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E-Scooter Movement Data Analysis

Exploring uses of active transport facilities, travel speeds, helmet use, and scooter types

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Executive Summary

This project was commissioned by the Queensland Government through the Department of Transport and Main Roads (TMR). The study focused on collecting baseline data on e-scooter riding behaviour and exploring the compliance behaviour of e-scooter riders in Brisbane upon the changes in regulations in November 2022. The research objectives were:

1. To document trends in e-scooter use and behaviour.
2. To compare and contrast e-scooter riders' compliance behaviour before and after changes in road rules, including speed and helmet use
3. To assess whether riders' compliance behaviours vary across different devices, locations, and infrastructure types.
4. To explore the connection between cycling and walking infrastructure and e-scooter road rules compliance
5. To assist in evaluating other e-scooter regulations.

This research utilised observational data captured from traffic cameras at eight locations across Brisbane in October 2022 and October 2023, resulting in over 200 hours of traffic video and 600k observations. The key findings from the data analysis are as follows.

- Separated infrastructure produces road rules compliance. When riders have a choice between a footpath and a bike lane or a separated cycle track, fewer riders choose the footpath.
- Little to no change in road rules compliance was found after the rule change.
- There are more e-scooter riders in the central business district (CBD) than at urban locations and more e-scooter riders at urban locations than in suburban locations.
- There are more public e-scooter riders in the CBD and more private e-scooter riders in urban and suburban locations.
- E-scooter riders are more likely to be wearing a helmet if on road (general traffic lane, bike lane, or separated cycle way) compared with being on a footpath.
- A higher share of private e-scooter riders wear helmets compared to public scooters.
- Scooter speed is increasing. Both public and private scooters saw a speed increase from 2022 to 2023. For private scooters this was just over 1 kilometre per hour and highly significant. For public scooter riders this was about 0.25 km/h and significant at the 10 percent level.
- Footpath speed compliance is low at 52%, but speeds exceeding 20 km/h on footpath were only 15.2%. Speed compliance is higher on roads (general traffic lane, bike lane, or separated cycleway) at 82%.
- Speed compliance increases with urban density. Speed compliance is highest in the CBD, less at urban locations and less still in suburban locations
- Those wearing helmets ride faster, and those with full-face helmets ride the fastest.

- When riders have a choice between a footpath and a cycleway, even fewer riders choose the footpath.

Chapter 1 Introduction

1.1 Project Background

Brisbane, Australia as the first and most progressive local council area in micromobility served as the context for the study. Though regulations have been in place since the introduction of shred e-scooters in 2018, the safety of the riders and path users has always been a concern. In November 2022, the Queensland Government through the Department of Transport and Main Roads (TMR) addressed the safety concerns by revising the e-scooter road rules, which led to the commencement of this project.

This project was commissioned by TMR as part of the multiversity TAP to explore the safety implications of the changes in e-scooter road rules in Queensland, Australia. Whilst a study by Haworth et al. (2021) investigated the volume and pattern of e-scooter rides following the introduction of public personal mobility devices (PMD) in November 2018, this study is the first to focus on comparing e-scooter riders' compliance behaviour before and after the road rules change, including travel speed, the use of helmets, Infrastructure type, and type of scooters. Thus, the study offers novel findings that contribute to practical implications for several stakeholders including academics, regulators, and PMD users.

1.2 Literature Review

1.2.1 Introduction

Electric scooters, known as e-scooters, are "scooters with a standing design with a handlebar, deck and wheels that are propelled by an electric motor" (Shaheen & Cohen, 2019, p. 3) though some are equipped with seating (Beam Mobility, n.d.). There are two distinct types of e-scooters based on ownership: privately owned and publicly shared. Whilst data on the number of privately owned e-scooters is limited, worldwide public e-scooter services alone are expected to reach a user base of 143.4 million people by 2028 (Statista, 2023). Since the first large-scale public e-scooter program debuted in the United States in 2017, e-scooters have gained traction as an alternative transportation mode for urban areas around the world (Ventsislavova et al., 2024), substituting trips that were made by walking, public transport, and cars (Chang et al., 2019; Laa & Leth, 2020). Therefore, its rapid infiltration into the urban transportation system has sparked conversations about its integration, including matters of legislation.

1.2.2 Development of worldwide e-scooter regulatory frameworks

Early e-scooter governance started in late 2017 when the Santa Monica city authority imposed an interim ban on the operation of a public e-scooter provider, Bird, which launched their product without the city's permission (Field & Jon, 2021). The ordinance then began imposing the legislation gradually, starting with a temporary permit and then a trial program with a capped number of e-scooters operated (Lien & Etehad, 2018). Over the span of late 2017 to 2019, cities around the world have been trying to grapple with ways to regulate e-scooters. On the stricter side, cities such as San Francisco, followed Santa Monica's suit (McFarland, 2019), prohibiting public e-scooter schemes on shared facilities which was then followed by a trial period. Some cities like Paris adopted a more relaxed approach, allowing an estimated 20,000 e-scooters in the city from mid-2018 to 2019 (Field & Jon, 2021).

The earlier phases of e-scooter introduction has posed significant challenges to countries there were early adopters as companies swiftly flooded the streets with their product in response to the market needs (Riggs et al., 2021). The city's authorities then had to work under a limited timeframe to regulate the deployment of e-scooters. They were trying to balance crafting effective legislation to ensure public safety and fostering sustainable mobility. These efforts aim to enhance urban transportation while addressing the rapid rise in demand for e-scooters. However, e-scooter governance often falls behind technology development (Field & Jon, 2021; Kazemzadeh et al., 2023) and is inconsistent between states and/or countries that share the same code of law (Fang et al., 2018; Serra et al., 2021).

In the United States, the recognition of PMDs, including e-scooters, is the responsibility of the states. However, by the end of 2018, only 10 states had passed legislation recognising e-scooters separating their identity from other motor vehicles. By 2023, only 25 out of 50 states have enacted state statutes regulating e-scooters (National Conference of State Legislatures, 2023), despite an exponential growth in popularity (Serra et al., 2021). Within the states, an evaluation of 61 cities in the United States by Riggs et al. (2021) found approaches to adopting e-scooters varied from city to city. Nevertheless, they suggested a pilot program and vehicle cap as the best practice when launching e-scooter programs. This approach allows cities to study policies and adjust the number of e-scooters while ensuring equity (Riggs et al., 2021). Country and city officials used a pilot program to pave the way for a permanent regulating system. It provides authorities with the flexibility to adjust certain elements concerning the public interest, such as the number of operators, location restriction, incentivise scheme, equity policy, the total number of scooters deployed, and the number of scooters per operator (Field & Jon, 2021). Additionally, it also enables the smooth integration of E-scooters into urban transportation, avoiding the 'arrive first, ask later' practice that caused complications in early adopter cities (Field & Jon, 2021; Laker, 2019; Riggs et al., 2021).

The use of 'trial' or pilot programs was prominent in the early development of e-scooter regulatory frameworks in many countries. In Australia in November 2018, the City of Brisbane, Queensland initiated Australia's first public e-scooter trial (Caldwell, 2018). Brisbane City Council adopted several regulatory measures to manage and control the deployment and usage of e-scooters, including fleet caps, incentives, and location restrictions (Field & Jon, 2021). Similarly, in 2019, the City of Adelaide, South Australia launched an e-scooter trial program with location restrictions (Government of South Australia, 2019). The pilot program approach was adopted by cities across Australia, including major cities such as Melbourne (City of Melbourne, 2022), and Sydney (New South Wales Government, 2022). The e-scooter introduction using a trial program also took place in Auckland, New Zealand in late 2018 (Field & Jon, 2021), and in the United Kingdom in 2020 (Wainwright, 2023).

Aside from deliberately planned trial programs, some countries have taken a different approach in the early phases of e-scooter regulation, emphasising legal recognition of e-scooters within their regulatory framework. In Europe, e-scooters are generally recognised as an L-category under the European Union (EU) Regulation No 168/ 2013. This regulation establishes harmonised rules and accelerates the adoption of type-approval legislation for this category of vehicles (European Commission, 2021; Sokolowski, 2020). However, member countries are responsible for their legislation regarding country-specific recognition in their road rules (Sokolowski, 2020). Therefore, e-scooters in Europe took off without official recognition in country legislation. For instance, the first public e-scooter from Lime was launched in Lisbon, Portugal in late 2018 (Lime, 2018). However, it was not until mid-2019 that Portugal proposed an amendment in its road rules, recognising the identity of e-scooters (Sokolowski, 2020). The same approach applies to France: public e-scooters landed on the streets of Paris in mid-2018 (Lime, 2018), with official legislation recognising e-scooters enacted in late 2019 (Sokolowski, 2020). However, during the period or in countries where there are no dedicated e-scooter road rules, other vehicle types of road rules usually apply (Sokolowski, 2020). For example, road rules for bicycles applied for e-scooters in Portugal, making it compulsory to wear a helmet. Similarly, an e-scooter is classified as a bike in Sweden, allowing it to be ridden on pavement but prohibiting it from being ridden on roads in traffic (Sokolowski, 2020).

In a similar vein, the United Kingdom (UK) road rules have classified e-scooters as motor vehicles (United Kingdom Department For Transport, 2023), requiring registration. However, most commercially available e-scooters do not meet the requirements of motor vehicles, thereby prohibiting e-scooter use in public spaces. Since July 2020, the UK has adopted interim regulations mirroring those for electrically assisted pedal cycles (EAPCs) (United Kingdom Department For Transport, 2023). These regulations restrict the maximum speed of the device to 25 km/h (15.5 mph) (United Kingdom Department For Transport, 2015) but increase the maximum power of the motor from 250W to 500W (United Kingdom Department For Transport, 2023). This adjustment has facilitated the implementation of public e-scooter trial schemes in several cities across the country (United Kingdom Department For Transport, 2020). However, private e-scooters remain prohibited from public facilities (United Kingdom Department For Transport, 2020). Nevertheless, regulators seek not only to introduce e-scooters as a new urban transportation mode but also to consider a safe environment for both riders and society. (Gössling, 2020; Kazemzadeh et al., 2023). Therefore, the following section will outline changes in e-scooter road rules after its introduction

1.2.3 Worldwide changes in e-scooter road rules

Regulators enforce rules on e-scooters during their introduction phase based on how e-scooters are categorised. In countries such as Austria, Belgium, Denmark, Germany, Singapore, and Spain, e-scooters are classified into a dedicated category (e.g. small and mini scooters with electric motors) (Kamphuis & van Schagen, 2020, p. 6; Singapore Land Transport Authority, 2022, p. 8). Alternatively, Scandinavian countries considered them as bicycles while countries like the Czech Republic and Portugal grouped them under light mopeds (Kamphuis & van Schagen, 2020). The categorisation usually dictates where riders can ride, license requirements, age limit, and mandatory helmet use (Kazemzadeh et al., 2023). However, these road rules are not uniform across countries. As demonstrated by the mentioned countries with dedicated e-scooter categories, only Austria has a compulsory helmet requirement but only for a rider under 12 years old (European Transport Safety Council, 2020). Meanwhile, only Singapore required a written theory test to be able to ride an e-scooter (Singapore Land Transport Authority, 2022).

However, the prevalence of e-scooters in cities worldwide has been accompanied by safety risks to both riders and users of shared facilities. This increased risk is illustrated by the increase in injuries associated with e-scooter use (Haworth et al., 2021). Therefore, local governments have adjusted their road rules based on repeated incidents or when new data has come to light. There are several changes in e-scooter road rules this study has observed. First and the most controversial is e-scooter usage on the footpath. In Singapore, e-scooters have been allowed on the footpath during its introduction in 2017. However, since 2019, Singapore authorities have banned e-scooters from riding on footpaths as a result of a safety review concerning increased incidents of e-scooter riders and pedestrians (Singapore Land Transport Authority, 2019). The banning trend has also been seen in multiple cities, such as Madrid (Ojea, 2018), Paris (Buckley, 2019), and Vienna (Gesley, 2019).

The second observed change is the increasing use of technology to strengthen e-scooter compliance. The 'soft' enforcement has been increasingly common due to the accessibility of public e-scooters reliance on a smartphone application to unlock, ride, and pay. The use of the application in conjunction with other technologies like Global Positioning System (GPS) enables the authorities to enforce certain road rules such as speed limits and parking in certain areas or impose no-go zones. In 2020, Lime introduced its geofencing technology, which is a technology to create virtual geographic boundaries (Lime, 2020). Since then, we have observed an increasing use of this technology. For example, in Canberra, geofencing is used to prohibit parking near rivers to prevent vandalism (Bladen, 2020). Another example is from Milton Keynes, England, where the authorities use geofencing to limit usable locations (Topham, 2020). However, technologies are by no means bulletproof. There are times when technology like geofencing is inconsistent across operators and areas (Field & Jon, 2021), and is also not applicable to privately owned e-scooters.

Finally, a drastic change in road rules observed occurred in Paris, where the city authorities have decided to remove public e-scooters in late 2023 (Chrisafis, 2023). Paris was the first adopter of the public e-scooter scheme in Europe and is now the first city in Europe that has reversed their stance on public e-scooters. Moreover, from March 2024 Malta will also follow Paris's practice, becoming the first nation that ban public e-scooters (European Transport Safety Council, 2023). Nevertheless, both Malta and Paris, France still allow private e-scooter use in public spaces. Notable changes in worldwide e-scooter road rules are presented in Figure 1.

Aside from changes in road rules, there are several themes observed across worldwide e-scooter road rules. First is the speed limit. In most cities, the speed limit of e-scooters is in the range of 20-25 km/h (Haworth et al., 2021; Riggs et al., 2021; Singapore Land Transport

Authority, 2022; Sokolowski, 2020; United Kingdom Department For Transport, 2020). Second, is a consensus of prohibiting passengers. Unlike other e-scooter road rules, carrying passengers is an unsafe riding practice globally. Third is riding under the influence. Riding under the influence has been associated with the severity of the injury among riders (Kazemzadeh et al., 2023). Therefore, most countries have introduced a law pertaining to Blood Alcohol Content (BAC), prohibiting users from riding while intoxicated (European Consumer Centre Germany, 2023; Sexton et al., 2023). Lastly, mobile phone usage while riding. Using a mobile phone while riding creates road distraction and often leads to an accident (Gioldasis et al., 2021). Hence, most countries prohibit phone usage while riding (European Consumer Centre Germany, 2023; United Kingdom Department For Transport, 2020). Helmet use is not mandatory in most countries globally, albeit the most crucial accessory to prevent head injuries (Serra et al., 2021).

The global e-scooter regulatory landscape has varied along a continuum from the most restrictive to the most relaxed, depending on the countries and local authorities. This is also the case in Australia where the approach to e-scooter road rules varies between cities and states, which is discussed in the following section.

Figure 1: Timeline of worldwide e-scooter regulation key dates

1.2.4 Summary of e-scooter road rules in Australia

In Australia, there are three levels of government: the Commonwealth government, state governments, and local governments. The leading authority for road rules, are state governments, through departments like the Queensland Government Department of Transport and Main Roads, and for enforcement through police like the Queensland Police Service. The Commonwealth Government is only involved in law related to importation. The laws focus on classifying e-scooters and ensuring that imported devices meet specific size and power wattage requirements (Department of Infrastructure Transport Regional Development Communications and the Arts, 2021; Pace et al., 2021). City councils work in conjunction with state authorities and are responsible for permitting public e-scooters, public safety, and developing appropriate infrastructure (Pace et al., 2021).

In New South Wales, personal e-scooters are illegal. The state government has implemented a public e-scooter scheme trial since July 2022 (New South Wales

Government, 2022). Within trial locations, e-scooter riders can ride on bicycle paths, shared paths, separated bicycle paths, roads, and on-road bicycle lanes on which the speed limit is up to 50 km/h but not on footpaths (Transport for NSW, 2023). The speed limit is set at 20 km/h on bicycle paths/lanes and roads but 10 km/h on shared paths (Transport for NSW, 2023). In the same vein, Victoria has adopted a public e-scooter scheme trial since February 2022 across three cities: Melbourne, Port Philip and Yarra (City of Melbourne, 2022). However, along with the third extension of the shared program (Abbott, 2023), Victoria has allowed both private and public e-scooters across the state (VicRoads, 2023). Therefore, e-scooter riders can ride on bicycle paths, shared paths, separated bicycle paths, roads, and on-road bicycle lanes on which the speed limit is up to 60 km/h but not on footpaths (VicRoads, n.d.). The speed limit is set at 20 km/h across all permitted facilities (VicRoads, 2023)

In the Australian Capital Territory, e-scooters have been recognised in state road rules since December 2019 (Transport Canberra, n.d.-b), allowing the use of private e-scooters. Shared e-scooters began September 2020 (Transport Canberra, n.d.-c). In the Australian Capital Territory, e-scooters are allowed on almost all public facilities, including bicycle paths, shared paths, separated bicycle paths, and footpaths (Transport Canberra, 2021). However, e-scooters are not allowed on the road and on-road bicycle lanes unless there is no footpath, shared path or nature strip next to the road or it is impracticable to travel in those areas (Transport Canberra, 2021). The speed limit is set at 25 km/h on every allowed space except the footpath at 15 km/h (Transport Canberra, n.d.-b). Western Australia is also one of the Australian states that allows both public and private e-scooter riders in public spaces. E-scooters can be ridden on most public facilities, including footpaths, shared paths, bicycle paths, on-road bicycle lanes where the speed limit is 50 km/h or less, and roads that have no dividing lines and with a speed limit of 50 km/h or less. The speed limit is set at 10 km/h on footpaths, including pedestrian crossings, and 25 km/h on other permitted paths (Government of Western Australia, n.d.).

In the Northern Territory, e-scooters are allowed only through a public scheme (Northern Territory Government, n.d.), limiting their use only in the city of Darwin (City of Darwin, n.d.). The official recognition of e-scooters was recorded on 16 February 2023 (Northern Territory Government, 2023). Within the permitted locations, e-scooters can be ridden on shared paths, footpaths, and on-road bicycle lanes but not on the road unless there is no allowed path nearby or impractical to travel on one of those (Northern Territory Government, n.d.). Moreover, travel on the road upon the mentioned criteria is only allowed up to 50m and the speed limit is set at 15km/h across permitted paths (Northern Territory Government, n.d.).

In South Australia, public e-scooters are allowed through a trial scheme (Kelsall, 2023). Within the trial location, e-scooters are only allowed to ride shared paths, footpaths, and local roads that have a speed limit of 50km/h or less, no dividing line or median strip, but not a one-way road with more than one marked lane (My Licence Government of South Australia, n.d.). E-scooters can ride on the road only to avoid obstruction on permitted paths up to 50m and speed must not exceed 15 km/h on any paths (My Licence Government of

South Australia, n.d.). On the other hand, in Tasmania, both public and private e-scooters have been allowed since December 2021 (Transport Service Tasmanian Government, n.d.). E-scooters are allowed to ride on bicycle paths, shared paths, separated bicycle paths, on-road bicycle lanes, footpaths, and local roads which have a speed limit of 50km/h or less, no dividing lines or median strip, and no multiple lanes if a one-way road (Transport Service Tasmanian Government, n.d.). The speed limit is set at 15 km/h for footpaths and 25 km/h for other allowed paths (Transport Service Tasmanian Government, n.d.).

In Queensland, e-scooters are classified as Personal Mobility Devices (PMDs). The term was first introduced in August 2013 to facilitate the introduction of Segways (Brisbane City Council, 2023). Queensland was the first state in Australia to welcome e-scooters. Public e-scooters became available in Brisbane in November 2018. In December 2018, road rules were amended allowing the operation of e-scooters in the state (O'Keeffe, 2019). Prior to the road rules changes in 2022, Queensland considered e-scooter riders as pedestrians, allowing them to ride at a full speed limit (25 km/h) on footpaths but preventing them from using on-road bike facilities (Pace et al., 2021). In light of increased concerns about the safety of other road users and pedestrians (Vallmuur et al., 2023) Queensland authorities then introduced the new e-scooter road rules in November 2022 (Courty, 2022). The new road rules set a new speed threshold on footpaths to reduce incidents with pedestrians. In order to accommodate increasing demand for e-scooters, the changed road rules also allow e-scooters to ride on bike lanes on the roads with a speed limit of 50 km/h or less, as well as physically separated on-road bike lanes (Courty, 2022). Moreover, the new road rules increased fines for non-compliance. Therefore, Queensland has the most accommodating e-scooter regulations in Australia, allowing both private as well as public e-scooter use statewide. To summarise Queensland's current e-scooter road rules, e-scooters can be ridden on bicycle paths, shared paths, separated bicycle paths, on-road bicycle lanes with a speed limit of 50km/h or less, footpaths, and local roads with 50km/h or less and no dividing line (Queensland Government, n.d.). The speed limit is set at 12 km/h for footpaths and 25 km/h for other allowed paths (Queensland Government, n.d.).

In Australia, wearing a bicycle helmet is mandatory when riding an e-scooter. Riding under the influence of drugs or alcohol, using a mobile phone while riding, and carrying a passenger are prohibited. A driver license is not required. The minimum age for riders is 16 in most states, except for the Northern Territory and South Australia, where it is 18, and Australian Capital Territory, where it is 12 (Government of Western Australia, n.d.; My Licence Government of South Australia, n.d.; Northern Territory Government, n.d.; Queensland Government, n.d.; Transport Canberra, n.d.-a; Transport for NSW, 2023; Transport Service Tasmanian Government, n.d.; VicRoads, 2023, n.d.). Table 1 summarises the existing e-scooter legislation in Australia at the time of publication.

Despite the change in road rules, existing research has yet to address associated changes in compliance behaviour. Haworth et al. (2021) investigated the compliance behaviour of private and public e-scooter riders in 2019 in Brisbane, Australia. The study found that public e-scooter riders are more likely to exhibit illegal behaviours (e.g. riding on roads) compared to private scooter riders. The findings also pointed toward a decreasing trend in non-compliance behaviour as device ownership increases, discussing riding experience as a factor affecting compliance behaviour. A study looking at injuries in the United States also confirms the ‘novelty effect’ among first-time riders using shared e-scooters, showing that a high proportion of e-scooter-related injuries occur among this group (Sexton et al., 2023). On the other hand, Ventsislavova et al. (2024) have investigated the compliance behaviour of riders and non-riders. The study found that riders with a better understanding of road rules were more likely to comply with those rules. The study also mentioned a result that contradicts the earlier novelty effect, suggesting that private e-scooter riders are more likely to engage in non-compliance behaviour (Ventsislavova et al., 2024).

In response to the gap in the literature, this study aims to examine the compliance behaviours upon the Queensland, Australia e-scooter road rules changes in November 2022. This study addresses multiple compliance behaviours, such as speed limit, helmet use, and riding on permitted paths whether the riders have complied with the change in road rules. The investigation will compare compliance behaviour using factors such as device ownership, time, location, location characteristics and rider characteristics.

State	Private devices	Age Limit	Speed Limit*	Where you can ride
Queensland	Allowed	16	12km/h on footpaths and 25 km/h on other paths	**Footpaths**, Bicycle paths, Shared paths, Separated bicycle paths, and On-road bicycle lanes (with speed limits up to 60 km/h)
New South Wales	Prohibited	16	10km/h on shared paths and 20km/h on other paths	Bicycle paths, Shared paths, Separated bicycle paths, **Roads**, and On-road bicycle lanes (with speed limits up to 50 km/h)
Victoria	Allowed	16	20 km/h	Bicycle paths, Shared paths, Separated bicycle paths, **Roads**, and On-road bicycle lanes (with speed limits up to 60 km/h)
Australia Capital Territory	Allowed	12	15km/h on footpaths and 25 km/h on other paths	**Footpaths**, Bicycle paths, Shared paths, and Separated bicycle paths
South Australia	Prohibited	18	15km/h	**Footpaths**, Shared paths, and local roads (with speed limit up to 50km/h and no dividing line or median strip, and not a multiple-lane one-way road)
Tasmania	Allowed	16	15km/h on footpaths and 25 km/h on other paths	**Footpaths**, Bicycle paths, Shared paths, Separated bicycle paths, On-road bicycle lanes (with speed limit up to 50km/h), and local roads (with speed limit up to 50km/h and no dividing line or median strip, and not a multiple-lane one-way road)
Northern Territory	Prohibited	18	15km/h	**Footpaths**, Shared paths, and On-road bicycle lanes
Western Australia	Allowed	16	10km/h on footpaths and 25 km/h on other paths	**Footpaths**, Bicycle paths, Shared paths, On-road bicycle lanes (with speed limit up to 50km/h), and roads (with speed limit up to 50km/h and no dividing line)

*Unless otherwise signed

Table 1: Summary of E-scooter Legislation in Australia

1.3 Scope and Objectives

The project aimed to identify the impact of e-scooter road rules reform in Queensland, Australia. The research objectives were:

1. To document trends in e-scooter use and behaviour.
2. To compare and contrast the riders' compliance behaviour before and after the regulation reform, including speed and helmet use
3. To assess whether riders' compliance behaviours vary across different devices, locations, and infrastructure types.
4. To explore the connection between cycling and walking infrastructure and e-scooter road rules compliance
5. To assist in evaluating other e-scooter regulations.

