastructure preference

The third and final empirical chapter based on research question three revealed that while AVs introduced new considerations for infrastructure design, the fundamental importance of high-quality, physically separated infrastructure remained paramount and was largely similar linked the responses participants gave in all other research questions. Results to research question 3 on bicycle users' infrastructure preferences show that AV interactions were most complex in shared spaces. This presented both potential opportunities for safer interactions and challenges related to AV operational inefficiencies and psychological burden. Importantly, these dynamics varied across different bicycle user typologies.

Bicycle users maintained a strong, consistent preference for separated infrastructure. There were minimal comfort level differences between AVs and conventional vehicles in

separated infrastructure environments, compared to significant discomfort in shared spaces. Qualitative data reinforced participants' desire for clear, physically separated bicycle infrastructure that reduced their psychological burden and increased predictability. Despite some participants suggesting AVs might be more predictable than conventional vehicles, this did not diminish the importance of separation. Findings from research question three concluded that transportation planning should not assume increased vehicle autonomy would diminish the need for dedicated bicycle infrastructure. These insights on infrastructure preference from living lab participants provide critical guidance, and a useful (if not indicative proxy), for policymakers and urban planners seeking to maintain and increase bicycle mode share in an increasingly AI-mediated transportation landscape on a city-wide scale.

8.5 Theoretical contributions

The following contributions are made in direct response to previous literature and foundational studies relating to AV and bicycle interaction. The established discourse, in many cases, is shaped by these theories and in order to best connect the present research to discourse and make a suitable contribution, the structures and processes of these theories must be incremented to better design future research and frame future discourse. Without evolutions to theory, the impacts of AI-mediated transport systems and AV-bicycle user interaction will not be accurately, adequately, or appropriately captured. Antiquated theories that do not adapt to the novel factors ushered-in by AVs, there will continue to be an inadequate understanding of the latest technological transportation evolution. The contributions to theory outlined in this section pull together the empirical chapters and connect them to previous literature through evolved theory.

8.5.1 Evolving the Theory of Planned Behaviour for Bicycle Urbanism Research

In section 3.3.1, TPB was highlighted as an influential theory for understanding an individual's behavioural intention and lays a useful foundation to assess and structure behavioural determinants. While several scholars have identified opportunities to improve TPB, its influential foundation remains useful.

In a further extension of TPB, there is an opportunity to specifically tailor TPB to bicycle urbanism research. Throughout this dissertation, elements of TPB were used to inform the inputs to and the structure of research questions for all empirical chapters. However, in multiple instances, *proxies* for the inputs to TPB were used to understand the influences on behavioural intent. As a tool that could be used to understand trip generation and mode split in urban areas, a Bicycle TPB could include some of the most influential factors that impact a bicycle users' likelihood to cycle. Other researchers have done ample foundational work on a potential Bicycle TPB including work on motivators, deterrents, and policies (Pucher & Buehler, 2008; Winters et al., 2011). The inputs, subject to further study, could include many of the elements in the proposed Hierarchy of Bicycle User Needs in AV Environments (Figure 5.7.1) the presence of high-quality bicycle infrastructure, ability to communicate, and a sense of safety and comfort.

Additionally, there also is merit in developing an evolved theory that can respond to unique geographies and technology factors. Noting that the built environment significantly shapes individuals' perceptions and evaluations of bicycle use, a behavioural factor such as *perceived bicycle ecosystem quality* that encompasses infrastructure, traffic stress levels, and the overall design of the urban environment as a direct influence on attitudes towards bicycle use. Social norms also vary based on location and can be geographically dependent. Cities with high bicycle mode share and strong bicycle cultures may create social pressure to ride a bicycle or the acceptance of bicycle use as a normal mode of transport even with AVs. TPB could evolve in this sense to include something like *local cycling culture embeddedness* directly, however, McLeod et al.'s (2020) cycling maturity index was used to supplement TPB in lieu of creating a customised theory before making empirical observations. The built environment, through unique urban geographies and morphologies also can directly determine an individual's actual and perceived ability to use a bicycle safely and comfortably in urban environments. The availability of protected bike lanes, the presence of traffic calming measures, and the connectivity of the bicycle network varies across localities and could be encompassed in a bicycle-centric *accessibility and quality of bicycle infrastructure* as a behavioural determinant which aligns with prevailing discourse.

In some specific examples based on research from the living labs in this research, a consistent pattern in bicycle user attitudes toward AVs emerges depending on the context of each location. In mature bicycle urbanism cities like Aalborg (Denmark) and Linköping (Sweden), participants showed more positive attitudes toward bicycle use, even when considering AV interactions. The critical factor across all locations was dedicated bicycle infrastructure, with Montréal (Canada) demonstrating that positive bicycle user attitudes persisted primarily in areas with good separation from traffic. These findings collectively emphasise that while bicycle culture is a contributing factor, physical separation, and its variation across geographies remains fundamental to maintaining perceived safety.

8.5.2 Adaptations of the Mineta Transportation Institute's Level of Traffic Stress to include AV variables

The system used to assess level of traffic stress used to classify living lab in Chapter 4 was based on a system that assesses traffic stress on four levels and takes into consideration several tables that incorporate speed limit, infrastructure configuration (bike lane placement), traffic mix, and intersection design. These are all important factors to consider when assessing traffic stress for bicycle users. However, these metrics were designed for San Diego, California. There are no other practical ways to assess traffic stress for low-stress bicycling that are as comprehensive and maintained. While the LTS framework is useful, it was made with one city in mind and does not account for all factors that participants cited as important for riding a bicycle with an AV.

There is an opportunity to expand the framework to make it more universal for more cities and urban morphologies. While the current framework is most useful for North American bicycle user experience and traffic stress assessment, enhancements for other countries and continents would be pertinent. Of particular relevance to the results of this study would be the inclusion or mode split of AVs in a specific city. While the magnitude of impact that the share of AVs would behave should be the subject of further study, the inclusion of new mobility and AI-mediated transport systems would be a useful factor for consideration in the LTS framework.

8.6 Methodological Contributions

As outlined in section 4.8, this research presents three significant methodological contributions to AV interaction studies. First, the study introduces an innovative interdisciplinary approach by synthesizing theories from urban geography, behavioural psychology, and cycling research, providing a more comprehensive framework for understanding travel behaviour and bicycle use in the context of emerging AV technologies. Second, the research offers a novel multi-city data collection methodology that targets AV interaction living labs outside a prevalent research hub (the United States), demonstrating a flexible and rapidly deployable approach to studying understudied regions. Third, the study provides a methodological template for cross-cultural sampling of targeted groups, successfully implementing an approach that can be expanded and refined as AV technology continues to evolve, with potential for more extensive longitudinal studies across diverse geographical and cultural contexts. These methodological contributions collectively contribute to a more nuanced and adaptable research approach in the emerging field of AI-mediated mobility systems.

8.7 Policy Implications

Scholars have posited that “technology, behaviour, the built environment and infrastructure, and the role that the public-sector” (Botello et al., 2019, p. 2) will all have an outsized role to play in influencing attitudes, behaviours, and cycling trips. This largely reinforces the findings and conclusions that research from this project has led to. Each of the empirical chapters have presented succinct tools for policymakers to use in developing policies for a transport system in an era that includes AVs.

Firstly, when understanding the attitudes of bicycle users towards AVs and the feedback that can be drawn from empirical data, Figure 5.7.1 suggest that high quality infrastructure will continue to lay the foundation for fostering an acceptable environment for bicycle users with AVs. Once the foundational need is met, the next most important implications to consider are (in order of priority) the importance of communication and trust between bicycle users and other vehicles, safety and comfort, an orderly and regulated transition

between COVs and AVs, and an overall lens of modal integration that acknowledges the equal right of all road users, especially bicycle users.

Secondly, to better prepare for the impact on cycling trips and behaviour, the AV/Bicycle User Readiness Table presented in Table 6.7.1 can be used as a quick reference to consider factors related to four overarching themes: bicycle user typologies and behaviour, key demographic considerations, infrastructure impact, and an implementation strategy. The theme-based factors all have corresponding impacts and planning recommendations.

Table 6.7.1 provides a comprehensive overview of factors affecting the integration of AVs with bicycle infrastructure. It identifies four cyclist typologies, with "Strong & Fearless" and "Enthusied & Confident" being early adopters who are more readily adaptable, while "Interested but Concerned" and "No Way No How" require more supportive infrastructure and education programs. Key demographic considerations highlight gender, age, income, and employment as significant influences, suggesting tailored outreach and equitable infrastructure improvements. Infrastructure impacts emphasise the importance of separated facilities, clear signage, and integration points to improve comfort and confidence for all users. Finally, an implementation strategy focusing on gradual user adaptation, prioritizing infrastructure over technology, and aligning strategies with local bicycle cultures is recommended to ensure successful AV-bicycle integration.

Thirdly, the influence that AVs will have on bicycle user infrastructure preference can be summarised simply: bicycle users emphasise the need for safe separated infrastructure. This is not a new implication for policymakers and planners. Where AVs may have been treated as a reason to slow the roll-out of this type of bicycle infrastructure, it is clearly demonstrated in the data from this study that planners and policymakers should be emboldened to continue extending separated bicycle infrastructure. This is particularly pertinent because the AV shuttles involved in the living lab data collection sites were slow and cautious which may have produced unexpected results where respondents still demanded high quality cycling infrastructure. In the conclusion of Chapter 7, Figure 7.7.1 denotes an Infrastructure Preference Hierarchy that presents a set of measures in order from most important to least important, based on study participant input. The implications that policies will have on safety, equity, and mobility justice are major considerations to contemplate when planning for AVs in urban environments. Transportation is ultimately a

common resource and necessity, and it must equitably afford everyone access to mobility without regard for immutable qualities or by predisposing them to a singular mode of transportation. True transportation access enables mobility choice through mobility justice.

8.8 Reflections on Mobility Justice

Reflecting on mobility justice in the context of research on AVs and urban bicycle use, or urban transportation more broadly, reveals several considerations. A key reflection is on the historical and potential perpetuation of transport subordination. The research discussed throughout highlights how the current transport system has historically subordinated vulnerable transport methods like bicycling to the dominance of automobility.

