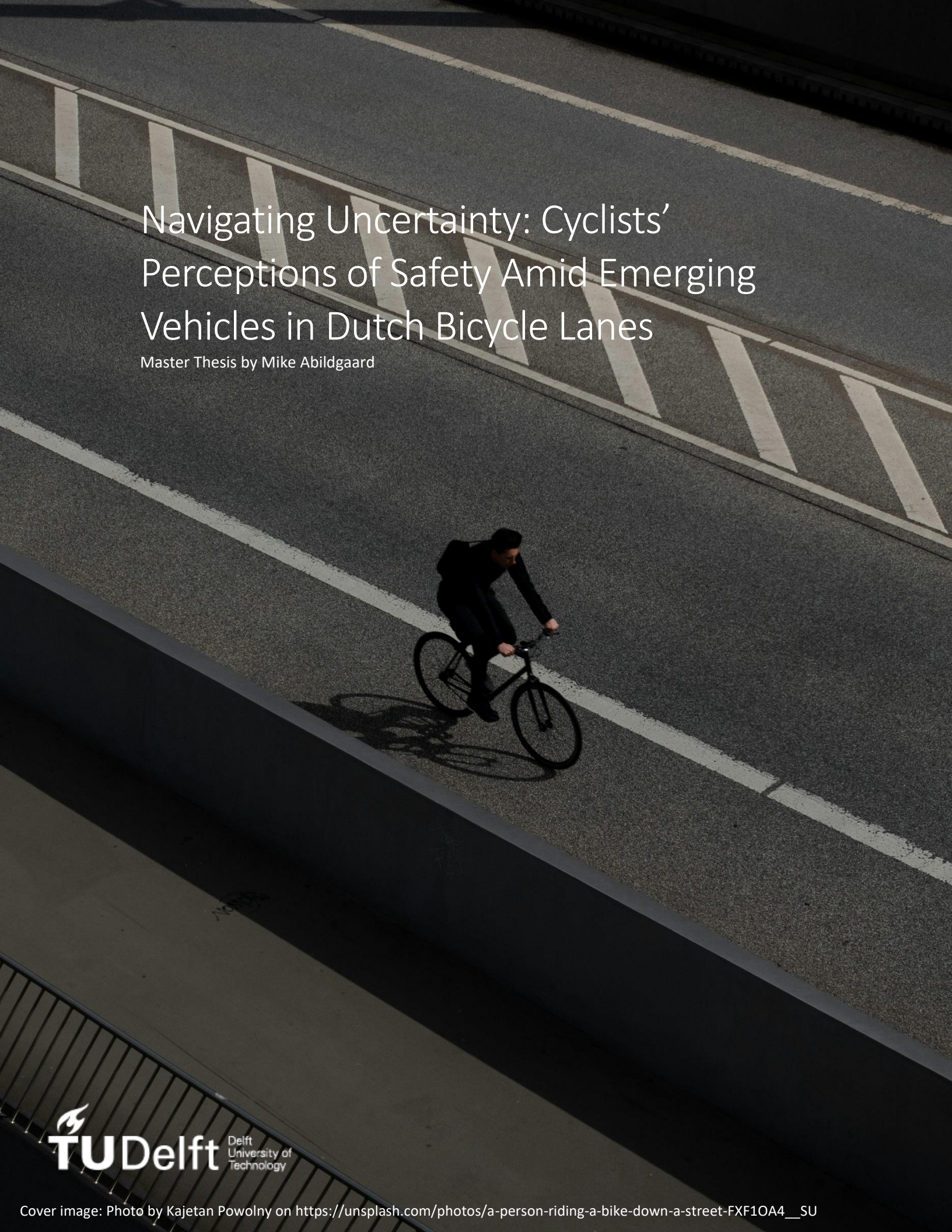




Navigating Uncertainty: Cyclists' Perceptions of Safety Amid Emerging Vehicles in Dutch Bicycle Lanes

Master Thesis by Mike Abildgaard

Navigating Uncertainty: Cyclists' Perceptions of Safety Amid Emerging Vehicles in Dutch Bicycle Lanes

Master thesis submitted to Delft University of Technology
in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in Management of Technology

Faculty of Technology, Policy and Management

by

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To be defended in public on July 17th 2026

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Executive Summary

Cycling is a cornerstone of Dutch mobility and is internationally recognised as a safe, efficient, and sustainable mode of transport. However, Dutch cycling environments are becoming increasingly diverse due to the growing presence of electric bicycles, speed pedelecs, fatbikes, cargo bikes, delivery vehicles, and other emerging mobility technologies. While previous research has predominantly focused on objective safety outcomes such as crashes, injuries, and infrastructure design, considerably less is known about how cyclists experience safety within these evolving environments. Understanding perceived safety is essential, as it influences cycling behaviour, route choice, and long-term participation in cycling.

This study explores how cyclists experience and navigate safety in Dutch bicycle lanes amid the increasing presence of emerging vehicles and mobility technologies. Rather than examining objective safety risks alone, the research investigates how cyclists interpret interactions, respond to uncertainty, and adapt their behaviour within increasingly complex traffic environments. The study is guided by the central research question: *How do cyclists experience and navigate safety in an urban road environment increasingly shaped by new vehicles and emerging technologies?*

A qualitative research design was adopted to capture cyclists' lived experiences. Semi-structured interviews were conducted with 32 participants representing diverse ages, genders, cycling experience levels, cycling frequencies, and familiarity with Dutch cycling culture. The sample included both Dutch and international cyclists, enabling comparison across different user groups. Interview data were analysed using Reflexive Thematic Analysis, informed by risk perception theory and a socio-technical systems perspective.

The findings indicate that participants continue to regard the Dutch cycling system as highly functional and supportive of everyday mobility. Nevertheless, they also perceive cycling environments as becoming increasingly diverse, dynamic, and cognitively demanding. Contrary to expectations, participants rarely identified individual vehicle types as the principal source of perceived danger. Instead, safety concerns were primarily associated with uncertainty surrounding the behaviour of other road users and the increasing difficulty of interpreting, anticipating, and responding to interactions.

Six interconnected themes emerged from the analysis: interactional uncertainty, cognitive burden, trust and interpretability, adaptive burden, cumulative strain, and social categorisation. Together, these themes describe how cyclists experience and respond to an increasingly heterogeneous cycling environment. The findings demonstrate that emerging vehicles influence perceived safety indirectly by reducing behavioural predictability, increasing mental effort, generating emotional responses such as stress and frustration, and encouraging behavioural adaptations including defensive cycling, route changes, and avoidance strategies. Participants also relied on mental models and social categorisation to interpret unfamiliar road users and manage uncertainty during interactions.

The study further demonstrates that these experiences are not evenly distributed across cyclists. Older cyclists, international cyclists, less experienced cyclists, and parents cycling with children generally reported greater vulnerability and relied more heavily on avoidance-based adaptation strategies. These findings suggest that increasing complexity within cycling environments may disproportionately affect groups with lower adaptive capacity or greater perceived consequences of conflicts.

Drawing upon risk perception theory and socio-technical systems thinking, the study proposes that perceived cycling safety emerges through a common interactional process. Increasing vehicle diversity reduces behavioural predictability, which elevates cognitive burden and emotional strain. Cyclists subsequently adapt their behaviour in order to restore a sense of control and maintain acceptable levels of perceived safety. Perceived safety is therefore conceptualised not as a fixed property of infrastructure or an objective measure of crash risk, but as an emergent phenomenon arising from interactions between technologies, infrastructure, behavioural norms, and individual interpretation.

This study contributes to the existing literature in four principal ways. First, it extends previous empirical research on cyclists' perceived safety by demonstrating that cyclists primarily experience emerging mobility technologies through increasing interactional uncertainty rather than through individual vehicle types. Second, it identifies interactional uncertainty, cognitive burden, adaptive burden, cumulative strain, and social categorisation as interconnected mechanisms through which perceived safety is constructed within increasingly heterogeneous cycling environments. Third, it contributes to qualitative cycling safety research by providing an in-depth account of how these mechanisms develop through everyday interactions rather than isolated safety-critical events. Finally, the study contributes to socio-technical transport research by demonstrating that successful integration of emerging mobility technologies depends not only on accommodating new vehicles within existing infrastructure but also on preserving behavioural predictability and shared expectations between increasingly diverse road users.

From a practical perspective, the findings suggest that policymakers and infrastructure planners should focus not only on reducing objective safety risks but also on maintaining behavioural predictability within increasingly diverse cycling environments. Infrastructure design, vehicle regulation, speed management, behavioural interventions, and education should collectively support clear expectations and understandable interactions between different road users. As Dutch cycling infrastructure continues to accommodate new mobility technologies, preserving predictability may be just as important as improving objective safety outcomes.

Several limitations should be considered when interpreting the findings. As a qualitative study based on 32 interviews, the results provide rich contextual insights but are not statistically generalisable to the wider Dutch cycling population. Older cyclists and users of specialised bicycle types were relatively underrepresented, and the findings reflect cyclists' perceptions rather than objective measures of safety or behaviour. Future research could combine qualitative insights with observational or quantitative methods to examine how interactional uncertainty influences perceived safety across different cyclist populations and infrastructure contexts.

Overall, the study concludes that the principal challenge associated with emerging mobility technologies is not the technologies themselves, but the uncertainty and complexity they introduce into everyday cycling interactions. The long-term success of Dutch cycling infrastructure will therefore depend not only on accommodating technological innovation but also on maintaining environments that remain predictable, understandable, and accessible for an increasingly diverse population of cyclists.

AI Use Statement

This thesis was developed with the assistance of digital writing and language support tools, including OpenAI's ChatGPT, Superhuman Platform's Grammarly, and DeepL Translator, which were used as supplementary tools during the research and writing process.

ChatGPT was used to assist with language refinement, improving the clarity and structure of academic writing, brainstorming ideas, reorganising sections and suggesting revisions. Grammarly was used to improve grammar, spelling, punctuation, readability, and writing style, while DeepL Translator was used to support the translation of selected words, phrases, and passages between Dutch and English to ensure linguistic accuracy and consistency.

These tools were also used to provide feedback on the logical flow of arguments, propose alternative formulations, and improve the presentation of results and discussion. All AI-generated or software-assisted suggestions were critically evaluated, independently verified, and adapted where necessary before being incorporated into the thesis.

The research design, literature selection, data collection, interview conduct, coding, interpretation of findings, and all academic conclusions were carried out solely by the author. The author remained fully responsible for all content presented in this thesis, including the accuracy of the information, the interpretation of the results, the appropriate use and citation of sources, and compliance with the academic integrity standards of Delft University of Technology.

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1. Introduction

1.1 Background

Cycling plays a central role in Dutch society, accounting for approximately 28% of all trips in the Netherlands (KiM, 2024). Despite the country's international reputation as one of the safest cycling nations, cyclists remain the largest group of road traffic fatalities. According to the latest SWOV and CBS figures, cyclists accounted for over one-third of all road deaths, with electric bicycles involved in a substantial proportion of fatal crashes (SWOV, 2026; CBS, 2026). At the same time, recent research has shown that increasing cyclist volumes and greater diversity of road users not only influence objective crash risk but also negatively affect cyclists' perceived safety, particularly under crowded conditions (Uijtendewilligen, 2024). These developments suggest that maintaining cycling safety in the Netherlands requires attention not only to preventing crashes but also to understanding how cyclists experience increasingly complex cycling environments.

Despite this reputation, recent developments suggest that Dutch cycling environments are becoming increasingly complex. Although cycling remains one of the safest and most popular transport modes, cyclists now account for the largest group of road traffic fatalities in the Netherlands. In 2023, 270 cyclists lost their lives in traffic crashes, representing almost 40% of all road traffic fatalities, and for the fourth consecutive year more cyclists were killed than occupants of passenger cars. Furthermore, at least 40% of these fatal cyclist crashes involved an e-bike, reflecting the growing influence of new mobility technologies within the Dutch cycling system (CBS, 2024). At the same time, emergency department visits following bicycle accidents have increased alongside the rapid growth in e-bike use, particularly among older cyclists and younger riders, raising concerns about how changing bicycle traffic is affecting road safety (Nijman et al., 2022).

These developments have also led to increasing public and political debate surrounding emerging vehicle types such as fatbikes, high-speed e-bikes, and other forms of micromobility. Policymakers, municipalities, and road safety organisations have raised concerns regarding increasing speed differences, behavioural diversity, and the suitability of existing cycling infrastructure for accommodating an increasingly heterogeneous mix of users. While these discussions often focus on crash statistics, regulations, and infrastructure design, considerably less attention has been paid to how cyclists themselves experience these changing environments.

At the same time, urban mobility systems are undergoing rapid transformation. The emergence of new mobility technologies is altering how transport infrastructure is used and experienced (Jiao, 2021; Sabbaghian et al., 2023). These developments have increased the diversity of users sharing cycling infrastructure and introduced new forms of interaction within environments originally designed for relatively homogeneous bicycle traffic. Rather than changing only the physical characteristics of traffic, this transformation also changes the social dynamics of cycling by introducing greater variation in speeds, manoeuvrability, behavioural norms, and user expectations.

Recent studies demonstrate that these changes have important safety implications. The growing popularity of electric bicycles and e-scooters has been associated with increasing numbers of traffic injuries and new forms of interaction between road users (Fernandez et al., 2024; Schepers et al., 2018). However, while substantial research has examined objective safety outcomes, considerably less is known about how cyclists experience these increasingly diverse traffic environments in everyday practice.

Together, these developments suggest that the challenge facing Dutch cycling infrastructure is no longer solely maintaining objective safety, but also ensuring that increasingly diverse traffic environments remain understandable, predictable, and comfortable for cyclists. This raises important questions regarding how cyclists experience and navigate safety within increasingly diverse and technologically complex cycling environments.

1.2 Problem Statement

Traditionally, Dutch cycling infrastructure has been designed around relatively predictable interactions between cyclists, pedestrians, and motor vehicles. However, the growing presence of emerging mobility technologies challenges this predictability. New vehicle types differ from conventional bicycles in terms of speed, acceleration, size, manoeuvrability, and user characteristics (Alm & Koglin, 2022; Nikitas et al., 2021). Consequently, cyclists are increasingly required to interact with a wider variety of road users operating under different behavioural patterns and mobility needs.

While infrastructure and policy frameworks continue to adapt to these developments, understanding of their influence on cyclists' subjective experiences remains limited. Existing research has primarily focused on objective safety indicators such as crash rates, injury severity, and infrastructure design characteristics (Schepers et al., 2013; van Petegem et al., 2021; Uijtdewilligen et al., 2023). Although these studies provide valuable insights into physical safety outcomes, they offer less understanding of how cyclists interpret and navigate safety within everyday traffic situations.

This distinction is important because perceived safety strongly influences cycling behaviour. Individuals may avoid particular routes, reduce cycling frequency, or refrain from cycling altogether when they perceive traffic environments as unsafe, regardless of objective risk levels (Harms et al., 2015; Møller & Hels, 2008). Understanding perceived safety is therefore essential for maintaining and expanding cycling participation within evolving urban mobility systems.

1.3 Research Objective

The objective of this study is to explore how cyclists experience, interpret, and navigate safety within urban road environments increasingly shaped by emerging vehicles and mobility technologies.

Rather than focusing solely on objective safety outcomes, the study examines how cyclists perceive risk, how they adapt their behaviour in response to changing traffic conditions, and how these experiences influence continued cycling participation.

By adopting a qualitative interview-based approach, the study seeks to generate an in-depth understanding of perceived safety as a socially and contextually constructed phenomenon situated within a changing socio-technical mobility system.

1.4 Research Questions

Main Research Question:

How do cyclists experience and navigate safety in an urban road environment increasingly shaped by new vehicles and emerging technologies?

Sub-questions:

1. How do new vehicles and technologies (such as e-scooters, e-bikes, and delivery robots) shape cyclists' perceptions of safety?
2. In what ways do cyclists adapt their behaviours (such as route choice, speed, or avoidance) in response to emerging mobility technologies sharing their space?
3. What safety concerns, conflict experiences, or emotional factors contribute to cyclists reducing or ceasing their cycling activity?

1.5 Scientific and Societal Relevance

Scientific Relevance

This study contributes to the growing body of research on cycling safety by extending existing empirical knowledge of cyclists' perceived safety within increasingly diverse urban mobility systems. Previous research has demonstrated that perceived safety is influenced by infrastructure characteristics, previous experiences, cycling experience, and attitudes towards risk (Bösehans & Massola, 2018; Griffin et al., 2020; Kummeneje & Rundmo, 2020). However, comparatively little is known about the interactional mechanisms through which these perceptions are formed within bicycle lanes accommodating an increasingly heterogeneous mix of users and vehicle types.

By adopting a qualitative approach, this study complements existing quantitative evidence and provides an in-depth understanding of how cyclists interpret, anticipate, and respond to emerging mobility technologies during everyday travel. Rather than conceptualising perceived safety as a direct consequence of individual vehicle types or infrastructure characteristics, the findings demonstrate that perceived safety emerges through a dynamic interaction between technological diversity, behavioural predictability, cognitive effort, and behavioural adaptation.

The study further contributes to Management of Technology literature by illustrating how socio-technical system transformations influence everyday user experiences. It demonstrates that successful integration of emerging mobility technologies depends not only on infrastructure and regulation but also on maintaining behavioural predictability and shared expectations among increasingly diverse road users.

Societal Relevance

Understanding perceived safety is increasingly important as cities seek to promote cycling as a sustainable transport mode. Although infrastructure investments may successfully reduce objective risks, cyclists may still avoid particular routes or reduce participation if they perceive environments as difficult to navigate or unpredictable.