1.4 Methodology

1.4.1 Infrastructure types

In this study, the infrastructure types studied were categorised as follows:

- A general traffic lane is a type of infrastructure where PMDs share the road with other vehicles, including cars and bicycles.
- An on-road bike lane is a type of infrastructure that is a designated lane within the roadway specifically for bicycles and PMDs.
- A separated cycleway is a physically separated lane within the roadway for bicycles and PMDs.
- In referring to "on road' throughout the we are including all three infrastructure types above.

The sample of each infrastructure types studied is presented in Figure 2

Figure 2: Infrastructure Types Studied

1.4.2 Data Collection

Data were collected as video footage using HD cameras installed at 8 nominated sites. Each site had two cameras installed except site 1, which only required one camera due to the AI processing requirements. The traffic video was filmed between 5 am to 10 pm on the dates shown in Table 2 except Site 6 which did not include Saturday 29/10/2022 due to equipment issues. Sunday 30/10/2022 was filmed as a replacement. Data collection sites and their characteristics are shown in Table 3. A map of data collection sites is presented in Figure 3.

Day	Dates
Saturday	15-Oct-2022
Sunday	16-Oct-2022
Tuesday	18-Oct-2022
Wednesday	26-Oct-2022
Thursday	27-Oct-2022
Saturday	29-Oct-2022
Saturday	14-Oct-2023
Tuesday	17-Oct-2023
Wednesday	18-Oct-2023
Thursday	19-Oct-2023
Saturday	21-Oct-2023
Sunday	22-Oct-2023

Table 2: Day and dates of data collection

Site ID	Site Name	Category	Infrastructure Type	Posted traffic speed
1	Adelaide St, Brisbane CBD	CBD	On-road Bicycle Lane	40 km/h
2	Annerley Rd, Dutton Park	Urban	Separated cycleway (Northbound) On-road Bicycle Lane (Southbound)	60 km/h
3	Melbourne St, South Brisbane	Urban	On-road Bicycle Lane	40 km/h
4	Sylvan Rd, Toowong	Suburban	On-road Bicycle Lane	50 km/h
5	Dickson St, Wooloowin	Suburban	On-road Bicycle Lane	60 km/h
6	Elizabeth St & Edward St, Brisbane CBD	CBD	Separated cycleway	40 km/h
7	Eagle St, Brisbane CBD	CBD	General Traffic Lane	40 km/h
8	Parkland Boulevard, Roma St Parklands	Urban	General Traffic Lane	40 km/h

Table 3: Data collection sites and characteristics

After data collection, video records were developed into a data set by TTM Consulting Pty Ltd using both automated processing and manual counts. Data processing yielded six data dimensions:

- Class of path/road user (PMD, Cyclist, Pedestrian, Mobility Aid),
- Speed of PMD and Cyclist in kilometres per hour,
- Age classification for PMDs (Adult or child),
- Helmet used for PMDs and Cyclists (Helmet, No helmet),
- Scooter ownership (Private or Public), and,
- Time and direction of the travel.

Furthermore, video footage was reviewed and processed manually to provide additional data classification of the type of helmet used (Bicycle helmet or Full-face helmet) for e-scooter riders. Data processing resulted in 605,029 data entries which were then validated. The validation methodology and results are discussed in the following sections.

1.4.3 Data Validation

Prior to the data analysis, the team conducted data validation using an overall difference approach (Kothuri et al., 2017). Pedestrian, bicycle, and PMD traffic from raw video footage were manually counted for both the 2022 and 2023 datasets. The counts were done in five-minute intervals during three traffic density periods on Tuesday: Morning (6:00-6:05 am), Evening (4:30-4:35 pm), and Night (8:30-8:35 pm). The rationale behind the day selected is that weekdays are when most traffic occurs, and Tuesday is the only common weekday available in both the 2022 and 2023 datasets. A total of 1426 counts were recorded. Out of 1426 manual counts, 1143 were identified as pedestrians, 221 as bicycles, and 62 were identified as e-scooters. In comparison, TTM identified a total of 1419 counts, 1142 as pedestrians, 215 as bicycles, and 62 as e-scooters. The extracted data was then calculated using Kothuri et al. (2017) practice to determine the accuracy of the traffic count from the system. The data validation calculations were done using the formula $\left|\frac{c-m}{m}\right|$ where c are the machine learning counts and m are the manual counts. The result illustrates the percentage difference between the algorithm and manual traffic count of three main types of path users: pedestrians, cyclists, and PMDs. However, the overall differences formula typically compares various automatic traffic counting systems to assess their performance, as demonstrated by Bellucci and Cipriani (2010). Thus, we cannot definitively claim the accuracy of AMAG traffic AI processing. Nevertheless, it performed better than standard traffic count algorithms, such as YOLOv3. Hence, this result confirms the validity of the dataset extracted using AMAG traffic AI processing. The comparison of accuracy between the project's algorithm and other methods is shown in Table 3.

Authors	Algorithm/Method	Overall differences		
		Pedestrians	Cyclists	PMDs
TTM Consulting Dataset	AMAG traffic AI processing	0.79%	4.67%	20.60%
Apurv et al. (2021)	YOLOv3, MobileNetV2	0.96%	N/A	25.73%
Kocamaz et al. (2016)	Cascaded Detector	4.32%	6.70%	N/A
Messelodi et al. (2007)	Support Vector Machine	N/A	40.00%	N/A

Table 4: Data validation comparison

Figure 3: Map of the data collection sites

1.4.4 Data Analysis

Data analysis was performed using Python in Jupyter Notebook and various common packages including *pandas*, *numpy*, *matplotlib*, *seaborn,* and *statsmodels.api.*

The analysis was divided into four sections according to the research plan: PMD Volume Analysis, PMD Speed Analysis, PMD Helmet Use Analysis, and Logistic Regressions.

- PMD Volume Analysis examines usage by location, year, scooter type, path type, day of week, and path width.
- PMD Speed Analysis examines many aspects of the observed speed of PMD users. The observed speeds were analysed with respect to compliance and differences between classes. The data is split along scooter type, path type, location, helmet type, time of day, and various combinations of these classifications.
- PMD Helmet Use Analysis considered helmet use (basic compliance, and also helmet type in terms of full face versus ordinary helmet). The analysis was performed with respect to location, speed and speed limit zone.

Lastly, three logistic regression analyses were performed for helmet law compliance, speed compliance in 12 km/h zones, and speed compliance in 25 km/h zones. The observed variables in the data were used to predict road rules compliance or non-compliance.

Chapter 2 Findings

2.1 PMD Volume Analysis

2.1.1 Overall Volume Analysis

The following figures analyse the volume distribution of the observed scooter data, with classifications based on ownership (private vs. public e-scooters), e-scooter location (CBD/Urban/Suburban), infrastructure type (general traffic lane, on-road bike lane, separated cycleway), helmet use, and combinations of these variables.

Figure 4, below, shows the number of trips by type (cyclist, private/public PMD) and year (2022 and 2023). There is a significant change in the proportion of private (and thus public) PMDs between 2022 and 2023. Private PMDs are 56% of the observations in 2022 but only 50% in 2023. Note that in 2022, not all PMD trips are labelled with “private” or “public” so “total” in both years has been calculated as the sum of “private” and “public” for consistency.

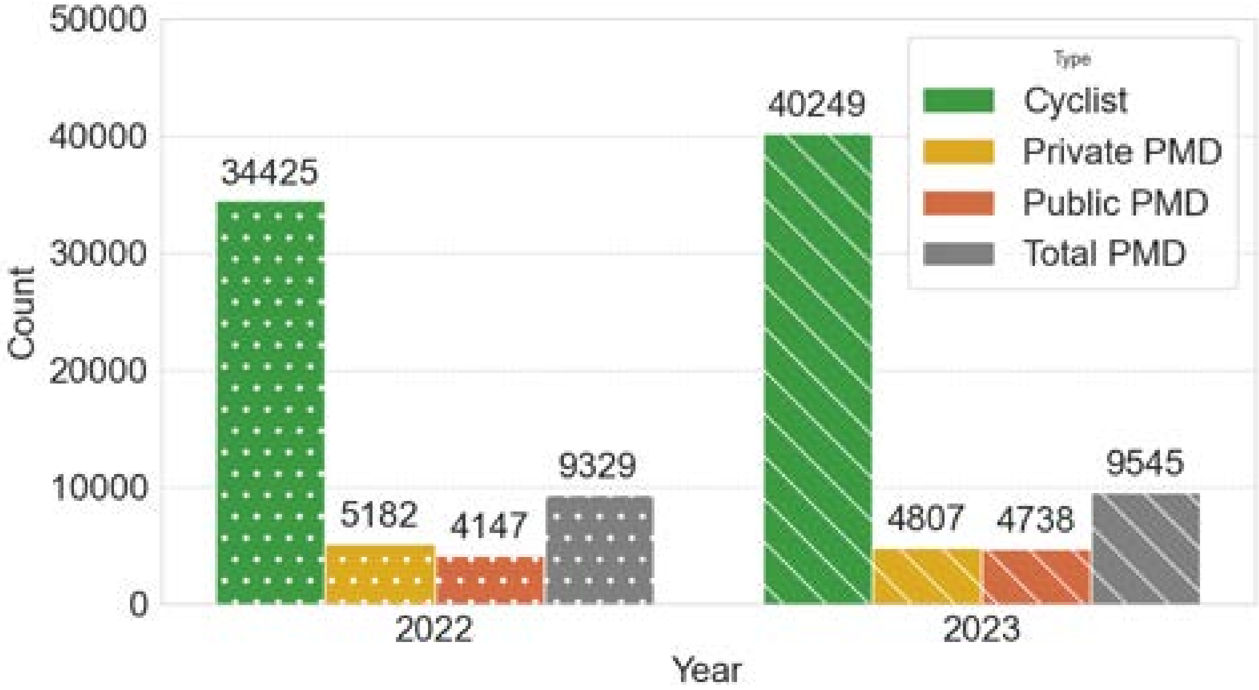

Figure 4: Trip by Type and Year

Figure 5 shows the counts of observations by location (CBD, Urban, and Suburban) and Scooter Type (Private or Public). Most of the observations were in the CBD locations, where more than half the scooters observed were public; while in the Urban and Suburban locations, most of the scooters observed were private.

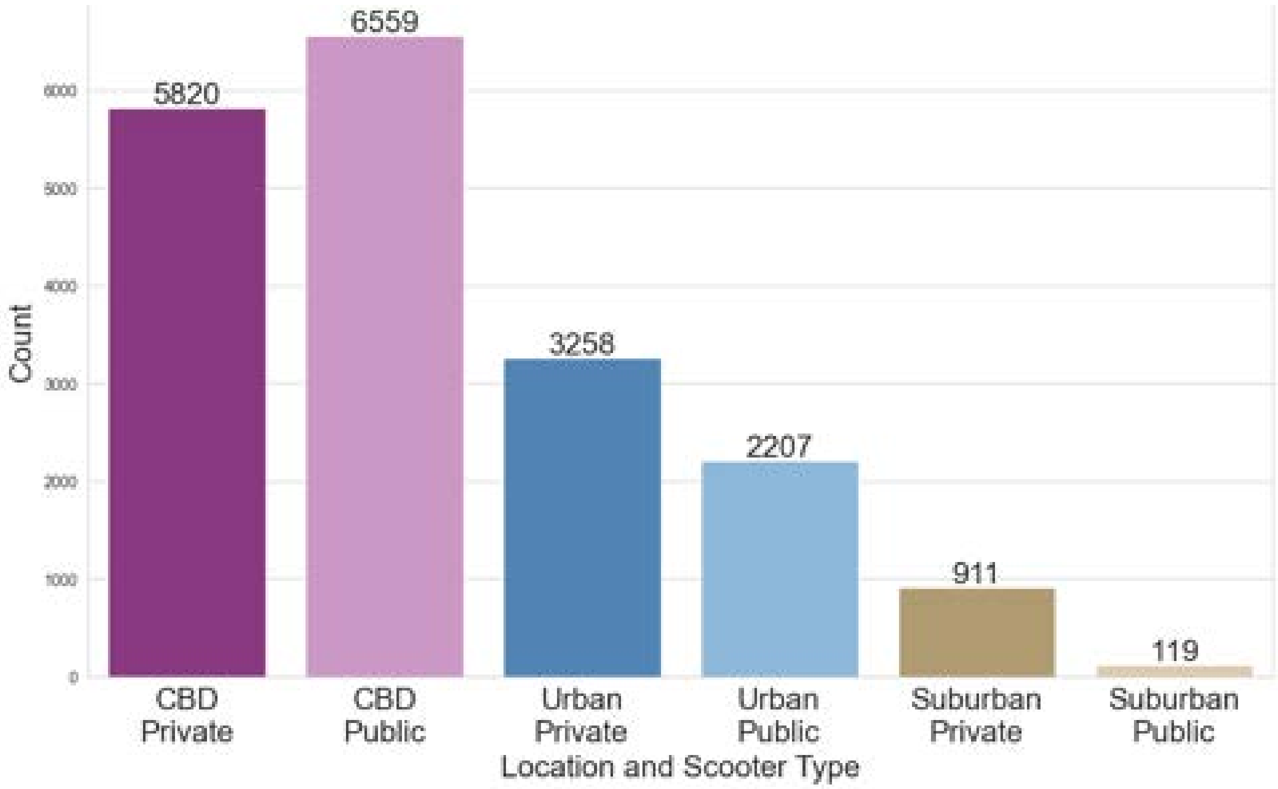

Figure 5: PMD Volumes by Location and Scooter Type

Figures 6, 7 and 8 provide the overall changes in usage between the years 2022 and 2023 in the CBD, Urban and Suburban locations. In the Suburban locations in Toowong, and Wooloowin almost all observations were private PMDs.

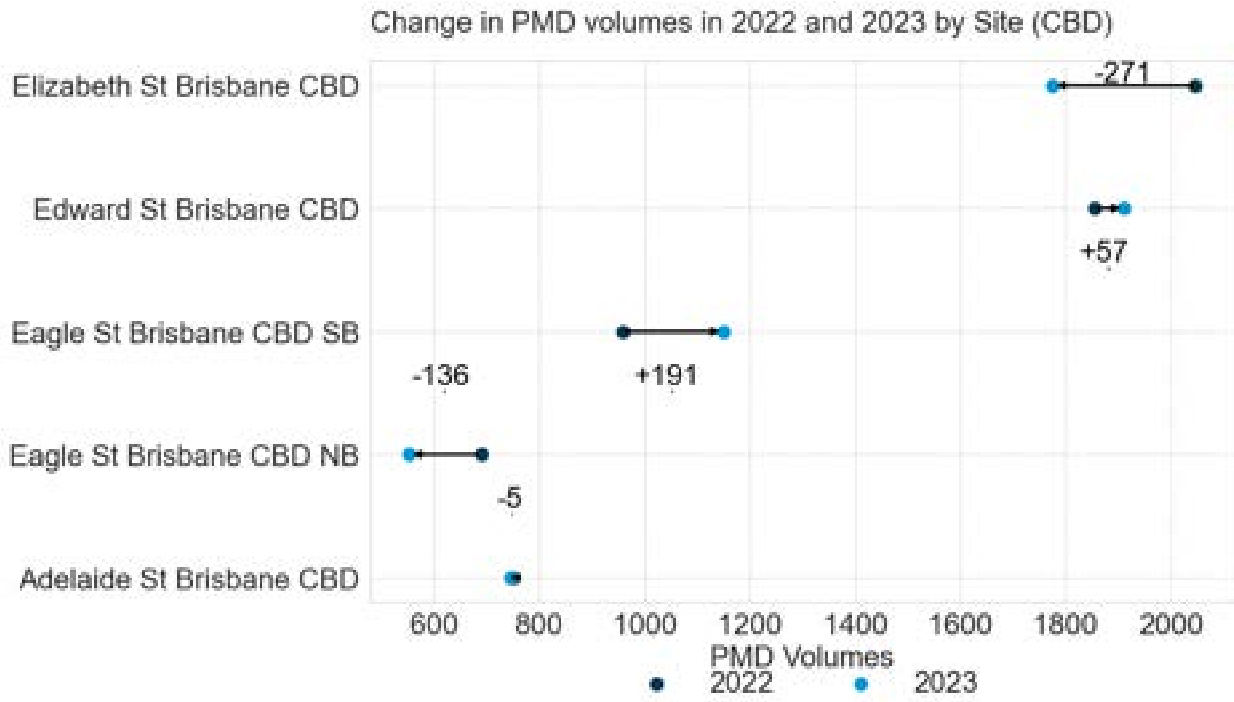

Figure 6: PMD Change in Volume (CBD Locations)

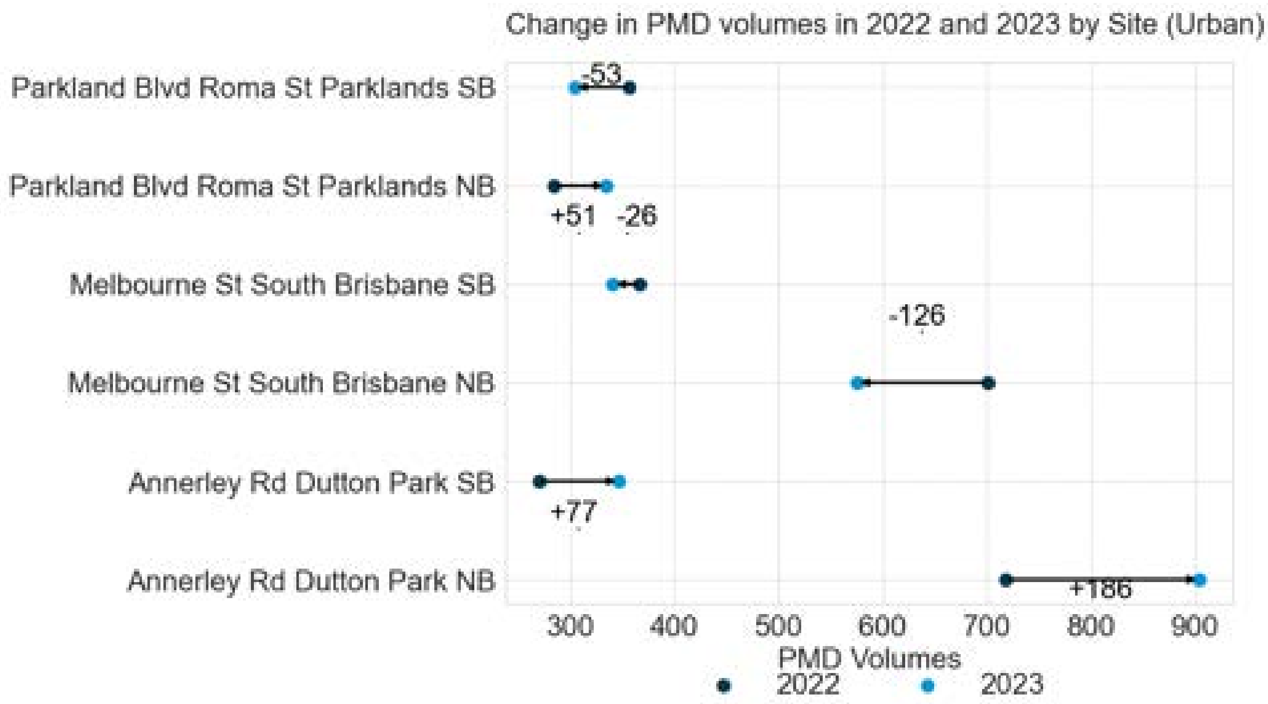

Figure 7: PMD Change in Volume (Urban Locations)

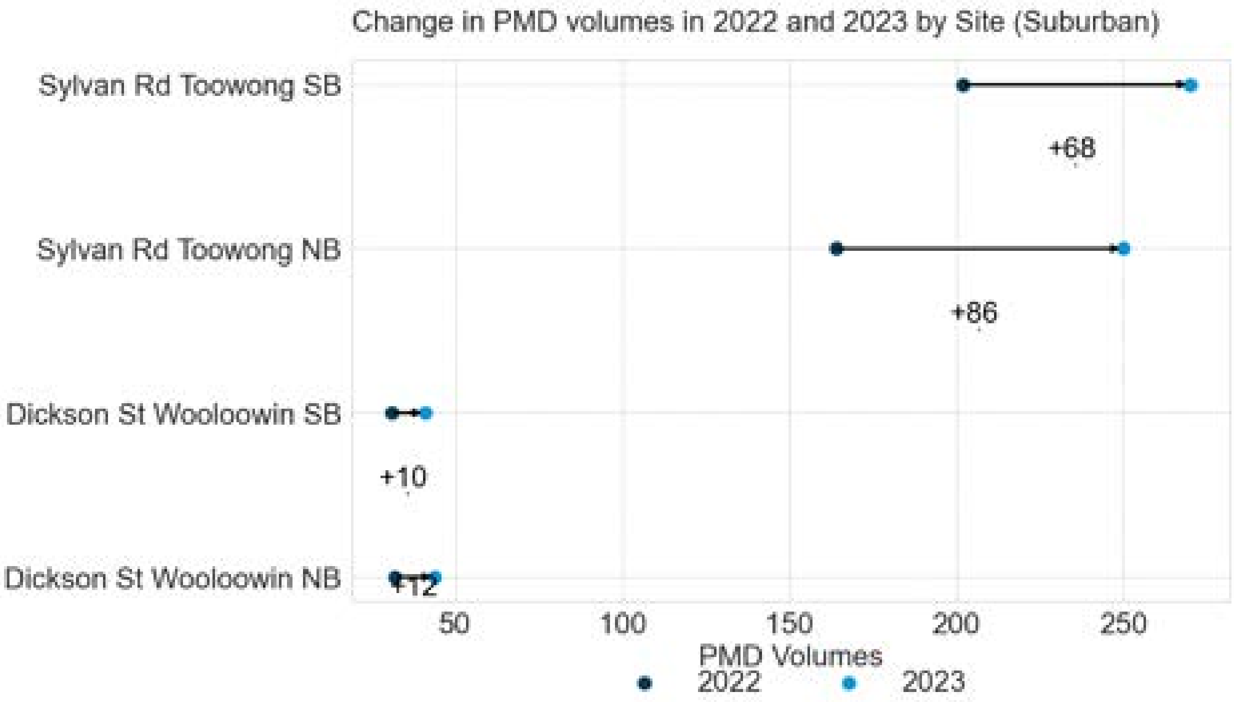

Figure 8: PMD Change in Volume (Suburban Locations)

Figures 9 through 16 show PMD volumes classified by three different splits: Public/Private, 2022/2023, and Weekday/Weekend. For all volume figures, the weekday usage depicts a bimodal pattern reflecting morning and afternoon commuting periods in the 6pm-9am and 3pm-6pm bins. The weekend usage is a gradual increase throughout the day with the highest usage in the 3pm-6pm period, followed by a decrease. Both patterns are similar to those observed in bike-sharing schemes worldwide (Caulfield et al., 2017), including the former CityCycle scheme in Brisbane.