It is understood that AVs may only be available for the wealthy, which Sheller describes as “mobile elites” (Sheller, 2018). In a similar way to how auto-dominant transport systems exclude those who cannot drive or afford to drive. A techno-deterministic view may posit that AVs solve part of this issue by removing the requirement for an individual to be able to operate a vehicle. However, this dismisses the fact that urban morphology and cities have been shaped by and for private ownership, operation, and storage of personal vehicles thereby subordinating all other modes of transportation. This further undermines the fact that in the United States about 1 in 10 people do not drive. These groups are overrepresented by lower-income households, racialised individuals, and those under the age of 30 (Schaeffer, 2024). Another example from Canada notes that 20-40% of people in a community cannot, should not, or prefer not to drive (Litman, 2022). Given diverse transport needs and the dominant transport systems at play, this precludes advancing mobility justice in many ways.

In Chapter 6, a concluding argument was made that that a reason for higher levels of acceptability among low-income participants could be that their acceptance of bicycle use with AVs may be tied to their hopes for increased accessibility, affordability, and potential benefits from these technologies. Similar optimism for AVs has been found among people with special needs (Kassens-Noor et al., 2021). However, if unregulated market forces

continue to shape transportation systems, equity-deprived groups that seek equitable access to mobility are often subordinated to privileged, mobile elites who would likely have earlier and easier access to AVs. This would quash any hopes for increased mobility and negates proven methods to improve mobility by allowing for safer and broader access to more transportation options including walking, biking, and public transportation in addition to conventional or autonomous vehicles.

In line with several scholars' calls to recalibrate transportation planning to prioritise people rather than motorised traffic, AVs could present an enormous opportunity to improve mobility justice or to worsen it (Gaio & Cugurullo, 2023; Sheller, 2018; Urry, 2004). Bicycle users consistently prioritise safe, separated infrastructure which is a fundamental need that transcends technological changes in transportation. The potential for AVs to enhance urban mobility hinges on thoughtful regulation. As argued throughout, AVs can be regulated to promote health, safety, equity, and access— all of which are core principles of mobility justice. Empirical findings regarding active transportation user's needs and concerns provide valuable insights to inform regulatory frameworks. By understanding how non-occupants, especially bicycle users, experience and interact with AVs, this research addresses a critical gap in the literature, which has historically privileged the occupant perspective. This shift in focus is essential for comprehensive mobility justice, ensuring all road users' experiences are considered in transportation planning and policy.

Geographically speaking, much of the issues with automobility resonate and are echoed in scholarship on urban morphology and spatial justice. Street design, land use, and zoning codes contribute to the marginalization of non-motorised transport modes through systematic prevailing forces and perpetuate unintended consequences influenced by power dynamics such as economic forces and social struggles (Soja, 2010). More broadly, spatial justice not only in the form of mobility justice, perpetuates broader social inequalities through the division of space, control, and land use, which raises philosophical questions such as who has the right to the city, first discussed by Lefebvre (1967). For example, policies that prioritise road or highway expansion over bicycle networks disproportionately benefit car owners while limiting mobility for low-income communities that rely on bicycles, reinforcing spatial segregation and restricting access to economic opportunities.

As concluded in this chapter, AVs could perpetuate continued inequalities and further create a divide of mobility have- and have-nots. This is pertinent among bicycle users where those who are less affected by traffic stress and who are unintimidated by current urban and street design paradigms remain unaffected and those who are more affected become even more marginalised. The promise of SAVs could align with mobility justice objectives by potentially creating safer, more space-efficient urban environments if regulated. A major contribution of this research is understanding the conditions under which a transition from COVs to AVs could benefit vulnerable road users rather than exacerbate existing inequities. This suggests that mobility justice in an AI-mediated transport era requires not only technological innovation but intentional design choices that prioritise human-centered mobility systems accessible to all road users regardless of mode choice.

8.9 Limitations

The research design of this study took several risks to empirically observe bicycle use with autonomous vehicles to create a pioneering study that spanned different bicycle urbanism maturities, urban geographies, and societies. The goal was to set a baseline study design to provide a specific interpretation of one type of road user. In so doing, a novel dataset was created to answer the research questions. This novel data faced several study limitations that must be acknowledged, some of which have been briefly introduced throughout the dissertation. While the results align with other peer-reviewed work, there are limitations that emerged which should be controlled for in future work and taken into consideration when interpreting the results.

It should be self-evident that the AV shuttles used to assess bicycle user interaction, attitudes, and acceptability do not necessarily represent the state of the art of AVs. While this may introduce a useful baseline, this is a limitation that should be acknowledged and may perhaps yield contrasting results to a free-floating AV that can operate at faster speeds and do not follow a predictable route. However, it is anticipated that many of the communication issues raised by participants will remain as important factors.

The time-constraints of the living lab site visits meant that there was no ability to conduct a truly longitudinal study. The data collection tools necessitated that participants recall

their experiences with an AV and this may have led to recall bias thereby compromising the accuracy of participant interaction accounts.

Language/cultural barriers and incongruencies may have also been present. While the data collection tools were adequately localised to each living lab location, there may have been small inconsistencies with the cultural meaning of certain words used for the survey portion of the study. While this limitation is acknowledged, qualitative data collection was conducted in English to ensure language consistency. However, by conducting qualitative research in English, this may have presented a barrier for some participants and their perspectives may not be adequately represented.

The sample size meant that some statistical relationships did not attract sufficient results to draw reliable conclusions. This could be enhanced by increasing response rates through incentives, broadening the reach of participant recruitment efforts, or narrowing the scope of research instruments. Sample sizes could also naturally grow when the scale and deployment of AVs increases, in which case there may naturally be more reliable data and readily statistically significant relationships if the methods or research design are repeated.

8.10 Recommendations for Future Research

There are several areas where this research can be expanded on and/or replicated with enhancements based on several learnings. The multi-jurisdictional approach is a useful method for gaining insight into more holistic perspectives that have a broader application. Many of the limitations outlined above can be translated into recommendations for future research. Along these lines, many of these recommendations are direct applications to overcome future limitations but also to expand understanding.

First, future study could assess more granular variability in infrastructure quality, perhaps through a Bicycle LTS framework. The current LTS framework did not provide sufficient opportunity to assess, in detail, some specific instances. While this detail would strengthen future work, it would also add significant workload to the data collection and stress classification system. If resources are limited, it would be important to balance detail with resource availability.

Second, future research should aim to include larger, more diverse samples to capture a broader range of experiences. The recruitment and data collection for this research was constrained by financial and human resources. The nature of free-floating AVs will naturally expand the coverage area, and likely, the recruitment base. However, more recruitment channels such as monetised online advertising and the availability of incentives would encourage more participants. During one site visit, a similar study was recruiting participants and offered a financial incentive which likely impacted the recruitment for this study.

Third, this study was conducted in the Global North and in countries that have somewhat similar Western cultures. In noting that there is geographical variation in bicycle user behaviour, future studies should aim to replicate and build on this research in other parts of the world. These more extensive global studies should interrogate what underlying cultural or infrastructural factors driving cultural differences, which could inform targeted interventions to promote bicycle use. It would be pertinent to have targeted regional studies that can be structured around a broader global effort, depending on resource availability.

Finally, the study should be repeated in locations where there are free-floating and privately operated AVs that represent a more progressed version of AV technology. The theoretical and methodological contributions from this study, in addition to these recommendations, should be operationalised to deepen an understanding of AVs on bicycle users in urban areas.

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10. Appendices

This section provides additional detail in appendices which outline research tools and more technical/contextual information on the mechanics of the research project.

10.1 Bicycle Urbanism Maturity Table

Planning for Cycling Maturity Model (McLeod et al., 2020)

<i>Maturity theme</i>	<i>Maturity stage</i>					
	0. Marginalised/ignored	1. Haphazard	2. Tactical	3. Strategic	4. Practice	5. Culture
<i>General Definition</i>	Practices are extremely immature, constrained entirely by barriers, or do not practically exist. Likely stuck in Vicious Cycles.	Basic immature practice. Isolated or advocacy may occasionally realise limited success – in spite of barriers.	Practices organized to deliver the easiest successes and can overcome weak barriers at the small/medium scale	Effective practices begin to establish common mechanisms to overcome barriers and realise moderate success	Effective actions are continuously delivering positive outcomes. Potential to move towards international best practice	Actions are international best practice, unconstrained by barriers. Success is self-sustaining and self-improving in Virtuous Cycles
<i>Planning Attitudes and Integration (see Pucher and Buehler, 2008; Stead, 2008)</i>	Cycling completely marginalised or ignored in most planning	Cycling accepted as a recreational pursuit only, little or no formal provision for cycling in street space. Limited policy recognition of the benefits of cycling	General usefulness of cycling is acknowledged but viewed as mostly recreational and/or implementation is variable. Cycling is generally secondary to vehicles	Cycling accepted as a legitimate part of “balance” with vehicles, some coordination of measures. Measures that compromise car travel are broadly not supported	Cycling consistently provided priority as a basic planning principle. Many benefits of cycling are recognised. Cycling consciously placed ahead of vehicle mobility in all but some circumstances	Land use, urban design, and transport planning centre entirely on urban sustainability. Cycling is a core urban transport mode. Benefits diverse and compound through time
<i>Who Are Cyclists in the Eyes of Decision-Makers? (e.g. Portland Geller Categorizations) (see Section 3.1)</i>	“We don't know/don't care”	Strong and Fearless (on weekends only)	Enthusied and Confident	Coalitions of many different groups and types of cyclists, especially at cycling hotspots (e.g. universities)	Most people, most of the time – including many Interested But Concerned cyclists	Everybody