Insights into how emerging mobility technologies influence perceived safety can therefore support policymakers, planners, and infrastructure designers in developing cycling environments that remain accessible, attractive, and inclusive for diverse user groups.

1.6 Thesis Structure

This thesis consists of five chapters. Chapter 2 presents the literature review and theoretical background. It begins by discussing cycling safety within the Dutch context before examining the growing presence of emerging mobility technologies and their implications for urban transport systems. Subsequently, the chapter explores theories of perceived safety, risk perception, behavioural adaptation, and socio-technical systems thinking. The chapter concludes by identifying the research gap and positioning the study within the existing body of literature.

Chapter 3 describes the methodology employed in this research. First, the qualitative research design and theoretical positioning of the study are explained. Subsequently, the conceptual framework is presented, illustrating the relationships between system-level mobility changes, individual risk appraisal processes, and behavioural adaptation. The operationalisation of the research questions, participant sampling strategy, data collection procedures, and thematic analysis approach are then discussed.

Chapter 4 presents the empirical findings derived from the interviews. The chapter begins with an overview of participant characteristics before exploring how cyclists experience a cycling system that is undergoing technological and behavioural change. The findings are subsequently organised around themes relating to predictability, risk appraisal, emotional responses, behavioural adaptation, and the social categorisation of different road users. At last a synthesis of the findings is presented, highlighting the relationships between these themes and their contribution to understanding perceived cycling safety.

Chapter 5 discusses the findings in relation to existing literature and the theoretical perspectives presented earlier in the thesis. Particular attention is given to the role of predictability in shaping perceived safety, the increasing cognitive demands associated with cycling in complex traffic environments, and the behavioural adaptations cyclists employ in response to perceived risks. The chapter further discusses the implications of the findings from a socio-technical systems perspective and outlines relevant policy implications for cycling infrastructure and mobility planning. Finally, the limitations of the study and opportunities for future research are discussed before presenting the overall conclusions of the thesis.

The thesis concludes by reflecting on how emerging vehicles influence cyclists' perceptions of safety within Dutch bicycle lanes. Rather than viewing individual vehicle types as isolated safety issues, the study highlights the importance of predictability, behavioural expectations, and system complexity in shaping perceived safety and cycling participation.

2. Literature Review and Theoretical Background

2.1 Cycling Safety in the Dutch Context

The Netherlands is internationally recognised as one of the world's leading cycling nations, with cycling forming an integral component of everyday mobility. Approximately 28% of all trips are made by bicycle, supported by an extensive network of dedicated cycling infrastructure and decades of cycling-oriented transport policy (KiM, 2024; Pucher & Buehler, 2012). The Dutch cycling system is frequently regarded as an international benchmark due to its high cycling modal share, well-developed infrastructure, and comparatively favourable safety outcomes.

Despite these achievements, recent developments indicate that maintaining cycling safety has become increasingly complex. According to CBS (CBS, 2026), cyclists continue to account for the largest proportion of road traffic fatalities in the Netherlands, with electric bicycles involved in an increasing share of fatal crashes. Likewise, SWOV (2026) reports that while substantial progress has been made in reducing conflicts between cyclists and motor vehicles, new challenges have emerged as cycling infrastructure accommodates a growing diversity of vehicle types, operating speeds and user characteristics. Consequently, contemporary cycling safety can no longer be understood solely as a question of infrastructure quality or crash prevention, but increasingly as one of managing interactions within an evolving mobility system.

Traditionally, cycling safety research has predominantly evaluated objective safety outcomes through crash statistics, conflict analyses and infrastructure performance (Schepers et al., 2013; Van Petegem et al., 2021). This body of research has generated valuable evidence demonstrating that physically separated cycling infrastructure substantially reduces crash risks and improves traffic safety. However, objective safety represents only one dimension of how cyclists experience their environment. An infrastructure design that performs well according to safety statistics may nevertheless be perceived as uncomfortable, stressful or unpredictable by its users (Gössling & McRae, 2022). This distinction has increasingly shifted academic attention towards perceived safety as a complementary indicator of cycling quality.

Perceived safety refers to an individual's subjective assessment of comfort, vulnerability and confidence while travelling, and is shaped not only by objective risk but also by expectations, previous experiences, behavioural norms and interactions with surrounding road users (Harms et al., 2015; Møller & Hels, 2008). Previous studies consistently demonstrate that perceived safety strongly influences transport behaviour, including route choice, willingness to cycle and long-term cycling participation (Buehler & Dill, 2015; Gössling & McRae, 2022). Consequently, maintaining high levels of perceived safety is increasingly recognised as essential for sustaining cycling as a safe, attractive and widely adopted transport mode.

From a Management of Technology perspective, these developments illustrate a broader challenge associated with technological innovation. Cycling systems are socio-technical systems in which infrastructure, regulations, technologies and user behaviour continuously influence one another. As emerging mobility technologies become integrated into everyday transport systems, maintaining safety requires more than adapting physical infrastructure alone. It also requires understanding how technological innovations reshape interactions between users and how these changes influence everyday experiences of mobility. Perceived safety therefore provides

an important lens through which to examine whether technological innovations are successfully integrated into existing transport systems.

Taken together, the literature demonstrates that Dutch cycling remains highly successful from an objective mobility perspective, yet simultaneously faces increasing challenges associated with technological innovation and growing traffic diversity. While objective safety indicators remain essential for evaluating infrastructure performance, they provide only limited insight into how cyclists experience these evolving traffic environments. Understanding these subjective experiences is therefore essential for explaining how technological change influences everyday cycling behaviour and forms the basis for the following sections on emerging mobility technologies and system-level transformation.

2.2 Emerging Mobility Technologies and System-Level Transformation

Urban mobility systems are undergoing a period of rapid technological transformation. Advances in battery technology, electrification, digitalisation and sustainability policies have accelerated the development and adoption of emerging mobility technologies. These innovations are transforming established transport systems by introducing new actors, practices and interaction patterns that extend beyond the technologies themselves (Geels, 2002; Geels & Schot, 2007). While these innovations contribute to broader policy objectives such as reducing greenhouse gas emissions, improving accessibility and encouraging active mobility, they also fundamentally alter how existing transport systems operate.

From a Management of Technology perspective, these developments should not be understood merely as the introduction of additional vehicle types. Rather, they represent socio-technical innovations that reshape the relationships between technologies, infrastructure, institutions and users. Socio-technical transition theory argues that technological innovations become successful only when they are effectively integrated into existing systems of infrastructure, regulation, organisational arrangements and social practices (Geels, 2002; Geels & Schot, 2007). Consequently, the impacts of emerging mobility technologies cannot be explained solely through their technical characteristics. Instead, they emerge through the interactions that these technologies create within established transport systems.

Within Dutch cycling environments, these system-level transformations are particularly visible. Infrastructure originally designed for relatively homogeneous bicycle traffic is increasingly shared by conventional bicycles, e-bikes, fatbikes, speed pedelecs, cargo bicycles, delivery riders and other emerging mobility users. Although these vehicles frequently occupy the same physical space, they differ substantially in operating speed, acceleration, manoeuvrability, vehicle dimensions and rider behaviour (Alm & Koglin, 2022; Nikitas et al., 2021). These differences increase the diversity of interactions occurring within bicycle lanes and create environments characterised by greater speed heterogeneity, interaction density and spatial competition.

Recent quantitative studies provide growing evidence that these technological changes influence both objective safety and traffic dynamics. Research has associated the increasing use of electric bicycles and e-scooters with higher numbers of traffic injuries, partly due to greater operating speeds and changing interaction patterns between road users (Fernandez et al., 2024). Similarly, Cloud et al. (2023) found that the introduction of shared e-scooter systems in

several European cities was accompanied by measurable increases in reported traffic injuries, particularly where existing infrastructure was not designed to accommodate these vehicles. At the same time, other studies demonstrate that technological innovation does not necessarily produce negative safety outcomes. Edwards et al. (2025), for example, observed reductions in cyclist collisions following the introduction of shared e-scooter schemes in parts of England, suggesting that the safety effects of emerging mobility technologies depend strongly on the broader transport system in which they are introduced.

While these quantitative studies have substantially improved understanding of crash risks, injury patterns and infrastructure requirements, they generally evaluate vehicle categories independently. E-bikes, e-scooters, cargo bikes and speed pedelecs are commonly analysed as separate transport modes, with relatively limited attention given to the cumulative effects of multiple innovations operating simultaneously within the same cycling environment. Consequently, existing research provides detailed knowledge regarding the objective safety characteristics of individual vehicle types, but considerably less understanding of how increasing technological diversity reshapes the everyday experiences of cyclists.

Qualitative research has begun to address this gap by examining how cyclists interpret increasingly diverse traffic environments. Rather than identifying individual vehicle types as inherently problematic, these studies suggest that technological innovations influence cyclists primarily by changing interaction processes. Greater variation in operating speeds, behavioural norms and manoeuvrability requires cyclists to continuously interpret unfamiliar situations, negotiate shared space and anticipate a wider range of possible behaviours (Gössling & McRae, 2022; Marincek, 2023). Emerging technologies therefore influence safety not only through objective exposure to risk, but also by changing the cognitive and social demands associated with everyday cycling.

Taken together, the literature suggests that emerging mobility technologies should not be conceptualised as isolated transport innovations. Instead, they constitute system-level transformations that alter the functioning of cycling environments through changes in interaction patterns, behavioural expectations and technological diversity. Although quantitative research has successfully documented changes in crash risks, traffic volumes and infrastructure performance, considerably less is known about how cyclists experience these transformations in everyday practice. Understanding these subjective experiences therefore represents an important next step in explaining how technological innovation influences perceived cycling safety.

2.3 Perceived Safety and Risk Perception

Cycling safety has traditionally been evaluated through objective indicators such as crash frequencies, injury severity, and infrastructure performance. These measures remain essential for evaluating the physical safety of transport systems and have substantially contributed to improving cycling infrastructure in the Netherlands (Schepers et al., 2013; Van Petegem et al., 2021). However, an increasing body of literature argues that objective safety alone provides only a partial understanding of cyclists' experiences. Transport environments that perform well according to conventional safety indicators may nevertheless be perceived as stressful,

uncomfortable, or unpredictable, influencing travel behaviour independently of actual crash risk (Gössling & McRae, 2022).

Perceived safety refers to an individual's subjective judgement of how safe they feel while travelling rather than the objectively measurable probability of being involved in a crash. Unlike objective safety, perceived safety is shaped by cognitive and emotional processes through which individuals interpret uncertainty, vulnerability, and control within their surrounding environment (Slovic, 1987; Møller & Hels, 2008). These evaluations are influenced by previous experiences, familiarity with the environment, trust in other road users, confidence in one's own cycling abilities, and expectations regarding the behaviour of others (Harms et al., 2015). Consequently, individuals often base travel decisions on how safe they feel rather than on statistical estimates of crash likelihood.

Recent empirical research has increasingly demonstrated that cyclists actively construct perceptions of safety through their everyday interactions with other road users. Rather than responding solely to objective hazards or infrastructure characteristics, cyclists continuously interpret behavioural cues, negotiate shared space, and anticipate the intentions of surrounding traffic. This perspective shifts attention away from infrastructure alone towards the interactional processes through which perceived safety is produced.

For example, Bösehans and Massola (2018) explored cyclists' experiences in São Paulo using qualitative interviews and found that perceptions of risk were strongly influenced by previous interactions with other road users rather than by objective danger alone. Participants frequently described feelings of vulnerability, uncertainty, and the need to remain constantly vigilant while cycling. Rather than evaluating isolated traffic situations, cyclists interpreted safety through the accumulation of previous experiences, particularly those involving unexpected or difficult interactions with motorists. These findings suggest that perceived safety emerges through continuous interpretation of social interactions rather than simply reflecting measurable crash risks.

Similarly, Griffin et al. (2020) demonstrated that previous cycling experience substantially influences how individuals perceive crash risk. Comparing drivers with and without extensive cycling experience, the study found that experienced cyclists identified different hazards, anticipated potential conflicts more effectively, and evaluated traffic situations differently from less experienced road users. These findings indicate that perceptions of safety are not uniform across cyclists but are shaped by experience, familiarity, and developed interpretive skills. Consequently, cyclists with different backgrounds may experience identical traffic environments in fundamentally different ways.

Further evidence is provided by Kummeneje and Rundmo (2020), who investigated the relationship between attitudes, perceived risk, and cycling behaviour among Norwegian cyclists. Their study showed that cyclists reporting higher levels of perceived risk generally adopted more cautious riding behaviours and engaged in fewer deliberate risk-taking practices. Importantly, the authors argued that behavioural adaptation was closely linked to subjective perceptions of risk rather than objective safety conditions, reinforcing the notion that behavioural responses are primarily driven by how cyclists interpret their environment.

Together, these studies illustrate that perceived safety extends beyond infrastructure quality or objective crash statistics. Cyclists continuously evaluate the behaviour of surrounding road users, interpret social cues, and adapt their behaviour accordingly. Perceived safety therefore emerges through ongoing interactions between individual judgement, previous experiences, and the surrounding traffic environment.

The rapid emergence of new mobility technologies further complicates these interactional processes. Recent quantitative studies have demonstrated associations between increasing vehicle diversity, speed heterogeneity, and changing crash patterns (Cloud et al., 2023; Fernandez et al., 2024). Survey-based studies likewise report relationships between infrastructure quality and perceived safety (Gössling & McRae, 2022). However, many of these studies continue to examine emerging vehicles as isolated explanatory variables rather than considering how increasing technological diversity transforms the interactional processes through which cyclists experience safety.

Qualitative research has begun to address this limitation. Rather than describing safety exclusively in terms of crash risk, recent studies show that cyclists frequently discuss uncertainty, trust, behavioural expectations, and cognitive effort when explaining why particular situations feel safe or unsafe (Gössling & McRae, 2022; Marincek, 2023). Safety is therefore increasingly understood as a socially constructed experience that develops through continuous interpretation of the intentions and likely behaviour of surrounding road users.

Despite these advances, an important gap remains. Existing empirical studies have primarily examined interactions between cyclists and motor vehicles, differences in risk perception across user groups, or the relationship between perceived risk and behavioural adaptation. Comparatively little attention has been paid to how cyclists experience increasingly heterogeneous bicycle lanes in which multiple emerging vehicle types interact simultaneously. As bicycle infrastructure accommodates growing diversity in vehicle speeds, manoeuvrability, and behavioural norms, understanding how cyclists interpret this increasing complexity represents an important next step in explaining perceived cycling safety.

2.4 Behavioural Adaptation in Response to Emerging Mobility Technologies

Behavioural adaptation describes the process through which individuals modify their actions in response to perceived changes in their environment. Within transport research, behavioural adaptation has traditionally been explained using theories such as Risk Homeostasis Theory (Wilde, 1982), which proposes that individuals adjust their behaviour to maintain an acceptable level of perceived risk. According to this perspective, improvements in objective safety may encourage individuals to behave more confidently, while increasing perceptions of risk may result in more cautious behaviour.

Although Risk Homeostasis Theory provides a useful theoretical foundation, more recent research suggests that behavioural adaptation is considerably more dynamic than simple risk compensation. Rather than responding to objective risks alone, road users continuously interpret changing traffic conditions and adapt their behaviour according to contextual information, previous experiences and expectations regarding the behaviour of others (Fuller, 2005; Rundmo & Iversen, 2004). Behavioural adaptation should therefore be understood as an

ongoing process of interpretation and adjustment rather than a single response to changes in objective safety.

Within cycling environments, behavioural adaptation may include a wide range of coping strategies. Previous studies have shown that cyclists modify their route choice, travelling speed, lane positioning and overtaking behaviour in response to perceived traffic complexity and infrastructure characteristics (Buehler & Dill, 2015; Schepers et al., 2013). Cyclists may also choose to avoid certain routes, alter the timing of journeys or increase their visual attention when they anticipate more demanding traffic situations. These adaptations enable cyclists to continue travelling despite experiencing greater complexity within the cycling environment.

The emergence of new mobility technologies introduces additional reasons for behavioural adaptation. Electrically assisted bicycles, speed pedelecs, cargo bikes and other emerging vehicle types differ substantially in speed, acceleration, size and manoeuvrability from conventional bicycles (Alm & Koglin, 2022; Nikitas et al., 2021). Consequently, cyclists increasingly encounter situations that require them to interpret unfamiliar behaviours, negotiate overtaking manoeuvres and anticipate interactions with road users operating under different behavioural norms. Recent qualitative research suggests that these adaptations are not driven solely by the physical presence of new vehicles but also by increasing uncertainty regarding how these vehicles are likely to behave within shared cycling spaces (Marincek, 2023).

From a socio-technical perspective, behavioural adaptation represents an important mechanism through which users respond to technological innovation. Technologies do not simply alter transport systems by introducing new technical capabilities; they also require users to develop new routines, expectations and interaction strategies. The successful integration of emerging mobility technologies therefore depends not only on infrastructure or regulation, but also on the ability of users to adapt to increasingly heterogeneous traffic environments. Understanding these adaptive processes is consequently essential for explaining how technological innovation influences perceived safety.

Despite growing interest in behavioural adaptation, much of the existing literature focuses on observable behavioural outcomes, such as route choice or speed adjustments. Comparatively less attention has been devoted to understanding the cognitive processes that precede these adaptations, including how cyclists interpret uncertainty, anticipate the behaviour of surrounding road users and decide when behavioural adjustments are necessary. Qualitative research is particularly well suited to examining these underlying processes because it allows participants to explain how they experience and respond to increasingly complex traffic environments.