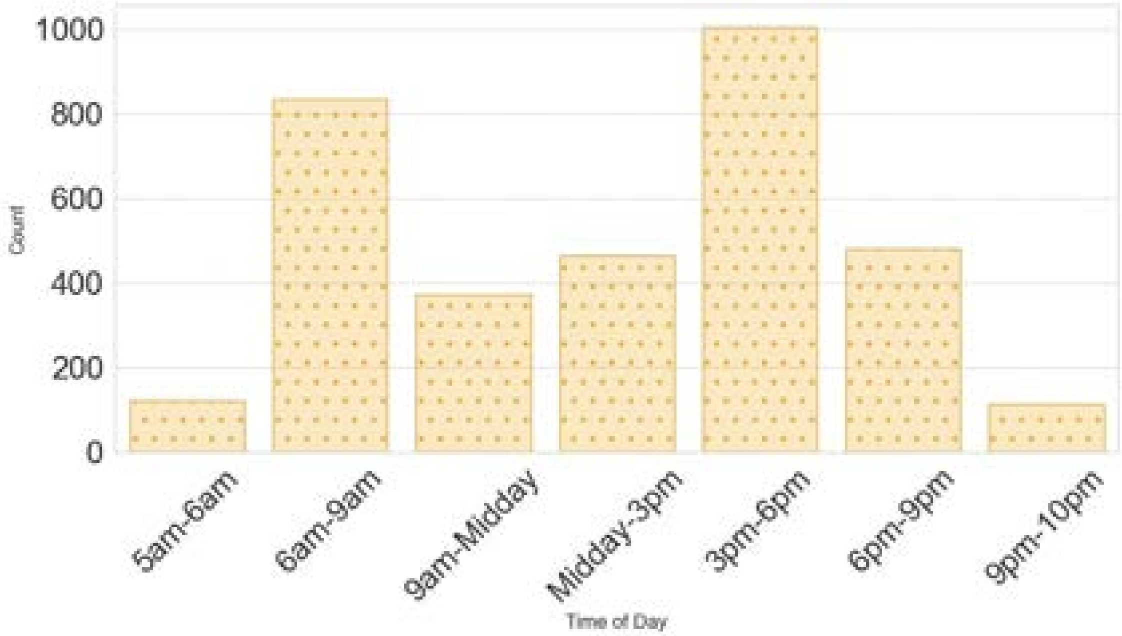

Figure 9: Private PMD usage by time of day - Weekdays (2022)

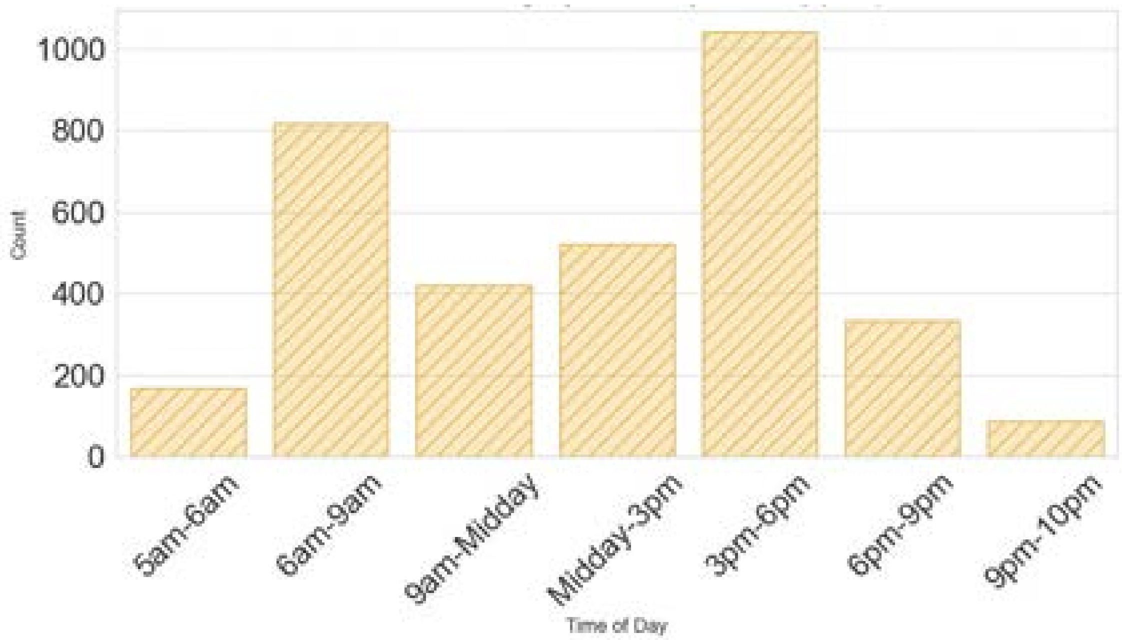

Figure 10: Private PMD usage by time of day - Weekdays (2023)

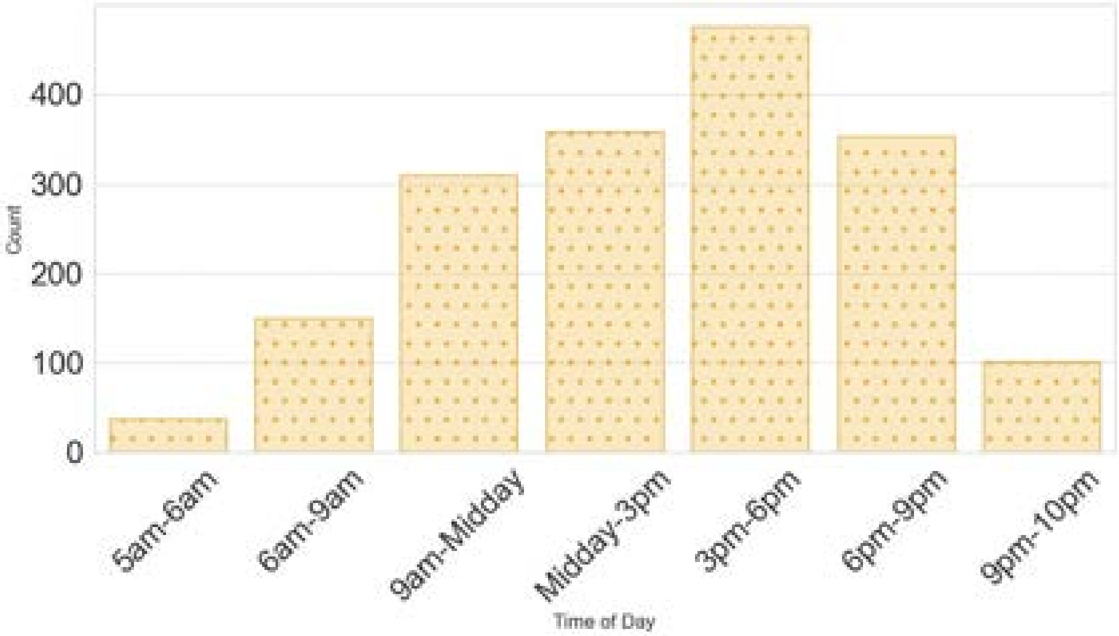

Figure 11: Private PMD usage by time of day - Weekends (2022)

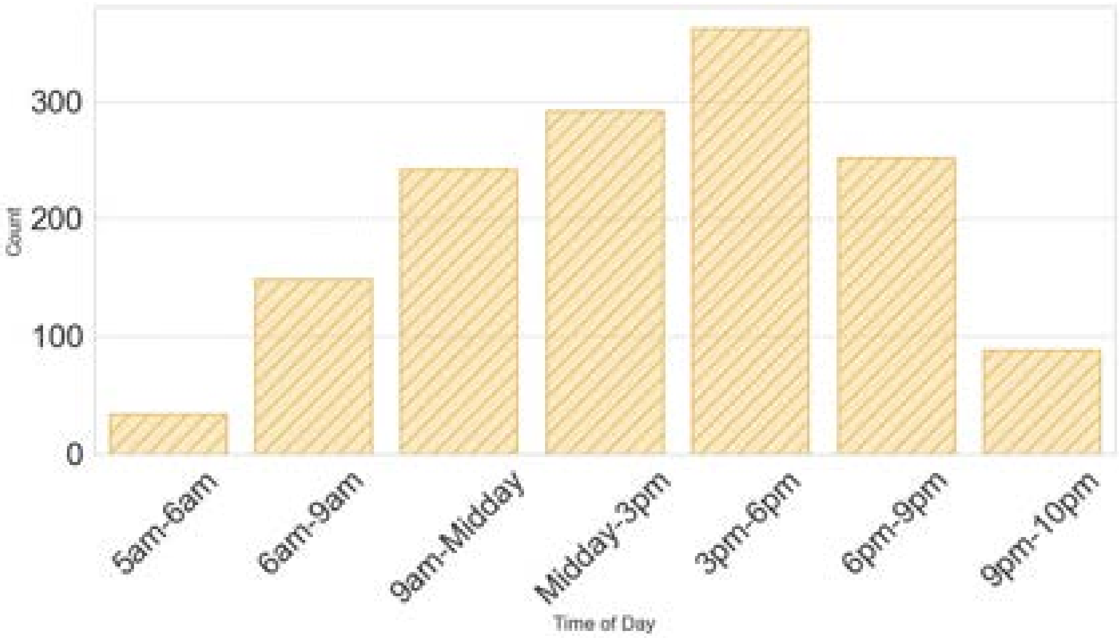

Figure 12: Private PMD usage by time of day - Weekends (2023)

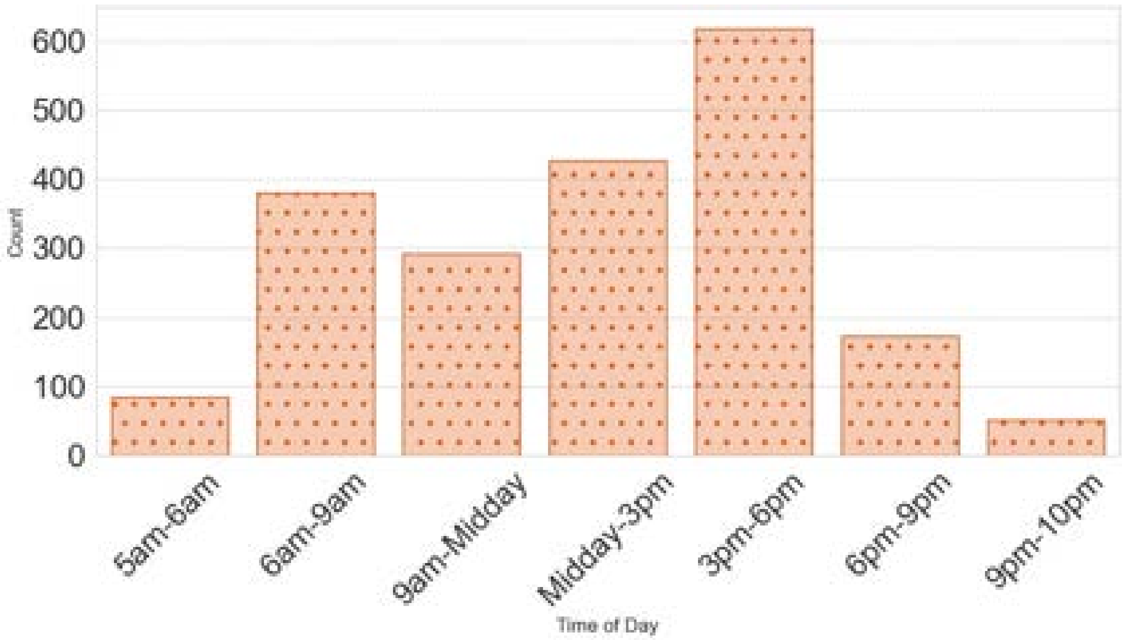

Figure 13: Public PMD usage by time of day - Weekdays (2022)

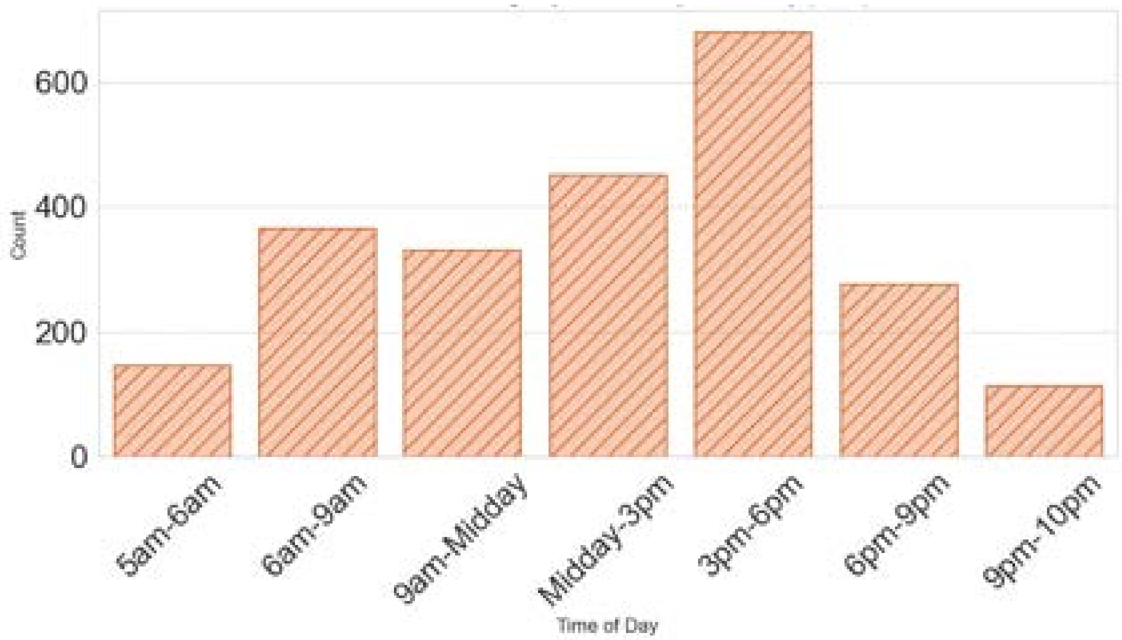

Figure 14: Public PMD usage by time of day - Weekdays (2023)

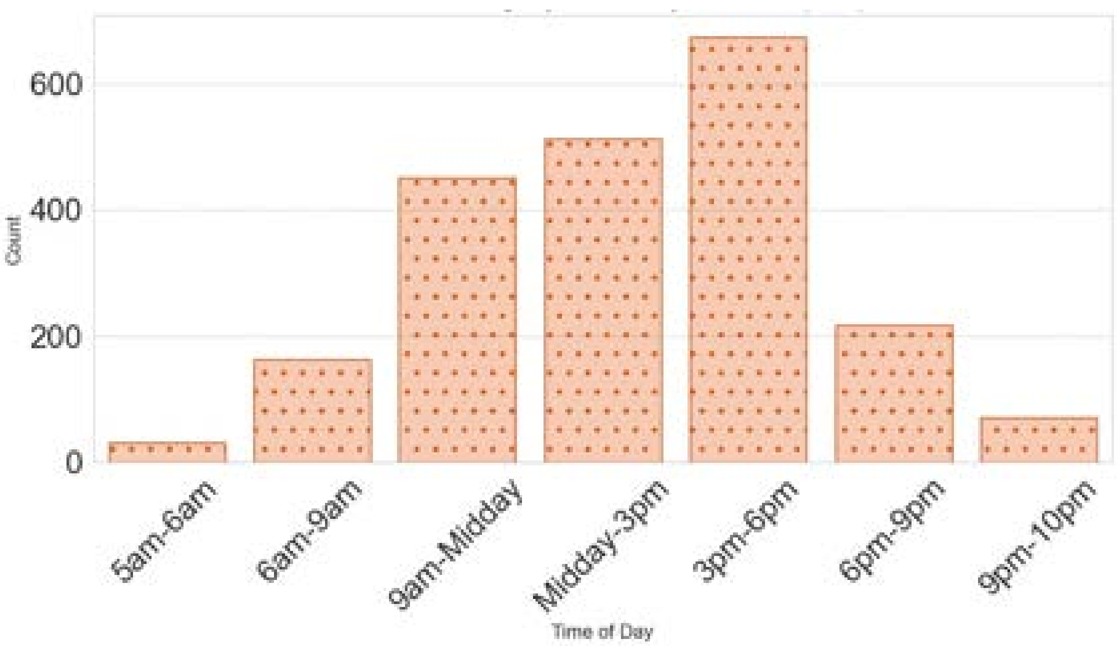

Figure 15: Public PMD usage by time of day - Weekends (2022)

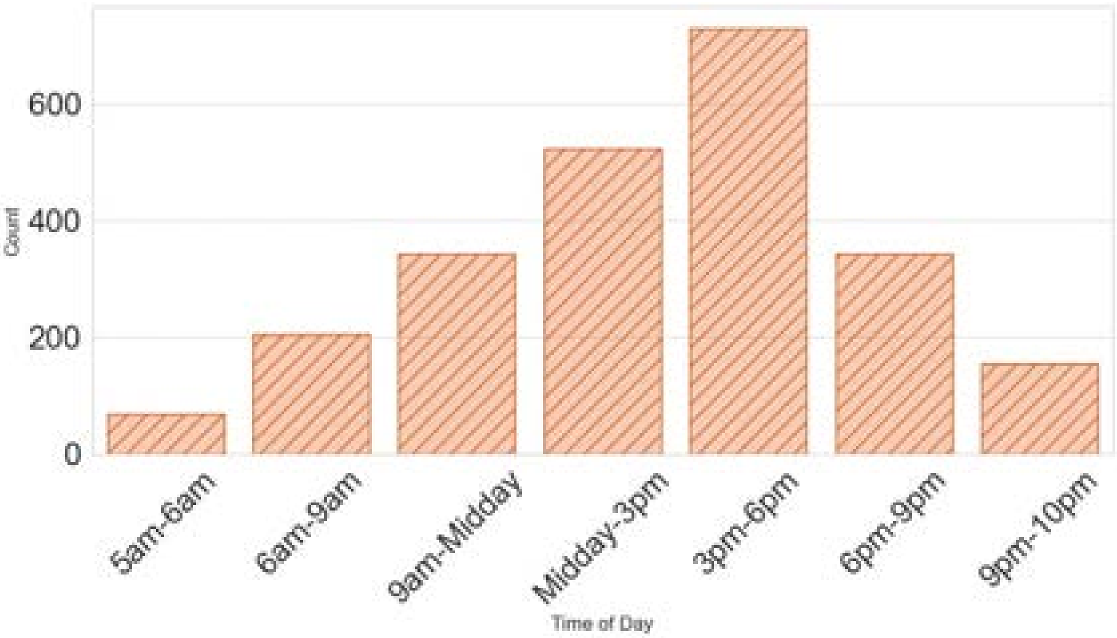

Figure 16: Public PMD usage by time of day - Weekends (2023)

2.1.2 Footpaths Volume Analysis

The proportion of PMD use on footpaths was studied in three different location types: general traffic lane, bike lane, and separated cycleway. The results are shown in Figures 17, 18, and 19 below. Where a separated cycleway is present, only about 6% of private PMDs and 14% of public PMDs are ridden on the adjacent footpath. In all three cases, public PMD users were more likely than private PMD users to use the footpath. This is not necessarily ideal if the footpath is crowded with pedestrians. In each case, there is no significant difference in proportions between 2022 and 2023. Possible reasons for this include public PMD users taking short trips close to their destination in the CBD or public PMD users being less well-informed about PMD laws compared to private PMD users. Furthermore, public PMDs were generally limited (through geofencing) to the CBD or nearby areas.

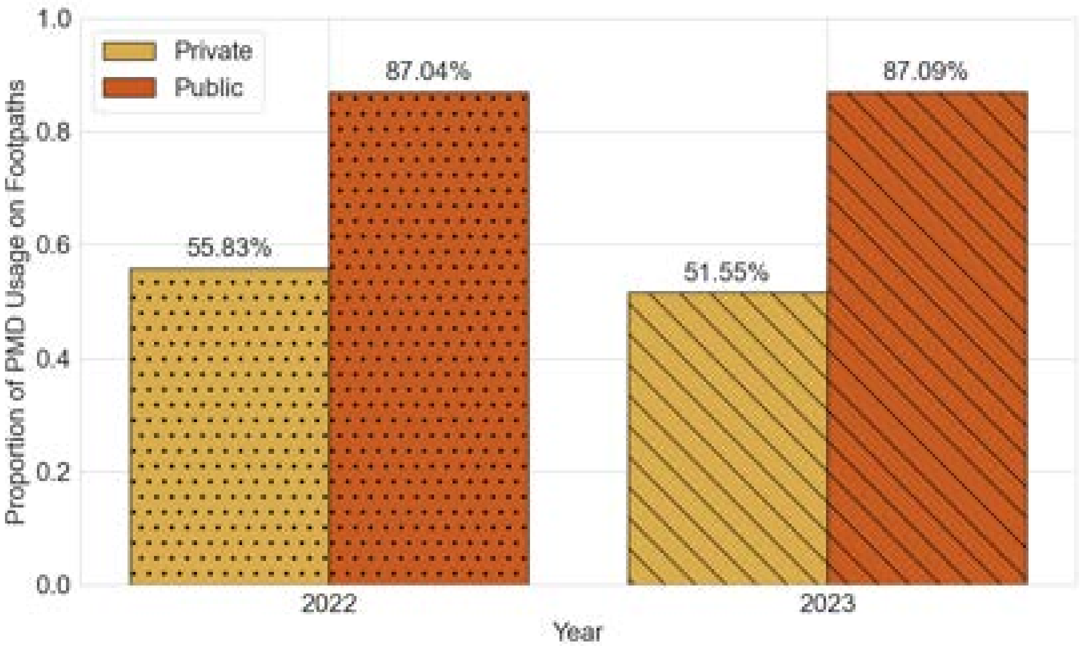

Figure 17: PMD Usage on Footpaths (where general traffic lane present)

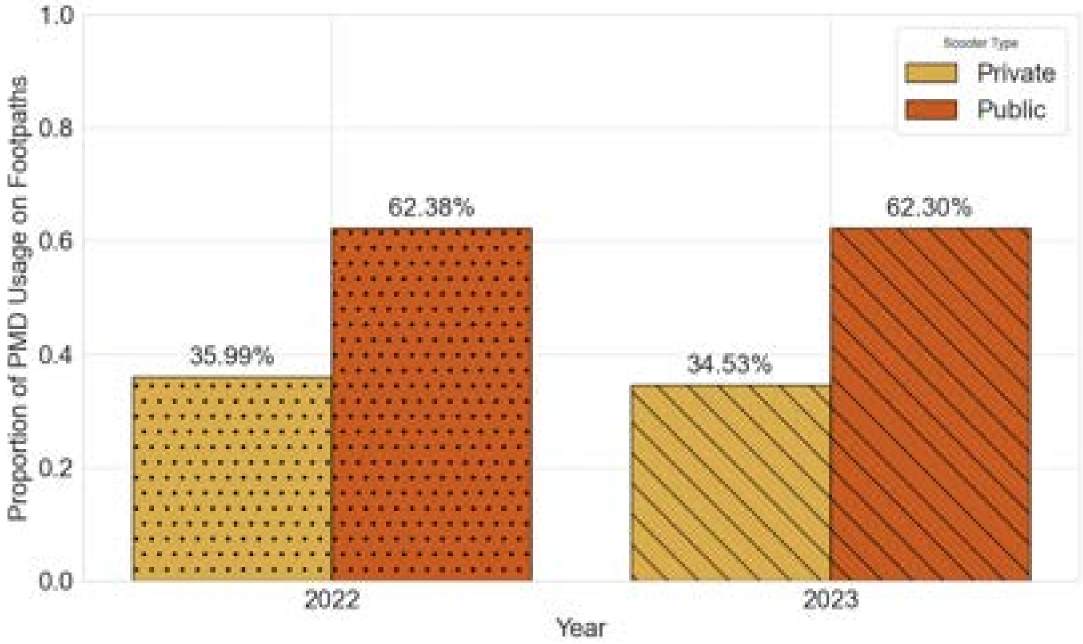

Figure 18: PMD Usage on Footpaths (where bike lane present)

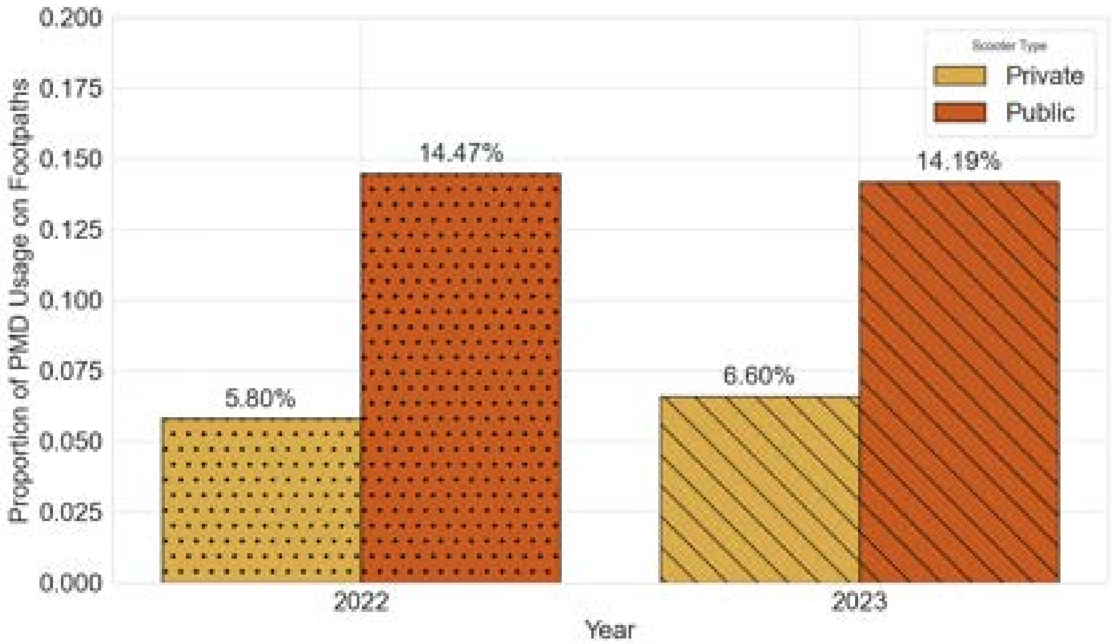

Figure 19: PMD Usage on Footpaths (where cycleway present)

Additionally, we examined the connection between footpath widths and footpath usage at each of the sites. The results are in Figure 20. A strong correlation of about 0.7 between the footpath width in metres and the proportion of PMD usage on the footpath was found.