<i>Maturity theme</i>	<i>Maturity stage</i>					
	<i>0. Marginalised/ignored</i>	<i>1. Haphazard</i>	<i>2. Tactical</i>	<i>3. Strategic</i>	<i>4. Practice</i>	<i>5. Culture</i>
<i>Commitment for Coordinated Investment for Network Development (to realise Spatial Opportunity) (see Section 4.1)</i>	Practically none	Piecemeal funding sufficient only for occasional pet projects	Some continuity of funding to allow slow incremental development of a limited network	Funding is adequate to permit construction of a “core” network to support major demands	Funding available for any investment in the network justified to achieve network “completeness”	Cycling network universally funded as core public infrastructure
<i>Integration with Land Use Planning Practices (Process Opportunity) (see Buehler et al., 2017; Pucher and Buehler, 2008; Section 4.1)</i>	Land use planning is entirely separate to cycling	Occasional provision for minimum cycling facilities in developments. Requirements. Measures mostly limited to individual lot planning	Consistent provision for basic cycling facilities in urban development. Some local/neighbourhood scale planning for cycling	Consistent provision for cycling, with some design to prioritize cycling. Effective and consistent cycle planning at both lot and neighbourhood planning scales	Land use planning consistently embeds excellent cycling facilities. Integration at lot, neighbourhood, and metropolitan scale	All land use planning processes routinely deliver urban form and infrastructure suited for cycling. Planning systems embed continuous improvement
<i>Integration with Public Transport (see Pucher and Buehler, 2009; Section 3)</i>	Practically none	Basic measures with limited contemplation of user needs (e.g. ad hoc bicycle parking). Cycling and public transport may compete for funding	Some consistent coordination efforts, e.g. secure bicycle parking at major train stations. Some awareness of needs along whole journey	Public transport agencies play major role in facilitating cycling (e.g. operating bike share at stations). Whole journey considered in planning	Public transport and cycling designed to operate together. Integration consistent across networks	Cycling and public transport are part of the same sustainable urban transport system
<i>Policy Consistency, Longevity (Hull, 2008)</i>	No real policy – invisible (Aldred, 2012b, p. 86)	Intermittent policy, replaced regularly. Cycling policy suffers from turbulent political volatility	Cycle planning builds upon previous policy. Political vulnerability may be carefully managed	Policy details change through time, but underlying strategy is consistent. Consensus for basic cycling objectives	Cycling policy consistent through time. Positive outcomes of past policy form basis for further consensus	Policy builds on improvement in compounding positive feedback loops

Maturity theme	Maturity stage					
	0. Marginalised/ignored	1. Haphazard	2. Tactical	3. Strategic	4. Practice	5. Culture
<i>Vulnerability of Cycling Projects/Implementation (Sirkis, 2000)</i>	Any cycling projects infrequent, mostly token in nature	Projects easily cancelled by stakeholder or institutional concerns (e.g. where they conflict with car-based planning metrics, etc.)	Projects can be realized through heavy engagement and lobbying by dedicated advocates. Political advocacy often critical	Regular collaborations may facilitate cycling projects within planning agencies, but still vulnerable to some politicization	Mature consensus approach to implementing cycling projects. Effective collaboration between politicians, advocates, and planners	Cycling core to all urban transportation and development projects and decision-making
<i>Safety Management Approach (see Section 3.2)</i>	Limited or no consideration of safety. Designs commonly compromise cyclists	Safety considered in aggregated statistical terms. Rules and laws approach to safety	Safety only considered in terms of design standards and expert judgement.	Perceptive safety considered in most design. ‘Safety in numbers’ effects acknowledged	Cyclists’ perceptions and needs integrated in planning and design; design achieves increasing ‘safety in numbers’	Cycling is universally safe and is perceived as such
<i>Safety Enforcement (see Aldred, 2012b)</i>	Cyclists are secondary road users with limited practical legal protection	Cyclists have legal protections which may be poorly enforced. Cyclists are “responsible” for their own safety (Parkin and Koorey, 2012, p. 138)	Cyclists have basic legal protections with occasional enforcement. Cyclists may be able to carefully manage risks to their own safety	Cyclists acknowledged as vulnerable, with traffic laws consistently enforced. Policy sometimes seeks to minimize external risks	Cyclists broadly protected above motorists through liability assigned in law. Particular protection for more vulnerable cyclists (Pucher and Buehler, 2008, p. 512).	External risk of transport modes forms basis for how liability is enforced. All cyclists enjoy a system based upon fundamental entitlement to safety

<i>Maturity theme</i>	<i>Maturity stage</i>					
	<i>0. Marginalised/ignored</i>	<i>1. Haphazard</i>	<i>2. Tactical</i>	<i>3. Strategic</i>	<i>4. Practice</i>	<i>5. Culture</i>
<i>Health Promotion (see Cole et al., 2010)</i>	No interface between public health and cycle planning	Informal or occasional weak collaboration between public health and transport agencies. Results are inconsistent	Basic formal partnerships between public health and other professionals, though actions may reflect bias towards leisure cycling	Cycling for transport is formally recognised as public health initiative; health professionals involved in cycle planning	Cycling forms major part of preventative public health initiatives; health professionals integral in transport decision-making	Cycling supports universal active transport participation and delivers excellent public health outcomes
<i>Infrastructure Design Standards, Quality Attributes, and Design Governance (see Section 3.1)</i>	Practically no effective cycling design guidance. Cycling is frequently compromised by designs intended to increase motorised vehicle capacity	Technical or prescriptive design guidance with limited implementation. May be some hierarchical dictation of basic cycling design standards between levels of government	Design guidance is clearly articulated but not consistently applied. Some collaboration between layers of government to implement agreed minimum standards for cycling facilities	Design guidance based on specific quality attributes. Some integration of cycling in other technical policy. Governments consistent in their definition of quality cycling infrastructure	Design guidance reflects quality attributes; a wide range of cyclists are involved in their definition. Coordination between all layers and agencies within government to deliver high-quality facilities	Cycling user needs are central in all urban design. Aligned requirements between governments, enacted in all works projects. Continual refinement and improvement
<i>Use of Network Planning Tools (Spatial Opportunity/Coordinated Investment Approach) (see Section 4.1)</i>	Limited network-scale thinking or investment	Basic desktop mapping among planners to develop an aspirational network	Some collaborative mapping between planning agencies to develop a vision for an aspirational network	Collaborative destination mapping or network analysis used to prioritize route projects	Cyclists involved in defining network measures and participatory use of network tools to guide decisions	Networks are ubiquitous and continually refined to meet sustainable transport needs
<i>Incentives, Competitiveness with Private Vehicle Travel (see Section 4.2)</i>	Incentives or subsidies for car ownership and use (e.g. free car parking)	Basic management of car parking may have inadvertent benefits for cycling	Systematic management of car parking and access supports demand for increased utility cycling	Parking management and congestion charging has coordinated flow-on benefits for cycling	Direct incentives for cycling and disincentives for driving to maximize cycling mode share	Cycling is most efficient and competitive mode, returns consistent economic benefits for society

<i>Maturity theme</i>	<i>Maturity stage</i>					
	<i>0. Marginalised/ignored</i>	<i>1. Haphazard</i>	<i>2. Tactical</i>	<i>3. Strategic</i>	<i>4. Practice</i>	<i>5. Culture</i>
<i>Typical Source of Leadership</i>	Advocates are ignored by all	Advocates have small wins, often despite planners and politicians	Advocates have some key allies in planning agencies	Advocates have many allies in planning agencies	Planning agencies work closely and continuously with allies	Planning agencies are advocates

10.2 Sample Participation Invitations

10.2.1 English Participation Invitation Slip (Whitby (Toronto) – cancelled)



 **How will driverless vehicles impact you?**

help with my PhD research by taking a quick survey

 **Shape the future of driverless vehicle and bicycle interaction.**

You do not need to be a regular bicycle user to participate.

This study is part of a PhD project and needs your responses to be a success. Answers will remain anonymous.

scan with your phone's camera ➔
or visit: rtac.me/whitby

 Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

takes just
7 min





hej, nabo!

deltag i en kort undersøgelse



Hjælp os med at forstå,
hvordan førerløse køretøjer
vil påvirke cyklisme i byer.

Denne undersøgelse er en del af et phd-
projekt og for at det bliver en succes har vi
brug for dine inputs! Svarene er anonyme.

foto af: holo

**scan med din
mobil ➡**

eller besøg: rtac.me/aalborg



tager kun
5 min



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The University of Dublin

i samarbejde
med:



**Aalborg
Kommune**



**AALBORG
UNIVERSITET**



ride the
autonomous city

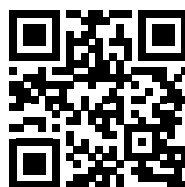
**svp répondre
à un court
sondage pour
ma recherche
doctorale !**

seulement
7 min



Please take a short survey to help with
my PhD research!

**visitez:
rtac.me/mtl**



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en collaboration
avec:



McGill
UNIVERSITY



CIRM
CRIEM
Centre for Interdisciplinary
Research on Montréal
Centre de recherches interdisciplinaires
en études montréalaises

school of natural sciences research ethics project ID: 2021-07



ride the
autonomous city

Kan du cykla? Can you ride a bike?

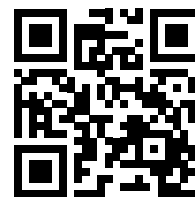
Svara på en kort enkät till min doktorand- forskning!



takes just
7 min

Please take a short survey to help with
my PhD research!

go to:
RTAC.ME/LKPG



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in collaboration
with:

vti

school of natural sciences research ethics project ID: 2021-07



ride the
autonomous city

Kan du sykle? Can you ride a bike?

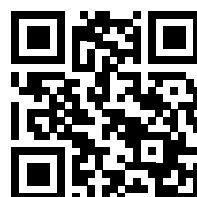
Svar på en kort undersøkelse for min doktor- gradsforskning



takes just
7 min

Please take a short survey to help with
my PhD research!

go to:
RTAC.ME/SVG



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The University of Dublin

in collaboration
with:

Universitetet
i Stavanger

For questions or info, contact Alex: gaioa@tcd.ie // school of natural sciences research ethics project ID: 2021-07

10.3 Ethics Approval

School of Natural Sciences (SNS) Research Ethics Policy

School of Natural Sciences, Trinity College Dublin

In line with Trinity College Dublin's Policy on Good Research Practice, all research in the School of Natural Sciences (SNS) should be conducted according to the overarching ethical principles of "respect for the individual subject or population, beneficence and the absence of maleficence (research should have the maximum benefit with minimal harm) and justice."

All individuals involved in research should facilitate and ensure research is conducted ethically. Ethical conduct in research is a shared responsibility. Primary responsibility rests with the Principal Investigator(s). Ethical responsibilities and legal obligations may overlap. All staff and students conducting research are required to ensure that their research is carried out in compliance with this policy. Ethical review is required before any studies involving human subjects, other living organisms and/or the natural environment, encompassing biosphere, geosphere, hydrosphere and atmosphere, commence. This requirement applies to staff, postgraduate and undergraduate students and volunteers/interns. Field- and laboratory work cannot commence until ethical review has been completed and approval has been gained. Staff or students planning to undertake research should complete the Research Ethics Application (Appendix 2).