Taken together, the literature suggests that behavioural adaptation is not simply a reaction to increased objective risk but an active process through which cyclists manage technological and social complexity within evolving transport systems. Examining these adaptive strategies therefore provides valuable insight into how emerging mobility technologies influence cyclists' everyday experiences and offers an important link between system-level technological transformation and perceived safety.

2.5 A Socio-Technical Perspective on Perceived Cycling Safety

The preceding sections demonstrate that cycling safety cannot be understood solely through infrastructure characteristics, vehicle technologies or individual behaviour. Rather, these elements continuously influence one another within a broader socio-technical mobility system. From a Management of Technology perspective, technological innovation is not viewed simply as the introduction of new artefacts but as a process through which technologies, users, institutions and infrastructure co-evolve over time (Geels, 2002; Geels & Schot, 2007). Consequently, understanding the societal impacts of emerging mobility technologies requires examining how these innovations become embedded within existing transport systems.

Socio-technical systems consist of interconnected technological, organisational, institutional and behavioural components that together shape system performance (Geels, 2004). Within the Dutch cycling system, infrastructure, traffic regulations, mobility technologies and cyclist behaviour have historically evolved in close alignment, contributing to internationally recognised levels of cycling participation and safety (Pucher & Buehler, 2012). The rapid emergence of electrically assisted bicycles, fatbikes, speed pedelecs and other forms of micromobility introduces new technological capabilities that challenge this previously stable configuration. These innovations alter not only physical traffic characteristics but also behavioural expectations, interaction patterns and established social norms regarding the use of cycling infrastructure.

This perspective shifts attention from individual technologies towards the interactions that technological innovation creates. Emerging mobility technologies rarely operate independently. Instead, they influence how different road users negotiate shared space, interpret one another's behaviour and adapt their own decisions within increasingly heterogeneous cycling environments. Consequently, the societal impact of technological innovation depends not only on technical performance but also on whether users are able to integrate these technologies into existing patterns of everyday mobility.

Within this study, perceived safety is conceptualised as an important indicator of successful socio-technical integration. Traditional transport research frequently evaluates technological innovation through objective performance indicators such as efficiency, capacity or crash reduction. While these measures remain essential, they provide only a partial understanding of innovation success. Technologies that improve objective system performance may nevertheless generate uncertainty, discomfort or behavioural adaptation if users struggle to interpret new interaction patterns. Perceived safety therefore offers insight into whether technological innovation is accepted, understood and successfully accommodated by its users.

This perspective aligns closely with recent developments within Management of Technology research, which increasingly recognises that technological innovation is shaped as much by human behaviour and organisational processes as by technological capability itself. Successful innovation therefore depends not only on designing effective technologies but also on understanding how these technologies influence user behaviour, decision-making and everyday practices. Examining cyclists' experiences consequently provides valuable insight into the broader societal integration of emerging mobility technologies.

Drawing together the literature reviewed throughout this chapter, the present study proposes that emerging mobility technologies influence cyclists' perceived safety indirectly through system-level transformations. The introduction of new technologies increases speed heterogeneity, interaction density and spatial competition, thereby altering interaction processes within cycling environments. These changes require cyclists to continuously interpret the behaviour and intentions of surrounding road users, shaping how safe they perceive the environment to be and how they subsequently adapt their own behaviour. Rather than viewing perceived safety as a direct consequence of individual vehicle types, this perspective conceptualises it as an emergent property of interactions within an evolving socio-technical mobility system.

2.6 Research Gap and Theoretical Contribution

The literature reviewed throughout this chapter demonstrates that considerable progress has been made in understanding cycling safety from multiple disciplinary perspectives. Research on cycling infrastructure has generated extensive evidence regarding the effectiveness of different infrastructure designs in reducing crash risks and improving objective safety outcomes (Schepers et al., 2013; Van Petegem et al., 2021). Likewise, studies on emerging mobility technologies have documented how electrically assisted bicycles, shared micromobility, and other innovations are reshaping urban transport systems through changing speed profiles, infrastructure demands, and traffic interactions (Cloud et al., 2023; Fernandez et al., 2024). A separate body of literature has examined perceived safety and behavioural adaptation, demonstrating that subjective experiences influence cyclists' route choice, willingness to cycle, and everyday travel behaviour (Harms et al., 2015; Møller & Hels, 2008).

More recently, empirical studies have begun to explore cyclists' lived experiences of safety. Qualitative research has shown that perceptions of risk are strongly influenced by previous experiences, interactions with other road users, and feelings of vulnerability rather than by objective crash risk alone (Bösehans & Massola, 2018). Other studies demonstrate that cycling experience influences how individuals recognise hazards and evaluate potentially dangerous situations (Griffin et al., 2020), while perceived risk has been shown to influence behavioural adaptation and willingness to engage in risky cycling behaviour (Kummeneje & Rundmo, 2020). Collectively, these studies demonstrate that perceived safety is an active and socially constructed process rather than a simple reflection of objective traffic conditions.

Although these empirical studies have substantially advanced understanding of cyclists' experiences, several important limitations remain.

First, many empirical studies examine interactions between cyclists and motor vehicles or investigate general attitudes towards cycling safety. Comparatively little attention has been devoted to understanding how cyclists experience increasingly heterogeneous bicycle lanes in which multiple emerging vehicle types coexist within the same infrastructure. Consequently, relatively little is known about how increasing technological diversity influences everyday cycling experiences.

Second, previous research has generally examined individual determinants of perceived safety, such as infrastructure quality, previous experiences, cycling experience, or attitudes towards risk. While these studies identify important correlates of perceived safety, they provide less insight into the interactional mechanisms through which these perceptions are formed during everyday cycling. In particular, relatively little attention has been given to how cyclists continuously interpret, anticipate, and negotiate the behaviour of surrounding road users within increasingly dynamic traffic environments.

Third, although emerging mobility technologies have received growing attention within transport research, they are frequently investigated as separate vehicle categories. Studies commonly focus on e-bikes, e-scooters, or cargo bicycles individually, emphasising objective crash risk, injury patterns, or infrastructure requirements. This approach provides valuable knowledge regarding the safety implications of specific technologies but offers less understanding of how multiple innovations collectively reshape the cycling environment through changes in interaction patterns, behavioural expectations, and perceived uncertainty.

From a Management of Technology perspective, these limitations represent an important theoretical gap. Emerging mobility technologies should not be understood simply as additional transport modes but as innovations that transform socio-technical mobility systems. Their societal impacts depend not only on technical performance or objective safety outcomes but also on how successfully they become integrated into existing patterns of infrastructure use, behavioural expectations, and interactions between road users. Understanding this process requires examining how cyclists experience technological change as part of everyday mobility rather than evaluating individual technologies in isolation.

This study addresses these gaps by exploring cyclists' lived experiences within Dutch bicycle lanes that are increasingly characterised by technological diversity. Rather than investigating specific vehicle categories independently, the study examines how cyclists experience the cumulative effects of multiple emerging vehicle types operating simultaneously within shared cycling environments. By adopting a qualitative approach, the study complements existing quantitative evidence and moves beyond identifying determinants of perceived safety to explain the interactional processes through which perceived safety is produced, maintained, and negotiated.

This study makes four principal contributions to the existing literature.

First, it extends empirical research on cyclists' perceived safety by demonstrating that interactions with emerging vehicles are experienced primarily through increasing behavioural uncertainty rather than through the presence of individual vehicle types. This shifts attention from vehicle-specific safety concerns towards the interactional processes through which cyclists construct perceptions of safety.

Second, it contributes to perceived safety literature by identifying interactional uncertainty as the central mechanism linking increasing technological diversity to cognitive effort, emotional responses, and behavioural adaptation. In doing so, the study moves beyond previous research that has primarily examined individual determinants of perceived safety.

Third, the study contributes methodologically by providing an in-depth qualitative account of cyclists' lived experiences within one of the world's most mature cycling systems. Whereas previous empirical studies have often relied on surveys or examined isolated traffic situations, this research captures how cyclists interpret increasingly complex interactions across their everyday journeys.

Finally, the study contributes to Management of Technology literature by demonstrating how technological innovation reshapes socio-technical mobility systems through changes in everyday interactions, behavioural expectations, and user interpretation. The findings therefore suggest that successful integration of emerging mobility technologies depends not only on infrastructure and regulation but also on maintaining behavioural predictability and shared expectations between increasingly diverse road users.

Taken together, these contributions position the study at the intersection of cycling safety research, perceived safety literature, and socio-technical transition theory. Rather than conceptualising perceived safety as a direct consequence of infrastructure quality or individual vehicle types, the study proposes that it emerges through ongoing interactional processes shaped by technological change. In doing so, the research extends existing empirical knowledge of cyclists' experiences while offering a broader conceptual understanding of how technological diversity influences perceived safety within contemporary cycling environments.

3. Methodology

3.1 Research Design

This study adopts a qualitative, interpretivist research design to explore how cyclists experience and navigate safety within urban road environments increasingly shaped by emerging mobility technologies. The objective is not to measure objective safety outcomes or crash probabilities, but to understand how cyclists construct, interpret, and respond to perceptions of safety during everyday travel.

A qualitative approach was considered most appropriate because perceived safety is inherently subjective and context dependent. Feelings of safety emerge through lived experiences, interactions with other road users, and interpretations of uncertainty within the transport environment. Semi-structured interviews therefore provide an opportunity to capture the meanings participants attach to their experiences while allowing themes to emerge inductively from the data.

The study is situated within a socio-technical understanding of transport systems, in which safety is viewed as an emergent property arising from interactions between infrastructure, technologies, human actors, institutional structures, and behavioural norms. This perspective aligns with research traditions within the Department of Transport & Logistics and the Department of Safety & Security Science at TU Delft.

3.2 Theoretical Positioning

3.2.1 Risk Perception Theory

This study is theoretically grounded in risk perception theory. Risk perception research demonstrates that perceived safety is shaped not only by objective hazard exposure but also by cognitive, affective, and contextual factors that influence how individuals interpret uncertainty and vulnerability (Slovic, 1987; Weber & Johnson, 2009).

Within this perspective, cyclists evaluate safety through mechanisms such as:

- Perceived controllability
- Familiarity versus novelty
- Trust in other road users
- Perceived vulnerability
- Emotional responses such as fear and stress

Consequently, perceived safety may differ substantially from objective safety indicators. Individuals may feel unsafe despite low crash risk or feel comfortable despite elevated objective hazards. This distinction is particularly relevant in cycling environments undergoing rapid technological change.

3.2.2 Safety as a Socio-Technical Phenomenon

In addition to risk perception theory, this study adopts a socio-technical systems perspective. Safety is conceptualised not as the outcome of isolated individual decisions but as an emergent property arising from interactions between system components.

From this perspective, changes in transport technologies, infrastructure design, traffic composition, and behavioural norms collectively shape cyclists' experiences of safety. Emerging mobility technologies therefore influence safety not only through their physical characteristics but also through their effects on interaction patterns, predictability, and system complexity.

This perspective is consistent with systems-based safety approaches that conceptualise safety as a dynamic property emerging from interactions between humans, technologies, and organisational structures.

3.3 Conceptual Framework

Building upon risk perception theory and socio-technical systems thinking, a conceptual framework was developed to guide data collection and analysis.

The framework proposes that perceived cycling safety emerges through interactions between three interconnected layers:

1. System-Level Transformations

The introduction of emerging mobility technologies such as e-bikes, speed pedelecs, fatbikes, delivery scooters, and other micromobility devices alters:

- Speed heterogeneity
- Interaction density
- Spatial competition
- Predictability of manoeuvres
- Formal and informal traffic norms

These developments introduce additional variability and complexity into the cycling environment.

Recent quantitative evidence supports the assumption that Dutch cycling environments are undergoing system-level transformation. First, speed heterogeneity has increased due to the growing presence of electrically assisted and higher-speed vehicles. Standard e-bikes provide assistance up to 25 km/h, while speed pedelecs can reach 45 km/h and are therefore legally treated as mopeds (SWOV, 2022). The number of registered speed pedelecs in the Netherlands increased from approximately 15,300 in 2019 to 35,400 in 2025, illustrating the growing presence of faster vehicle types within the broader cycling system (CBS, 2025). Second, interaction density has increased as cycling remains a highly intensive mode of everyday transport: Dutch residents made approximately 4.8 billion bicycle trips and cycled 18.2 billion kilometres in 2022 (KiM, 2024). Third, spatial competition has become more relevant because increasingly diverse users and vehicle types share infrastructure that was originally designed

around more homogeneous bicycle traffic. Recent Dutch research shows that crowding on cycling infrastructure negatively affects both route preferences and perceived safety, particularly among older cyclists and women (Uijtdewilligen et al., 2024b). These findings provide quantitative support for conceptualising system-level transformation as a combination of speed heterogeneity, interaction density and spatial competition among others.

2. Individual Risk Appraisal

Cyclists interpret these system changes through cognitive and affective processes including:

- Perceived controllability
- Familiarity versus novelty
- Trust in other road users
- Perceived vulnerability

These mechanisms influence how cyclists evaluate safety within specific situations.

3. Behavioural Adaptation and System Feedback

In response to perceived changes in risk, cyclists adapt their behaviour through:

- Route modification
- Speed adjustment
- Increased vigilance
- Avoidance strategies
- Reduced cycling participation

These adaptations subsequently alter exposure patterns and interaction dynamics within the broader transport system.

The framework therefore conceptualises safety as a dynamic process rather than a fixed condition.

Dynamic Interaction Structure

The framework proposes the following anticipated interaction sequence:

1. Emerging mobility technologies alter system conditions.
2. These changes affect interaction patterns and behavioural predictability.
3. Cyclists interpret these changes through cognitive and affective risk appraisal processes.
4. Perceived risk influences behavioural adaptation strategies.
5. Behavioural adaptations alter future exposure and interaction patterns.
6. Experiences feed back into future perceptions of safety.

Figure 1 presents the conceptual framework used to guide the study.

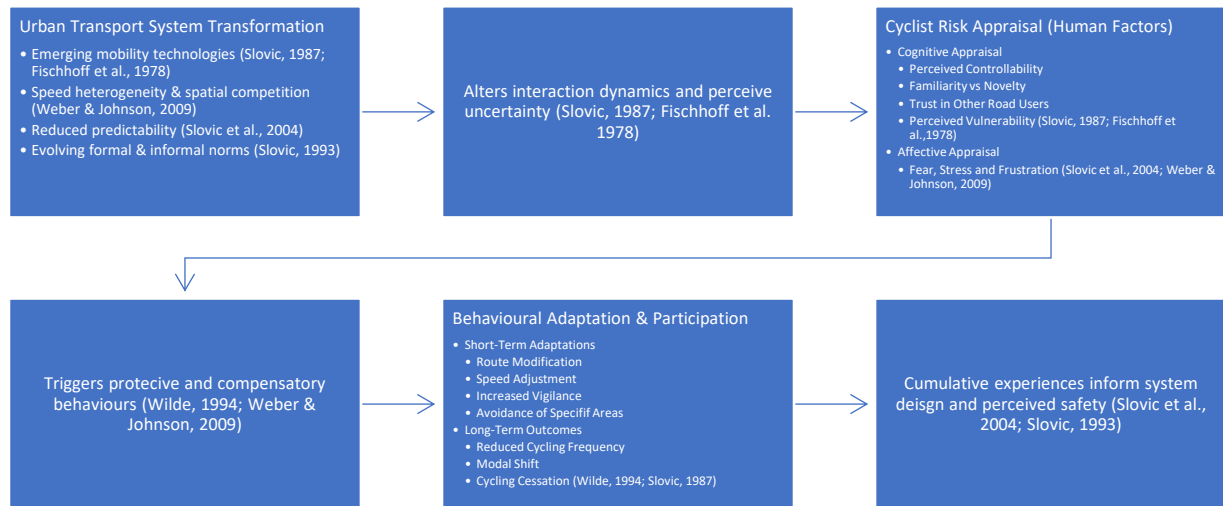


Figure 1: Conceptual framework of perceived cycling safety within a transforming urban socio-technical system.

The framework integrates transport system changes (Slovic, 1987; Fischhoff et al., 1978; Weber & Johnson, 2009), cognitive and affective risk appraisal processes (Slovic et al., 2004; Weber & Johnson, 2009), and behavioural adaptation strategies (Wilde, 1994; Slovic, 1987). Feedback loops illustrate how cyclist experiences and adaptations influence both perceived safety and future system evolution.

3.4 Operationalisation of Research Questions

The conceptual framework informed the development of interview themes and analytical categories. Each research question was linked to specific theoretical constructs derived from risk perception literature.

Research Question 1: How do new vehicles and technologies shape cyclists' perceptions of safety?

Interview themes:

- First encounters with emerging technologies
- Predictability of new vehicles
- Speed differences and spatial conflicts
- Visibility and detectability
- Trust in operators
- Rule compliance
- Comparison with traditional road users
- Contexts associated with increased or reduced perceived risk

Underlying theoretical constructs:

- Perceived controllability (Slovic, 1987)
- Familiarity and novelty (Fischhoff et al., 1978)
- Uncertainty and ambiguity (Weber & Johnson, 2009)
- Trust and social norms (Slovic, 1993)

Research Question 2: How do cyclists adapt their behaviour in response to emerging mobility technologies?