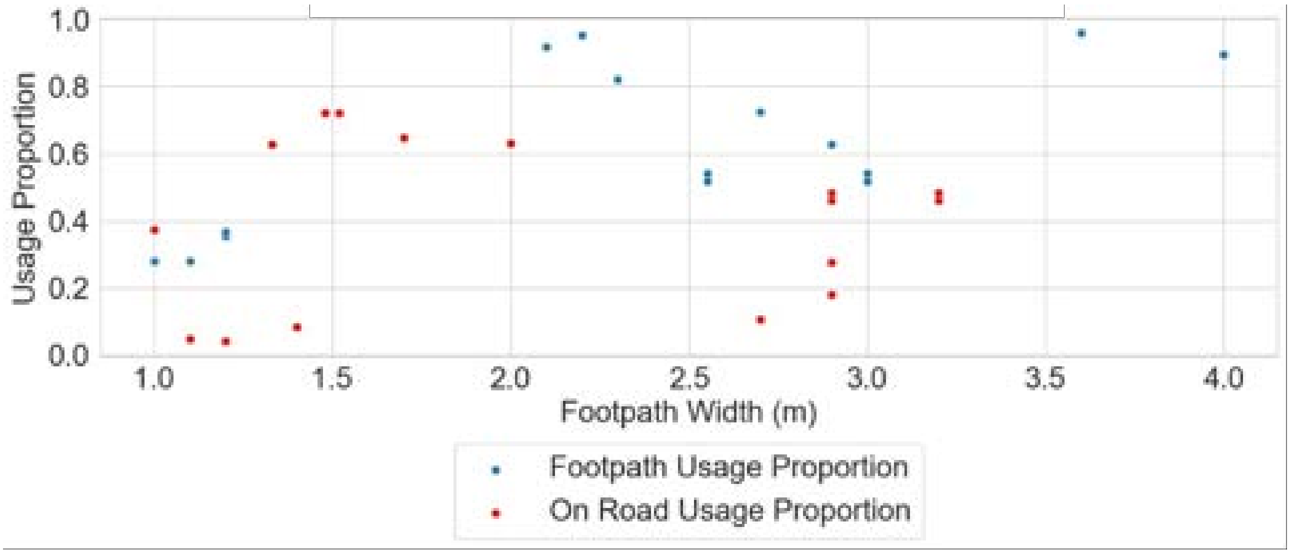

Figure 20: PMD Usage on Footpaths (where cycleway present)

2.2 PMD Speed Analysis

We examined the speed distribution of PMD rides, splitting the data according to e-scooter ownership, path type, helmet classification, infrastructure type, and combinations of these variables. Figure 21 provides the initial speed distribution by scooter type (Public or Private). Considering the highest speed limit of 25 km/h, at least 19% and 4% of observations for Private and Public PMDs, respectively, are above this limit.

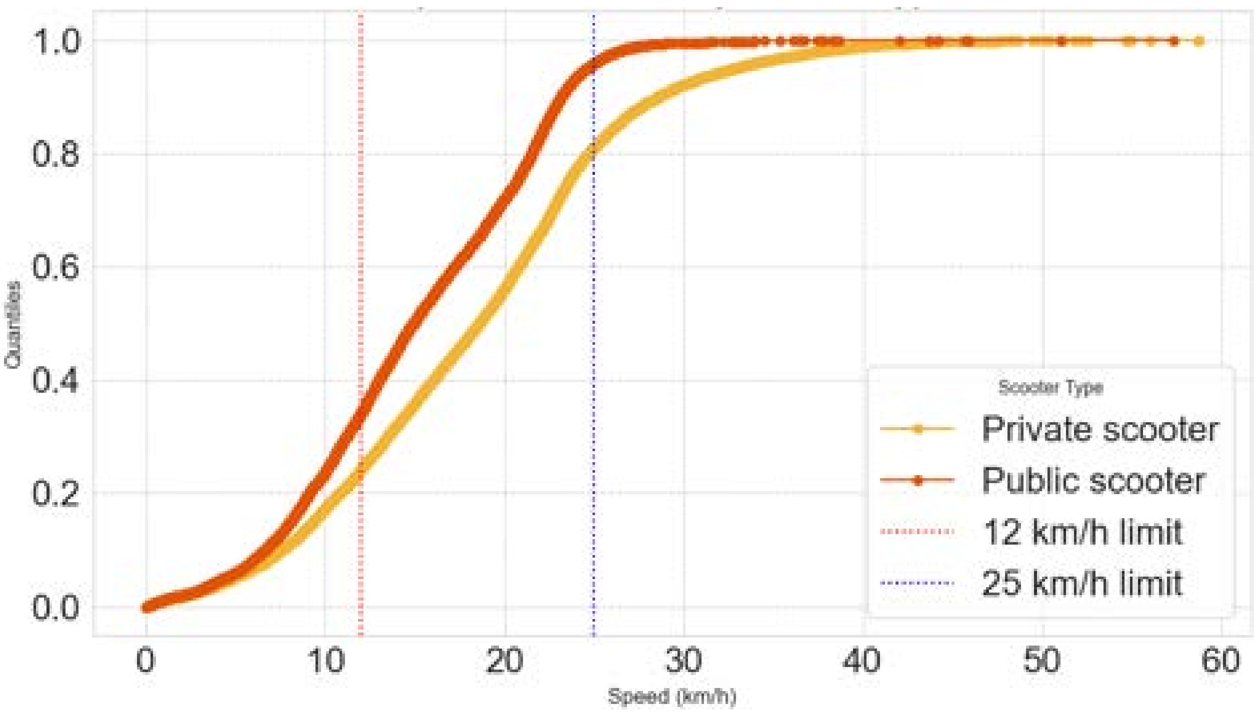

Figure 21: Speed distribution by scooter type

To consider the different speed limits on footpaths and roads, we split the data between footpath and on road as shown in Figure 22. Only, 52% of trips on footpaths complied with the 12 km/h limit, whereas 82% of on-road trips (general traffic lane, bike lane, cycleway) complied with the 25 km/h limit.

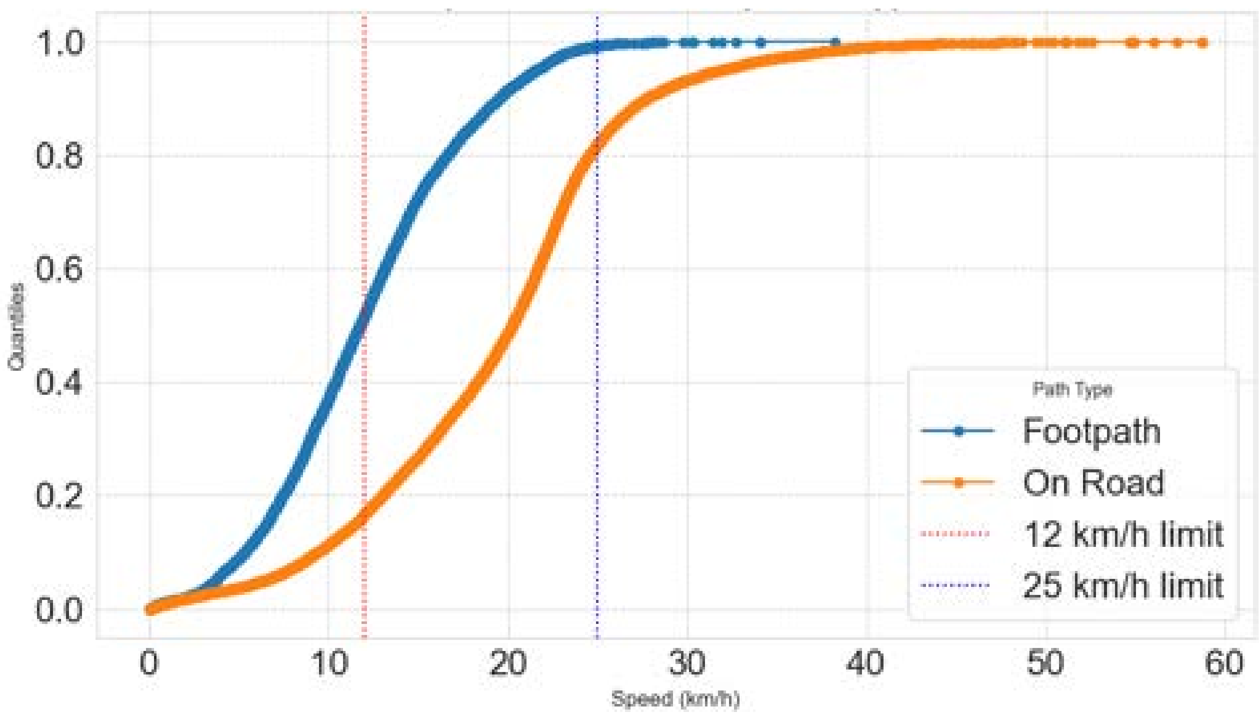

Figure 22: Speed distribution by path type

Table 5 and Table 6 show the proportion of trips above the speed limit in 2.5 km/h blocks from 12 km/h zones and 25 km/h zones, respectively.

Speed range (km/h)	Proportion of trips
>12.0	48.17%
>14.5	30.41%
>17.0	18.39%
>19.5	10.08%
>22.0	4.30%
>24.5	1.02%
>27.0	0.30%
>29.5	0.14%
>32.0	0.06%
>34.5	0.02%
>37.0	0.02%

Table 5: Percentage of PMD riders from 12 km/h zones in speed ranges above 12 km/h

Speed range (km/h)	Proportion of trips
>25.0	18.10%
>27.5	10.51%
>30.0	6.84%
>32.5	4.61%
>35.0	2.92%
>37.5	1.78%
>40.0	1.03%
>42.5	0.62%
>45.0	0.36%
>47.5	0.22%
>50.0	0.14%
>52.5	0.07%
>55.0	0.03%
>57.5	0.02%

Table 6: Percentage of PMD riders from 25 km/h zones in speed ranges above 25 km/h

Figure 23 and Figure 24 further split the data into 12 km/h zones and 25 km/h zones, respectively as the percentage of rides that exceeded the speed limit by the time of day, using data from 5am to 10pm.

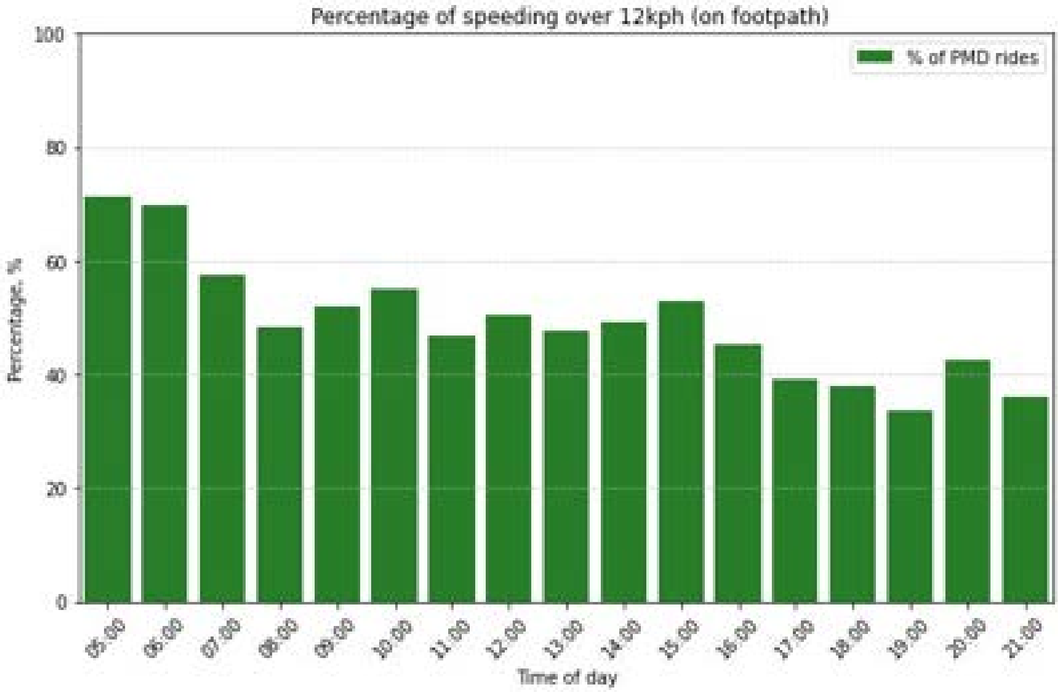

Figure 23: Speed distribution by the time of day (on footpath 12km/h speed limit)

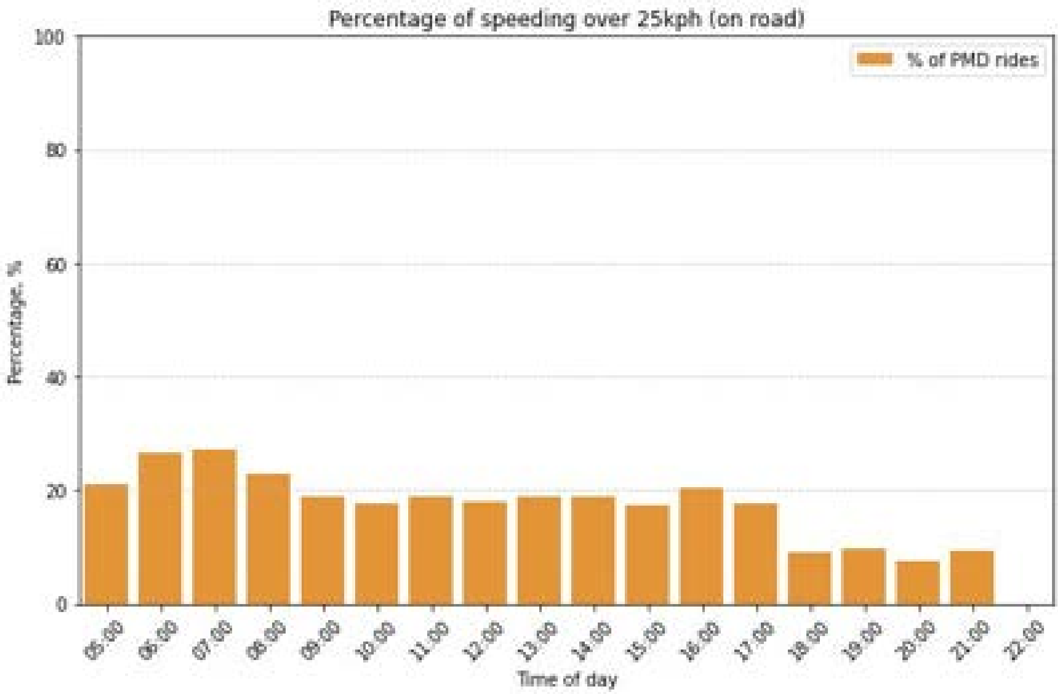

Figure 24: Speed distribution by the time of day (on-road 25km/h speed limit)

Figure 25 reveals the data split by scooter type (private and public) and infrastructure type (footpath and on-road). Both "Public on footpath" and "private on footpath" rides depict similar speed distribution, with 52% and 51% respectively complying with the 12 km/h limit. However, On-road speed compliance differed significantly depending on scooter ownership. While 93% of public PMD rides complied with the speed limit, only 75% of private PMD rides were compliant. This indicates that many private PMDs were not compliant with the importation guidelines that limit e-scooter speeds to a maximum of 25km/h (Department of Infrastructure Transport Regional Development Communications and the Arts, 2021) and confirms the effectiveness of 'soft' enforcement using technology like speed-limiting software.

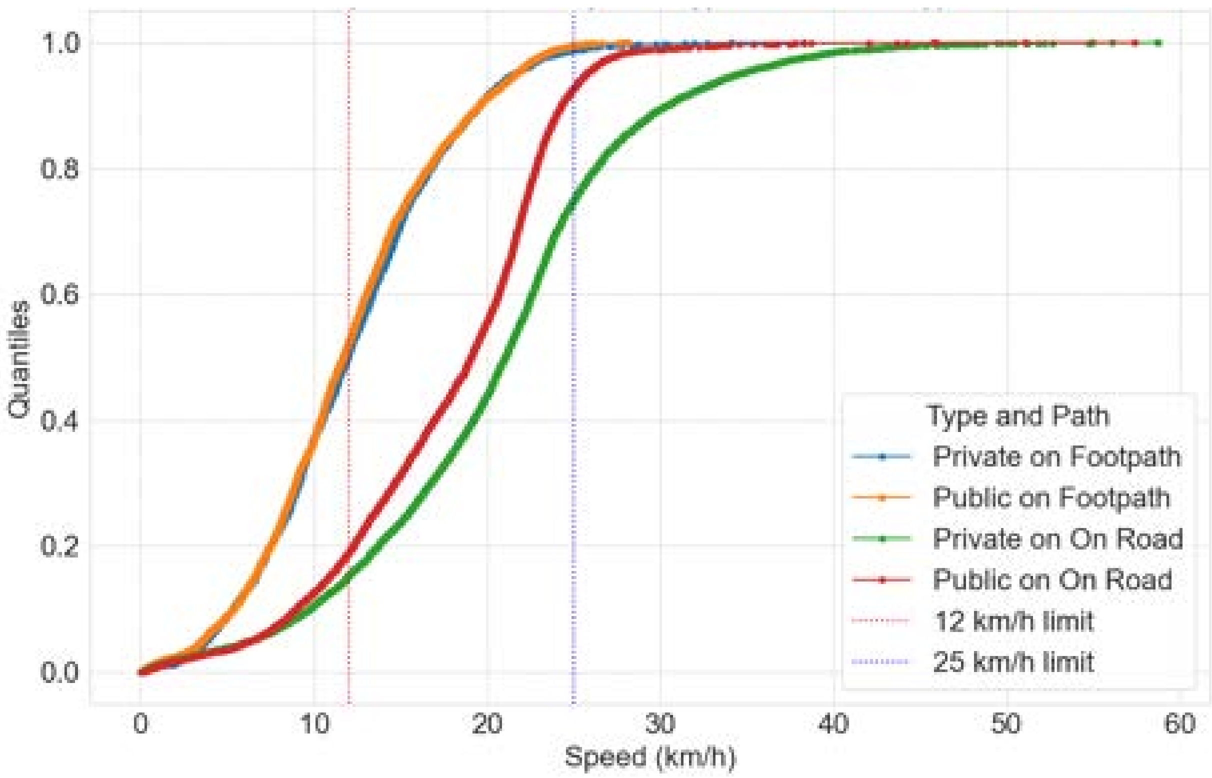

Figure 25: Speed distribution by path type and scooter type

Figure 26 provides an analysis of PMD speed by observed helmet classification (no helmet, helmet, and full-face helmet). In areas with a 25 km/h speed limit, the speed compliance rate is 94% for riders without helmets, 87% for riders with helmets, and 58% for riders with full-face helmets. This demonstrates risk compensation, where riders tend to travel faster when they have more protection.

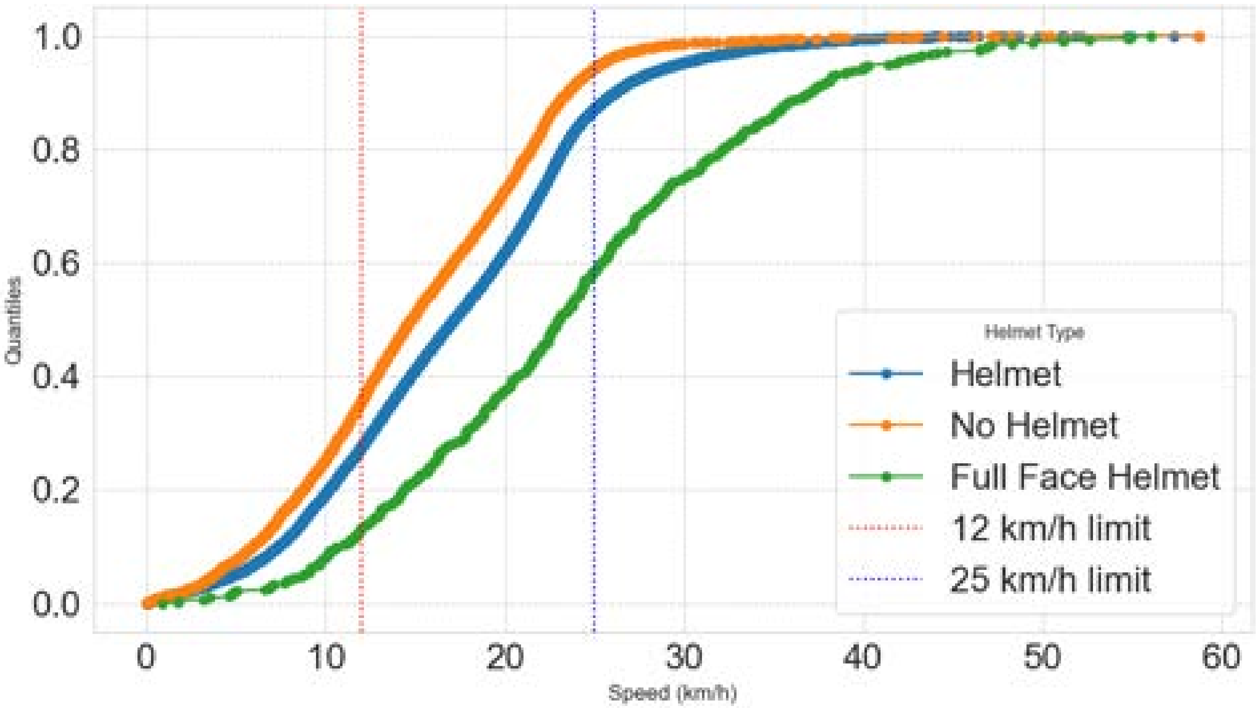

Figure 26 Speed distribution by helmet type

Figure 27 provides the speed distribution plot further split by helmet and scooter type. Only a few observations for full-face helmets with public scooters were captured; hence, they are omitted here . The results show that compliance with the 25 km/h speed limit varies across device type (Public/Private) and Helmet classification (No helmet/helmet/Full-face helmet). For riders without helmets, the compliance rate is 96% in public devices and 92% in private devices. For riders wearing standard helmets, the compliance rate was 96% for public devices but dropped to 80% in private devices. The lowest compliance was observed among riders wearing full-face helmets with private scooters, as only 57% were compliant with the speed limit.