Projects involving researchers from other Schools or institutions which have ethical approval from those bodies do not need further ethical approval, but evidence of the approval must be submitted to the SNS REC.

The process for applying for ethical approval is outlined in the following steps:

- 1. Read the Trinity College Dublin [Policy on Good Research Practice](#)**

- 2. Complete the [SNS Research Ethics Application](#).** Applications should be sent to the Chair of the Research Ethics Committee, [Stephen Waldren](#). **Deadlines** for ethical approval submission are on the **15th of each month**, and the School of Natural Sciences Research Ethics Committee will aim to respond by the **1st of the following month**.

All researchers must complete the **Section 1** 'Applicant Details' and **Section 2** 'Initial Research Ethics Checklist'. If the study is desk-based or does not include interaction with live organisms, including humans as research models, nor does it involve working in natural or human-made outdoor habitats, then it is deemed not to require ethical approval, and the study can proceed without the approval of an ethics committee, but

the completed and signed (Section 5) form should be submitted to the REC. If the study is deemed to require ethical approval, then the applicant should complete **Section 3** 'Checklist for School REC suitability' to determine if the application is suitable for consideration by the School REC. Checklists for student projects must be endorsed by their supervisor. If the study is suitable for consideration by a Level 1 committee (ie none of section 3 questions were answered "Yes" without the possibility of mitigation to reduce ethical risk), the researcher should complete **Section 4** 'Ethical Approval Application'. Students should ensure that this is approved by the project supervisor before being sent to the Chair of the REC (as indicated on the form). *All researchers must complete **Section 5** 'Declaration'.*

If any of the answers to the checklist in Section 3 are yes, and suitable mitigation cannot be applied, the study requires the approval of a Level 2 committee. The applicant should then download the application and procedures for the appropriate Level 2 REC ([the Faculty of Engineering, Mathematics and Science REC](#), or the [Animal REC for vertebrate research](#)).

All animal (vertebrate) research must be ultimately approved by the Animal REC; research involving vertebrates in their natural habitats will be assessed by the SNS REC initially and then the decisions will be overseen by the AREC, but any research involving vertebrates in a laboratory setting needs to be submitted directly to the AREC. Please see HPRA [guidelines](#).

3. Submit participant information and informed consent forms where applicable (Appendix 2).

4. The ethics application will be reviewed by two members of the SNS Research Ethics Committee and returned to the applicant by the 1st of the month following submission.

5. Respond if necessary to any requests for further information, or clarification, that the committee might make in relation to the approval request. Discuss these with your supervisor where necessary. Both student and supervisor will be given notice when REC decision is made.

6. For projects of more than one year duration, if there are changes to the project details which may have a bearing on ethical considerations, then applicants must submit an [annual report](#) (Appendix 3). **All applicants must submit an [end of project report](#) upon completion of the study (Appendix 4).**

10.3.1 Research Ethics Application

Research Ethics Application

School of Natural Sciences, Trinity College Dublin

Section 1: Applicant Details

Name (Student/lead researcher)	Alexander Gaio
Staff/Student Number	20328775
Applicant E-mail Address	GAIOA@tcd.ie
Name(s) of Additional Researcher(s)	<i>The following collaborators are preliminary and listed based on ongoing discussions. They are not confirmed as of this writing.</i> Ditte Bendix Lanng (Aalborg University) Amer Schalaby (University of Toronto)
Name of Supervisor (for students)	Federico Cugurullo
Supervisor E-mail Address	CUGURULF@tcd.ie
What School/Discipline are you affiliated to?	Department of Geography School of Natural Sciences
Title of Project	Ride the autonomous city: an analysis of cycling in the age of self-driving cars
Brief description of the project (max 200 words)	<i>Ride the autonomous city</i> investigates the impact of autonomous vehicles in cities as it relates to people on bikes. It aims to investigate cyclist attitudes towards autonomous vehicles and to what extent the prevalence of the technology will impact travel behaviour among those who use a bicycle. The survey- and interview-based study is aimed primarily in urban settings and will be focusing recruitment around pre-existing driverless shuttle pilot test sites/precincts that are already being operated by local governments. This comes, simultaneously, as bicycles are forming a more significant part of the transportation landscape and related policy due to their ability to improve health, environmental, and transportation efficiency woes. The findings of this study aim to inform how a future of autonomous mobility and cycling can co-exist to maximise positive outcomes in the public

	interest. The findings will be useful for researchers and policymakers alike. Data collection methods will include (web-based) questionnaires, interviews, and field observation. Participants will be selected by convenience due to the narrow qualifying criteria and limited number of individuals who will have interacted with an autonomous vehicle. Sites are selected due to the availability of an autonomous vehicle and likelihood of cyclists interacting with the autonomous vehicle. Preliminary site selection incorporates sites with high cycling mode share, and areas where the same people will encounter an autonomous vehicle on a regular basis (i.e. on a cycling thoroughfare or in a specific residential neighbourhood). Anticipated sample size is 100 participants per site. A test site in Aalborg, DK is the first planned test site where data will be collected in collaboration with the City of Aalborg and Aalborg University. Preliminary discussions are also underway with the City of Toronto to include research questions in an online survey tool for participants (residents) in an affected site. No personal information will be used or processed for recruitment. Publicly accessible open data point layers will be used to identify the number of mailing addresses in the catchment area for survey invitation distribution. Additional means of recruitment will rely on local social media channels, local community groups, and advertising. Some survey questions will be integrated into the official City-administered panel questionnaire. The approach will use stratified sampling and participants will be recruited to participate in a panel where they will inform research on the driverless shuttle in their neighbourhood. More information on the project background, the duration of involvement, eligibility criteria, study outcomes, risks of participating, confidentiality measures, data retention, and opt-out instructions can be found in the appendices.

	No compensation or incentives are planned for participants in the study.
Highlight the category that best describes the research	Full-time postgraduate research project
Has this application been submitted to another TCD Ethics Committee for approval?¹⁰	No
Has ethical approval for this project been sought from outside TCD? What was the outcome?	No

¹⁰ All research involving animals (vertebrates) must ultimately be approved by the Animal Research Ethics Committee (AREC); research involving vertebrates in their natural habitats will be assessed by the SNS REC initially and then the decisions will be overseen by the AREC, but any research involving vertebrates in a laboratory setting needs to be submitted directly to the AREC.

Section 2: Initial Research Ethics Checklist

DOES YOUR RESEARCH PROJECT FALL CLEARLY UNDER ANY OF THE FOLLOWING CATEGORIES?

	YES	NO
1. Quality assurance study (e.g. assessment of teaching practice) ¹¹		X
2. Audits of standard practice (not involving identifiable records)		X
3. Research on existing publically available information, documents or data (i.e. already gathered and in the public domain)		X

If you have answered YES to one or more of the above questions, your research project can proceed without the need for ethical approval from the School Research Ethics Committee (REC). Please be aware that all researchers have a responsibility to follow TCD's Policy on Good Research Practice, (available [here](#)) as well as any academic or professional code of practice or guidelines relevant to the specific research project. Even if you answer YES to one of the above question, **please return a signed (Section 5) copy of this form to the Chair of the SNS REC** as a record must be kept of all projects.

If you have answered NO to all of the above questions, proceed to Section 3 to determine whether your application is suitable for consideration for the School REC or if the application needs to be evaluated by a Level 2 committee.

¹¹ Quality assurance and audit studies do not routinely require ethical approval. However, if following the study there is scope to publish the findings of a study, an REC may grant a letter of approval if required.

Section 3: Checklist for School REC suitability

This checklist needs to be completed in order to determine whether your application is considered “low risk” and is therefore suitable for consideration by the School REC¹².

Please indicate if your application falls into any of the categories below (categories from TCD “Criteria for Research Ethics Committees” [document](#), Jan 2014). Answer “NO” if your work does not involve the scenario. Answer “YES” if it does and ethical risks cannot be mitigated. Answer “YES but see...” if ethical risks can be mitigated by appropriate actions such as designing the study to minimize the chances of potentially endangering people, populations of study organisms and/or the environment (and list these in Section 4).

	NO	YES	YES but see mitigation strategy in Section 4
1. Surveys asking questions of a sensitive or private nature			X
2. Questionnaires or observational studies involving children or vulnerable adults.	X		
3. Research where there is a risk of a participant feeling undue pressure to participate by virtue of his/her relationship with the researcher (e.g. student/supervisor; patient/clinician).	X		
4. Projects involving a justifiable degree of deception.	X		
5. Analysis of archival irrevocably anonymised human tissue samples for which consent for research was not originally given, and was not acquired in the course of clinical treatment. (Archived samples taken for a previous research study must always get new ethical approval).	X		
6. Research involving invasive procedures on humans (other than those listed above).	X		

¹² In situations where research ethics approval has been granted by an appropriate body outside TCD, approval must also be sought from an appropriate TCD REC, although, at the discretion of the REC chair, the submission may qualify for fast-tracked approval.

7. Research other questionnaires or observational studies involving vulnerable persons ¹³ .	X		
8. Research where identifiable information obtained may have legal, economic or social consequences for research subjects.	X		
9. Research that may identify illegal activity on the part of the participant.	X		
10. Projects where each subject is paid (over and above token gestures).	X		
11. Research that may potentially cause irrevocable damage to ¹⁴ the population of subjects, and/or researchers, and/or 3 rd parties, and/or the environment. See note below.	X		
12. Research involving the collection of human tissue.	X		
13. Research that may have a direct military application.	X		
14. Potentially harmful research involving humans conducted outside Ireland ¹⁵ .	X		
15. Research involving psychological intervention.	X		

¹³ Vulnerable persons: Certain individuals who face excessive risk of being enrolled in research include those with limitations in their ability to provide informed consent to research because of factors such as immaturity or cognitive impairment. Vulnerability can also stem from individuals' relationships with others, and it is imperative that coercive situations are avoided. Such cases may occur when an employee/student/dependent is asked to participate in research being conducted by a supervisor/mentor. Additional social factors, such as poverty and lack of access to health care, can also make individuals vulnerable to coercion, exploitation or other risks and need to be considered and appropriately mitigated for.

¹⁴ Relevant Health and Safety Risk Assessment forms must be completed before work can be undertaken.

¹⁵ Does not apply to material publically available in another jurisdiction. Note that the same ethical standards will apply to research carried out by SNS researchers within and outside of Ireland. Work must comply with legal requirements of the State in which it is carried out.