Interview themes:

- Route choice adjustments
- Time-of-day adaptations
- Defensive cycling
- Speed modulation
- Increased vigilance
- Informal negotiation strategies
- Long-term versus short-term adaptation

Underlying theoretical constructs:

- Risk homeostasis (Wilde, 1994)
- Coping and protective behaviour (Weber & Johnson, 2009)
- Experiential risk processing (Fischhoff et al., 1978)

Research Question 3: What factors contribute to cyclists reducing or ceasing cycling participation?

Interview themes:

- Near-miss experiences
- Emotional responses
- Accumulation of unsafe experiences
- Thresholds of acceptability
- Reduced cycling frequency
- Modal substitution
- Conditions for continued cycling

Underlying theoretical constructs:

- Affect heuristic (Slovic et al., 2004)
- Cumulative risk perception
- Behavioural avoidance (Wilde, 1994)

3.5 Participant Sampling

A purposive sampling strategy was employed to capture a diverse range of cycling experiences and perspectives relevant to the research objective. Because the study aimed to explore how cyclists experience and navigate safety within an evolving mobility environment, participants were selected based on characteristics expected to influence perceptions of safety, interpretations of risk, and behavioural adaptation.

This study specifically focused on cyclists because the research objective was to understand how cyclists perceive safety within increasingly diverse bicycle lane environments. While emerging vehicle users, such as e-bike riders, speed pedelec users or scooter riders, also contribute to these interactions, cyclists represent the infrastructure users whose behaviour and perceived safety are most directly affected by the changing composition of bicycle traffic. Furthermore, cyclists constitute the largest user group of Dutch bicycle infrastructure and represent the population for whom maintaining a safe and attractive cycling environment is essential to achieving broader mobility, sustainability and public health objectives (KiM, 2024). Limiting the participant population to cyclists therefore allowed the study to obtain an in-depth understanding of how one stakeholder group experiences these system-level transformations, rather than comparing perceptions across multiple transport modes.

Particular attention was given to variation in:

- Age
- Gender
- Cycling frequency
- Cycling experience
- Familiarity with Dutch cycling culture
- Exposure to different traffic environments

Previous research suggests that perceptions of safety are influenced by factors such as experience, familiarity, confidence, and perceived vulnerability. Consequently, the sampling strategy sought to include participants with differing levels of cycling experience and varying degrees of familiarity with Dutch cycling infrastructure.

Participants were recruited using purposive sampling through two complementary channels. First, Dutch cyclists were recruited via the Fietzersbond, which enabled access to respondents with varying cycling habits, ages and levels of cycling experience. Second, international participants were recruited through student networks at TU Delft. This recruitment strategy enabled the inclusion of respondents with diverse cycling backgrounds, including participants who had extensive experience cycling in the Netherlands as well as international students who had only recently become familiar with Dutch cycling infrastructure.

Purposive sampling was selected to maximise variation across participant characteristics that were expected to influence perceptions of cycling safety, rather than to obtain a statistically representative sample (Patton, 2015). Recruitment continued until sufficient diversity was achieved and no substantially new insights emerged from additional interviews.

The inclusion criteria were:

- At least 18 years of age
- Experience cycling within Dutch urban or suburban environments
- At least one cycling trip during the previous six months
- Willingness to participate in a recorded interview

The final sample consisted of participants with substantial variation in age, gender, cycling experience and familiarity with Dutch cycling infrastructure. Both frequent and occasional cyclists were represented, as well as participants who primarily cycled in highly urban environments and those with experience in suburban settings. The sample further included both Dutch participants, who generally possessed extensive experience navigating Dutch bicycle infrastructure, and international participants who offered perspectives from alternative cycling cultures.

Although considerable diversity was achieved across most sampling dimensions, some groups were less well represented. Older cyclists, who are known to experience relatively high crash risks and different perceptions of cycling safety, were slightly underrepresented. Likewise, users of specialised bicycle types, such as speed pedelecs or cargo bicycles, constituted only a small proportion of the sample. Consequently, the findings primarily reflect the experiences of conventional cyclists, although many participants regularly interacted with these emerging vehicle types during their daily journeys. These limitations should be considered when interpreting the transferability of the findings.

A total of 32 participants were included in the final sample. Participants represented a broad range of ages, cycling frequencies, and experience levels, enabling examination of common patterns as well as differences between user groups. The sample included experienced Dutch cyclists, international students, parents cycling with children, and older cyclists, allowing exploration of how perceived safety may vary across different mobility experiences and levels of vulnerability.

Table 1: Participant characteristics

<i>Characteristic</i>	<i>Distribution</i>
<i>Total participants</i>	32
<i>Dutch cyclists</i>	23 (71.9%)
<i>International cyclists</i>	9 (28.1%)
<i>Female</i>	15 (46.9%)
<i>Male</i>	17 (53.1%)
<i>Age range</i>	18–68 years
<i>Mean age</i>	34.3 years
<i>Median age</i>	29.5 years
<i>High cycling experience</i>	14 (43.8%)
<i>Medium cycling experience</i>	10 (31.3%)
<i>Low cycling experience</i>	6 (18.8%)
<i>Very low cycling experience</i>	2 (6.3%)
<i>Daily cyclists</i>	16 (50.0%)
<i>Frequent/regular cyclists</i>	7 (21.9%)
<i>Occasional cyclists</i>	6 (18.8%)
<i>Rare/irregular cyclists</i>	3 (9.4%)

Note: Frequent/regular cyclists include participants reporting frequent, regular, or approximately four cycling trips per week.

The final sample consisted of 32 participants representing a broad range of cycling experiences and backgrounds. Twenty-three participants identified as Dutch cyclists and nine as international cyclists. The sample included 15 female and 17 male participants and ranged in age from 18 to 68 years ($M = 34.3$ years; $Md = 29.5$ years).

Substantial variation was also present in cycling experience and frequency. Fourteen participants reported high levels of cycling experience, ten reported medium experience, and eight reported low or very low experience. Half of the participants cycled daily, while the remaining participants varied from frequent users to occasional or irregular cyclists. This diversity enabled exploration of how perceived safety, uncertainty, and behavioural adaptation are experienced across different user groups, including experienced Dutch cyclists, international cyclists, and less frequent cyclists.

Table 2: Participant groups relevant to the analysis

<i>Participant Group</i>	<i>Number</i>
<i>Dutch cyclists</i>	23
<i>International cyclists</i>	9
<i>Younger cyclists (18–29 years)</i>	16
<i>Middle-aged cyclists (30–49 years)</i>	9
<i>Older cyclists (50+ years)</i>	7
<i>High-experience cyclists</i>	14
<i>Low/very low experience cyclists</i>	8
<i>Daily cyclists</i>	16
<i>Non-daily cyclists</i>	16

3.6 Data Collection

Data were collected through semi-structured face-to-face interviews as they provide sufficient structure to address the research questions while allowing participants to elaborate on experiences, perceptions, and interpretations in their own words. Interviews lasted approximately 40–60 minutes and were conducted in quiet university, public, or private locations chosen to facilitate open discussion. All interviews were recorded and subsequently transcribed for analysis.

The interview guide was organised around five thematic blocks:

Cycling Practices

Participants described their typical cycling behaviour, including:

- Travel purposes
- Cycling frequency
- Common routes

- Cycling experience

Perceptions of Safety

Participants reflected on:

- Situations perceived as safe or unsafe
- Feelings of vulnerability
- Sources of uncertainty
- Trust in other road users

Conflict Experiences

Participants discussed:

- Near misses
- Safety-critical incidents
- Difficult interactions
- Memorable cycling experiences

Behavioural Adaptation

Participants described:

- Defensive cycling behaviours
- Route modifications
- Avoidance strategies
- Changes in cycling habits over time

Future Mobility and Policy

Participants reflected on:

- Emerging mobility technologies
- Infrastructure improvements
- Regulatory measures
- Future developments in Dutch cycling environments

To facilitate discussion regarding different vehicle types, photo elicitation techniques were incorporated into the interviews. Participants were shown images of a range of vehicles currently present within Dutch cycling environments, including traditional bicycles, electric bicycles, fatbikes, speed pedelecs, scooters, delivery scooters, cargo bikes, recumbent bicycles, city cars, delivery vans, and e-steps.

The use of visual prompts encouraged participants to discuss experiences that might otherwise have remained implicit and enabled more detailed exploration of expectations, associations, and perceived risks associated with different vehicle categories.

3.7 Data Analysis

Interview transcripts were analysed using Reflexive Thematic Analysis following the approach proposed by Braun and Clarke (2022). Reflexive Thematic Analysis was considered appropriate because the objective of the study was not merely to identify recurring topics, but to develop an interpretive understanding of how cyclists experience and make sense of safety within changing mobility environments.

The analysis followed five iterative stages:

1. Familiarisation with the data
2. Initial coding
3. Theme development
4. Theme review
5. Theme definition and refinement

Throughout the analysis, coding combined deductive and inductive approaches.

Deductive coding was informed by:

- Risk perception theory
- Socio-technical systems theory
- The conceptual framework
- The research questions

Inductive coding allowed themes to emerge directly from participants' accounts without requiring all observations to fit predefined theoretical categories.

This combination enabled the analysis to remain theoretically informed while maintaining sensitivity to participants' lived experiences and interpretations.

3.7.1 Theme Development Process

Theme development occurred through an iterative process of coding, comparison, interpretation, and refinement.

The first stage involved open coding of the interview transcripts. Codes were assigned to segments of text that captured meaningful aspects of participants' experiences, perceptions, emotions, and behavioural responses. Examples of initial codes included uncertainty regarding intentions, vigilance, route avoidance, speed differences, trust in other road users, behavioural unpredictability, stress, frustration, and adaptation.

Following initial coding, related codes were grouped into broader conceptual categories. For example, codes relating to anticipation difficulties, behavioural ambiguity, and uncertainty regarding intentions were clustered together. Similarly, codes relating to monitoring behaviour, vigilance, and increased attention were grouped into a broader category relating to cognitive burden.

These categories were subsequently reviewed across the entire dataset and refined into higher-order themes that captured recurring patterns of meaning. Throughout this process, themes were continuously compared against the original transcripts to ensure that interpretations remained grounded in participants' accounts and accurately reflected the diversity of experiences within the sample.

The final themes represented not only recurring experiences but also the mechanisms through which participants interpreted and responded to changing cycling environments. This process ultimately resulted in themes relating to interactional uncertainty, cognitive burden, emotional responses, behavioural adaptation, and social categorisation.

Table 3: Final themes emerging from the analysis

<i>Final Theme</i>	<i>Description</i>	<i>Example Codes</i>
<i>Interactional Uncertainty</i>	Difficulties anticipating and interpreting the behaviour of others	Behavioural ambiguity, unclear intentions, unpredictability, uncertainty regarding rules
<i>Cognitive Burden</i>	Increased mental effort required to navigate the cycling environment	Vigilance, monitoring, scanning, concentration, mental effort
<i>Trust and Interpretability</i>	Perceptions of competence, predictability, and familiarity among road users	Trust, behavioural expectations, competence, familiarity
<i>Adaptive Burden</i>	Behavioural changes used to manage uncertainty and maintain safety	Defensive cycling, route changes, avoidance, withdrawal
<i>Cumulative Strain</i>	The gradual accumulation of stress, uncertainty, and near-conflict experiences	Repeated stress, vigilance, frustration, near misses
<i>Social Categorisation</i>	Use of vehicle categories as heuristics for anticipating behaviour	Stereotypes, mental models, assumptions regarding riders

Interactional uncertainty emerged as the central organising concept linking the six themes. Participants consistently described difficulties anticipating and interpreting the behaviour of others, while the remaining themes capture the cognitive, emotional, behavioural, and social consequences of this uncertainty.

3.7.2 Reflexivity and Interpretation

Consistent with Reflexive Thematic Analysis, themes were not treated as objective features that simply emerged from the data. Rather, they were understood as interpretive constructions developed through engagement between the researcher, the data, and the theoretical framework.

The analysis therefore involved continuous reflection on how participants described their experiences and how these descriptions related to concepts from risk perception theory and socio-technical systems thinking. The objective was not merely to catalogue participant opinions but to develop an analytical understanding of the processes through which perceived safety was produced and maintained.

While the interview guide was developed deductively based on the literature review, conceptual framework and research questions, the thematic analysis remained open to new patterns emerging from the data. Consequently, the interview topics should not be interpreted as predetermined themes but rather as sensitising concepts that guided data collection. During analysis, several themes aligned closely with the initial conceptual framework, including vehicle characteristics, infrastructure characteristics and behavioural adaptation. However, other themes emerged inductively from participants' accounts. In particular, predictability emerged as a central mechanism through which cyclists interpreted interactions with new vehicle types. Rather than discussing speed heterogeneity or infrastructure characteristics in isolation, participants consistently described uncertainty regarding the behaviour of other road users as the primary determinant of perceived safety. Likewise, participants frequently described an increased need for vigilance and anticipation, resulting in greater cognitive effort while cycling. These inductively identified themes were subsequently incorporated into the analytical framework and formed an important part of the final thematic structure.

4. Results

4.1 Participant Characteristics

A total of 32 participants were interviewed for this study. Participants were purposively selected to capture variation in age, gender, cycling frequency, cycling experience, and familiarity with Dutch cycling culture. The sample included both Dutch and international cyclists ranging from younger students to older adults with decades of cycling experience. Cycling frequency varied from daily commuting to occasional use, although most participants reported cycling multiple times per week.

The diversity within the sample enabled exploration of how perceived safety is experienced across different user groups and cycling contexts. While several themes emerged consistently across participants, important differences were observed between experienced Dutch cyclists, international cyclists, older cyclists, and parents cycling with children. These differences are highlighted throughout the chapter where relevant.

The findings are organised around five interconnected themes that emerged from the analysis. First, participants described cycling as occurring within a mobility system undergoing significant change. Second, they discussed how increasing vehicle diversity generated uncertainty regarding the behaviour of other road users. Third, they described how this uncertainty influenced cognitive and emotional experiences while cycling. Fourth, participants explained how they adapted their behaviour to manage perceived risks and uncertainty. Finally, they reflected on how vehicle categories became social cues used to anticipate and interpret the behaviour of others.

Across all themes, a common process emerged. Increasing vehicle diversity appeared to influence perceived safety not primarily through the presence of specific vehicle types, but through its effects on predictability, interpretability, and the ability of cyclists to confidently anticipate interactions. The chapter therefore focuses not only on what participants experienced, but also on the mechanisms through which these experiences shaped perceptions of safety.

4.2 Cycling in a System Under Transition

4.2.1 Cycling as an Essential but Increasingly Demanding Practice

Across all 32 interviews, participants described cycling as an essential and largely positive part of everyday life. Cycling was widely perceived as efficient, convenient, healthy, and deeply embedded within Dutch mobility culture. All participants emphasised that the Dutch cycling system continues to function well and remains an attractive mode of transport for everyday travel.

At the same time, 26 of the 32 participants described cycling as becoming more demanding than in the past. Rather than portraying cycling as fundamentally unsafe, respondents referred to a gradual increase in the attention, vigilance and active management required during everyday journeys. The remaining participants also acknowledged changes in the cycling environment, although they generally characterised these as manageable and emphasised that cycling remained functional and enjoyable.

Many participants linked these developments to the growing diversity of vehicles sharing cycling infrastructure, increasing traffic density and changing behavioural patterns among road users. Rather than identifying a single cause, respondents frequently described the cumulative effect of these developments on their everyday cycling experience.

As one participant explained:

“Cycling still works really well here, but it's no longer something you do without thinking. I feel like I'm constantly scanning what everyone else is about to do.” (Female, 37)

This observation illustrates an important mechanism emerging throughout the findings. Participants did not primarily describe safety in terms of danger. Instead, they consistently discussed the increasing effort required to understand, anticipate and interpret the behaviour of surrounding road users. The findings therefore suggest that the primary change experienced by participants is not necessarily a reduction in safety, but a reduction in behavioural certainty. Cycling remains possible, attractive and functional, yet increasingly requires active interpretation and management of surrounding interactions.

4.2.2 The Transition from Automatic to Active Cycling

One of the clearest patterns emerging from the interviews was a perceived transition from what participants described as automatic cycling towards active cycling. Rather than relying on established assumptions regarding the behaviour of others, cyclists increasingly reported monitoring, interpreting, and anticipating surrounding traffic.

Participants frequently described checking behind them more often, monitoring approaching vehicles, and continuously evaluating potential conflicts. These behaviours were particularly visible among experienced Dutch cyclists who could compare current conditions with earlier cycling experiences.

“It's not that I suddenly feel unsafe all the time, but it definitely feels more stressful than it used to. There's just much more happening around you now.” (Female, 39)

Importantly, participants rarely attributed these experiences to a single vehicle category. Instead, they described a broader transformation involving increasing speed differences, greater behavioural diversity, and more complex interaction patterns.

The findings suggest that increasing vehicle diversity alters not only the physical composition of the cycling environment but also the cognitive work required to navigate it. Cycling increasingly involves anticipating the actions of others, interpreting intentions, and managing uncertainty. As a result, participants frequently portrayed cycling as becoming a more active and cognitively demanding practice.

Rather than simply travelling from one location to another, cyclists described themselves as continuously engaged in a process of monitoring and negotiation. This shift from automatic to active cycling emerged as one of the central themes underpinning subsequent findings regarding uncertainty, cognitive burden, behavioural adaptation, and perceived safety.

4.3 Emerging Vehicles as Sources of Interactional Uncertainty

4.3.1 Encountering Novel Mobility Technologies

Participants frequently described emerging vehicles as challenging established expectations regarding how interactions within the cycling environment unfold. Importantly, respondents rarely characterised these vehicles as inherently dangerous. Instead, difficulties emerged because new vehicle types disrupted existing assumptions regarding speed, manoeuvrability, positioning, and behavioural norms.