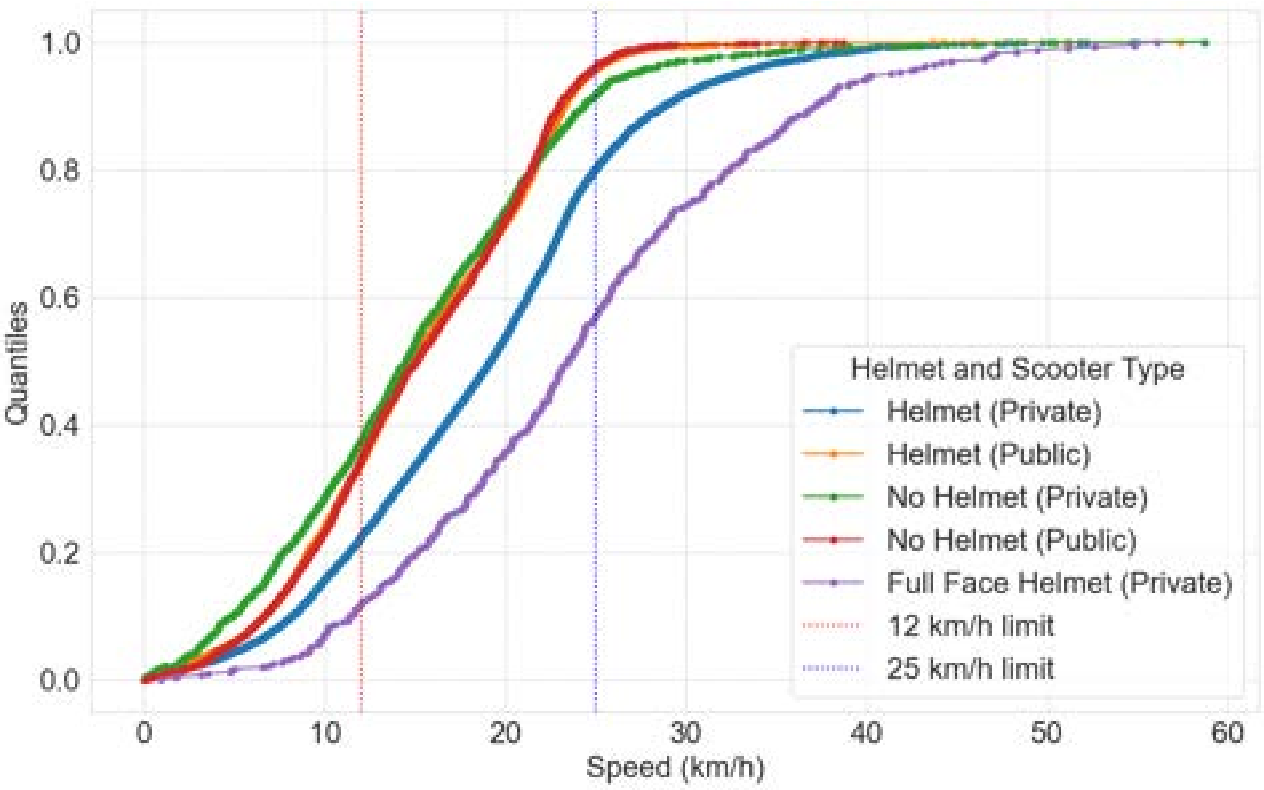

Figure 27: Speed distribution by helmet type and scooter type

Figure 28 depicts the speed distribution by location type (CBD, Urban, Suburban). Speed profiles increased with lower population density. The compliance rates with a 25 km/h speed limit are 97%, 74%, and 60% respectively in CBD, Urban, and Suburban locations.

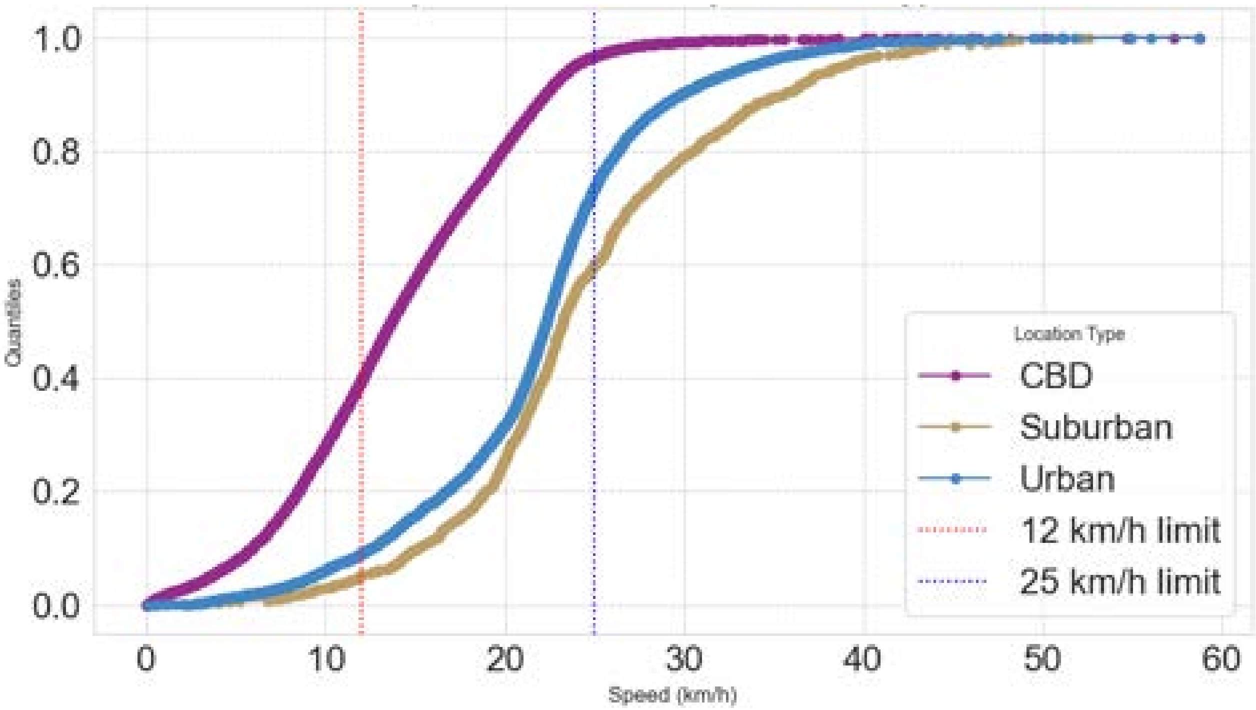

Figure 28: Speed distribution by location type

Figure 29 reveals a further split by location type and scooter type (private or public). The red line (public/suburban) has very few observations and may contain misclassifications as the line changes direction abruptly at 25 km/h. Notably, geofencing may have prevented public PMD use in the suburban locations studied.

In general, in the CBD public and private speeds were similar (orange and blue lines). Public PMD riders in the CBD were 99% compliant with a 25 km/h limit. In urban locations, private PMD riders were significantly faster (that is, the purple line is right of the brown line). The fastest classification (green line) was private PMDs in suburban locations. Only 57% of these observations were compliant with a 25 km/h limit.

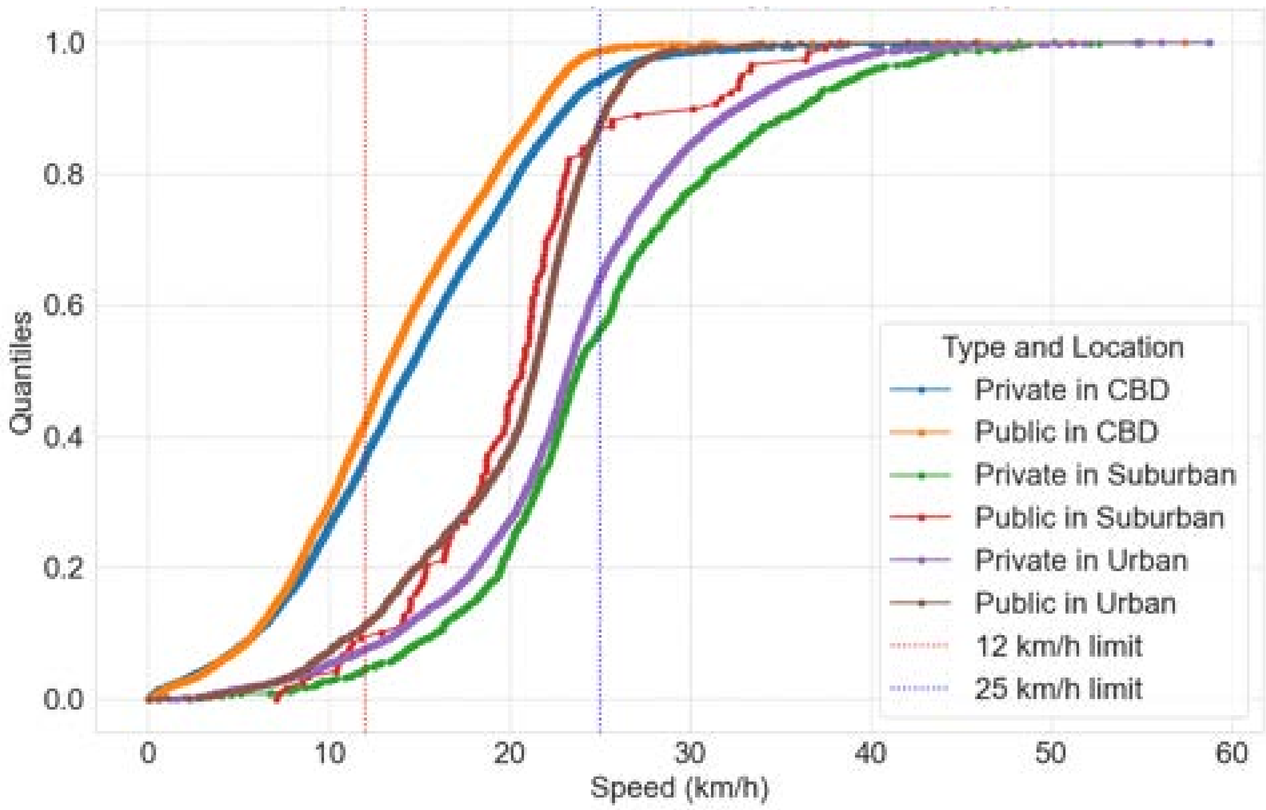

Figure 29: Speed distribution by location type and scooter type

Table 7, Table 8 and Table 9 reveal the proportion of on-road trips above the 25 km/h speed limit in 2.5 km/h blocks from 40, 50 and 60 km/h speed limit zones, respectively. In the locations chosen for our study, the 50 km/h zone was on Sylvan Road, Toowong while the 60 km/h zones were on Annerley Road, Dutton Park and Dickson St, Woolowin.

It is notable that in the 50 km/h zone (i.e. Sylvan Road) the proportion of trips over 25 km/h is 47% while in the 60 km/h zones (Annerley Road and Dickson St) the proportion of trips over 25 km/h is only 24%. A September 2024 BikeSpot report ranked Sylvan Road as the number 1 unsafe spot for cyclists in Brisbane while Dickson St on the North Brisbane Bikeway was ranked as the number 3 safe spot. Thus, an effect may be present which causes non-footpath riders to attempt to reduce the speed differential between themselves and motor vehicle traffic on Sylvan Road.

Speed range (km/h)	Proportion of trips
>25.0	14.61%
>27.5	7.97%
>30.0	4.93%
>32.5	3.27%
>35.0	2.03%
>37.5	1.32%
>40.0	0.76%
>42.5	0.44%
>45.0	0.24%
>47.5	0.16%
>50.0	0.14%
>52.5	0.07%
>55.0	0.04%
>57.5	0.02%

Table 7: Percentage of on-road PMD riders from 40 km/h speed limit zones in speed ranges above 25 km/h

Speed range (km/h)	Proportion of trips
>25.0	47.04%
>27.5	32.21%
>30.0	23.32%
>32.5	16.98%
>35.0	11.19%
>37.5	6.47%
>40.0	3.37%
>42.5	1.89%
>45.0	0.67%
>47.5	0.27%

Table 8: Percentage of on-road PMD riders from 50 km/h speed limit zones in speed ranges above 25 km/h

Speed range (km/h)	Proportion of trips
>25.0	23.85%
>27.5	14.42%
>30.0	9.72%
>32.5	6.39%
>35.0	4.06%
>37.5	2.23%
>40.0	1.40%
>42.5	1.02%
>45.0	0.82%
>47.5	0.48%
>50.0	0.19%
>52.5	0.10%

Table 9: Percentage of on-road PMD riders from 60 km/h road speed limit zones in speed ranges above 25 km/h

Figure 30 provides a speed analysis by hour of day in the three location types (CBD, Urban, Suburban). In suburban locations, the average speed frequently exceeded 25 km/h for hours in the middle of the day. In the CBD, average speeds were higher in the early morning.

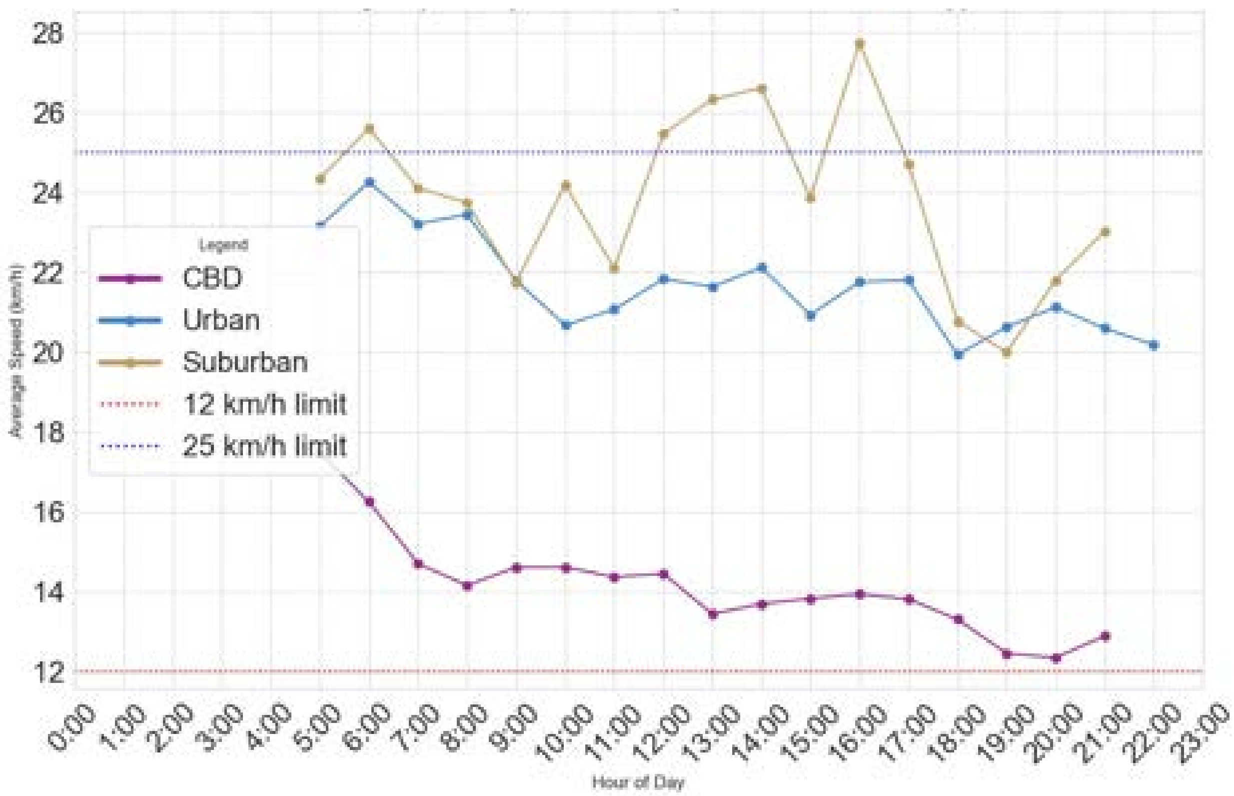

Figure 30: Average speed by hour for each location type

Figure 31 details the analysis of average speed by time of day on footpaths. On CBD footpaths, the average speed exceeded 12 km/h before 7am. On urban footpaths, it exceeded 12 km/h outside peak travel times. On suburban footpaths, the average speed dropped below 12 km/h only from 6-10 am and 5-8 pm.

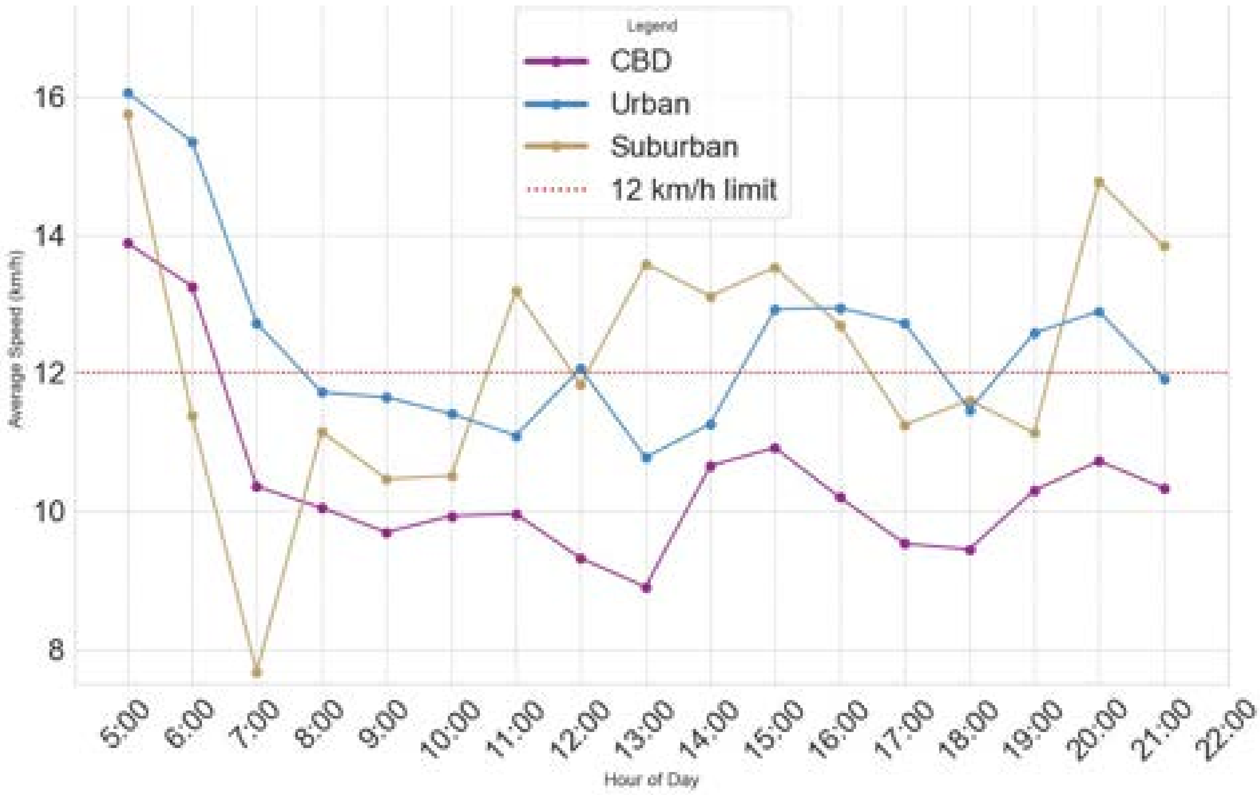

Figure 31: Average speed by hour for different location types for riding on footpaths

Figures 32 to 34 illustrate the compliance rate in 12 km/h speed zones by location type and time of day. The plots depict CBD, Urban, and Suburban locations in that order. Compliance rates decreased as locations move further from the CBD to Urban and Suburban areas.

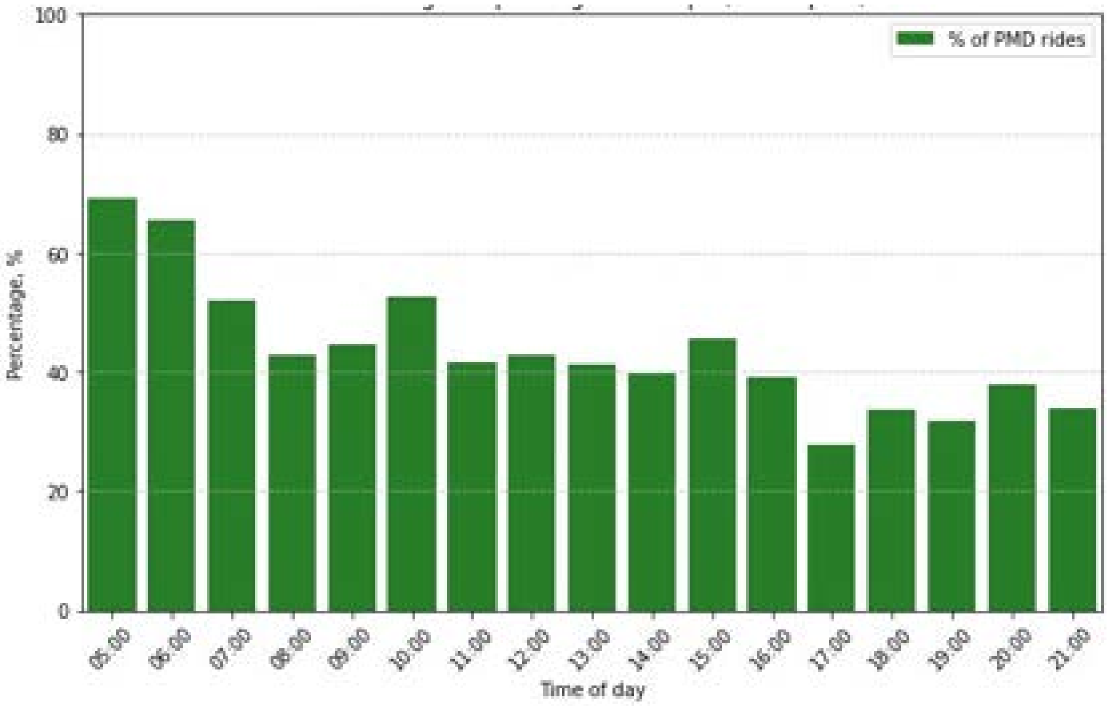

Figure 32: Speed limit compliance on footpaths (12km/h) by location by time of day in the CBD

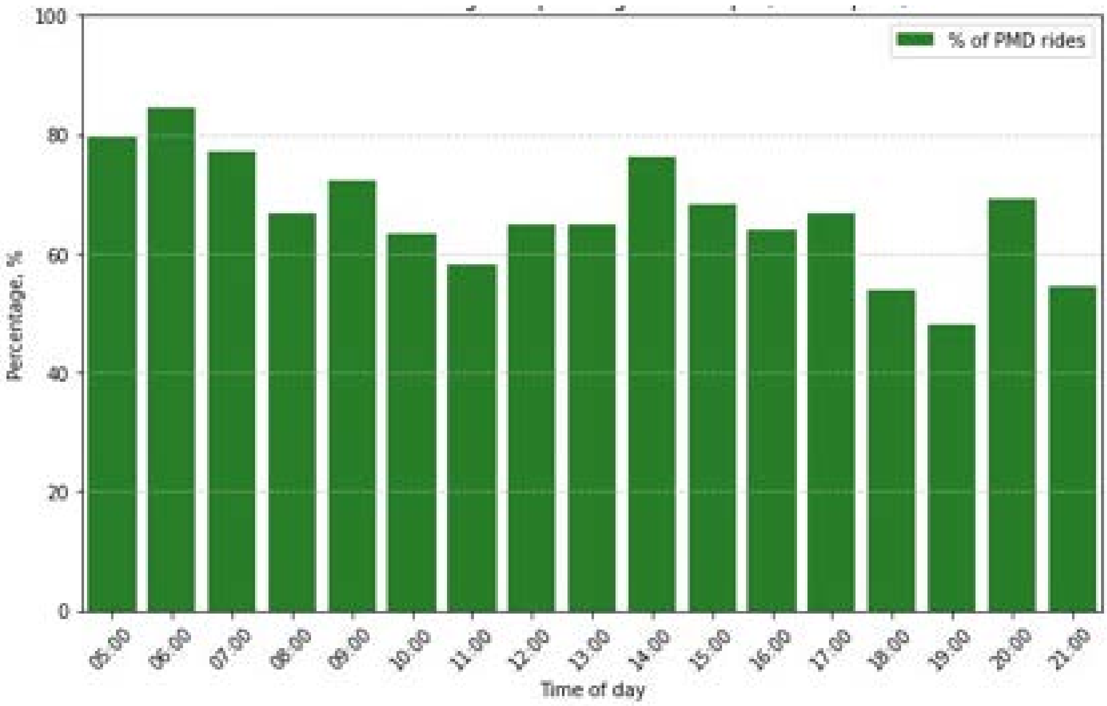

Figure 33: Speed limit compliance on footpaths (12km/h) by location by time of day in Urban areas

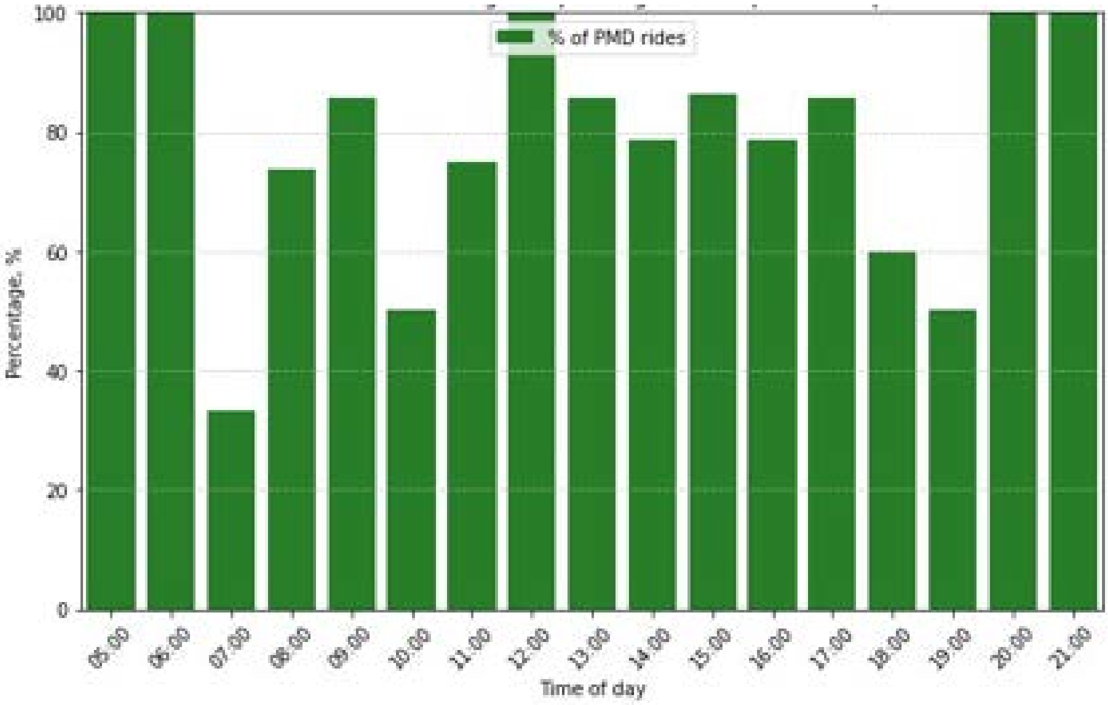

Figure 34: Speed limit compliance on footpaths (12km/h) by location by time of day in Suburban areas

Figures 35 and 36 provide the counts and proportions of speed limit noncompliance across four infrastructure types: footpath, general traffic lane, on-road bicycle lane, and separated cycleway, for the years 2022 and 2023. Compared to 2022, the proportion of non-compliance increased in 2023 across three infrastructure types, except on separated cycleway compliance was highest.