Official Approval/licensed research: Research involving elements that may cause harm to the environment, to invertebrate animals or plants; or deal with endangered fauna and/or flora and/or protected areas; or involve the use of elements that may cause harm to humans, including research staff; may need formal approval/licensing by outside body, and such approval for the research (e.g. from the relevant Government Department) must be attached to this application. If formal approval for the work has been granted please give details in the box below:

Approval for work granted by:	N/A
Licences held relating to research activities	N/A
Details of approval:	N/A

If you have answered YES to any of the above questions and cannot mitigate ethical risks, then the application is deemed to be of moderate or high risk (*i.e. risk or discomfort is greater than that usually encountered during normal daily life*) and should be submitted to the appropriate Level 2 Ethics Committee. The applicant should download the application and procedures for the appropriate Level 2 REC ([the Faculty of Engineering, Mathematics and Science REC](#), or the [Animal REC for vertebrate research](#)).

If you have not answered YES to any question in Section 3, your application can be submitted for consideration by the SNS REC after completion of Section 4.

Section 4: Ethical Approval Application Form for School of Natural Sciences Level 1 REC

All student applications should be reviewed and approved by the project supervisor prior to submission.

Project Description

Title of research project	Ride the autonomous city
Start date of research project	01 August 2020 (planned)
End date of research project	31 August 2024 (estimated)
Potential ethical issues	
As outlined in section 1, the research project aims to investigate cyclist attitudes towards autonomous vehicles and to what extent the prevalence of the technology will impact travel behaviour among those who use a bicycle. It further aims to develop an understanding of cycling infrastructure preferences in a future with autonomous vehicles. Data collection will occur through three methods: web-based survey, semi-structured interviews, and behavioural observation. The project is designed and will be carried out in accordance with the highest ethical standards of research practice (as laid out in relevant legislation and professional codes of practice; see 'Published ethical guidelines to be followed' below). However, ethical issues that may arise include: 1. Non-physical risks related to the collection of personal data (participant names on consent forms). Collected personal data is unlikely to cause harm to research participants or the researcher. However, sufficient due-diligence and security measures will be taken to mitigate any potential risks including: a. Storing consent forms separately from collected data b. Using data encryption and password protection on files and electronic storage devices c. Ensuring electronic devices and memory storage are stored in a secure area 2. Collection of identifiable information that has legal, economic, or social ramifications for participants. The tendency of participants to feel obliged to participate will be addressed through measures that obtain informed consent with a particular emphasis on <i>voluntary</i> participation. The information sheet for the project is designed to ensure that participants are well-informed and made aware of what the research entails and how collected data will be used. 3. Participant anonymity will be made a top priority, especially for any responses that may elicit personal or sensitive information. Participants will be assigned pseudonyms or other unique identifiers that safeguard their personal identity to reduce the chances of being identified. Personally-identifiable data will be hashed wherever possible before data storage. 4. Minimal physical risk for the researcher and participants. Physical actions involved in field research include observation from a distance, distributing promotional material, and conducting in-person interviews/surveys. Participants will only be asked to complete surveys or answer interview questions for this study; physical interaction with autonomous	

vehicles is out-of-scope for this study. Furthermore, there will be situations where the researcher will be conducting independent research during interviews and observations. Occupational health and safety guidelines for relevant jurisdictions will be observed. Additional safety precautions and other mitigating measures will be used to minimise the risk to the researcher.

- a. This study will not include direct experimentation with autonomous vehicles. Participants will be recruited based on their pre-existing real-life exposure and proximity to already operating autonomous vehicles. As an added safety assurance measure, the AV pilot projects included in this study operate in legislative environments that do not permit them to travel faster than 20km/h.

Ethical considerations, reducing potential risks and mitigating impacts

Data storage

Data collection and processing undertaken during the research will comply with relevant legislation, rules, and best practice to preserve the anonymity of participants and to secure data storage. Confidential participant information will only be captured on their consent forms. Recordings will not contain any personal information about participants before the start of the interview. Data will be stored and destroyed in line with relevant legislation and rules during the research, including GDPR. When identifying data is deemed necessary, identifiers (such as email addresses) will be anonymised and hashed. Identifiers not necessary for research will not be collected or destroyed once hashed. Data will be stored and encrypted digitally in Trinity-supplied Google Drive secured using complex credentials and two-factor authentication. Transcription will be carried out in a private space. All personal identification will be removed or changed during transcription.

In some cases, interviews will be audio recorded (with the participant's consent) and later transcribed by a professional verified transcription service. In the case of virtual interviews, the interview will be recorded (where consented), and the audio will be extracted for transcription. Personal identifiers (e.g., names) will be replaced during the transcription process, and an agreed pseudonymization protocol applied.

When transcriptions are completed, transcriptions will be handled with caution, stored in the secure location when not in use. The full transcripts will only be accessible to researchers. Digital copies of the files will be encrypted, password-protected and stored securely. Identifying information will not be published with the results of this research.

To ensure high standards in complying with current Data Protection legislation, the research project will be guided by applicable legislation and stated data protection principles for data collection, storage, protection, retention, destruction, and publication/dissemination. All research participants will be provided with an information sheet (see appendix) detailing all necessary

aspects of the research project so that they can make an informed decision on participating in the study. Interview participants will be informed of this as part of the consent process for the study and given the opportunity to withdraw their participation in the study at any time. Only the researcher will have access to the data collected, and it will be used only for the purposes of the study and destroyed after the stipulated data retention period. To ensure the integrity and quality of the research data and increase the potential for data sharing, audio transcriptions will be checked and anonymised prior to archiving.

Furthermore, the applicant (identified in Section 1) will engage in training on data protection as provided by TCD's Information Compliance Office, particularly with regards updates to data protection regulations (e.g. the European Union's General Data Protection Regulation (GDPR), and other directives/regulations that may arise in the project's life-cycle).

The consent forms contain explanations of how data will be stored and include a privacy notice. In terms of logistics the following steps and measures will also be taken:

- Consent forms will be digitised with scanning and uploaded to Trinity-supplied Google Drive which uses encryption, complex credentials, and two-factor authentication. Paper originals will be securely destroyed once digital records are made.
- Digital recordings, where applicable, will be deleted as soon as an authoritative transcript or metadata is created
- Data stored digitally will not contain identifying information and will only reference unique participants with hashed information or aliases
- Data that includes confidential details (including contact information) may be kept for up to 10 years so that, if necessary, I can contact participants during the course of the research project. It will be destroyed as soon as the project is either:
 - a. aborted, or;
 - b. completed (resulting in a degree award)
- Anonymised data may be stored indefinitely

Data will remain confidential unless there is a legal requirement to produce it, or if information disclosed may cause concern about potential harm to an individual. In the latter case, a resulting discussion will occur in confidence with the supervisor identified in Section 1 to determine if any further action is necessary.

Published ethical guidelines to be followed

- EU Directive 95/46/EC.¹⁶

¹⁶ Data Protection Commissioner (2018) 'EU Directive 95/46/EC – the Data Protection Directive'. Accessed online at: <https://www.dataprotection.ie/docs/EU-Directive-95-46-EC/89.htm>.

- EU General Data Protection Regulation (GDPR), replacing Directive 95/46/EC from 25th May 2018 onwards.¹⁷
- Irish legislation including the Data Protection Act 1988, the Data Protection (Amendment) Act 2003 (bringing Irish law in line with EU Data Protection Directive 95/46/EC) and guidance on data protection and the forthcoming GDPR given by the office of the Data Protection Commissioner.¹⁸
- TCD's Policy on Good Research Practice¹⁹, information compliance policies²⁰, and broader university policies on ethics, data protection, dignity and respect, equality, cloud computing, and IT security²¹.
- School (Natural Sciences) and Department (Geography) codes of practice, ethical guidelines, and health and safety policies.
- International best research practice²².
- American Association for Public Opinion Research Code of Professional Ethics and Practice
- RESPECT Code of Practice

Additionally, the Code of Professional Conduct for the applicable Provincial Planning Association will act as guidelines for research undertaken in Canada. <https://cip-icu.ca/Careers-in-Planning/Codes-of-Professional-Conduct>

¹⁷ European Union Council (2016) *General Data Protection Regulation*. Accessed online at:

<http://data.consilium.europa.eu/doc/document/ST-5419-2016-INIT/en/pdf>

¹⁸ Data Protection Commissioner (2018) DPC website, accessible at:

<https://www.dataprotection.ie/docs/Home/4.htm> .

¹⁹ Trinity College Dublin (2014) *Policy on Good Research Practice*.

²⁰ Trinity College Dublin (2015) Information compliance office website, accessible at:

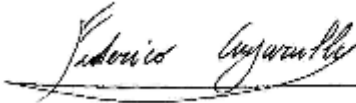
https://www.tcd.ie/info_compliance/ .

²¹ TCD policy website, accessible at: <https://www.tcd.ie/about/policies/> .

²² E.g. Association of Internet Researchers (AOIR) (2012) *Ethical decision-making and internet research*.

Accessed online at: <https://aoir.org/reports/ethics2.pdf> .

Section 5: Declaration

Signature of applicant <i>I declare that the information given herein is accurate. I have read the TCD Ethics Policy and will follow the guidelines therein. I have read and understood the TCD Data Protection Policy.</i>	Signature:  Date: 14 June 2021
Signature of Supervisor (in case of students) <i>I declare that the information given herein is accurate. I have read the Ethics Policy and will follow the guidelines therein.</i>	Signature:  Date: 14 June 2021

To be completed following REC review:

Approval by the School's Ethics Committee <i>Based on the information available on this form, the SNS REC believes the ethical risks in this project are negligible and will be appropriately mitigated during the course of the research²³.</i>	 Trinity College Dublin The University of Dublin School of Natural Sciences Research Ethics Committee Sign/Stamp:  Date: 19/11/21

²³ Primary responsibility for ensuring ethical conduct in research rests with the Principal Investigator(s).

Ride the Autonomous City
Information Sheet (Template)

Title of study: An analysis of cycling in the age of self-driving cars
PhD Research Study – Department of Geography, Trinity College Dublin

You are being invited to participate in a research study. Before deciding, you need to understand why the research is being done and what it would involve for you. Please read this information leaflet carefully. If anything is unclear or you would like more information, please ask questions. Thank you for taking time to decide whether to participate.