The findings suggest that emerging vehicles generate uncertainty by challenging the mental models cyclists use to interpret and anticipate the behaviour of others. Traditional cyclists, pedestrians, and motor vehicles were generally perceived as familiar categories governed by relatively stable expectations. Emerging vehicle types, by contrast, often occupied an ambiguous position between established categories, making their behaviour more difficult to interpret.

As one participant explained:

“At first I honestly didn’t really know how to react to them. They move differently from normal bikes, especially the fatbikes and scooters.” (Female, 23)

Participants repeatedly referred to situations in which they lacked confidence in their ability to anticipate acceleration patterns, overtaking behaviour, lane positioning, or compliance with cycling norms. These experiences suggest that novelty itself influences perceived safety by reducing behavioural familiarity and increasing uncertainty.

Differences between participant groups were also apparent. Experienced Dutch cyclists generally described these interactions as frustrating but manageable, whereas international cyclists more frequently described them as confusing or overwhelming. For international participants, adapting to emerging vehicles often occurred simultaneously with adapting to Dutch cycling culture more broadly.

“The old rhythm of cycling kind of made sense. Now there are so many different speeds and behaviours mixed together.” (Female, 39)

These findings indicate that participants were not simply responding to new technologies themselves. Rather, they were responding to the uncertainty generated when established behavioural expectations could no longer be relied upon.

4.3.2 The Absence of Stable Mental Models

Across all interviews, predictability emerged as one of the most important factors shaping perceived safety. Participants consistently associated feelings of safety with their ability to construct reliable expectations regarding the behaviour of surrounding road users. The findings suggest that predictability functions as a key mechanism through which perceived safety is produced.

Traditional cyclists were generally regarded as relatively predictable because participants felt familiar with the behavioural norms governing interactions within Dutch cycling environments. Shared expectations regarding overtaking, signalling, lane positioning, and speed selection enabled cyclists to anticipate future actions with a reasonable degree of confidence.

“With normal cyclists you kind of know what people are going to do. With scooters and some e-bikes, I feel like I’m guessing much more.” (Female, 62)

Importantly, participants did not describe unpredictability as a single phenomenon. Instead, three distinct forms of uncertainty emerged from the data.

The first involved unfamiliarity. Participants lacked sufficient experience interacting with certain vehicle categories and therefore found their behaviour difficult to anticipate.

The second involved inconsistency. Respondents described situations in which users of the same vehicle type behaved in markedly different ways, making it difficult to establish stable expectations.

The third involved conflicting behavioural norms. Participants frequently observed that some road users appeared to behave according to cycling conventions while others operated more like motorised traffic, creating ambiguity regarding right-of-way, overtaking behaviour, and interaction patterns.

As one participant explained:

“The difficult part isn’t only the speed. It’s that you can’t always read their intentions properly anymore.” (Male, 27)

This finding highlights an important distinction. Participants were generally willing to share infrastructure with a wide range of vehicles when their behaviour remained understandable. Difficulties emerged when intentions became difficult to interpret or behavioural patterns appeared inconsistent. Perceived safety therefore appears to depend not only on physical characteristics but also on the extent to which behaviour remains interpretable.

4.3.3 Speed as a Source of Temporal Uncertainty

Although speed differentials were mentioned throughout the interviews, participants rarely portrayed speed itself as the primary problem. Instead, speed became problematic because it reduced the time available to observe, interpret, and respond to developing situations.

The findings suggest that speed contributes to perceived risk through a process of temporal uncertainty. Faster vehicles reduced the window of time available for cyclists to assess situations, anticipate intentions, and make appropriate decisions. As interactions unfolded more rapidly, participants reported greater difficulty interpreting surrounding behaviour.

“You think someone is far away, but suddenly they’re already next to you.” (Female, 60)

Similarly, another participant explained:

“Everything happens quicker now, so you have less time to react.” (Male, 35)

Participants therefore experienced speed not only as a physical characteristic but also as a challenge to anticipation. Reduced reaction margins limited opportunities to gather information and increased the likelihood that interactions would feel uncertain or difficult to manage.

This effect appeared particularly pronounced among older cyclists and parents cycling with children. These groups frequently emphasised the importance of having sufficient time to interpret situations and respond appropriately.

“When you have children on the bike, fast overtaking suddenly feels much more serious.”
(Female, 38)

The findings therefore suggest that speed influences perceived safety primarily through its effects on interpretability and reaction time rather than through speed alone.

4.3.4 Infrastructure Constraints, Behavioural Diversity and Interaction Complexity

Participants consistently linked experiences of uncertainty to specific infrastructural contexts. Busy intersections, station environments, narrow cycle lanes, and poorly illuminated areas were repeatedly identified as locations where perceived safety concerns intensified.

The common feature across these locations was not necessarily objective danger but interaction complexity. Participants described these environments as requiring simultaneous interpretation of multiple movements, intentions, and potential conflicts.

“At busy intersections you’re constantly checking different directions at the same time.”
(Female, 27)

Similarly:

“Near the station it feels like everyone is moving differently and you’re trying to predict all of it at once.” (Male, 24)

These findings suggest that uncertainty is not generated solely by emerging vehicles or solely by infrastructure. Rather, uncertainty emerges from the interaction between increasing behavioural diversity and infrastructural conditions that make interpretation more difficult.

Participants frequently noted that infrastructure designed for relatively homogeneous bicycle traffic now accommodates users travelling at different speeds, operating different vehicle types, and following different behavioural conventions. As diversity increased, existing infrastructural constraints became more visible.

The findings therefore indicate that emerging vehicles amplify existing interactional pressures within cycling environments rather than creating entirely new challenges. Perceived safety appears to depend not only on the physical characteristics of infrastructure but also on its capacity to support understandable and manageable interactions between increasingly diverse users.

Participants did not attribute increasing interaction complexity solely to infrastructure constraints or the presence of additional vehicle types. Many also perceived changes in the behaviour of other road users. Respondents frequently described surrounding traffic as becoming less predictable due to greater variation in riding styles, speeds and interaction norms. Several participants observed that some cyclists and riders appeared more likely to overtake unexpectedly, travel at higher speeds, or make manoeuvres that were more difficult to anticipate than in the past. Rather than identifying one specific user group as responsible,

participants generally described a broader shift towards greater behavioural diversity within the cycling environment. This increased behavioural variability was repeatedly linked to the greater cognitive effort required to interpret the intentions of surrounding road users and contributed to the overall complexity of everyday cycling. Across the interviews, the majority of participants associated increasing interaction complexity not only with greater traffic volumes but also with changes in the behaviour of surrounding road users.

4.4 Cognitive Burden, Emotional Responses and the Experience of Uncertainty

4.4.1 Cognitive Burden and Continuous Vigilance

One of the strongest themes emerging from the interviews was the increasing cognitive burden associated with everyday cycling. Participants repeatedly described safety as requiring continuous monitoring, interpretation, and anticipation of surrounding behaviour. The findings suggest that uncertainty is experienced not only emotionally but also cognitively, increasing the mental effort required to participate in the cycling environment.

Rather than describing cycling as inherently dangerous, respondents frequently portrayed it as mentally demanding. Maintaining a sense of safety appeared to require constant assessment of surrounding traffic, interpretation of intentions, and anticipation of potential conflicts. Participants often explained that they no longer felt able to rely on established assumptions regarding the behaviour of other road users.

As one participant explained:

“I notice that I arrive more mentally tired after cycling through the city now.” (Female, 34)

Similarly, another participant noted:

“You can’t really switch off anymore while cycling.” (Male, 41)

These comments reveal an important mechanism through which uncertainty influences perceptions of safety. Participants did not necessarily feel unsafe because collisions were likely. Instead, they felt that safety increasingly depended upon their ability to continuously monitor and manage uncertainty within the surrounding environment.

Across the interviews, respondents described checking behind them more frequently, monitoring speed differences more actively, and paying closer attention to the behaviour of others. These actions were often presented as necessary responses to increasing complexity rather than conscious safety strategies.

Importantly, participants frequently evaluated cycling environments according to the amount of effort required to remain safe. Environments that demanded continuous vigilance were often experienced as less comfortable and less safe, even when no incidents occurred. This finding suggests that perceived safety extends beyond objective risk and includes the cognitive demands associated with navigating everyday traffic situations.

The data therefore indicate that increasing vehicle diversity influences cycling experiences not only through physical interactions but also through the mental effort required to interpret and anticipate those interactions.

4.4.2 Emotional Responses to Increasing Complexity

In addition to cognitive burden, participants described a range of emotional responses associated with navigating increasingly diverse cycling environments. Stress, frustration, irritation, and fear emerged throughout the interviews, although these emotions were often linked to uncertainty rather than direct experiences of danger.

The findings suggest that emotional responses were most likely to emerge when participants felt unable to confidently anticipate the behaviour of surrounding road users. Situations characterised by ambiguity, inconsistency, or limited reaction time frequently generated feelings of discomfort and tension.

“It’s not one thing that makes it stressful. It’s everything happening at the same time.” (Female, 39)

This observation illustrates how emotional responses often emerged from the cumulative management of multiple uncertainties rather than from a single identifiable threat. Participants frequently described feeling mentally overloaded by the need to monitor numerous vehicles, interpret different behavioural patterns, and continuously adjust their actions.

Frustration was particularly common in situations where participants perceived the behaviour of others as difficult to understand or inconsistent with established norms. Delivery scooters, unsafe overtaking manoeuvres, and blocked cycle lanes were frequently cited as sources of irritation because they disrupted expectations regarding how interactions should unfold.

Fear was reported less frequently than stress or frustration, but when present it was often associated with situations involving reduced reaction margins, close overtaking, or increased vulnerability. Older cyclists and parents cycling with children were particularly likely to describe these experiences.

“When it’s just me, I can usually deal with it. When my child is with me, I notice that I experience those situations very differently.” (Female, 38)

Differences between participant groups were also evident. Experienced Dutch cyclists often framed stressful interactions as manageable challenges requiring adaptation. International cyclists more frequently described uncertainty and anxiety resulting from unfamiliar interaction patterns. Older participants frequently emphasised reduced confidence when navigating situations involving high speeds or complex interactions.

Taken together, these findings suggest that emotional responses are closely linked to cyclists' perceived ability to understand and manage their environment. Feelings of stress, frustration, and fear often emerged when participants felt unable to confidently interpret the actions of others.

4.4.3 Cumulative Strain and the Normalisation of Risk

A particularly important finding concerns the cumulative nature of perceived safety. Participants rarely identified a single incident as the primary source of concern. Instead, many described a gradual process through which repeated experiences of uncertainty, near-conflict, and behavioural ambiguity influenced how safe they felt while cycling.

Nearly all participants reported experiencing safety-critical situations such as close overtaking, blocked cycle lanes, unexpected manoeuvres, conflicts at intersections, or situations requiring evasive action. However, these experiences were rarely discussed as isolated events. Rather, respondents frequently portrayed them as relatively common features of everyday cycling.

“Those moments happen surprisingly often actually.” (Male, 30)

Importantly, participants generally did not interpret these experiences as evidence that the cycling system was fundamentally unsafe. Instead, many appeared to normalise these events as part of contemporary cycling practice. This normalisation process was visible in the way respondents described adapting their expectations and behaviour over time.

“You start expecting conflict before it even happens.” (Male, 52)

The significance of these experiences appeared to lie less in their severity than in their repetition. Participants frequently emphasised that individual incidents mattered because they formed part of a broader pattern of uncertainty and vigilance.

“It’s not one dramatic event. It’s that the same stressful situations keep happening over and over.” (Male, 68)

Several respondents also attached greater importance to near-misses than to actual collisions. Situations in which harm was narrowly avoided often generated strong emotional reactions because they reinforced feelings of vulnerability and uncertainty.

“It didn’t hit me, but afterwards your body still reacts like something serious almost happened.” (Female, 24)

The findings therefore suggest that perceived safety is shaped not only by major incidents but also by the accumulation of smaller experiences that require attention, interpretation, and behavioural adjustment. Repeated exposure to uncertainty appeared to contribute to a broader sense of strain that influenced how participants experienced the cycling environment as a whole.

This finding highlights the importance of considering everyday interactions when examining perceived safety. Participants rarely based their assessments solely on crashes or severe incidents. Instead, perceptions of safety emerged through repeated experiences of managing uncertainty during routine journeys.

Across participants, these accounts suggested that increasing technological diversity had changed the character of everyday cycling itself. Rather than describing cycling as an automatic activity performed with little conscious effort, participants increasingly portrayed it as requiring continuous monitoring, interpretation, and anticipation of surrounding road users. This perceived transition from automatic to active cycling emerged as one of the central mechanisms through which interactional uncertainty influenced perceptions of safety and provided an important bridge to the behavioural adaptations discussed in the following section.

4.5 Behavioural Adaptation as a Response to Uncertainty

4.5.1 Defensive Cycling and Increased Vigilance

Participants consistently reported adapting their behaviour in response to changing traffic conditions. The most common adaptation involved adopting a more defensive cycling style characterised by increased vigilance, greater caution, and more deliberate decision-making. The findings suggest that defensive cycling functions as a mechanism through which cyclists attempt to manage uncertainty and maintain a sense of control within an increasingly complex environment.

Respondents frequently described reducing speed in uncertain situations, increasing following distances, checking blind spots more frequently, and allowing additional time for interactions to unfold. These behaviours were rarely described as formal safety strategies. Instead, participants portrayed them as gradual adaptations that had developed through repeated exposure to situations they perceived as difficult to anticipate.

“I definitely ride more defensively than I used to.” (Female, 39)

Similarly, another participant explained:

“I’m constantly checking what others are about to do now.” (Female, 28)

Importantly, these adaptations were not necessarily driven by fear. Participants generally viewed defensive cycling as a practical response to uncertainty. Increased vigilance enabled cyclists to compensate for situations in which the intentions or behaviour of others could not be confidently predicted.

The findings therefore suggest that behavioural adaptation serves an important regulatory function. By modifying their behaviour, cyclists attempt to restore predictability and reduce the uncertainty associated with increasingly diverse traffic environments. Defensive cycling can thus be understood as a strategy through which participants actively manage perceived safety.

4.5.2 Route Selection and Situational Avoidance

In addition to adapting behaviour during interactions, participants frequently described modifying where and when they cycled. Route selection emerged as one of the most common strategies for regulating exposure to uncertainty.

Rather than responding only to immediate situations, cyclists actively shaped their exposure to environments perceived as difficult to interpret or manage. Busy station areas, congested intersections, narrow cycling lanes, and poorly illuminated routes were frequently identified as locations participants sought to avoid when alternatives were available.

“I avoid the station area during rush hour whenever I can.” (Male, 24)

Others reported adjusting the timing of journeys in order to reduce interaction complexity.

“If it’s too busy, I sometimes just choose another way or don’t cycle at all.” (Female, 24)

The findings suggest that route selection and avoidance function as mechanisms through which cyclists regulate exposure to uncertainty. Rather than attempting to manage every interaction

directly, participants often reduced encounters with situations they expected to be difficult, stressful, or unpredictable.

Avoidance behaviours were particularly common among international cyclists, older participants, and those who described themselves as less confident riders. These groups frequently reported avoiding locations associated with high levels of behavioural diversity, speed differences, or congestion.

Importantly, participants rarely portrayed these decisions as evidence of fear. Instead, route modifications were often presented as rational and efficient responses to environments requiring disproportionate effort to navigate. Through route selection and avoidance, cyclists sought to preserve feelings of control while maintaining cycling as a viable mode of transport.

4.5.3 Selective Withdrawal and Unequal Consequences

Although most participants remained committed cyclists, the interviews revealed evidence of more substantial forms of adaptation. Some respondents described reducing their cycling frequency, avoiding specific types of trips, or considering alternative modes of transport under certain conditions.

The findings suggest that adaptation occurs along a continuum ranging from minor behavioural adjustments to selective withdrawal from particular situations. Importantly, these more substantial adaptations were most commonly observed among participants who described themselves as more vulnerable or less confident cyclists.

“At night I’m much more selective about where I cycle now.” (Female, 33)

Similarly, another participant explained:

“There are some routes where I simply prefer taking another mode of transport now.” (Male, 23)

A particularly notable finding was that these decisions were rarely linked to single negative experiences. Instead, participants described selective withdrawal as a consequence of repeated exposure to uncertainty, stress, and situations requiring continuous adaptation.

Older cyclists frequently discussed reduced confidence when interacting with fast-moving vehicles or navigating highly congested environments. Parents cycling with children often described a lower tolerance for uncertainty because interactions carried greater perceived consequences. International cyclists sometimes reported avoiding locations where local interaction norms felt difficult to interpret.

These findings indicate that the consequences of increasing uncertainty are not evenly distributed across user groups. Experienced Dutch cyclists often described uncertainty as manageable and possessed extensive knowledge of local cycling norms that supported adaptation. In contrast, less experienced or more vulnerable cyclists were more likely to rely on avoidance strategies and selective withdrawal.

The findings therefore suggest that behavioural adaptation is not always a neutral process. While adaptation enables many cyclists to continue participating in the cycling system, it also

places additional demands on users. The need to continuously modify behaviour, avoid certain environments, or restrict participation can itself be understood as a form of burden.

Consequently, perceived safety is influenced not only by whether cyclists are able to adapt, but also by the effort required to do so. This observation highlights an important equity dimension of cycling safety, as increasing complexity may disproportionately affect those with fewer resources, less experience, or greater vulnerability.