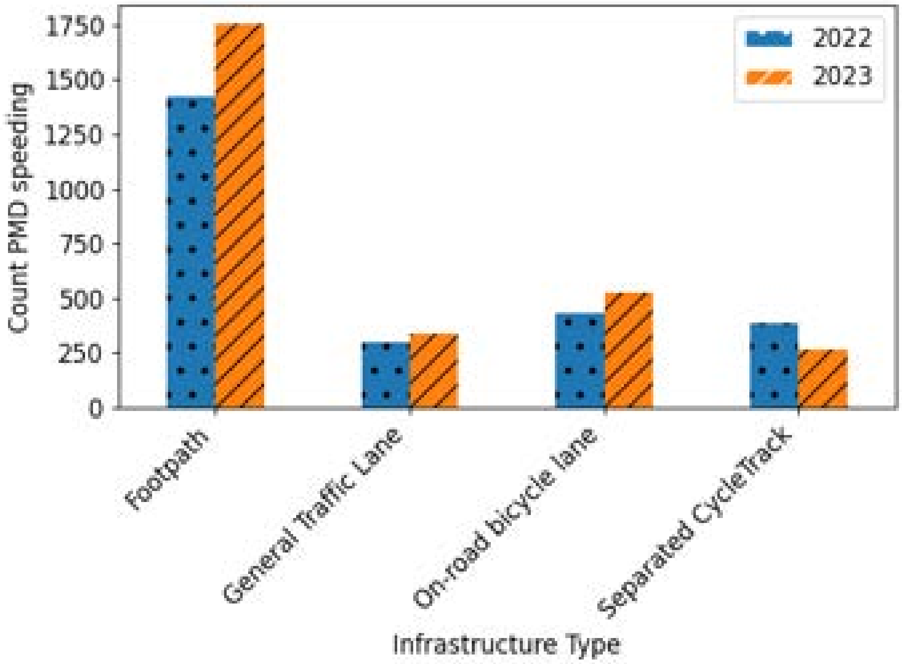

Figure 35: Speed limit noncompliance t by type of infrastructure (by count)

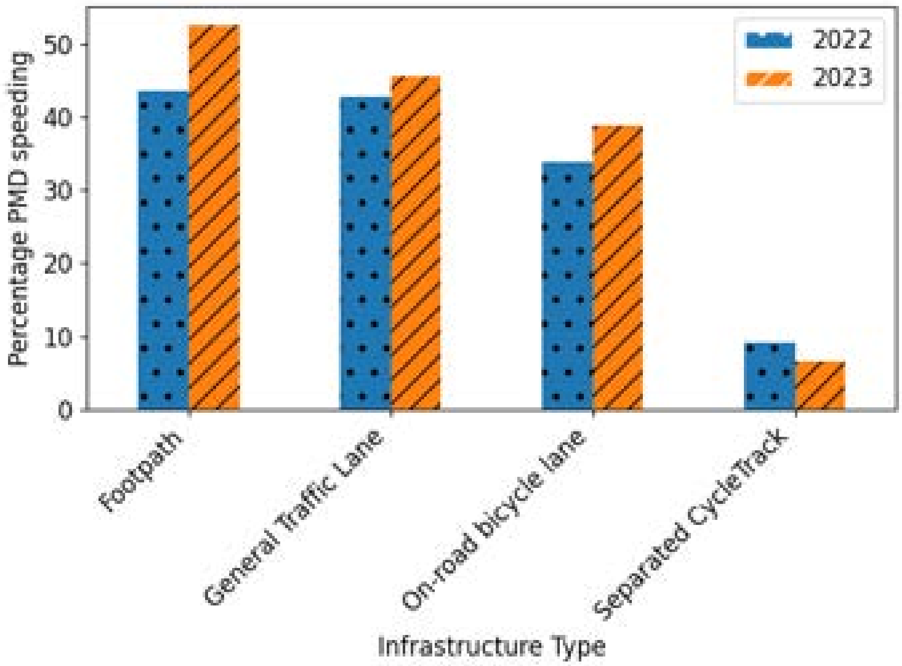

Figure 36: Speed limit noncompliance in each infrastructure (by percentage)

Figure 37, the average speed by hour, segregated by location and plotted by time of day. In CBD locations, the average speed was always below 25 km/h. In urban locations, the average speed exceeded 25 km/h from 5 to 6am, indicating non-compliance with the higher speed limit. In suburban locations, the average speed exceeds 25 km/h from 5 am to 6 pm.

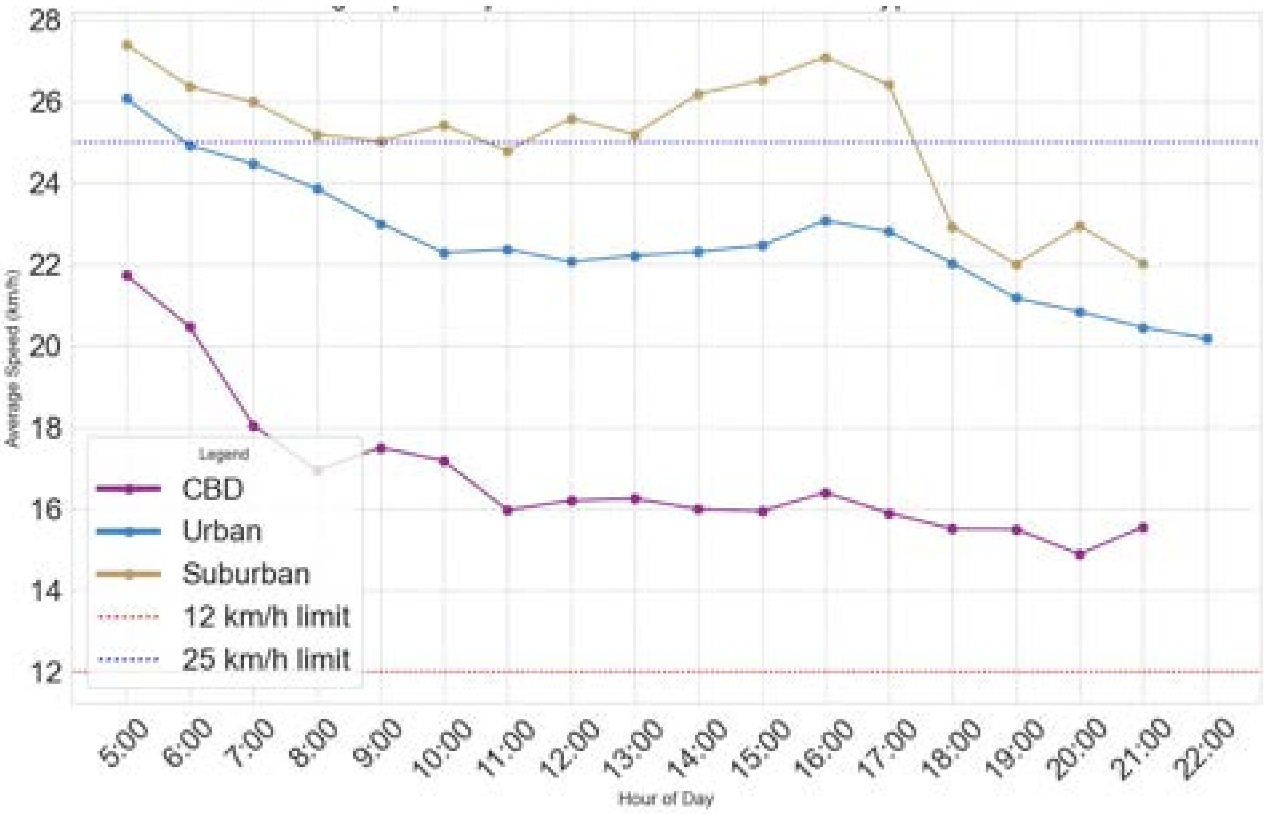

Figure 37: Average speed by hour for different location types on road

Figures 38 to 40 provide the percentage of on-road speeding above a 25 km/h limit by time of day and location (CBD, Urban, Suburban). The data indicates that suburbs further away from the CBD experienced a higher the proportion of speeding PMD users.

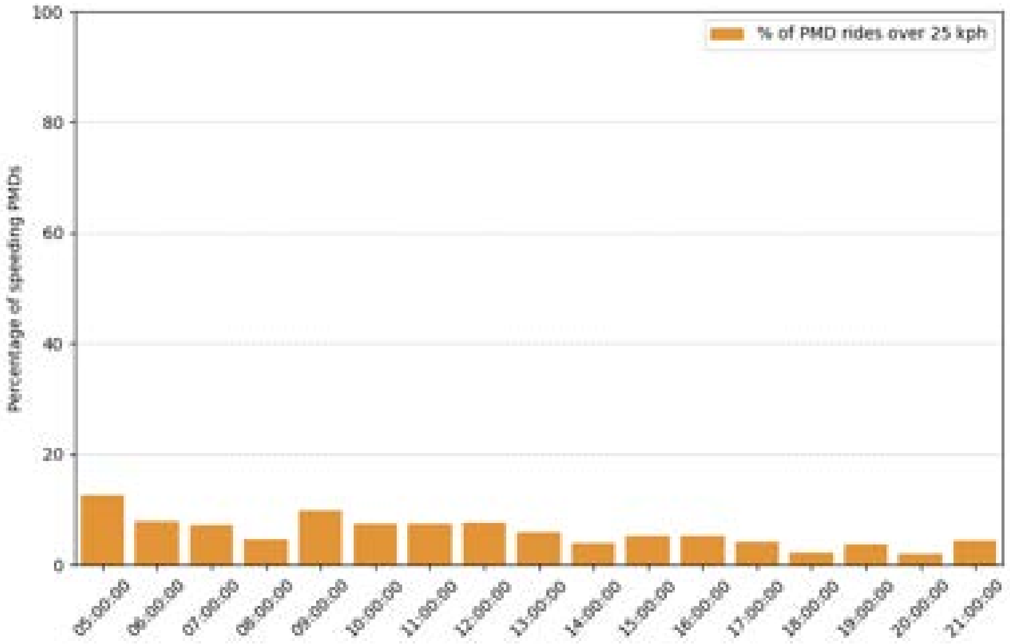

Figure 38: Percentage of on-road PMD rides over 25 km/h by time of day (CBD)

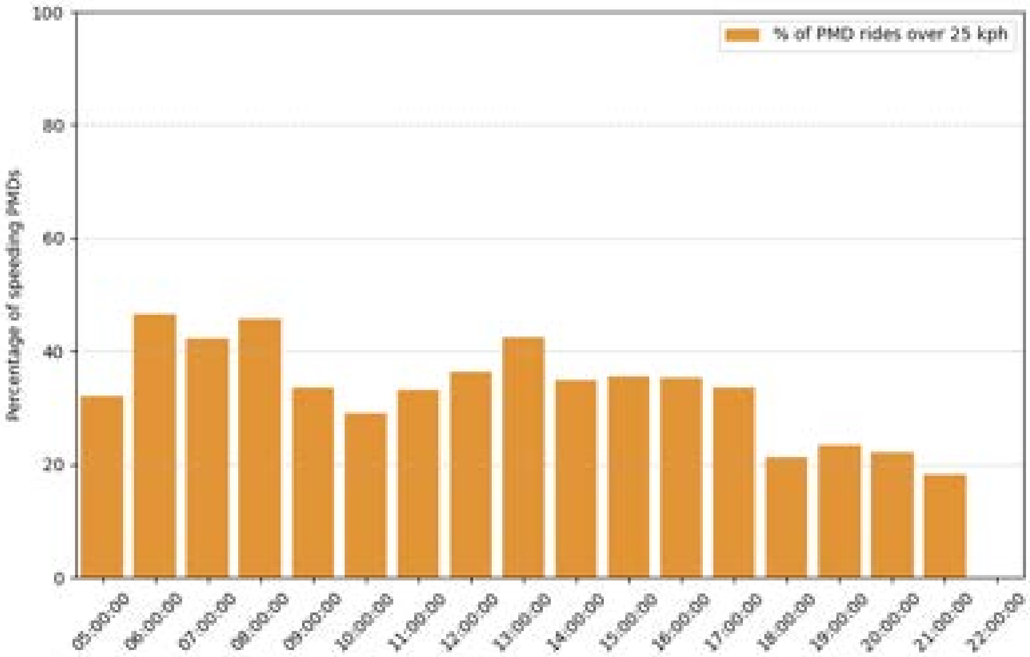

Figure 39: Percentage of on-road PMD rides over 25 km/h by time of day (Urban)

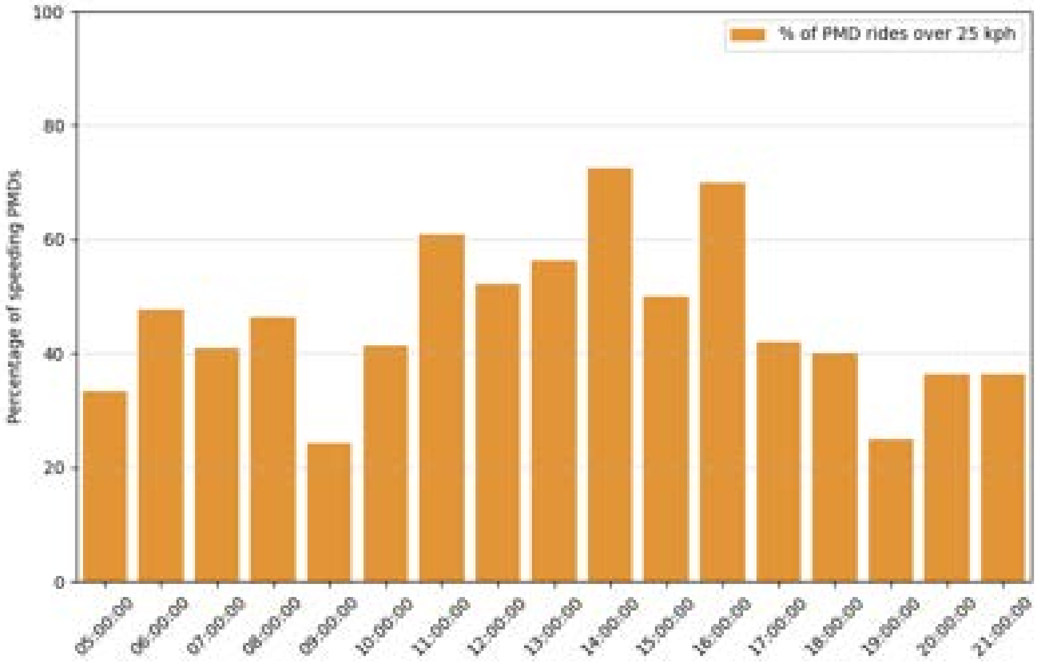

Figure 40: Percentage of on-road PMD rides over 25 km/h by time of day (Suburban)

Figures 41 and 42 provide the percentage of speeding in 12 km/h and 25 km/h speed limit zones by time of day and scooter type. A larger proportion of private PMD rides exceeded the speed limit, likely because public PMDs are usually equipped with geofencing technology to automatically reduce speed in certain areas (Haworth et al., 2021).

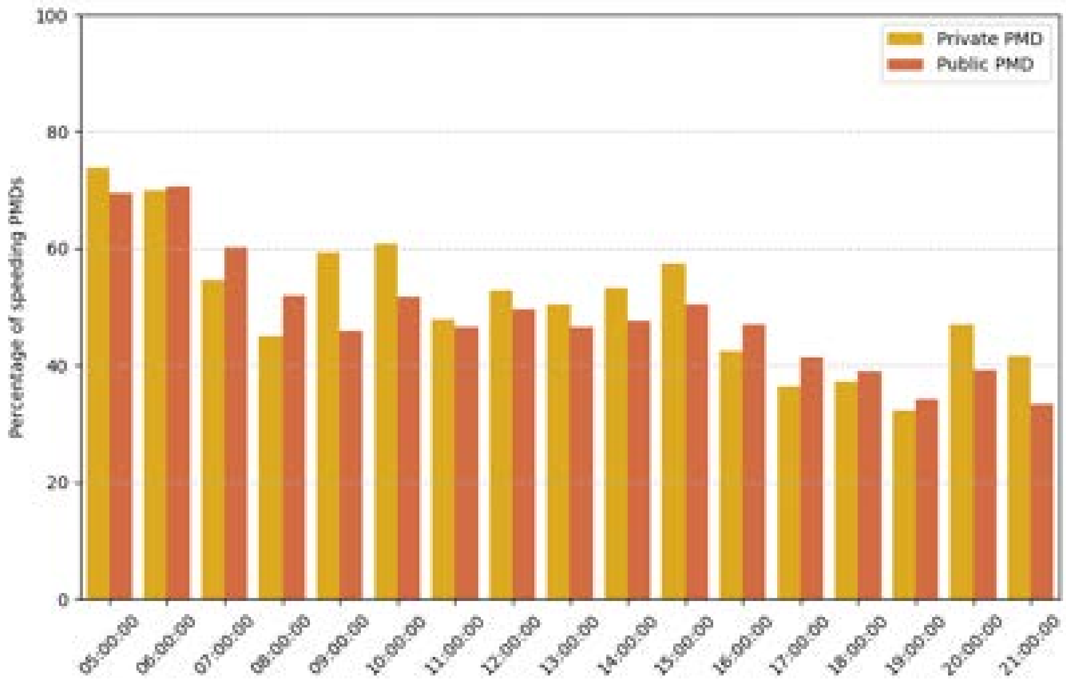

Figure 41: Comparison of private vs public PMD speeding (On Footpath 12km/h)

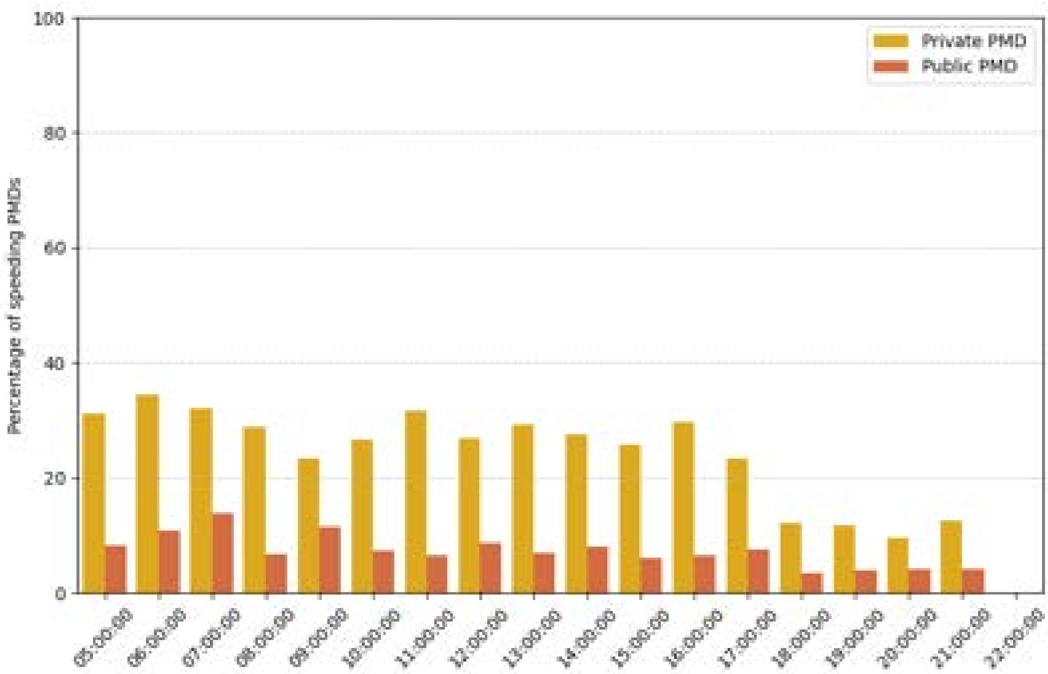

Figure 42: Comparison of private vs public PMD speeding (On Road 25 km/h)

Figures 43 to 45 depict average speeds by the hour for all PMDs, including both riding on footpaths and on roads, further categorised into public and private PMDs. Figure 41 illustrates that average speeds exceeded 12 km/h for all types. Figure 42 indicates that on footpaths, both public and private PMD riders were compliant after 4pm in terms of average speed but non-compliant before 9am. It's important to consider whether the study zones were speed-limited for public PMDs. Figure 43 depicts that average speeds on roads were compliant throughout all hours.