DETAILS OF THE RESEARCH TEAM

This study is being conducted by Alexander Gaio forming part of the requirements for a PhD in the Department of Geography, Trinity College Dublin. The research is being supervised by Dr. Federico Cugurullo. Our contact details are included below. The study has School of Natural Sciences Research Ethics Committee approval.

INTRODUCTION: WHAT IS THE STUDY ABOUT?

The purpose of this study is to gain an understanding of how people riding bicycles will interact with autonomous vehicles by understanding their attitudes, behaviours, and preferences. The purpose of this survey is to gather data for one aspect of the research project, which seeks to understand attitudes towards autonomous vehicles, behaviours influenced by autonomous vehicles, and the infrastructure preferences of bicycle users.

CRITERIA FOR SELECTION: WHY HAVE YOU BEEN INVITED TO TAKE PART?

You are invited to participate in this research project because you are a stakeholder in an area where there is an autonomous vehicle operating. The procedure involves filling an online survey that will take approximately 15 minutes.

PROCEDURES: WHAT WILL BE INVOLVED IN TAKING PART?

Participation in the study is entirely voluntary. If you agree to participate, you will be invited to take part in an interview with the researcher, Alexander Gaio. The interview will take about 20-30 minutes. This interview may be audio-recorded to facilitate analysis, but only if you are comfortable with this. You can be interviewed without being audio-recorded. If you do agree to be audio-recorded, recording can be paused or stopped at any time at your request.

VOLUNTARY PARTICIPATION: DO YOU HAVE TO TAKE PART IN THE RESEARCH?

Your participation is voluntary. You are not required to participate in this research. You can withdraw at any time and for any reason, or for no stated reason at all. If you would like to withdraw from the study following the anonymisation of interview transcripts, you can contact the researchers and use your assigned Interview Code. During the interview, you are free to pause/stop audio-recording, and/or decline to answer any question you do not wish to answer, for any reason and without consequence of any kind.

WHAT ARE THE RISKS, BENEFITS, AND REIMBURSEMENT ASSOCIATED WITH THE STUDY?

Participating in the research is not anticipated to cause you any disadvantages or discomfort. The potential physical and/or psychological harm or distress will be the same as any experienced in everyday life. There are no anticipated benefits as a result of participating in this study. No reimbursement or remuneration will be provided.

EXCLUSION FROM PARTICIPATION: WHAT CRITERIA EXCLUDES A PARTICIPANT FROM TAKING PART?

Participants may be excluded from participating if they are not over eighteen years of age. Those that do not give informed consent will not be eligible to participate.

CONFIDENTIALITY: WILL TAKING PART BE CONFIDENTIAL?

Your identity will remain strictly confidential. Your name will not be published and will not be disclosed to anyone outside the study. You will remain anonymous in any report on the findings of this research. This will be ensured by changing your name and disguising any details in your interview that may reveal your identity or the identities of any of the people you speak about. You are not requested to give your name to the researcher, unless you wish to do so. All information that you provide will only be identifiable by an Interview Code, to protect your identity. No-one outside of the research team will have access to the Interview Code linking you and your

information, as this will remain confidential and will be protected under Irish and EU data protection legislation.

It must be recognized that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the University will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent.

DATA PROTECTION: HOW WILL YOUR INFORMATION BE RECORDED, STORED, AND PROTECTED?

Before taking part in this study, you will be asked to sign and keep an Informed Consent form explaining your rights and providing details on how the information you provide will be recorded, stored, and protected. Your signed consent form, notes taken on your interview (if any), original audio recordings of your interview (if any), and transcripts of any recordings relating to you will be retained in a secure location in Trinity College Dublin until the expiration of the data retention period (normally 10 years after the end of the project), after which they will be safely destroyed (deleted and/or destroyed). The study is being conducted in line with freedom of information legislation – you are entitled to access the information you have provided at any time while it is in storage (as specified above) using your Interview Code. You are free to contact any of the researchers involved in the research at any time to seek further clarification and information.

PROJECT OUTPUTS: HOW WILL YOUR INFORMATION BE USED?

Anonymized data and disguised extracts from your interview may be combined with others and used/discussed in a PhD thesis, conference presentations, working papers, journal articles, books, and other academic publications. Research results can be shared with participants before publication, should you request to be notified of the results.

WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?

You may access your own data at any time under the Freedom of Information Act 2014.

If you have any questions about the study, please contact:

Alexander Gaio, PhD Research Student, Department of Geography, Trinity College Dublin

Email: gaioa@tcd.ie

Telephone: +353 (0)89 476 8995

Dr. Federico Cugurullo, Ussher Assistant Professor, Department of Geography, Trinity College Dublin.

Email: cugurulf@tcd.ie

Telephone: +353 (0)18 964 915

Template for Informed Consent Form

School of Natural Sciences, Trinity College Dublin

Title of research study: An analysis of cycling in the age of self-driving cars

This study and this consent form have been explained to me. I believe I understand what will happen if I agree to be part of this study.

I have read, or had read to me, this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction. I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights. I have received a copy of this agreement and I understand that, if there is a sponsoring company, a signed copy will be sent to that sponsor.

Name of sponsor: Trinity College Dublin

PARTICIPANT'S NAME:

PARTICIPANT'S SIGNATURE:

Date:

Date on which the participant was first furnished with this form:

Participants with literacy difficulties:

I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely and understands that they have the right to refuse or withdraw from the study at any time.

Print name of witness: _____

Signature of witness: _____

Date (Day/month/year) _____

Statement of investigator's responsibility: I have explained the nature, purpose, procedures, benefits, risks of, or alternatives to, this research study. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

Researcher's signature:

Date:

10.4 Focus Group/Interview Discussion Guide

Welcome

- McGill University (Tiohtiá:ke/Montreal) is situated on the unceded traditional territory of the Kanien'kehà:ka, a place which has long served as a site of meeting and exchange amongst many First Nations including the Kanien'kehà:ka of the Haudenosaunee Confederacy, Huron/Wendat, Abenaki, and Anishinaabeg. We recognise and respect the Kanien'kehà:ka as the traditional custodians of the lands and waters on which we meet today
- Thank you for joining today for a discussion on autonomous vehicle and bicycle interaction
- You have all been invited to participate because you:
 - have engaged with the study previously
 - are familiar with the autonomous vehicle
 - know how to ride a bicycle
- My name is Alex, I'm a PhD candidate affiliated with Trinity College Dublin and I am a visiting researcher here at McGill in the Centre for Interdisciplinary Research on Montreal
- The goal of today's session is to get a more nuanced look at how different cycling experiences are affected or stand to be affected by autonomous vehicles
- The study is bound by research ethics and academic integrity standards, including GDPR privacy legislation. This study was approved by the school of natural sciences ethics committee in 2021.
- We will be on a first name basis today, and in our later reports no names will be attached to comments. Any comments shared today are completely confidential.
- The discussion today will be recorded for later transcription, to ensure that no comments are missed, and your participation today indicates consent to be recorded, is this okay with everyone?
- We will have 90 minutes to discuss several topics related to urban cycling, traffic stress, and autonomous vehicles related to four themes:
 - Factors impacting urban cycling as impacted by the presence of autonomous vehicles
 - Level of stress and comfort in different street environments
 - Social acceptability of autonomous shuttles
 - Your individual accounts and forward-looking attitudes towards cycling with autonomous vehicles
- I will be here as a facilitator to steer the discussion and make sure we stay on-topic, my role today is primarily to listen to your comments
- Are there any questions before we begin?

Ground rules

- As a guide, I would ask that you please: - participate actively - speak one at a time - treat everyone's ideas with respect--don't criticise - minimise side conversations - keep focussed on the topic or question - There are no right or wrong answers but rather differing points of view. - Please share your point of view even if it differs from what others have said.
Introductions
- I'd like to go around the table to get everyone's name and to share your favourite way to stay cool during a Montréal heat wave - As we go around could you please also state if you consent to recording
Questions
Opening question - What experiences have you had with the autonomous shuttle? Introductory questions - From your perspective, how do you think autonomous vehicles will impact cycling? - How do you communicate with other road users? Transition questions - What factors impact urban cycling today? How will this change with autonomous vehicles? Key questions - Given the slow speeds of current autonomous shuttles, how does this impact your perception of traffic stress while cycling? - Would this change if autonomous shuttles operated at faster speeds? - In your social circles how acceptable are autonomous vehicles and what role would they play? How trustworthy are AVs? - How would autonomous vehicles detract from or improve urban cycling? - Would this make it more or less difficult to cycle in cities? - Consider measures of traffic calming. How can autonomous vehicles be used to influence traffic stress? To what extent is this possible? Ending question - Is there anything that has not been discussed that you would like to contribute?
Closing Remarks

- Many thanks for your participation in the study
- The study is designed to be replicated at a number of different AV test sites and the methods from Montréal will be applied to two additional test sites in the coming months in Linköping, SE and Stavanger, NO
- The findings will be used to form the basis of a PhD dissertation as well as several publications and conference papers
- All data used in these publications will be anonymous

10.5 Survey Questions

10.5.1 Screening Questions

1. Language Selection

- a. Arabic
- b. Danish
- c. English
- d. French
- e. Norwegian
- f. Swedish

2. Participation consent question

3. Are you physically able and do you know how to ride a bicycle?

Bicycles come in many form factors. If you are able to use a 'bicycle' equivalent such as a recumbent bicycle, tricycle, or other pedal-powered/pedal-assisted device (including hand pedalled), please consider it equivalent to a bicycle for the purposes of this survey.

- a. Yes
- b. No

4. Which environments will you ride a bicycle?

Select all that apply, then select 'next'.