Although participants generally regarded these behavioural adaptations as effective strategies for maintaining safety, they also highlighted the effort required to sustain them. Rather than representing isolated responses to particular situations, defensive cycling, route modifications, and increased vigilance had become integrated into many participants' everyday travel routines. These findings suggest that behavioural adaptation should not only be understood as a response to perceived risk but also as evidence of the increasing demands associated with navigating increasingly heterogeneous cycling environments.

4.6 Social Categorisation and Mental Models of Road Users

4.6.1 Vehicle Types as Heuristics for Managing Uncertainty

The findings indicate that cyclists frequently use vehicle categories as cognitive heuristics when interpreting and anticipating the behaviour of others. Rather than evaluating every interaction independently, participants often relied on vehicle types as signals from which behavioural expectations could be inferred. This suggests that social categorisation functions as a practical strategy for managing uncertainty within increasingly complex cycling environments.

Throughout the interviews, participants frequently described not only vehicles themselves but also assumptions regarding the people operating them. These assumptions influenced expectations regarding competence, predictability, rule compliance, and risk-taking behaviour. Vehicle categories therefore served as interpretive tools through which cyclists attempted to make sense of uncertain interactions.

Traditional cyclists were generally associated with familiarity and shared behavioural norms. E-bike users were frequently perceived as practical commuters, while cargo bike users were often associated with parents and family transport. In contrast, fatbikes, delivery scooters, and some emerging mobility technologies were more frequently associated with uncertainty regarding behaviour and interaction patterns.

One participant explained:

“When I see a normal cyclist, I kind of know what to expect. With some of the newer vehicles, I don't really have that feeling.” (Female, 37)

Table 4: Participant associations and perceived behavioural expectations of different vehicle types

<i>Vehicle Type</i>	<i>Common Participant Associations</i>	<i>Perceived Implications for Safety</i>

<i>Traditional Cyclists</i>	Experienced users operating within established cycling norms and informal rules	High predictability and trust. Behaviour is generally easy to anticipate and interpret.
<i>Electric Bike</i>	Commuters, older adults, and efficiency-oriented cyclists	Higher speeds reduce reaction margins, but behaviour is generally perceived as predictable and rule-compliant.
<i>Fatbike</i>	Younger riders, recreational users, and individuals perceived as less experienced	Uncertainty regarding speed choice, risk awareness, and adherence to informal cycling norms.
<i>Speed Pedelec</i>	Fast commuters travelling longer distances	Very high speeds increase overtaking conflicts and reduce the time available to interpret interactions.
<i>Scooter</i>	Motorised users operating between cycling and motor traffic environments	Perceived ambiguity regarding lane positioning, speed, and interaction norms.
<i>Delivery Scooter</i>	Riders operating under commercial time pressure and delivery deadlines	Expectations of urgency, aggressive manoeuvring, and increased likelihood of risk-taking behaviour.
<i>City Car</i>	Small urban vehicles competing for limited road space in dense environments	Potential source of conflicts at intersections and crossings due to differences in size, speed, and visibility.
<i>Delivery Van</i>	Commercial and logistical activity associated with loading and unloading operations	Obstruction of cycling infrastructure, blocked cycle lanes, and disruption of normal traffic flows.
<i>Recumbent Bike</i>	Niche and uncommon vehicle type with limited visibility in everyday traffic	Difficult to detect and anticipate due to unfamiliar appearance and low profile.
<i>Cargo Bike</i>	Parents, families, and users transporting goods or children	Occupy more space and can restrict overtaking opportunities, but generally perceived as cautious and predictable.
<i>E-Step</i>	Tourists, inexperienced users, and occasional riders	Uncertainty regarding stability, trajectory, and compliance with cycling norms, resulting in reduced predictability.

Importantly, these perceptions should not be interpreted as objective assessments of actual behaviour. Rather, they reveal how cyclists construct expectations in order to reduce uncertainty and navigate interactions efficiently. Vehicle categories became cognitive shortcuts that allowed participants to form rapid judgements regarding likely behaviour, particularly in situations where time for interpretation was limited.

The findings therefore suggest that social categorisation is closely linked to perceived safety. Cyclists appear to rely on categorisation processes to compensate for uncertainty, using vehicle types as indicators of how interactions are likely to unfold.

4.6.2 Trust, Competence and Behavioural Interpretability

Trust emerged as a central factor shaping perceptions of safety. Participants frequently described evaluating whether surrounding road users appeared competent, predictable, and familiar with cycling norms. Trust was therefore closely linked to behavioural interpretability rather than to vehicle characteristics alone.

Road users perceived as experienced, attentive, and familiar with the cycling environment were generally viewed as less threatening, regardless of vehicle type. Conversely, participants often expressed concern when they perceived riders as inexperienced, distracted, or unfamiliar with local traffic conventions.

Several participants discussed e-bike users as relatively predictable despite travelling at higher speeds because they were perceived as operating within recognisable behavioural norms. Cargo bike users were similarly viewed as generally cautious and attentive despite occupying more space within the cycling environment.

“Cargo bikes take up a lot of space, but usually you can tell what they're trying to do.” (Male, 35)

This observation highlights an important finding. Participants did not necessarily associate perceived risk with vehicle size or speed. Instead, concerns emerged when intentions became difficult to interpret or when behavioural expectations appeared unreliable.

Trust therefore appears to function as a consequence of interpretability. Cyclists felt safer around road users whose actions could be anticipated and whose behaviour aligned with familiar norms. Perceived competence was evaluated not only through what individuals did, but also through how understandable their behaviour appeared to others.

The findings suggest that perceived safety is influenced by the extent to which cyclists believe they can successfully interpret surrounding behaviour. Trust, predictability, and interpretability therefore emerge as closely interconnected components of everyday cycling experiences.

4.6.3 Stereotypes, Expectations and Behavioural Assumptions

The interviews also revealed the presence of shared stereotypes regarding particular vehicle-user combinations. Fatbike riders, delivery scooter operators, and some e-step users were frequently associated with specific behavioural expectations. However, these stereotypes functioned less as factual claims and more as practical heuristics through which cyclists attempted to anticipate behaviour.

Fatbike riders were often associated with younger users and higher speeds. Delivery scooter operators were frequently linked to commercial time pressures and urgency. E-step users were sometimes associated with inexperience or unfamiliarity with local cycling norms.

“You often assume they don't fully realise how risky their speed actually is.” (Male, 20)

Similarly, participants frequently interpreted delivery scooter behaviour through broader assumptions regarding delivery deadlines and commercial pressures.

“It feels like they're under pressure to get somewhere as quickly as possible.” (Male, 41)

Importantly, respondents rarely presented these assumptions as objective truths. Rather, they described them as expectations that influenced how they approached interactions. These expectations appeared to help cyclists make rapid decisions in situations characterised by uncertainty and limited information.

The findings therefore suggest that perceived safety is shaped not only by direct experiences but also by broader social narratives regarding different categories of road users. Cyclists continuously construct and revise mental models that help them anticipate behaviour and navigate increasingly diverse traffic environments.

From this perspective, social categorisation can be understood as an adaptive response to uncertainty. Vehicle categories become tools through which cyclists attempt to restore predictability within a mobility environment characterised by increasing behavioural diversity.

4.7 Synthesis of Findings

Across all participant groups, the findings suggest a common process through which perceived cycling safety is produced. While participants discussed a wide variety of vehicle types, situations, and experiences, a consistent pattern emerged regarding how these experiences were interpreted and managed.

Participants rarely described emerging vehicles as isolated safety hazards. Instead, they portrayed them as contributors to a broader transformation of the cycling environment. Increasing vehicle diversity introduced greater variation in speeds, manoeuvrability, interaction styles, and behavioural norms. As a result, cyclists frequently reported difficulty forming stable expectations regarding the behaviour of surrounding road users.

The most consistent finding throughout the interviews was therefore the central role of interactional uncertainty. Participants repeatedly associated feelings of safety with their ability to understand, anticipate, and interpret the actions of others. When behavioural expectations became less reliable, uncertainty increased and perceptions of safety declined.

As uncertainty increased, participants reported greater cognitive burden. Cycling was increasingly described as requiring active monitoring, continuous interpretation, and heightened vigilance. Rather than functioning as an automatic activity, cycling became a process of ongoing assessment and negotiation. Participants frequently described the need to monitor multiple sources of information simultaneously while continuously adapting to changing traffic situations.

These cognitive demands were accompanied by emotional responses including stress, frustration, irritation, and, in some cases, fear. Importantly, these emotions rarely emerged from single incidents. Instead, participants described a cumulative process through which repeated experiences of uncertainty, near-conflict, and behavioural ambiguity gradually contributed to emotional strain.

In response, cyclists developed a range of behavioural adaptation strategies. These included defensive cycling, route modification, avoidance of specific environments, temporal adjustments, and selective withdrawal from situations perceived as particularly demanding. Such adaptations enabled many participants to maintain acceptable levels of perceived safety despite increasing complexity within the cycling environment.

However, the findings also indicate that the consequences of uncertainty are not evenly distributed. Older cyclists, international cyclists, parents cycling with children, and less confident riders were more likely to describe avoidance behaviours and selective withdrawal. These groups often experienced uncertainty as more burdensome and reported greater difficulty adapting to increasingly complex traffic conditions.

Taken together, the findings suggest the following process through which perceived cycling safety is produced:

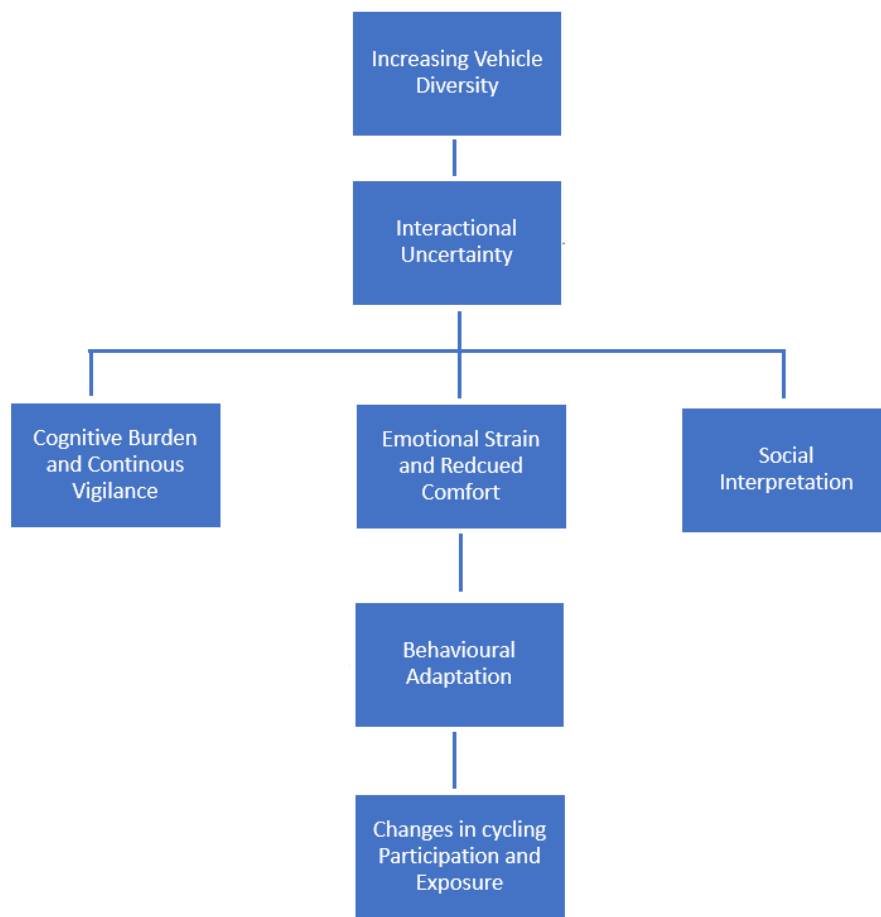


Figure 2: Process model of perceived cycling safety in a transforming urban mobility environment

This process was observed across participant groups, although its consequences varied according to age, experience, familiarity with Dutch cycling culture, and perceived vulnerability.

The findings therefore suggest that interactional uncertainty functions as the central organising concept linking the six themes identified throughout the analysis. Rather than representing independent dimensions of cyclists' experiences, cognitive burden, trust and interpretability, adaptive burden, cumulative strain, and social categorisation all emerged as interconnected responses to increasing uncertainty regarding the behaviour of surrounding road users. This interactional perspective illustrates how perceived safety is continuously produced through cyclists' efforts to interpret, anticipate, and negotiate increasingly diverse traffic environments, providing the conceptual foundation for the discussion presented in Chapter 5.

5. Discussion

5.1 Perceived Safety as Interactional Uncertainty

One of the central findings of this study is that cyclists rarely described emerging vehicles as inherently dangerous. Instead, participants consistently associated reductions in perceived safety with increasing uncertainty surrounding the behaviour of other road users. Rather than focusing on individual vehicle categories, cyclists emphasised the growing difficulty of interpreting intentions, anticipating manoeuvres, and predicting how others would behave within increasingly heterogeneous cycling environments. Perceived safety therefore emerged primarily through interactional processes rather than through the objective characteristics of particular vehicles.

This finding aligns with previous empirical research demonstrating that cyclists construct perceptions of safety through everyday interactions rather than objective crash risk alone. Bösehans and Massola (2018), for example, found that cyclists in São Paulo evaluated safety largely through previous experiences, behavioural uncertainty, and interactions with surrounding traffic. Participants in their study described feelings of vulnerability, the need for constant vigilance, and the importance of anticipating the actions of others. Similar processes were evident in the present study. Participants rarely referred to infrastructure or vehicle characteristics in isolation; instead, they consistently explained that uncertainty regarding the intentions of surrounding road users determined whether situations felt safe or unsafe.

The present findings also support broader qualitative work suggesting that cyclists interpret safety through trust, behavioural expectations, and familiarity rather than objective measures of risk (Gössling & McRae, 2022; Marincek, 2023). Across the interviews, participants frequently explained that interactions became stressful when the behaviour of others could no longer be confidently anticipated. This uncertainty arose not simply because new vehicles were present, but because greater diversity in vehicle speeds, manoeuvrability, rider experience, and behavioural norms made interactions increasingly difficult to interpret. Consequently, cyclists described perceived safety as emerging from the quality of interactions rather than from exposure to specific vehicle types.

At the same time, the present study extends previous empirical research in several important ways. Earlier studies have predominantly examined cyclists' interactions with motor vehicles or have focused on individual emerging transport modes such as e-bikes or e-scooters. By contrast, participants in this study rarely distinguished between specific vehicle categories when explaining why they felt unsafe. Instead, they described the cumulative consequences of increasing technological diversity within bicycle lanes. Conventional bicycles, fatbikes, speed pedelecs, cargo bicycles, delivery riders, scooters, and other road users collectively contributed to an environment in which behavioural expectations became less stable and interactions more difficult to predict.

This finding suggests that the principal challenge associated with emerging mobility technologies may not be the objective risks posed by individual vehicles but the interactional uncertainty created when multiple vehicle types coexist within infrastructure originally designed for relatively homogeneous bicycle traffic. Rather than conceptualising perceived safety as an

outcome of individual technologies, the findings indicate that it is more appropriately understood as an emergent property of increasingly complex interactions within a changing socio-technical mobility system.

From the perspective of risk perception theory, this finding reinforces the importance of uncertainty as a key determinant of perceived safety (Slovic, 1987). However, the present study moves beyond traditional interpretations of risk perception by demonstrating that uncertainty is not experienced solely as uncertainty about the probability of a crash. Instead, cyclists described uncertainty as a continuous process of interpreting social behaviour, negotiating shared space, and anticipating the actions of others. Perceived safety therefore appears to be produced through ongoing interaction rather than simply through assessments of objective danger.

Taken together, these findings suggest that maintaining perceived safety within future cycling environments will depend less on accommodating individual vehicle types and more on preserving behavioural predictability between increasingly diverse road users. As bicycle lanes continue to evolve, ensuring that interactions remain understandable and interpretable may become as important as reducing objective crash risks.

5.2 Predictability, Trust and Interpretability

A second important finding concerns the role of predictability in shaping cyclists' perceptions of safety. Across the interviews, participants consistently explained that they felt comfortable when they could anticipate how other road users were likely to behave, even when travelling in relatively busy environments. Conversely, situations became stressful when behavioural intentions were unclear or when cyclists encountered road users whose actions appeared inconsistent with established expectations. Predictability therefore emerged as a fundamental condition for perceived safety, allowing cyclists to make rapid and confident decisions while navigating increasingly complex bicycle lanes.

This finding is consistent with previous empirical research demonstrating that cyclists rely heavily on expectations regarding the behaviour of others when evaluating safety. Bösehans and Massola (2018) observed that cyclists frequently interpreted traffic situations through previous experiences, using familiarity with common behavioural patterns to anticipate potential conflicts. Likewise, participants in the present study rarely described objective speed or vehicle size as inherently problematic. Instead, they emphasised uncertainty surrounding how other road users would behave, particularly when approaching intersections, overtaking, or navigating crowded bicycle lanes. These findings reinforce the idea that behavioural predictability plays a central role in shaping cyclists' subjective experiences of safety.