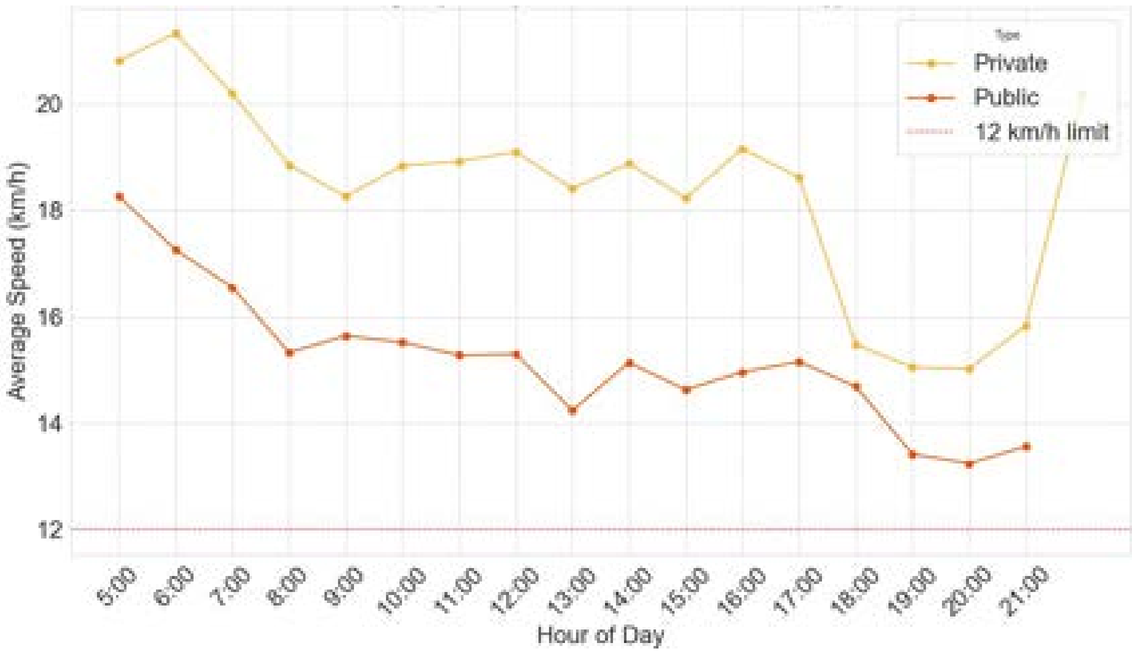

Figure 43: Average speed by hour for different scooter types

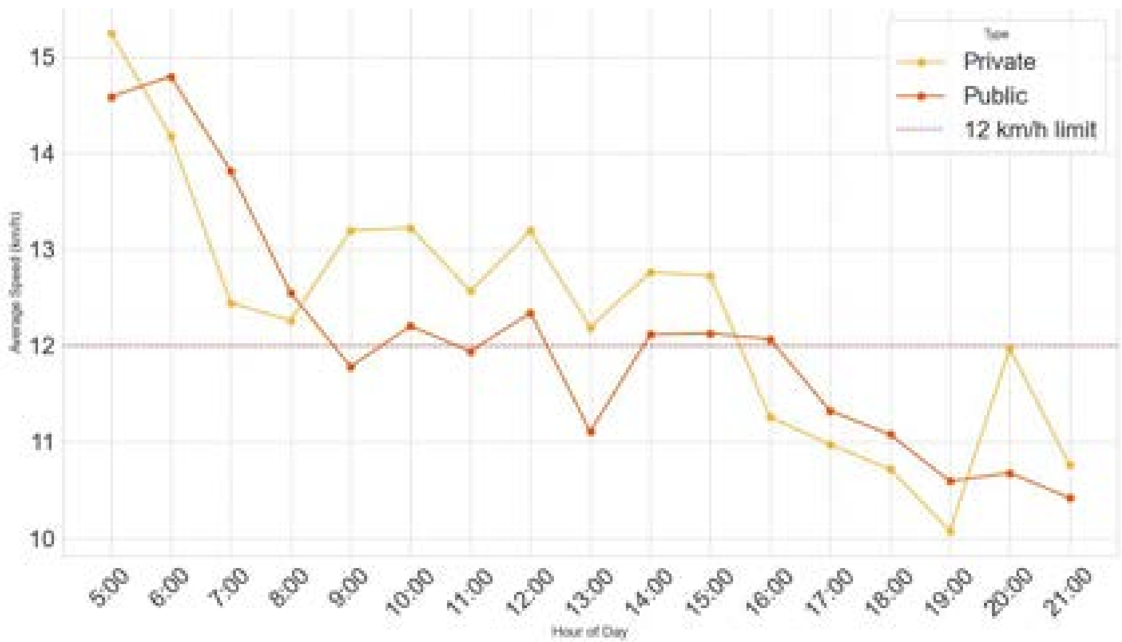

Figure 44: Average speed by hour for different scooter types on footpaths

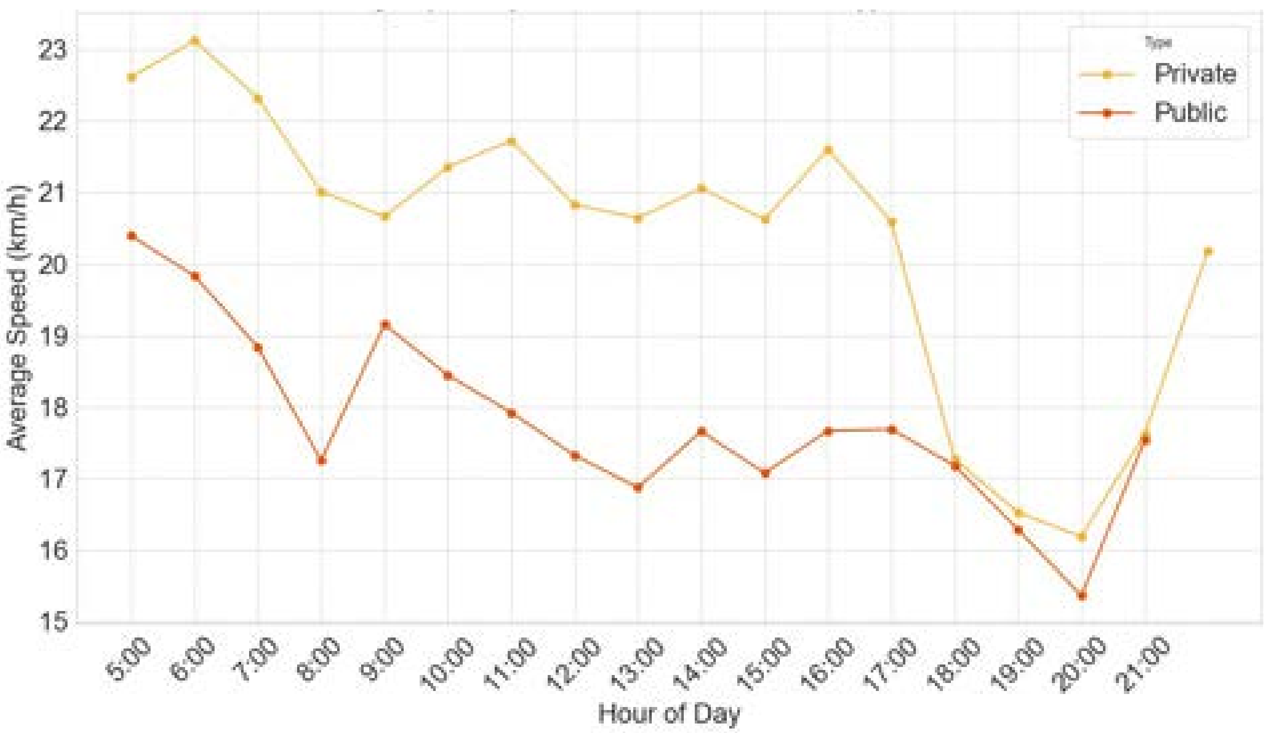

Figure 45: Average speed by hour for different scooter types on roads

In Figure 46, we present a quantile plot of speed to illustrate the increase in speeds between 2022 and 2023, split into private and public scooters. We conducted two-sample t-tests to determine if the speed increase was significant. For private PMDs, the average speed significantly increased from 17.83 to 18.93 km/h ($p < 0.001$). For public PMDs, the average speed significantly increased but at a lower rate from 14.96 to 15.23 km/h (significant at $p = 0.053$).

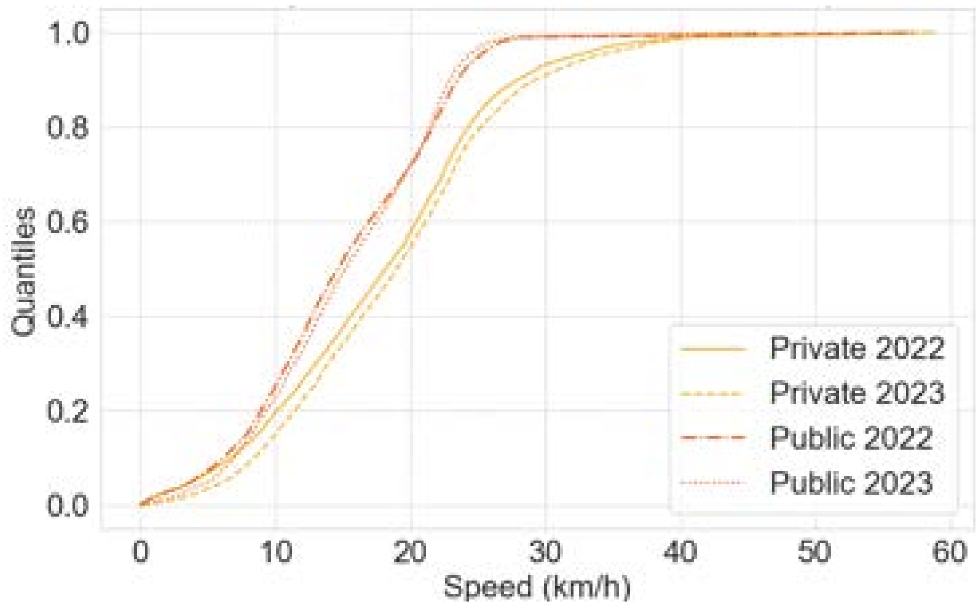

Figure 46: Quantile plot of speeds for private and public scooters (2022 vs 2023)

2.3 Helmet Use Analysis

Helmet compliance was studied for cyclists in the 2022 observations and 97.1% of cyclists observed were compliant with the helmet law; with the caveat that helmets worn but not fastened were counted as complying.

Figure 47 shows helmet law compliance depending on path type (footpath or on-road). Compliance is higher on roads, which could be explained by several factors such as risk compensation, the presence of faster-moving vehicles, or the higher proportion of private PMDs in an on-road environment. Figure 48 further splits public and private PMDs, illustrating that compliance with helmet laws is lower among public PMD riders. This may be due to factors such as helmet availability, shorter rides with public PMDs, risk compensation in lower-risk environments (e.g., footpaths, CBD), or unwillingness to wear a shared helmet. Figure 49 continues to examine the split between public and private PMDs, investigating helmet law compliance across three 25 km/h speed zone infrastructure types: general traffic lanes, bike lanes, and separated cycleway. Compliance rates are similar across these types, with lower compliance observed among public PMD users.

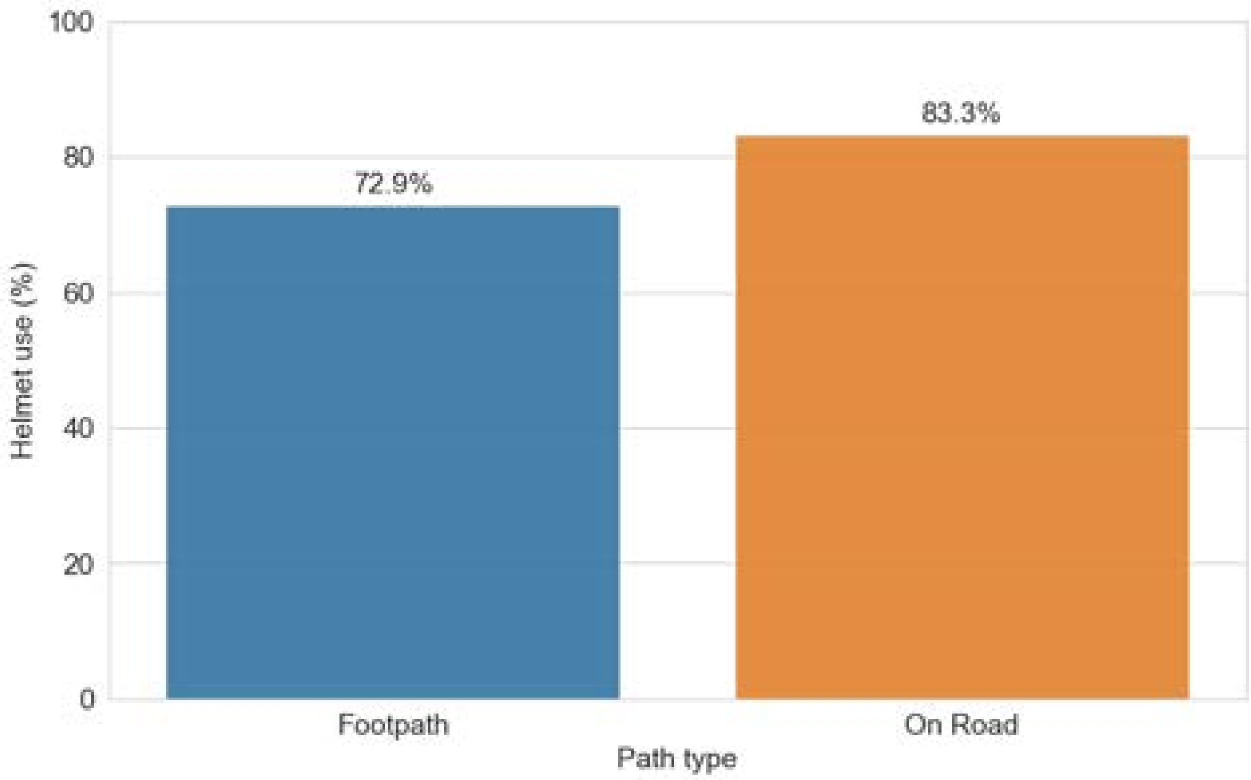

Figure 47: PMD riders helmet use by riding location (2022 and 2023 combined)

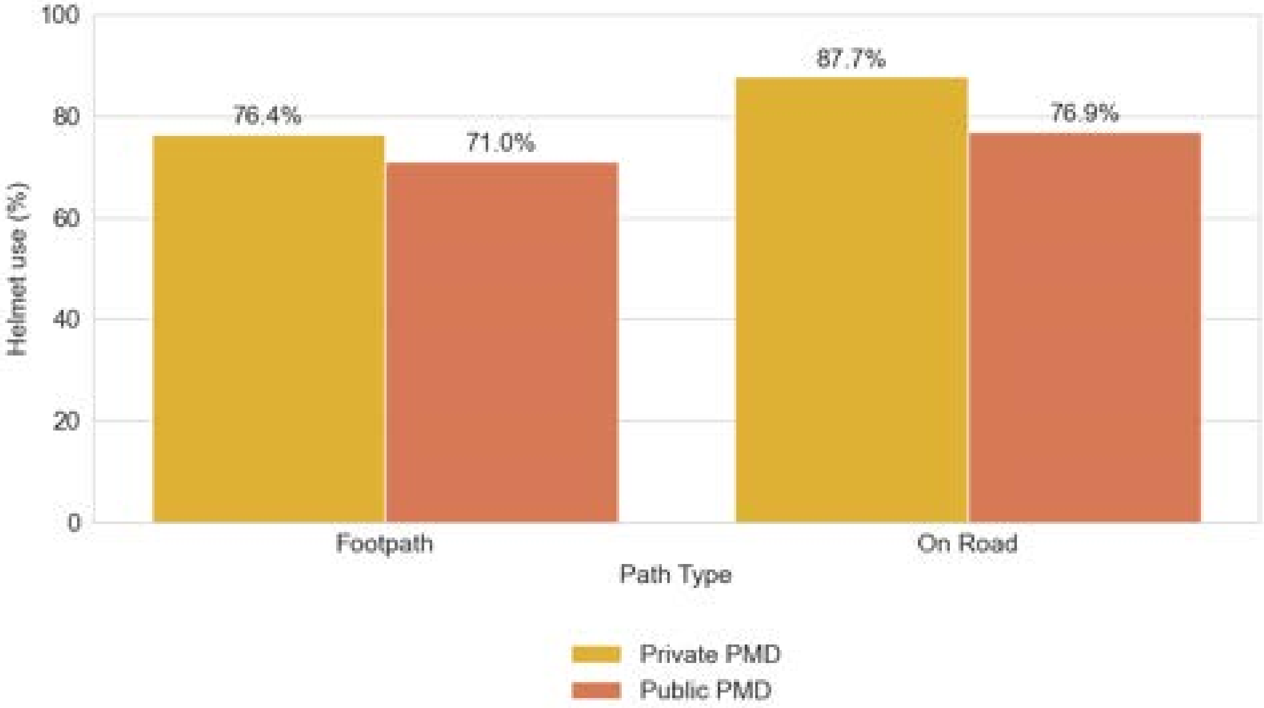

Figure 48: PMD riders helmet use by riding location and ownership (2022 and 2023 combined)

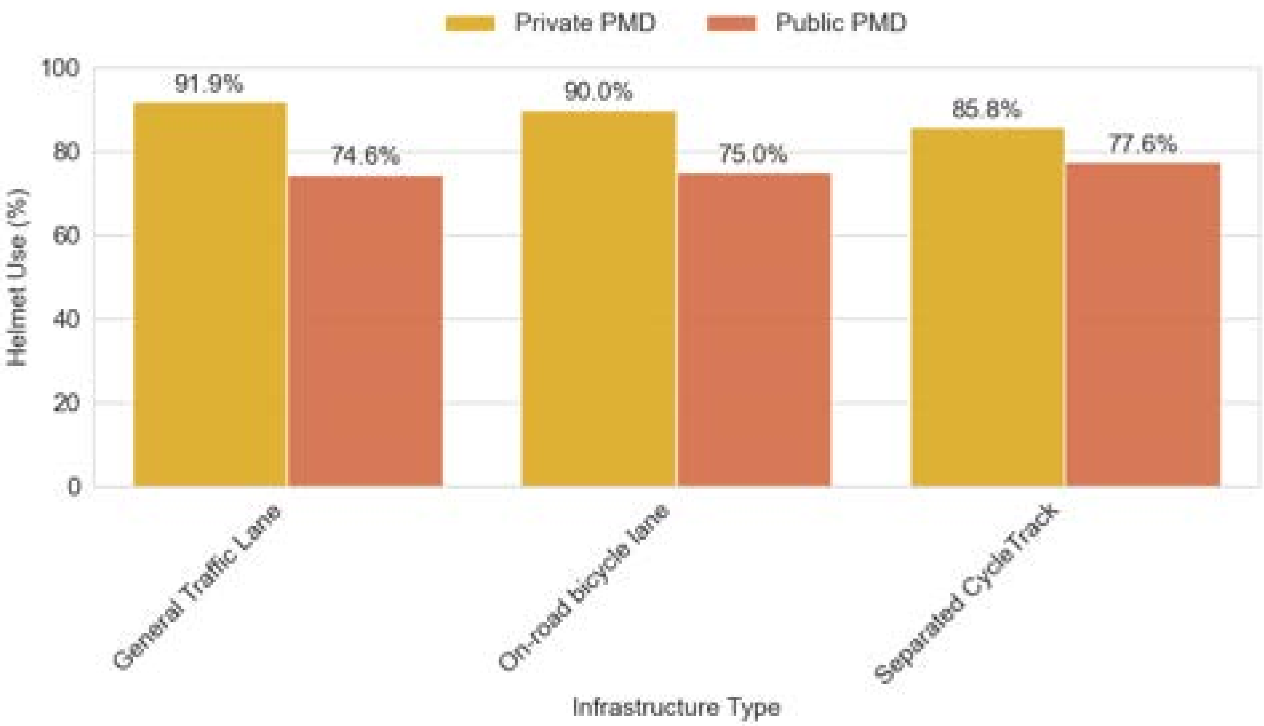

Figure 49: PMD riders helmet use by riding location in 25 km/h zones (2022 and 2023 combined)

Figure 50 below exhibits the average speed for riders wearing different helmet types. Risk compensation is evident, with riders wearing full-face helmets exceeding 25 km/h, while those without helmets ride slower than helmeted riders. Figure 51 shows a lower incidence of speeding among riders on the road.

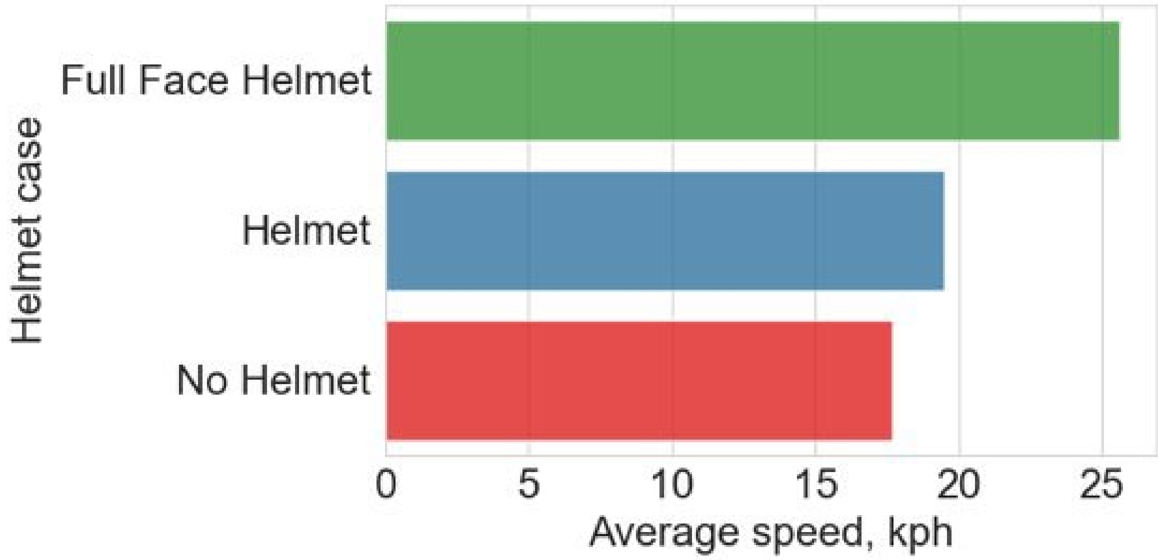

Figure 50: Average speed for different helmet types (2022 and 2023 combined)

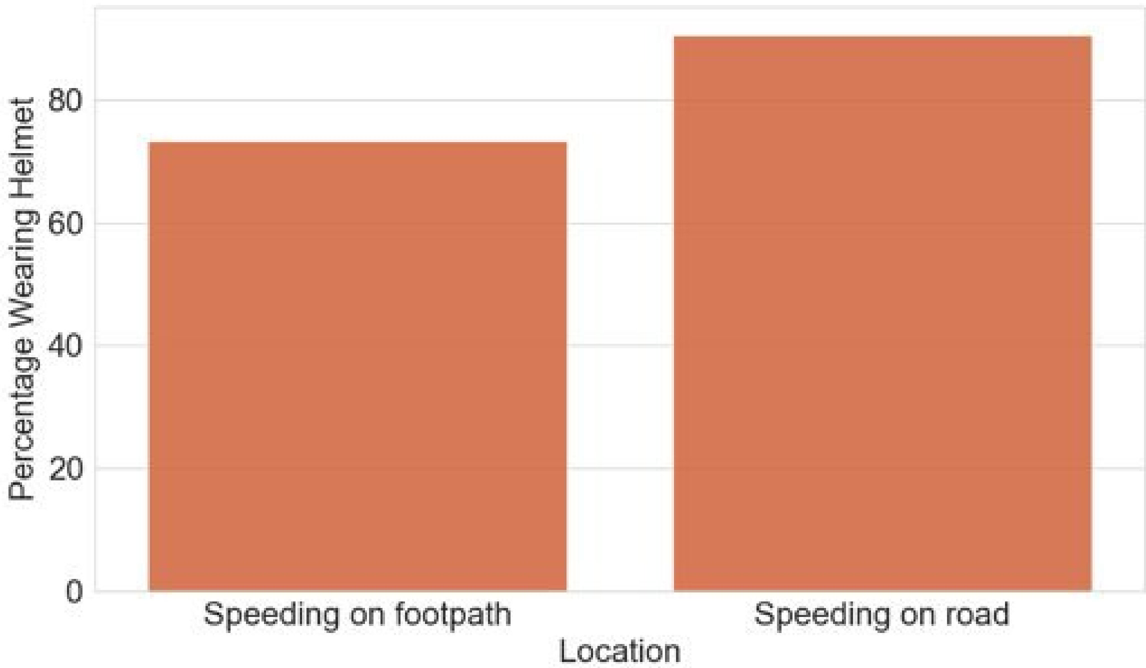

Figure 51: PMD riders helmet use by position and infrastructure (2022 and 2023 combined)

2.4 Logistic regression modelling

To provide a holistic understanding of the determinants of speed and helmet use compliance, three separate logistic regression models were run.

1. Assessing helmet use based on different variables: speed of travel, location of travel (CBD/Urban/Suburban), scooter type (private/public), commuting hour (6am-9am and 3pm-6pm Monday to Friday), weekend/weekday travel, posted speed limit (40, 50, 60 km/h), and infrastructure type (bike lane, general traffic lane, separated cycleway).
2. Assessing speed limit compliance in the case of 12 km/h speed zones (e.g. footpath) with the same variables, including helmet compliance and excluding speed
3. Assessing speed limit compliance in the case of 25 km/h speed zones (e.g. road, cycleway) with the same variables, including helmet compliance and excluding speed.