- a. Major Roads Without Bike Lanes/Cycle tracks
- b. Major Roads With Bike Lanes/Cycle tracks
- c. Residential Streets
- d. Bike Trails or Multi-use Paths through parks and green space

5. Which of the following apply to you?

- a. I have experienced the autonomous shuttle while biking
- b. I have not experienced the autonomous shuttle while biking

6. Do any of these apply to you?

Check all that apply

- a. I've been onboard the shuttle as a passenger
- b. I've interacted as a pedestrian (i.e. crossed the street in front of the vehicle)

- c. I've interacted as a driver (i.e. driven alongside the vehicle)
- d. I've observed the shuttle from a distance
- e. Other* (open-ended prompt if selected)
- f. I haven't yet interacted with the shuttle

10.5.2 Comfort Questions

7. Before the shuttle started, I felt comfortable knowing I would bike in an area with an autonomous shuttle
 - a. Strongly agree <5>
 - b. Somewhat agree <4>
 - c. Neither agree nor disagree <3>
 - d. Somewhat disagree <2>
 - e. Strongly disagree <1>
 - f. Not applicable <999>
8. The first time I encountered the autonomous shuttle I felt comfortable biking in the same area
 - a. Strongly agree <5>
 - b. Somewhat agree <4>
 - c. Neither agree nor disagree <3>
 - d. Somewhat disagree <2>
 - e. Strongly disagree <1>
 - f. Not applicable <999>
9. After encountering the autonomous shuttle many times, I feel comfortable biking in the same area
 - a. Strongly agree <5>
 - b. Somewhat agree <4>
 - c. Neither agree nor disagree <3>
 - d. Somewhat disagree <2>
 - e. Strongly disagree <1>
 - f. Not applicable <999>
10. I generally have a favourable impression of cycling with the autonomous shuttle
 - a. Strongly agree <5>

- b. Somewhat agree <4>
 - c. Neither agree nor disagree <3>
 - d. Somewhat disagree <2>
 - e. Strongly disagree <1>
11. Most people like me are comfortable cycling in an area with an autonomous shuttle
- a. Strongly agree <5>
 - b. Somewhat agree <4>
 - c. Neither agree nor disagree <3>
 - d. Somewhat disagree <2>
 - e. Strongly disagree <1>
12. Generally most people think that it is acceptable to cycle in an area with an autonomous shuttle
- a. Strongly agree <5>
 - b. Somewhat agree <4>
 - c. Neither agree nor disagree <3>
 - d. Somewhat disagree <2>
 - e. Strongly disagree <1>
13. Additional comments about your sense of comfort (optional)
- a. [Open-ended text field]

10.5.3 Trust Questions

14. Before cycling with the autonomous shuttle I felt the technology was trustworthy
- a. Strongly agree <5>
 - b. Somewhat agree <4>
 - c. Neither agree nor disagree <3>
 - d. Somewhat disagree <2>
 - e. Strongly disagree <1>
 - f. Not applicable <999>
15. After cycling with the autonomous shuttle I feel that the technology is trustworthy
- a. Strongly agree <5>
 - b. Somewhat agree <4>
 - c. Neither agree nor disagree <3>

d. Somewhat disagree <2>

e. Strongly disagree <1>

f. Not applicable <999>

16. Comments about your sense of trust (optional)

a. [Open-ended text field]

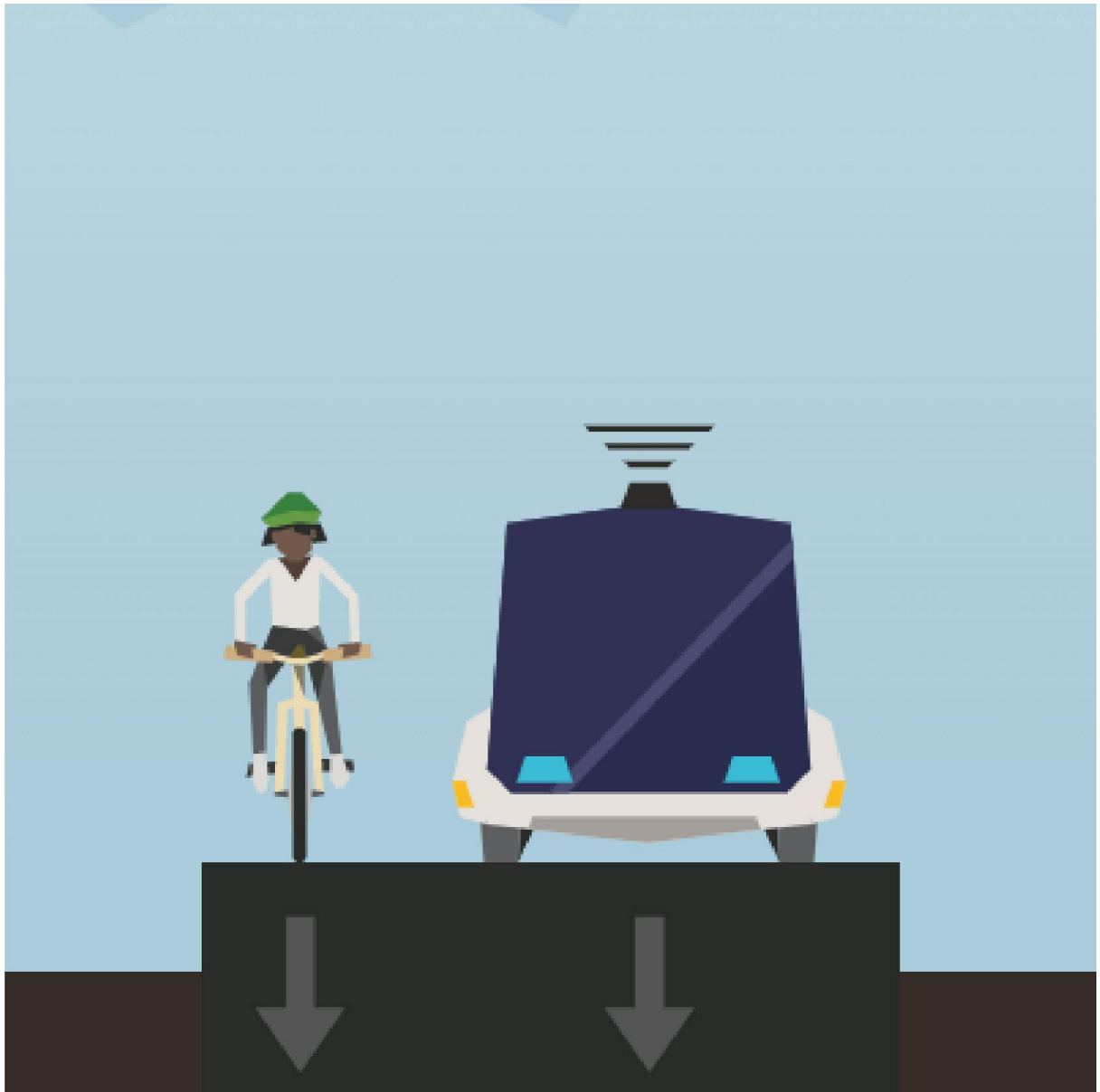
10.5.4 Behaviour Questions

How comfortable would the following situations make you feel while cycling?

Please state to what extent you agree or disagree with the following statements.

Consider this image:

An autonomous vehicle and bicycle on a street without separate bike space



17. Autonomous vehicles on roads without separate bike space would make me feel comfortable while cycling.

- a. Strongly agree <5>
- b. Somewhat agree <4>
- c. Neither agree nor disagree <3>
- d. Somewhat disagree <2>
- e. Strongly disagree <1>

18. Autonomous vehicles on roads without separate bike space would make me...

- a. Cycle much more <5>
- b. Cycle more <4>

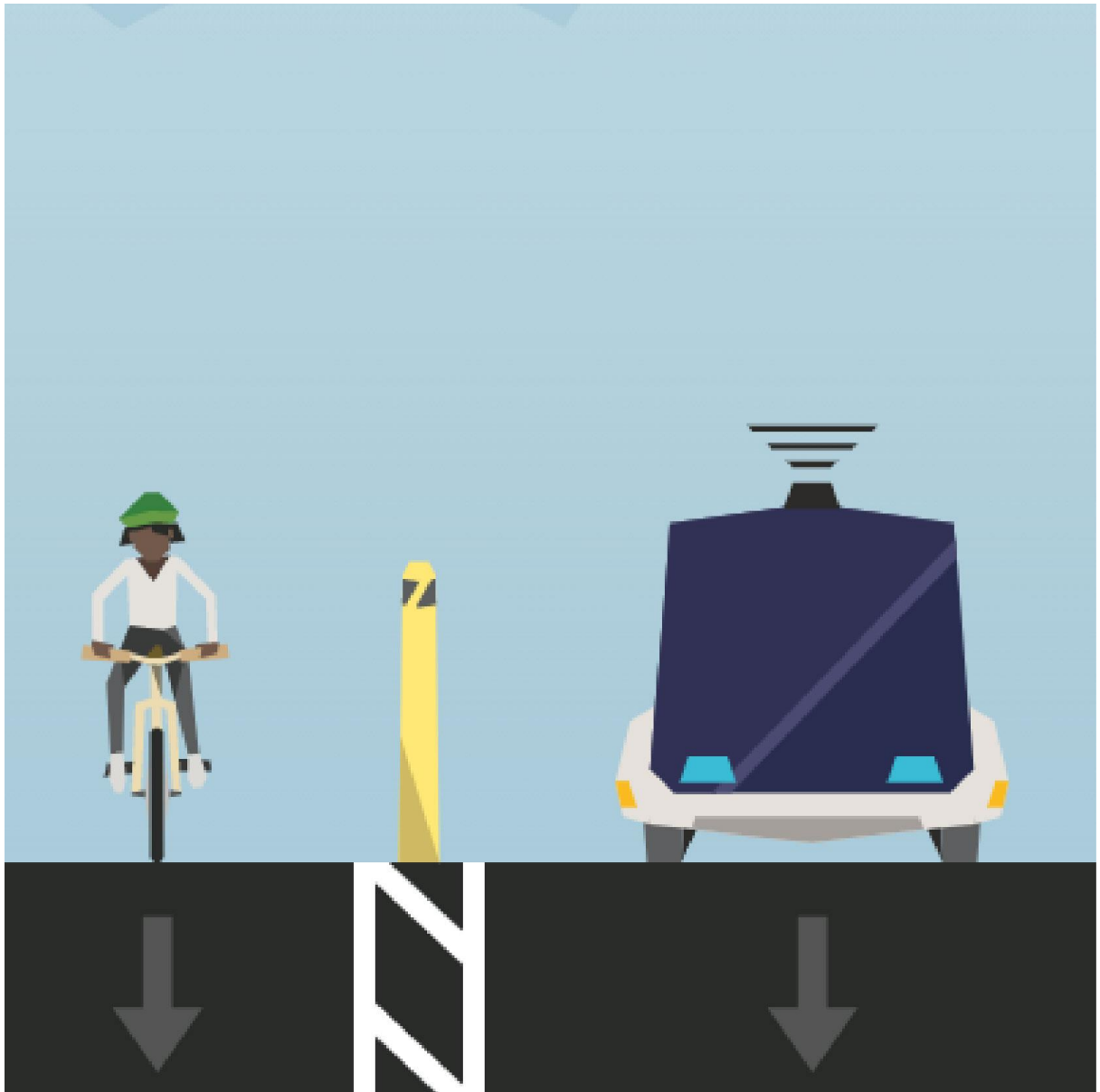
- c. Cycle the same amount <3>
- d. Cycle less <2>
- e. Cycle much less <1>