The findings also resonate with Griffin et al. (2020), who demonstrated that road users with substantial cycling experience identify and interpret hazards differently from those with limited cycling experience. Rather than simply perceiving lower levels of risk, experienced cyclists appear to develop more sophisticated strategies for recognising behavioural cues and anticipating potentially hazardous situations. A similar pattern emerged in the present study. Experienced Dutch cyclists generally described feeling capable of navigating increasingly diverse cycling environments, despite recognising that these environments had become more demanding over time. Their confidence did not stem from believing the environment had

become safer, but from their accumulated ability to interpret subtle behavioural signals, anticipate conflicts, and respond proactively.

In contrast, less experienced participants, particularly international cyclists unfamiliar with Dutch cycling culture, often reported greater uncertainty when interpreting the behaviour of surrounding road users. Many described difficulties understanding informal cycling norms, anticipating overtaking behaviour, or predicting how different vehicle users would respond in shared spaces. Rather than lacking technical cycling skills, these participants frequently lacked the contextual knowledge required to interpret interactions confidently. This suggests that predictability depends not only on observable behaviour but also on shared understandings of informal traffic conventions and expectations.

These findings also extend existing research on trust within transport systems. Previous studies have shown that trust in other road users contributes to perceptions of safety because it reduces the need for constant monitoring and allows individuals to assume that others will behave in expected ways (Gössling & McRae, 2022). The present study provides a more detailed explanation of how this trust operates during everyday cycling. Participants repeatedly described trust as something that had to be actively established through the interpretability of others' behaviour. When actions aligned with familiar behavioural patterns participants reported feeling able to predict interactions and maintain a sense of control. Conversely, unexpected manoeuvres or ambiguous behaviour quickly undermined trust, increasing both perceived uncertainty and mental effort.

An important contribution of this study is therefore the distinction between vehicle familiarity and behavioural familiarity. Existing discussions surrounding emerging mobility technologies often assume that unfamiliar vehicle types are themselves responsible for reducing perceived safety. However, participants in this study demonstrated that unfamiliarity alone was rarely sufficient to produce discomfort. Several respondents reported feeling comfortable interacting with fast e-bikes or cargo bicycles when their operators behaved in predictable ways. Conversely, conventional bicycles were sometimes described as equally problematic when ridden unpredictably or without regard for informal cycling norms. This finding suggests that behavioural consistency is considerably more important than vehicle category in determining whether interactions are experienced as safe.

From a socio-technical perspective, these findings illustrate that successful integration of emerging mobility technologies depends not only on accommodating new vehicles within existing infrastructure but also on preserving shared behavioural expectations among increasingly diverse users. Technologies become disruptive not simply because they differ technically from conventional bicycles, but because they introduce uncertainty into interaction patterns that have historically relied upon relatively stable and widely understood behavioural norms. As the diversity of users continues to increase, maintaining behavioural predictability may therefore become a central challenge for cycling policy and infrastructure design.

Taken together, these findings suggest that predictability functions as a key mechanism linking technological diversity to perceived safety. Rather than evaluating objective risks alone, cyclists continuously interpret behavioural cues, establish trust in surrounding road users, and anticipate likely actions before deciding how to respond. Perceived safety therefore emerges

not from the absence of risk but from the ability to confidently understand and interpret the behaviour of others within increasingly heterogeneous cycling environments.

5.3 Cognitive Burden and the End of Automatic Cycling

A third important finding of this study is that increasing technological diversity changes not only how cyclists evaluate safety but also how they experience the act of cycling itself. Across the interviews, participants repeatedly described cycling as becoming increasingly mentally demanding. Rather than simply identifying more hazards, they explained that they now devoted considerably more attention to interpreting the behaviour of surrounding road users, anticipating possible manoeuvres, and continuously monitoring the traffic environment. Cycling therefore appeared to require substantially greater cognitive effort than participants felt had been necessary in the past.

This finding complements previous empirical research suggesting that cyclists' perceptions of safety are shaped by continuous interpretation of their surroundings. Bösehans and Massola (2018) observed that cyclists frequently described remaining constantly alert while navigating urban traffic, particularly following previous negative experiences. Similarly, Gössling and McRae (2022) argue that perceived safety is strongly influenced by cyclists' confidence in understanding and anticipating surrounding traffic conditions. Participants in the present study described comparable processes, but extended these observations by explaining that increasing diversity within bicycle lanes has fundamentally altered the cognitive demands associated with everyday cycling.

Importantly, participants rarely attributed this increased mental effort to a single vehicle type. Instead, they described an environment characterised by greater behavioural variability, speed differences, and uncertainty regarding how different road users might act. Many explained that they were no longer able to rely upon previously established expectations when interacting with surrounding traffic. Instead, each encounter required continuous interpretation and reassessment of the intentions of other road users.

Several participants described this change as a transition from what they regarded as "automatic cycling" towards a much more deliberate and conscious activity. Experienced cyclists often explained that cycling had previously required relatively little conscious thought because interactions with other cyclists generally followed familiar behavioural patterns. As one participant noted, cycling had once been something they could do "almost without thinking," whereas they now felt compelled to monitor their surroundings continuously and actively anticipate the behaviour of others.

This transition from automatic to active cycling represents an important extension of previous empirical work. Existing studies have demonstrated that cyclists adapt their behaviour in response to perceived risk and changing traffic conditions (Kummeneje & Rundmo, 2020; Bösehans & Massola, 2018), yet comparatively little attention has been devoted to the cognitive processes that precede these behavioural adaptations. The present findings suggest that behavioural adaptation is only the visible outcome of a broader cognitive process in which cyclists first interpret uncertainty, evaluate possible scenarios, and decide whether behavioural adjustments are necessary. Increased vigilance therefore represents not simply a behavioural

response but evidence of a fundamental increase in the cognitive work required to navigate contemporary cycling environments.

The findings also highlight important differences between participant groups. Experienced Dutch cyclists frequently described increased mental effort while simultaneously expressing confidence in their ability to cope with changing traffic conditions. Their familiarity with Dutch cycling culture appeared to enable them to process increasingly complex interactions without substantially reducing their willingness to cycle. In contrast, international cyclists and participants with relatively limited cycling experience often described this increased cognitive demand as overwhelming. Many explained that the need to constantly interpret unfamiliar behaviours reduced their confidence and increased feelings of stress, particularly in busy urban environments. These findings suggest that cognitive burden is not experienced equally across cyclists but depends on previous experience, familiarity with local behavioural norms, and confidence in interpreting surrounding traffic.

From a risk perception perspective, these findings indicate that uncertainty generates more than heightened perceptions of danger; it also changes the cognitive processes through which cyclists interact with their environment. Traditional interpretations of risk perception emphasise how individuals evaluate the likelihood and severity of potential hazards (Slovic, 1987). However, the present findings suggest that increasing technological diversity influences perceived safety by increasing the mental effort required to make these evaluations in the first place. Cyclists described constantly scanning their surroundings, interpreting ambiguous behaviour, and preparing for multiple possible outcomes before deciding how to act. Consequently, perceived safety appears to depend not only on objective traffic conditions but also on whether the cognitive demands of navigating those conditions remain manageable.

Viewed from a socio-technical perspective, these findings illustrate that technological innovation alters mobility systems not only by changing infrastructure use or traffic composition but also by reshaping the cognitive relationship between users and their environment. As bicycle lanes accommodate increasingly diverse vehicle types, successful integration depends not only on reducing objective safety risks but also on limiting unnecessary cognitive complexity. Transport systems that require users to devote excessive attention to interpreting interactions may remain objectively safe while nevertheless being experienced as mentally demanding and psychologically stressful.

Taken together, these findings suggest that cognitive burden forms a crucial mechanism linking technological diversity to perceived safety. Rather than simply making cycling objectively more dangerous, increasing behavioural diversity transforms cycling from an activity that many participants once experienced as largely automatic into one requiring continuous interpretation, anticipation, and conscious decision-making. Maintaining behavioural predictability may therefore reduce not only objective conflicts but also the cognitive effort required to navigate increasingly heterogeneous cycling environments.

5.4 Adaptive Burden and Unequal Consequences

One of the clearest behavioural consequences of increasing interactional uncertainty was the wide range of adaptive strategies participants employed to maintain a sense of safety while

cycling. Across the interviews, respondents described continuously modifying their behaviour in response to changing traffic conditions. These adaptations included reducing speed, increasing following distances, selecting alternative routes, avoiding busy cycling corridors, delaying journeys, and adopting more defensive riding styles. Rather than representing isolated responses to particularly dangerous situations, these behavioural adjustments had become integrated into participants' everyday cycling routines.

These findings are consistent with previous empirical research demonstrating that cyclists modify their behaviour according to perceived rather than objective levels of risk. Kummeneje and Rundmo (2020), for example, found that Norwegian cyclists reporting higher levels of perceived risk generally adopted more cautious riding behaviours and engaged in fewer deliberate risk-taking practices. Similarly, Bösehans and Massola (2018) observed that previous negative experiences encouraged cyclists to become increasingly defensive when navigating complex urban traffic. Together, these studies demonstrate that behavioural adaptation is a common response to perceived uncertainty.

The present study supports these findings while providing a more detailed understanding of the processes through which behavioural adaptation develops. Participants rarely described consciously calculating risks before deciding how to respond. Instead, adaptations emerged gradually through repeated experiences of uncertainty, increasing vigilance, and the accumulation of interactions that required greater cognitive effort. Behavioural changes therefore appeared not as isolated decisions but as the outcome of an ongoing process through which cyclists continuously attempted to restore a manageable level of predictability within increasingly heterogeneous cycling environments.

Importantly, participants did not perceive these adaptations as neutral adjustments. Many described them as burdensome because they required additional planning, concentration, and behavioural restraint during journeys that had previously been relatively effortless. Choosing longer routes to avoid busy intersections, reducing cycling speed to create additional reaction time, or avoiding cycling during peak traffic periods frequently resulted in increased travel time, reduced convenience, and diminished enjoyment of cycling. Behavioural adaptation therefore functioned not only as a protective strategy but also as an indicator that participants perceived the cycling environment as becoming more demanding.

A particularly important finding concerns the unequal distribution of this adaptive burden. While almost all participants reported modifying their behaviour to some extent, the extent and consequences of these adaptations differed substantially between participant groups. Experienced Dutch cyclists generally described behavioural adjustments as relatively minor modifications that enabled them to continue cycling with confidence despite recognising increasing complexity. Their familiarity with Dutch cycling norms and extensive cycling experience appeared to support efficient interpretation of interactions, allowing them to maintain relatively stable cycling habits.

In contrast, international cyclists, less experienced cyclists, older participants, and parents cycling with children frequently described much more substantial adaptations. Several participants explained that they actively avoided particular routes, reduced the frequency of cycling, or relied on alternative modes of transport under certain conditions. These respondents

often perceived themselves as having fewer resources with which to manage increasing interactional complexity, resulting in greater reliance on avoidance-based coping strategies. Similar differences have previously been reported in studies showing that less experienced cyclists generally report lower levels of perceived safety and confidence (Griffin et al., 2020; Møller & Hels, 2008). However, the present findings extend this work by illustrating how these differences are translated into everyday mobility decisions through repeated experiences of uncertainty and cognitive effort.

These observations also contribute to ongoing discussions regarding behavioural adaptation within transport safety research. Traditional interpretations of behavioural adaptation, including Risk Homeostasis Theory (Wilde, 1982), often conceptualise adaptation as a process through which individuals maintain a preferred level of risk. While this perspective remains valuable, participants in the present study rarely described attempting to optimise or balance risk consciously. Instead, they consistently framed behavioural adaptation as an attempt to preserve a sense of comfort, predictability, and control while cycling. The primary objective was not to maintain a particular level of acceptable risk but to minimise uncertainty regarding the behaviour of others.

From a socio-technical perspective, these findings suggest that behavioural adaptation represents an important indicator of how successfully emerging mobility technologies are being integrated into existing cycling systems. When cyclists consistently modify their behaviour in order to compensate for increasing uncertainty, this indicates that adaptation is occurring not only at the individual level but also as a response to broader system-level transformation. The widespread adoption of defensive cycling strategies may therefore signal that existing infrastructure and behavioural norms are becoming increasingly misaligned with the growing diversity of users sharing Dutch bicycle lanes.

Taken together, these findings demonstrate that behavioural adaptation constitutes considerably more than a series of isolated safety responses. Instead, adaptation represents a continuous process through which cyclists attempt to manage increasing interactional uncertainty while preserving a sense of confidence and control. The study therefore extends previous empirical research by showing that behavioural adaptation should be understood not only as a consequence of perceived risk but also as evidence of the additional cognitive and behavioural work required to navigate increasingly heterogeneous cycling environments.

5.5 Cumulative Strain and Everyday Safety

An important finding emerging from this study is that participants rarely described individual interactions as decisive in shaping their perceptions of safety. Instead, many explained that their experiences developed gradually through the repeated accumulation of minor conflicts, near misses, unexpected interactions, and situations requiring increased vigilance. Although these individual events were often considered manageable in isolation, participants described their combined effect as producing a gradual increase in stress, caution, and mental fatigue over time. Perceived safety therefore appeared to be shaped not only by isolated incidents but also by the cumulative experience of navigating increasingly complex cycling environments.

This observation is consistent with previous empirical research demonstrating that previous experiences play an important role in shaping cyclists' perceptions of risk. Bösehans and Massola (2018) found that cyclists frequently interpreted current traffic situations through memories of earlier interactions, suggesting that perceptions of safety develop progressively rather than being determined solely by immediate circumstances. Similarly, Kummeneje and Rundmo (2020) demonstrated that perceived risk influences subsequent cycling behaviour, indicating that repeated experiences contribute to longer-term behavioural adjustment. The present findings support these observations while providing a richer understanding of how these experiences accumulate in everyday cycling practice.

Rather than describing a single event that fundamentally changed their behaviour, participants frequently explained that small experiences gradually altered how they approached cycling. Repeated encounters with unpredictable overtaking manoeuvres, uncertainty at intersections, or ambiguous behaviour from unfamiliar vehicle users slowly increased the attention they devoted to cycling. Many participants found it difficult to identify precisely when this change had occurred, instead describing a gradual realisation that cycling had become more mentally demanding than in the past.

This gradual accumulation represents an important extension of previous empirical research. Existing studies generally identify relationships between previous experiences, perceived risk, and behavioural adaptation but provide relatively limited insight into how these processes unfold over extended periods of everyday mobility. The present study suggests that perceived safety is continuously reconstructed through repeated interaction rather than being recalculated independently during each journey. Cyclists therefore carry previous experiences into future interactions, allowing earlier uncertainty, stress, and behavioural adaptations to influence subsequent interpretations of the traffic environment.

The findings also illustrate that cumulative strain extends beyond perceptions of danger. Participants frequently described feeling mentally tired after navigating particularly busy cycling environments, even when no objectively dangerous situations had occurred. Several respondents explained that they arrived at their destination feeling exhausted because they had spent the entire journey continuously monitoring surrounding traffic, anticipating possible conflicts, and preparing for unexpected behaviour. These descriptions suggest that the consequences of increasing technological diversity are not limited to physical safety but also include an important psychological dimension characterised by sustained cognitive and emotional effort.

Importantly, cumulative strain was not experienced equally across participant groups. Older cyclists, international cyclists, parents cycling with children, and participants reporting relatively limited cycling experience generally described becoming mentally fatigued more quickly than experienced Dutch cyclists. These participants often explained that repeated exposure to uncertainty gradually reduced their confidence, increased their reliance on avoidance strategies, and occasionally discouraged them from cycling altogether. In contrast, experienced cyclists often acknowledged similar experiences of increasing complexity while describing themselves as better able to accommodate these changes within their established cycling routines. These differences suggest that the cumulative consequences of interactional uncertainty are shaped

not only by the traffic environment itself but also by cyclists' previous experience, familiarity, and perceived ability to manage increasingly complex interactions.

From a risk perception perspective, these findings indicate that perceptions of safety should not be understood as static evaluations made independently during each journey. Instead, they appear to evolve through a continuous feedback process in which previous experiences influence future expectations, behavioural decisions, and interpretations of uncertainty. This perspective complements risk perception theory by demonstrating that cyclists' evaluations of safety are temporally embedded, with earlier experiences shaping how subsequent interactions are interpreted.

Viewed from a socio-technical perspective, cumulative strain may also provide an indication of the longer-term consequences of technological transformation within mobility systems. Emerging mobility technologies do not simply alter isolated interactions; they gradually reshape everyday travel by increasing the cognitive and emotional resources required to participate in the transport system. Even where objective safety remains relatively high, increasing interactional complexity may reduce the overall quality of the cycling experience if users repeatedly experience journeys as mentally demanding or psychologically exhausting.

Taken together, these findings suggest that cumulative strain constitutes an important mechanism linking repeated interactional uncertainty to longer-term behavioural change. Rather than resulting from individual critical incidents, reduced confidence, increased caution, and declining willingness to cycle appear to emerge gradually through the accumulation of many small experiences. The study therefore extends previous empirical research by demonstrating that the long-term influence of emerging mobility technologies lies not only in changing objective safety conditions but also in progressively reshaping how cyclists experience, interpret, and navigate everyday mobility.

5.6 Social Categorisation as a Strategy for Managing Uncertainty

The final theme emerging from this study concerns the role of social categorisation in shaping cyclists' perceptions of safety. Throughout the interviews, participants frequently associated particular vehicle types or rider groups with specific patterns of behaviour. Rather than evaluating each interaction independently, cyclists often relied upon previous experiences to form expectations regarding how different road users were likely to behave. These expectations influenced how participants interpreted approaching situations, anticipated potential conflicts, and adjusted their own behaviour before interactions occurred.

At first glance, these findings might appear to suggest that cyclists simply associate certain vehicle types with greater levels of risk. However, participants' accounts reveal a more nuanced process. Cyclists rarely described vehicle categories themselves as inherently dangerous. Instead, they associated particular vehicles with anticipated behavioural characteristics. For example, several participants expected speed pedelec riders to travel at higher speeds, associated delivery riders with hurried or unpredictable manoeuvres, and viewed conventional cyclists as generally more familiar with informal cycling norms. These expectations were not based solely on the physical characteristics of the vehicles but on accumulated experiences of interacting with their users.

This observation complements previous empirical studies demonstrating that cyclists interpret current traffic situations through previous experiences (Bösehans & Massola, 2018). Likewise, Griffin et al. (2020) showed that previous cycling experience influences how road users recognise hazards and interpret potentially dangerous situations. The present findings extend this work by illustrating one of the mechanisms through which these interpretations occur. Rather than evaluating every interaction from first principles, cyclists appeared to rely on simplified mental representations that allowed them to anticipate likely behaviour under conditions of increasing uncertainty.

These findings can be understood as the use of cognitive heuristics. In increasingly heterogeneous cycling environments, continuously evaluating every road user individually would require considerable mental effort. Participants instead described developing practical shortcuts that enabled them to interpret interactions rapidly and decide how much attention particular situations required. Social categorisation therefore appeared to function as a strategy for managing cognitive complexity rather than simply reflecting negative attitudes towards particular groups of road users.

Importantly, these categorisations were neither fixed nor universally shared. Participants frequently acknowledged that individuals did not always behave in accordance with their expectations and emphasised that behaviour ultimately depended on the person rather than the vehicle itself. Several respondents described changing their opinions after repeated positive interactions with riders whom they had initially regarded as unpredictable. These observations suggest that cyclists continuously revise their mental models as they accumulate new experiences, indicating that social categorisation is a dynamic rather than static process.

This finding also helps explain why behavioural predictability emerged as the central determinant of perceived safety throughout the study. Categorisation appeared to reduce uncertainty by providing cyclists with provisional expectations regarding how other road users were likely to behave. When observed behaviour aligned with these expectations, interactions generally remained manageable and participants reported feeling confident in their ability to respond appropriately. Conversely, when road users behaved in unexpected ways, these mental models quickly lost their predictive value, increasing uncertainty, cognitive effort, and emotional stress. Social categorisation therefore functioned not as an end in itself but as one component of a broader process through which cyclists attempted to maintain behavioural predictability within increasingly diverse cycling environments.

From a socio-technical perspective, these findings demonstrate that the integration of emerging mobility technologies involves more than adapting physical infrastructure or revising traffic regulations. Successful integration also requires the gradual development of shared behavioural expectations between increasingly diverse road users. Until such expectations become widely established, cyclists appear to compensate by constructing their own interpretive frameworks based on accumulated experience. Social categorisation may therefore represent an adaptive response to periods of socio-technical transition, during which formal rules and informal behavioural norms have not yet fully adjusted to increasing technological diversity.

The present findings contribute to the empirical literature by identifying an interactional mechanism that has received relatively little attention within previous research on cyclists'

perceived safety. Earlier studies have demonstrated that previous experiences influence perceptions of risk and behavioural adaptation (Bösehans & Massola, 2018; Kummeneje & Rundmo, 2020), but have devoted comparatively little attention to how cyclists organise these experiences in order to interpret future interactions. The present study suggests that social categorisation forms part of this interpretive process by enabling cyclists to reduce uncertainty and make sense of increasingly complex traffic environments.

Taken together, these findings indicate that social categorisation should not be understood merely as a source of bias or stereotyping but as a cognitive strategy that enables cyclists to navigate increasingly heterogeneous cycling systems. Although these mental models may sometimes oversimplify the behaviour of individual road users, they also appear to reduce cognitive demands by providing cyclists with provisional expectations that support rapid decision-making during everyday interactions.

5.7 A Socio-Technical Interpretation of Perceived Cycling Safety

The findings can be further understood through a socio-technical systems perspective. Throughout the interviews, participants rarely attributed safety concerns exclusively to individual road users or individual vehicle types. Instead, they frequently described safety as emerging from interactions between infrastructure, technologies, traffic conditions, behavioural norms, and broader social changes.

This observation supports systems-based approaches to safety, which conceptualise safety as an emergent property arising from interactions between system components rather than the actions of isolated individuals (Leveson, 2012; Rasmussen, 1997). The findings suggest that cyclists experience safety in a similar manner. Participants often interpreted problematic interactions as consequences of broader system dynamics rather than isolated failures.

For example, delivery scooter behaviour was frequently discussed in relation to commercial time pressures and platform-based delivery systems. Similarly, participants often linked conflicts involving emerging vehicles to infrastructure that was originally designed for a more homogeneous traffic environment. In both cases, safety concerns were understood as products of interactions between technologies, institutional arrangements, infrastructure constraints, and human behaviour.

The socio-technical perspective also helps explain why vehicle diversity emerged as such a significant theme throughout the study. Emerging vehicles did not simply introduce new physical characteristics into the cycling environment. They altered established interaction patterns, challenged existing behavioural expectations, and increased the complexity of coordinating movement between different users. The resulting uncertainty was therefore not generated by vehicles alone but by the broader transformation of the mobility system.

From this perspective, perceived cycling safety should be understood as an emergent outcome of relationships between infrastructure, technologies, social norms, and user interpretations. Safety is not located solely within infrastructure design, individual behaviour, or vehicle characteristics. Rather, it is produced through ongoing interactions between these elements.

This interpretation represents one of the study's primary theoretical contributions. By integrating risk perception theory with socio-technical systems thinking, the findings demonstrate how system-level changes are translated into individual experiences of uncertainty, cognitive burden, emotional strain, and behavioural adaptation.

5.8 Limitations and Future Research

Several limitations should be considered when interpreting the findings of this study. Rather than reducing the value of the research, these limitations reflect methodological choices that shaped the scope of the investigation and provide directions for future research.

First, the study focused exclusively on cyclists. This decision was made because the research aimed to understand how cyclists experience perceived safety within an increasingly diverse cycling environment. Consequently, the findings represent only one perspective within the broader cycling system. Emerging vehicle users, including e-bike riders, speed pedelec users, delivery riders and scooter users, may interpret the same interactions differently. Future research could adopt a multi-stakeholder approach by comparing the experiences and behavioural expectations of different user groups sharing Dutch cycling infrastructure.

Second, although the sample achieved substantial variation regarding age, gender, cycling experience, cycling frequency and familiarity with Dutch cycling infrastructure, some groups were less well represented. In particular, older cyclists, frequent users of specialised vehicles such as speed pedelecs and cargo bicycles, and cyclists from predominantly rural environments constituted only a small proportion of the sample. As these groups may experience interaction complexity differently, future studies could specifically target these populations to examine whether the mechanisms identified in this study are equally applicable across different cyclist groups.

Third, participants were recruited through the Fietzersbond and personal networks associated with TU Delft. While this recruitment strategy successfully achieved the desired diversity in cycling experience and background, it may also have resulted in a sample that was relatively engaged with cycling and more familiar with transport-related issues than the general population. Including participants recruited through municipalities, employers, community organisations or public intercept surveys could provide a broader representation of Dutch cyclists.

Fourth, this study examined perceived safety through participants' retrospective accounts of their everyday cycling experiences. Consequently, the findings describe how cyclists interpret and make sense of interactions rather than directly measuring behaviour during real-world cycling. Future research could combine interview data with naturalistic cycling observations, GPS tracking, eye-tracking or video-based conflict analysis to examine how perceived safety corresponds with actual behaviour in complex traffic situations.

A further consideration concerns the relationship between the conceptual framework and the empirical findings. The framework was initially developed from existing literature and therefore emphasised system-level concepts such as speed heterogeneity, interaction density and spatial competition. During the thematic analysis, however, participants rarely referred to these concepts directly. Instead, they consistently described the ability to anticipate and interpret the

behaviour of other road users as the primary determinant of perceived safety. Consequently, predictability emerged inductively as the central mechanism linking system-level transformations to cyclists' experiences. While this strengthens the theoretical contribution of the study, the relationship between these system-level characteristics and predictability was not explicitly operationalised or quantitatively measured. Future research could investigate this relationship using mixed-methods approaches that combine qualitative insights with behavioural observations or quantitative measures of predictability and cognitive workload.

Finally, one of the most important findings of this study was that participants rarely described emerging vehicle types as isolated safety problems. Instead, they consistently referred to increasing unpredictability, greater behavioural diversity and the growing cognitive effort required to interpret surrounding traffic. Predictability therefore emerged inductively as the central mechanism linking system-level transformations to perceived safety. While this study identified predictability as a recurring explanatory concept, it did not attempt to operationalise or quantitatively measure it. Future research could develop validated indicators of behavioural predictability and cognitive workload and investigate how these relate to infrastructure design, interaction density, speed heterogeneity and objective safety outcomes. Such work would provide an important next step towards integrating subjective and objective perspectives on cycling safety.

Taken together, these limitations highlight opportunities to further develop understanding of perceived cycling safety within increasingly complex mobility systems. Building on the mechanisms identified in this study may contribute to the design of cycling environments that are not only objectively safe but also understandable, predictable and comfortable for diverse groups of cyclists.

5.9 Conclusion

This study set out to explore how cyclists experience and navigate safety within Dutch bicycle lanes that are increasingly characterised by emerging mobility technologies and growing diversity among road users. Rather than examining objective safety outcomes, the research focused on how cyclists interpret interactions, construct perceptions of safety, and adapt their behaviour within an evolving socio-technical mobility system.

The findings demonstrate that emerging vehicles are rarely experienced as inherently unsafe. Instead, participants consistently described behavioural uncertainty as the primary factor shaping their perceptions of safety. Increasing diversity in vehicle characteristics, rider behaviour, and informal traffic norms reduced cyclists' ability to anticipate interactions confidently, increasing the cognitive effort required to navigate everyday journeys. Perceived safety therefore emerged not as a direct consequence of individual vehicle types but as the outcome of ongoing interactional processes through which cyclists interpreted and responded to increasingly complex traffic environments.

Building upon previous empirical research, this study demonstrates that these interactional processes are characterised by five closely interconnected mechanisms. Interactional uncertainty increases the cognitive effort required to interpret surrounding traffic, encouraging behavioural adaptation through defensive cycling and avoidance strategies. Repeated exposure

to these demanding interactions gradually contributes to cumulative strain, while cyclists simultaneously develop social categorisations and behavioural heuristics that help restore predictability and reduce uncertainty during future interactions. Together, these mechanisms explain how cyclists continuously construct and maintain perceptions of safety within changing cycling environments.

These findings extend existing empirical research in several important ways. Previous studies have demonstrated that cyclists' perceptions of safety are influenced by previous experiences, cycling experience, and attitudes towards risk (Bösehans & Massola, 2018; Griffin et al., 2020; Kummeneje & Rundmo, 2020). The present study complements this work by explaining the interactional processes through which these perceptions develop within increasingly heterogeneous bicycle lanes. Rather than focusing on isolated vehicle categories or objective safety outcomes, the findings demonstrate how technological diversity reshapes everyday cycling through changes in behavioural predictability, cognitive workload, and social interaction.

From a Management of Technology perspective, the findings further suggest that the successful integration of emerging mobility technologies should not be evaluated solely in terms of infrastructure performance or crash statistics. Technological innovation also transforms the behavioural expectations, cognitive demands, and interactional routines through which transport systems function. Maintaining behavioural predictability therefore emerges as an essential condition for preserving perceived safety within increasingly complex mobility systems.

Overall, this study argues that the principal challenge associated with emerging mobility technologies is not the introduction of new vehicles themselves but the increasing interactional complexity they generate. Future cycling environments will therefore depend not only on accommodating technological innovation but also on supporting interactions that remain understandable, predictable, and manageable for an increasingly diverse population of cyclists.

5.10 Policy Implications

The findings of this study also have implications for several ongoing policy developments in the Netherlands. National and municipal authorities increasingly recognise that the rapid diversification of bicycle traffic requires adaptations that extend beyond traditional infrastructure expansion. The findings suggest that these initiatives should be evaluated not only in terms of objective safety outcomes, but also in terms of their ability to preserve behavioural predictability and reduce interactional uncertainty.

One important example is the continued expansion of 30 km/h urban roads. Through the *Toekomstbeeld Fiets* and the *Strategisch Plan Verkeersveiligheid 2030*, the Dutch government encourages municipalities to lower speed limits on urban access roads where full physical separation between cyclists and motor vehicles is not feasible. Reducing motor vehicle speeds narrows speed differentials between transport modes and creates more predictable interactions, thereby addressing one of the key mechanisms identified in this study. While lower speed limits primarily target crash severity, the present findings suggest they may also improve perceived safety by making the behaviour of surrounding road users easier to anticipate.

A second policy discussion concerns the regulation of emerging bicycle types, particularly fatbikes and speed pedelecs. Recent national debates have considered measures such as

introducing a minimum age for fatbike users, mandatory helmet requirements for selected vehicle categories, and stricter enforcement of illegal modifications that increase vehicle speeds beyond legal limits. Although participants in this study rarely identified individual vehicle types as inherently unsafe, they consistently described uncertainty regarding the behaviour of riders operating faster or unfamiliar vehicles. These findings therefore support policy approaches that improve behavioural consistency and rule compliance rather than policies that focus exclusively on particular vehicle categories. Measures that increase predictability, through clearer regulations, enforcement or rider education, are likely to contribute more to perceived safety than vehicle-specific restrictions alone.

The findings also support current discussions regarding the redesign of cycling infrastructure. Dutch design guidelines have increasingly acknowledged that bicycle lanes now accommodate users travelling at substantially different speeds and using vehicles with varying dimensions. Where spatial constraints permit, wider bicycle lanes, overtaking space, and clearer functional separation between slower and faster cyclists may reduce interactional complexity by limiting the frequency of close encounters. Importantly, the findings suggest that infrastructure design should not only minimise conflict opportunities but also help cyclists understand what behaviour they can reasonably expect from others.

Finally, the findings highlight the importance of behavioural interventions alongside physical infrastructure measures. National campaigns promoting courteous cycling behaviour, improved communication between different user groups, and education for new users of electrically assisted bicycles may strengthen shared behavioural norms and improve interpretability during interactions. From a socio-technical perspective, successfully integrating emerging mobility technologies therefore depends not only on adapting infrastructure, but also on ensuring that users develop common expectations regarding appropriate behaviour within increasingly diverse cycling environments.

Ultimately, the findings suggest that successful integration of emerging mobility technologies depends not only on technological innovation itself, but also on governance arrangements that preserve behavioural predictability, support shared norms and enable different user groups to safely coexist within an evolving socio-technical mobility system.

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A. Interview Guide

Introduction and Rapport Building (Warm-up)

Objective: Build comfort and establish context.

Interviewer introduction:

“Thank you for taking the time to participate in this interview. I’m conducting research for my master’s thesis to better understand people’s experiences and perceptions related to cycling, particularly in everyday situations. Your insights will help identify challenges and opportunities for improving cycling conditions and policies.”

Ethics note:

“Before we start, I want to remind you that your participation is voluntary, and you may skip any question or stop at any time. Your responses will be anonymized.”

1. Can you tell me a bit about your background as a cyclist? How long have you been cycling, and for what purposes (e.g., commuting, leisure, sport)?
2. What does a typical cycling week look like for you? How often do you cycle, and what types of routes do you take?

Perceptions of Safety

Objective: Explore how participants perceive physical and psychological safety.

1. When cycling in your usual environment, do you generally feel safe? Why or why not?
2. Are there specific situations or locations where you feel more anxious, stressed, or intimidated?
3. Can you describe any strategies you use to feel safer on the road (e.g., timing, route choice)?
4. How do infrastructure elements such as bike lanes, lighting, or road surface affect your sense of safety?
5. Have you ever experienced a near-miss or crash while cycling? Could you describe what happened and how you felt during and after the event?

How did other road users behave in that situation?

Conflict Experiences

Objective: Investigate experiences of tension, near-misses, or collisions.

Make a small introduction about the research on other road users

Show pictures of vehicles and ask about their experiences with these vehicles

1. For each picture: Have you had any positive or negative interactions with this vehicle?
2. How do interactions with this vehicle make you feel?

3. Do you find the infrastructure adequate for sharing the road with this other user? Why or why not?
4. Is there anything else you would like to add to your experiences with this vehicle?

Behavioral Adaptation

Objective: Understand how cyclists modify their behavior due to perceived risks or other road users.

Now that you have seen these other vehicles: Are some types of vehicles more challenging to share space with?

1. Have you changed your cycling behavior over time because of any of these vehicles? For example, avoiding certain routes, times of day, or interactions? If not, is there any situation in which you will change your behavior?
2. Can you imagine a situation where you might reduce or stop cycling because of these new vehicles?

Impact and Policy Reflections

Objective: Gather participants' views on broader implications and solutions.

1. Considering this diversity of vehicles we now have on the road: From your perspective, should changes be made to improve cycling conditions? If so, what changes should be made?
2. What role do you think policymakers or urban planners should play in addressing these issues?
3. If you could send one message to decision-makers about cycling in your city, what would it be?

Closing

Objective: Allow participants to share any final thoughts.

1. Is there anything else you would like to share about your experiences as a cyclist?

Pictures of vehicles used in interviews



Electric Bike



Fatbike (follow up on electric bike)



Speed pedelec (faster than 25 km/h)



Scooter



Delivery scooter (follow up on scooter)



Citycar



Delivery van



Recumbent bicycle



Cargo bike



Electric step