19. Sharing the same street space with an autonomous vehicle would benefit cycling

- a. Strongly agree <5>
- b. Somewhat agree <4>
- c. Neither agree nor disagree <3>
- d. Somewhat disagree <2>
- e. Strongly disagree <1>

Now consider this image:

An autonomous vehicle and bicycle on a street with separate bike space



20. Autonomous vehicles on roads with separate bike space would make me feel comfortable while cycling.

- a. Strongly agree <5>
- b. Somewhat agree <4>
- c. Neither agree nor disagree <3>
- d. Somewhat disagree <2>
- e. Strongly disagree <1>

21. Autonomous vehicles on roads with separate bike space would make me...

- a. Cycle much more <5>
- b. Cycle more <4>

- c. Cycle the same amount <3>
- d. Cycle less <2>
- e. Cycle much less <1>

22. Separating space between autonomous vehicles and bicycles would benefit cycling

- a. Strongly agree <5>
- b. Somewhat agree <4>
- c. Neither agree nor disagree <3>
- d. Somewhat disagree <2>
- e. Strongly disagree <1>

And now, consider this image:

A human-operated vehicle and bicycle on a street without separate bike space

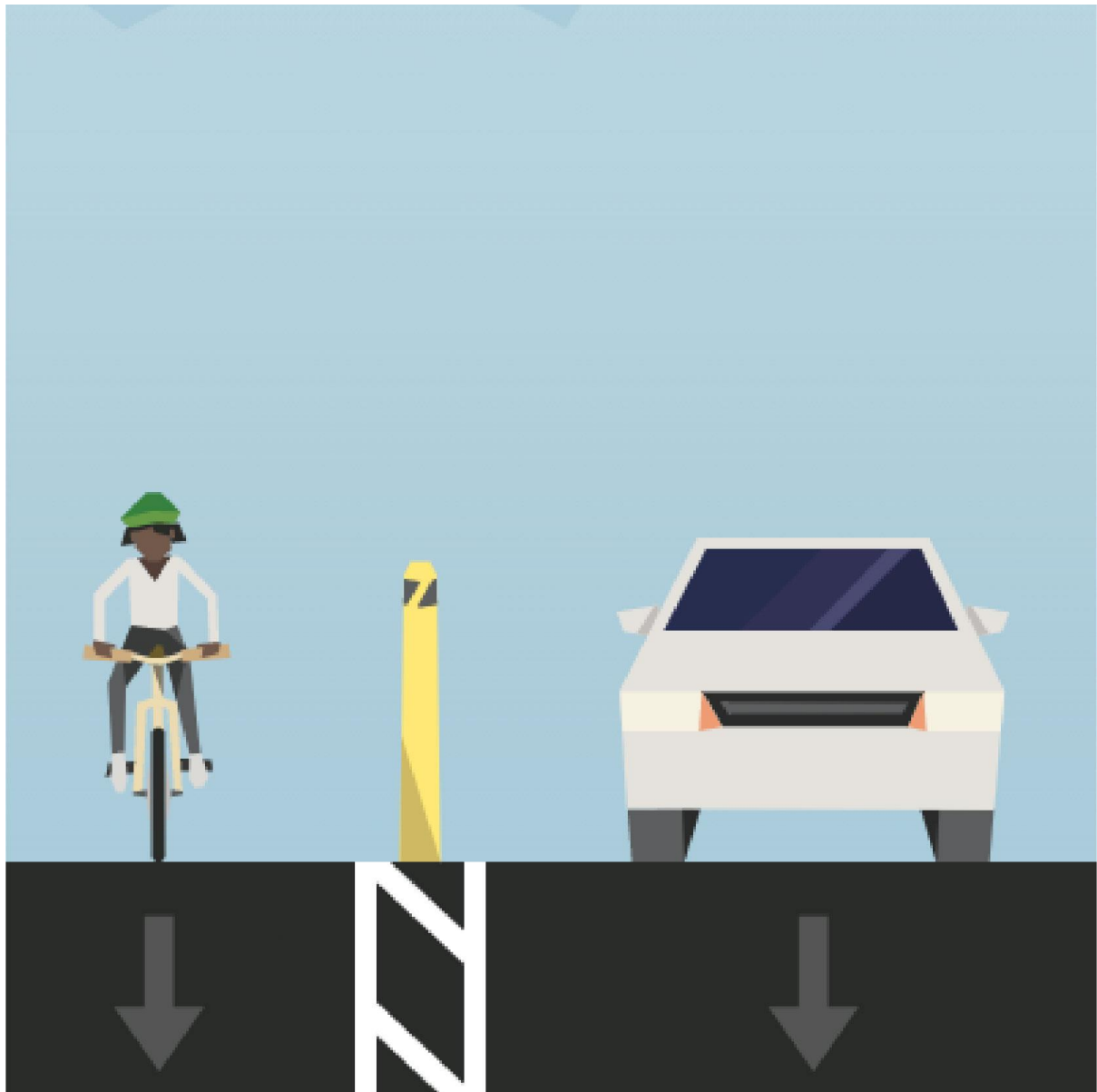


23. Human-operated vehicles on roads without separate bike space makes me feel comfortable while cycling.

- a. Strongly agree <5>
- b. Somewhat agree <4>
- c. Neither agree nor disagree <3>
- d. Somewhat disagree <2>
- e. Strongly disagree <1>

Lastly, consider this image:

A human-operated vehicle and bicycle on a street with separate bike space



24. Human-operated vehicles on roads with separate bike space makes me feel comfortable while cycling.

- a. Strongly agree <5>
- b. Somewhat agree <4>
- c. Neither agree nor disagree <3>
- d. Somewhat disagree <2>
- e. Strongly disagree <1>

10.5.5 Demographics Questions

25. Moving on... Do you ride a bike in these situations?

Select all that apply

- a. For recreation
- b. For fitness
- c. For visiting friends
- d. For shopping or running errands
- e. To go to work
- f. To go to school
- g. I don't ride a bicycle in any of these scenarios

26. What type of conditions will you ride a bike in?

- a. All weather conditions and seasons
- b. Only fair weather conditions

27. How often do you ride a bike?

- a. Daily
- b. At least once per week
- c. At least once per month
- d. At least once every six months
- e. At least once a year
- f. Less than once a year

28. Have you or anyone you know of stopped cycling because of the autonomous shuttle?

- a. Yes
- b. No

29. Could you please provide some details?

- a. [Open-ended text field]

30. What's your gender?

- a. Female
- b. Male
- c. Other
- d. Prefer not to say

31. Would you like to self-identify?

- a. Yes
- b. No

32. What is your gender?

- a. [Open-ended text field]

33. What's your age?

- a. 0-17
- b. 18-34
- c. 35-54
- d. 55+
- e. Prefer not to say

34. What is the highest degree or level of education you have completed?

- a. Some High School
- b. High School
- c. Trade School/College Diploma
- d. Bachelor's Degree
- e. Master's Degree
- f. Ph.D. or higher
- g. Prefer not to say

35. What's your employment status?

Please choose the option that best describes your current situation.

- a. Employed Full-Time
- b. Employed Part-Time
- c. Looking for work
- d. Retired
- e. Student
- f. Prefer not to say

36. What's your household income? [localised per living lab site]

- a. \$19,999 or less
- b. \$20,000 - \$49,999
- c. \$50,000 - \$99,999
- d. \$100,000 - \$199,999

- e. \$200,000 or more
 - f. Prefer not to say
37. Do you have children under the age of 12 in your care?
- a. Yes
 - b. No
38. How many?
- a. [Open-ended text field]
39. What's your ethnic origin?
- a. North American Aboriginal origins
 - b. Other North American origins
 - c. European origins
 - d. Caribbean origins
 - e. Latin, Central, and South American origins
 - f. African origins
 - g. Asian origins
 - h. Oceania origins
 - i. Prefer not to say
40. Do you have a driver's license?
- a. Yes
 - b. No
41. Compared to other people you know, how would you describe yourself?
- a. I am generally the last to try a new technology product
 - b. I am generally among the last to try a new technology product
 - c. I am generally in the middle when it comes to trying a new technology product
 - d. I am generally among the first to try a new technology product
 - e. I am generally the first to try a new technology product
 - f. Prefer not to say
42. Can we contact you for additional research related to this study?
- a. Yes
 - b. No
43. Please provide your email address:

a. [email text field]

10.6 Supplementary Acknowledgements

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Digital Resources

Many digital tools and resources were used to aid in producing this dissertation.

GIS software, QGIS, was used to process and interpret geographic data to systematically identify participant populations and to efficiently disseminate participation invitations. It was also used to determine AV operating environment characteristics, classify urban morphologies and street designs in the LTS framework, and to layer in place-based site selection factors.

Statistical analysis software was used to organise and interpret data and to understand key relationships, statistical validity, and to draw conclusions from the empirical data. The operations and tools used in SPSS Statistics made data interpretation more systematic and reliable.

Large-language model (LLM) natural language processing agents such as OpenAI ChatGPT, Anthropic Claude AI, and Google Notebook LM were used as dynamic tools to facilitate iterative discussion and feedback that supported brainstorming and refined semantics. Perplexity AI Search was used as a tool to supplement peer-reviewed article search and to ensure that the most recent relevant scientific material could be drawn upon for this dissertation. While these LLM tools generated text in response to carefully designed specific prompts and queries, all final interpretations, articulations, and conclusions are the author's own work. Data integrity was maintained throughout by adhering to strict anonymization by removing all identifying features.

As technology advances and improves the ability for people to make discoveries and work better, these tools were used as part of a suite of previous technological advances. All use

of LLM tools was supplementary. As AI literacy improves, these supplemental tools will likely be comparable to research tools that are commonplace in academia such as Grammarly, NVivo, ATLAS.ti, IBM SPSS Statistics, Microsoft Excel, Microsoft Word, Google Autocomplete, EndNote, and Zotero. This acknowledgement is provided to help ensure principles of transparency and uphold standards of research ethics.