Each regression model aimed to investigate factors influencing helmet use or speed limit compliance amongst PMD riders.

2.4.1 Helmet use assessment

In this case, the reference scenario was: Private scooter, CBD, 40 km/h speed limit, and separated cycleway. The baseline odds ratio for compliance in this scenario is 4.65, meaning that the odds of wearing a helmet are 4.65 times higher than *not* wearing a helmet.

The findings with significant p-values in the results (see Table 4 below) are as follows.

- For each additional 1 km/h increase in speed, the odds of helmet use increased by approximately 1%. This suggests a slight increase in the likelihood of helmet use with higher speeds, though the effect is small. Note that in the speed compliance logistic regression in 25 km/h zones, helmet use was related to lower speed compliance (risk compensation) and helmet use was not a significant predictor in 12 km/h zones.
- Using a public scooter decreased the odds of helmet use by about 38% compared to using a private scooter (odds ratio 0.62).
- During commuting hours, the odds of helmet use were 80% higher compared to non-commuting hours (odds ratio 1.80).
- On weekends, the odds of helmet use decreased by about 36% compared to weekdays (odds ratio 0.64).
- Being in a suburban location increased the odds of helmet use by 275% compared to the CBD (odds ratio 3.75).
- Being in an urban location increased the odds of helmet use by 49% compared to the CBD (odds ratio 1.49).
- A posted speed limit of 60 km/h increased the odds of helmet use by 31% compared to 40 km/h (odds ratio 1.31).
- Using an on-road bicycle lane decreased the odds of helmet use by 42% compared to a separated cycleway (odds ratio 0.58).

Variable name	coef	Std. err	Z	P> |z|	[0.025	0.975]
Const	1.5376	0.0850	18.1670	0.000	1.3720	1.7030
Speed	0.0112	0.0040	2.8130	0.005	0.0030	0.0190
Public Scooter	-0.4804	0.0510	-9.4070	0.000	-0.5800	-0.3800
During commuting hours	0.5856	0.0720	8.1620	0.000	0.4450	0.7260
Weekend	-0.4439	0.0580	-7.6510	0.000	-0.5580	-0.3300
Location Type: Suburban	1.3217	0.4950	2.6680	0.008	0.3510	2.2930
Location: Type: Urban	0.3976	0.1060	3.7360	0.000	0.1890	0.6060
Posted Speed: 50km/h	0.1622	0.5020	0.3230	0.747	-0.8220	1.1470
Posted Speed: 60km/h	0.2671	0.1140	2.3380	0.019	0.0430	0.4910
Bike Lane	-0.5464	0.0950	-5.7590	0.000	-0.7320	-0.3600
General Traffic Lane	0.0489	0.1100	0.4430	0.658	-0.1680	0.2650

Table 10: Helmet Compliance Logistic Regression Results

2.4.2 12 km/h speed zone compliance assessment

We investigated the factors that predicted speed limit compliance in 12 km/h speed limit zones and summarise the significant findings from this logistic regression below. The results are shown in Table 5.

- The baseline odds of compliance were about three times higher than the odds of non-compliance (odds ratio 3.13).
- Being in an urban location decreased the odds of compliance by about 72% compared to the CBD (odds ratio 0.28), indicating that riders in the CBD were much more compliant with the road rules.
- A posted speed limit of 50 km/h decreased the odds of compliance by about 82% compared to 40 km/h (odds ratio 0.18), and a posted speed limit of 60 km/h decreased the odds of compliance by about 72% compared to 40 km/h (odds ratio 0.28), suggesting that higher posted automobile speed limits result in lower speed compliance for PMDs.
- Using an on-road bicycle lane decreased the odds of compliance by about 32% compared to a separated cycleway (odds ratio 0.68), while using a general traffic lane decreased the odds of compliance by about 70% compared to a separated cycleway (odds ratio 0.30). This indicates that riders are much more likely to be compliant when using a separated cycleway.
- During commuting hours (6-9 am, 3-6 pm on weekdays), the odds of compliance were 18% higher compared to other hours (odds ratio 1.18), indicating higher compliance during these times.

Variable name	coef	Std. err	Z	P> |z|	[0.025	0.975]
Constant	1.1410	0.1070	10.6320	0.000	0.9310	1.3510
Helmet Compliance	0.0222	0.0600	0.3680	0.713	-0.0960	0.1400
Scooter Type: Public	-0.0975	0.0550	-1.7630	0.078	-0.2060	0.0110
During commuting hours	0.1675	0.0730	2.2790	0.023	0.0230	0.3120
Weekend	0.0401	0.0640	0.6280	0.530	-0.0850	0.1650
Location Type: Suburban	-0.4651	0.4100	-1.1340	0.257	-1.2690	0.3380
Location Type: Urban	-1.2727	0.0830	-15.4170	0.000	-1.4340	-1.1110
Posted Speed: 50km/h	-1.7214	0.4530	-3.8020	0.000	-2.6090	-0.8340
Posted Speed: 60km/h	-1.2792	0.1830	-6.9820	0.000	-1.6380	-0.9200
Bike Lane	-0.3821	0.0980	-3.9070	0.000	-0.5740	-0.1900
General Traffic Lane	-1.1961	0.0890	-13.3790	0.000	-1.3710	-1.0210

Table 11: 12 km/h Speed Zone Compliance Logistic Regression Results

2.4.3 25 km/h speed zone compliance assessment

Lastly, a logistic regression was run for speed limit compliance in 25 km/h zones. Full results are provided in Table 6.

- The baseline odds of compliance were about fifteen times higher than the odds of non-compliance (odds ratio 15.23).
- Wearing a helmet decreased the odds of compliance by about 27% compared to not wearing a helmet (odds ratio 0.73). This suggests that riders wearing a helmet were less likely to be compliant with the speed limit due to risk compensation.
- Using a public scooter increased the odds of compliance by about 215% compared to using a private scooter (odds ratio 3.15), indicating that public PMD users are much more likely to be compliant with speed limits in 25 km/h zones, noting that the public vehicles are speed limited by the providers to 25 km/h.
- On weekends, the odds of compliance were 18% higher compared to weekdays (odds ratio 1.18).
- Being in a suburban location decreased the odds of compliance by about 94% compared to the CBD (odds ratio 0.06), and being in an urban location decreased the odds of compliance by about 87% compared to the CBD (odds ratio 0.13). This suggests that riders in the CBD were much more likely to be compliant.
- A posted automobile speed limit of 50 km/h increased the odds of compliance by about 144% compared to 40 km/h (odds ratio 2.44), and a posted automobile speed limit of 60 km/h increased the odds of compliance by about 81% compared to 40 km/h (odds ratio 1.81).
- Using an on-road bicycle lane decreased the odds of compliance by about 42% compared to a separated cycleway (odds ratio 0.58), while using a general traffic lane decreased the odds of compliance by about 54% compared to a separated cycleway (odds ratio 0.46). This indicates that riders were much more likely to be compliant when using a separated cycleway.

Variable name	coef	Std. err	Z	P> |z|	[0.025	0.975]
Constant	2.7231	0.1020	26.7600	0.000	2.524	2.923
Helmet Compliance	-0.3164	0.0870	-3.6190	0.000	-0.488	-0.145
Scooter Type: Public	1.1481	0.0690	16.5580	0.000	1.012	1.284
During commuting hours	0.0199	0.0660	0.3020	0.763	-0.109	0.149
Weekend	0.1679	0.0700	2.4100	0.016	0.031	0.304
Location Type: Suburban	-2.8021	0.2720	-10.3070	0.000	-3.335	-2.269
Location Type: Urban	-2.0233	0.1120	-18.1380	0.000	-2.242	-1.805
Posted Speed: 50km/h	0.8924	0.2420	3.6840	0.000	0.418	1.367
Posted Speed: 60km/h	0.5940	0.1050	5.6660	0.000	0.389	0.799
Bike Lane	-0.5448	0.0990	-5.4860	0.000	-0.739	-0.350
General Traffic Lane	-0.7707	0.1170	-6.5730	0.000	-1.000	-0.541

Table 12: 25 km/h Speed Zone Compliance Logistic Regression Results

Chapter 3 Conclusion

This report examined PMD riding behaviour in eight different areas across Brisbane in October 2022 and October 2023. We used a manual count and machine learning approach of video to distinguish between bicycle riders, pedestrians and PMD users. As road rules changes occurred in Queensland in November 2022, a unique opportunity was presented to study of how use and behaviour changed after new laws were introduced.

A variety of analyses were performed studying speed, helmet use, and speed compliance based on observable splits in the data such as ownership (i.e. Public/Private PMD), path type (e.g. on-road/footpath), location (CBD/Urban/Suburban), year (2022 and 2023). Visualisations were performed along with significance tests and logistic regression modelling.

Significant results were found in terms of:

- Changes in private/public scooter proportions from 2022 to 2023. In 2022, private PMDs constituted 56% of the observations, but this decreased to 50% in 2023 (p.24).
- Footpath usage: A significant difference between public and private usage of footpaths was found. Public PMD riders are more likely than private PMD riders to use the footpath (p.32); and
- Footpath width: A higher proportion of rides were revealed on the footpath where the footpath width was greater (p.34).
- Speed and compliance issues in CBD, suburban and urban environments: speeds increasing and compliance decreasing with distance from CBD (p.42);
- Average PMD speeds from 2022 to 2023: For private PMDs, the average speed significantly increased from 17.83 to 18.93 km/h. For public PMDs, the average speed also significantly increased from 14.96 to 15.23 km/h (p.55).
- Helmet use risk compensation with respect to speed in all cases examined. Riders without helmets rode at lower speed and were more likely to be in compliance with speed limits, followed by riders with bicycle helmets, with riders with full-face helmets least compliant and fastest (p.58).
- Speed and helmet compliance in various domains; for instance, riders are more likely to be compliant with speed limit requirements on separated cycleways and with helmet requirements for private PMDs and in locations outside the CBD (p.59).
- Speed compliance in 12 km/h zones. CBD riders were more likely to be compliant with the speed limit than other areas (p.61).
- Speed compliance in 25 km/h zones. Riders wearing helmets were less likely to be compliant with the speed limit (risk compensation) (p.63).

Chapter 4 Discussion

4.1 Implications

Our analysis observed a significant shift in the proportion of private versus public PMDs from 2022 to 2023, with a notable decrease in Private PMDs from 56% of the observations in 2022 to 50% in 2023. This trend also aligns with the observation of Haworth et al. (2021), that public PMDs are growing in popularity in Brisbane. Moreover, this study is also the first to examine PMD volume based on the day of the week and the hour of the day. The volume analysis results indicate a pattern replicating the previous bike-sharing system (e.g. Brisbane CityCycle). The pattern shows higher PMD rides during two peak commuting hours (morning and evening) on weekdays but gradually increases and peaks in the evening on weekends. Both findings emphasise the role of e-scooters in complementing urban mobility needs.

Generally, bike lanes and cycleways discourage footpath riding. The findings demonstrate that private PMD riders use adjacent footpaths less than public PMD riders. This may be due to the understanding of newly implemented road rules that expand the type of designated infrastructure allowed for PMD riders. Public PMD riders are likely to have less experience than private ones (Haworth et al., 2021). Thus, they generally have a lesser knowledge and understanding of the road rules. Hence, public device users tend to ride on a known path, that is, a footpath, rather than on a recently allowed path like an on-road bike lane. However, we observed a steep decline in PMDs riding on the adjacent footpaths when a cycleway is present. This finding aligns with that of Zhang et al. (2021) which indicates that PMD users ride on the footpaths more than they prefer possibly due to the lack of bicycle infrastructure.

The report has identified a marginal but significant increase in speed. The average speed in 2023 rose from 17.83 to 18.93 km/h for private PMDs and from 14.96 to 15.23 km/h for public PMDs. The proportion of speed non-compliance increased in 2023 across three types of infrastructure, except on the separated cycleway, where it decreased. These results may indicate the lack of public awareness regarding changes in the speed limit, especially for the private PMD riders on the footpath where a sharp reduction was implemented. Nonetheless, it suggests that a structured facility, such as separate cycleways, not only promotes a safer riding environment but also encourages compliance behaviour.

In the 50 km/h speed limit zones, it was observed that 47% of riders exceeded the 25 km/h on-road PMD speed limit, which was inconsistent in comparison with the 40 km/h speed limit zones (15%) and 60 km/h speed limit zones (24%). The 50 km/h speed limit zone in the study was on Sylvan Road, Toowong, where riders may be attempting to lessen their speed differential with the motor vehicle traffic. A recent "BikeSpot" survey named this location as the top unsafe spot for riding in Brisbane.

The helmet use assessment results suggest risk compensation behaviours with speed compliance and helmet use, where riders wearing helmets are less likely to be compliant with the speed limit. This suggests that while protective gear like a helmet is crucial for PMD riding safety, it is also essential to address the potential for risk compensation behaviours. Nevertheless, helmet compliance behaviour remains high across device ownership and infrastructure types, indicating the effectiveness of enforcement mechanisms of well-established road rules like helmet requirements. One notable finding is public PMD riders have lesser helmet compliance even though a helmet is a standard equipment for every public PMDs operating in Brisbane. This might be from factors such as shorter rides with public PMDs, risk compensation in lower-risk environments (e.g., public PMD is observed riding more in CBD and on footpaths), an unwillingness to wear a shared helmet and/or missing helmets.

4.2 Recommendations

Several recommendations emerged from our data analysis. First pertaining to public awareness of road rules. We recommend mandates for the shared providers of e-scooters and the retailers of private scooters to educate users on road rules and related penalties. Currently, at private e-scooter retailers no such information is provided. And, for public schemes, the road rules and associated penalties are not clearly provided or provided at all to the users. This issue is further compounded is that the use timers for shared scooters often begin while the rules are being shown, which encourages users to skip through the notices quickly. Targeted education should be implemented to improve public awareness and understanding of the PMD road rules. For example, in addition to information about helmet use and speed limit, a dedicated page on permissible infrastructure for PMDs could be integrated into the signup process for public PMD users and purchase process for private PMDs. Moreover, information about road rules should be readily accessible to the public to support the awareness and understanding of road rules. This improved understanding ultimately increases compliance behaviour, as discussed in Ventsislavova et al. (2024).

To support the road rule changes, the Queensland Government rolled out a comprehensive communications campaign. This included social media advertising, billboards in key locations, and extensive online content on the TMR website and Streetsmarts. TMR also developed educational material for various stakeholders, including Queensland Police Service, schools and retailers. Brochures and business card sized handouts featuring a QR code link to Streetsmarts were also provided free of charge to the PMD industry, local governments and police for distribution to users. The Queensland Government consistently maintains its efforts to raise public awareness about PMD safety and specific PMD rules. The rules on where to ride and speed limits are topics TMR regularly addresses through its StreetSmarts social media and digital channels. StreetSmarts reaches between 1 and 1.5 million road users every month through organic and boosted posts (social media paid adverts). In addition to online communication, the brochures and small handouts also continue to be proactively distributed to key community stakeholders.

The second recommendation is dedicated to future research. As we have observed in this study, a risk compensation factor has played a role at the intersection of helmet use and speed compliance behaviour. Future studies could investigate whether the rider assesses risks accurately in different riding environments to mitigate the risk compensation effect on compliance behaviour. Moreover, whilst this study analyses the secondary data, that is, data derived from recorded traffic camera footage, future research could benefit from capturing primary data, especially from private PMD users and sellers. This approach might shed light on pending issues related to compliance. Future research can also look at the urban planning avenue. We have observed that dedicated bike infrastructure (e.g., cycleway) encourages compliance behaviour. Future studies can expand on this insight to accelerate the rollout of physically separated bike path infrastructure and potentially contribute to the PMD safety action plan.

References

Abbott, L. (2023). *Third time's a charm: Melbourne e-scooter trial extended again*. The Age. Retrieved 17-January-2024 from https://www.theage.com.au/national/victoria/third-time-s-a-charm-melbourne-e-scooter-trial-extended-again-20231004-p5e9pn.html#

Apurv, K., Tian, R., & Sherony, R. (2021). Detection of e-scooter riders in naturalistic scenes. *arXiv preprint arXiv:2111.14060*.

Beam Mobility. (n.d.). *Vehicles*. Retrieved 22-January-2024 from https://www.ridebeam.com/id/vehicles

Bellucci, P., & Cipriani, E. (2010). Data accuracy on automatic traffic counting: the SMART project results. *European Transport Research Review*, *2*(4), 175-187. https://doi.org/10.1007/s12544-010-0039-9

Bikespot.(2024) Bikeport 2023 National report. https://www.bikespot.org/reports

Bladen, L. (2020). *Canberra's e-scooters fleet will be equipped with technology which prevents them being parked near waterways*. Canberra Times. Retrieved 29-January-2024 from https://www.canberratimes.com.au/story/6888446/the-technology-which-will-prevent-e-scooters-being-dumped-in-lake-burley-griffin/

Brisbane City Council. (2023). *Personal mobility devices*. Retrieved 31-August-2024 from https://www.brisbane.qld.gov.au/laws-and-permits/laws-and-permits-for-residents/personal-mobility-devices#:~:text=Regulations%20to%20allow%20the%20use,and%20road%20rules%20for%20PMDs.

Buckley, J. (2019). *E-scooters suddenly appeared everywhere, but now they're riding into serious trouble*. CNN. Retrieved 29-January-2024 from https://edition.cnn.com/travel/article/electric-scooter-bans-world/index.html

Caldwell, F. (2018). *Dockless electric scooter-share scheme zooms in on Brisbane*. Brisbane Times. Retrieved 16-January-2024 from https://www.brisbanetimes.com.au/national/queensland/a-dockless-electric-scooter-share-scheme-is-coming-to-brisbane-20181108-p50ev6.html

Caulfield, B., O'Mahony, M., Brazil, W., & Weldon, P. (2017). Examining usage patterns of a bike-sharing scheme in a medium sized city. *Transportation research part A: policy and practice*, *100*, 152-161.

Chang, A., Miranda-Moreno, L., Clewlow, R., & Sun, L. (2019). *Trend or fad? Deciphering the Enablers of Micromobility in the U.S.* https://www.sae.org/binaries/content/assets/cm/content/topics/micromobility/sae-micromobility-trend-or-fad-report.pdf

Chrisafis, A. (2023). *Rented e-scooters cleared from Paris street on eve of ban*. The Guardian. Retrieved 10-January-2024 from https://www.theguardian.com/world/2023/aug/31/rented-e-scooters-cleared-from-paris-streets-on-eve-of-ban

City of Darwin. (n.d.). *E-scooters & E-bikes in the City of Darwin*. Retrieved 29-January-2024 from https://www.darwin.nt.gov.au/community/about-darwin/getting-around/e-scooters-e-bikes

City of Melbourne. (2022). *E-scooter trials in Victoria*. Retrieved 16-January-2024 from https://www.melbourne.vic.gov.au/parking-and-transport/Pages/e-scooters.aspx

Courty, A. (2022). *What are the new e-scooter laws and fines in Queensland?* ABC. Retrieved 16-January-2024 from https://www.abc.net.au/news/2022-11-01/qld-e-scooter-rule-changes-fines-mobility/101597546
Department of Infrastructure Transport Regional Development Communications and the Arts. (2021). *Importing e-scooter made easy*. Retrieved 15-January-2024 from https://www.infrastructure.gov.au/department/media/news/importing-e-scooters-made-easy
European Commission. (2021). *Road safety thematic report – Personal Mobility Devices*.
European Consumer Centre Germany. (2023). *Country overview: E-scooter regulations in Europe,*. Retrieved 16-January-2024 from https://www.evz.de/en/reisen-verkehr/e-mobilitaet/zweiraeder/e-scooter-regulations-in-europe.html#:~:text=long%2Ddistance%20trains.-,The%20blood%20alcohol%20limit%20is%200.5%20‰.,may%20also%20lose%20their%20licence.
European Transport Safety Council. (2020). *Austrian warnings over e-scooter safety*. Retrieved 16-January-2024 from https://etsc.eu/austrian-warnings-over-e-scooter-safety/
European Transport Safety Council. (2023). *Malta to ban rented e-scooters from March*. Retrieved 29-January-2024 from https://etsc.eu/malta-to-ban-rented-e-scooters-from-march/
Fang, K., Agrawal, A. W., & Hooper, A. (2018). Electric Kick Scooters on Sidewalks in Virginia but Not in California? A Review of How States Regulate Personal Transportation Devices.
Field, C., & Jon, I. (2021). E-scooters: a new smart mobility option? The case of Brisbane, Australia. *Planning Theory & Practice*, *22*(3), 368-396.
Gesley, J. (2019). *Austria: Ban on Riding E-Scooters on Sidewalks Enacted*. Library of Congress. Retrieved 29-January-2024 from https://www.loc.gov/item/global-legal-monitor/2019-05-31/austria-ban-on-riding-e-scooters-on-sidewalks-enacted/
Gioldasis, C., Christoforou, Z., & Seidowsky, R. (2021). Risk-taking behaviors of e-scooter users: A survey in Paris. *Accident Analysis & Prevention*, *163*, 106427.
Gössling, S. (2020). Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change. *Transportation Research Part D: Transport and Environment*, *79*, 102230.
Government of South Australia, D. f. I. a. T. (2019). *E-scooter trial rolled out in Adelaide CBD*. Retrieved 16-January-2024 from https://www.dit.sa.gov.au/news/archive?a=531168
Government of Western Australia. (n.d.). *eRideables*. Retrieved 31-August-2024 from https://www.wa.gov.au/organisation/road-safety-commission/erideables
Haworth, N., Schramm, A., & Twisk, D. (2021). Changes in shared and private e-scooter use in Brisbane, Australia and their safety implications. *Accident Analysis & Prevention*, *163*, 106451.
Kamphuis, K., & van Schagen, I. (2020). *E-scooters in Europe: legal status, usage and safety. Results of a survey in FERSI countries*. https://fersi.org/
Kazemzadeh, K., Haghani, M., & Sprei, F. (2023). Electric scooter safety: An integrative review of evidence from transport and medical research domains. *Sustainable Cities and Society*, *89*, 104313.

Kelsall, T. (2023). *Public green light for e-scooters on Adelaide streets*. InDaily. Retrieved 29-January-2024 from https://indaily.com.au/news/2023/12/18/public-green-light-for-e-scooters-on-adelaide-streets/

Kocamaz, M. K., Gong, J., & Pires, B. R. (2016). Vision-based counting of pedestrians and cyclists. 2016 IEEE winter conference on applications of computer vision (WACV),

Kothuri, S., Nordback, K., Schrope, A., Phillips, T., & Figliozzi, M. (2017). Bicycle and pedestrian counts at signalized intersections using existing infrastructure: Opportunities and challenges. *Transportation research record*, *2644*(1), 11-18.

Laa, B., & Leth, U. (2020). Survey of E-scooter users in Vienna: Who they are and how they ride. *Journal of transport geography*, *89*, 102874.

Laker, L. (2019). *Welcome, watch or ban: how should cities deal with electric scooters?* The Guardian. Retrieved 17-January-2024 from https://www.theguardian.com/cities/2019/jun/18/welcome-watch-or-ban-how-should-cities-deal-with-electric-scooters

Lien, T., & Etehad, M. (2018). *Santa Monica proposes tougher rules for Bird and other scooter rental companies*. Los Angeles Times. Retrieved 22-January-2024 from https://www.latimes.com/business/technology/la-fi-tn-santa-monica-scooter-pilot-20180607-story.html

Lime. (2018). *Lime Europe: New Cities, New Records And The #1 Travel App*. The Lime Times. Retrieved 26-January-2024 from https://www.li.me/en-co/blog/lime-europe-new-cities-new-records-travel-app

Lime. (2020). *Lime Introduces New Geofencing Technology, Setting Industry Standards For Scooters*. The Lime Times. Retrieved 29-January-2024 from https://www.li.me/en-au/blog/lime-introduces-new-geofencing-technology-setting-industry-standards-for-scooters

McFarland, M. (2019). *Bird scooters got kicked out of San Francisco but found a loophole back in*. CNN Business. Retrieved 23-January-2024 from https://edition.cnn.com/2019/05/15/tech/bird-san-francisco-rentals/index.html

Messelodi, S., Modena, C. M., & Cattoni, G. (2007). Vision-based bicycle/motorcycle classification. *Pattern recognition letters*, *28*(13), 1719-1726.

My Licence Government of South Australia. (n.d.). *E-Scooter trial laws and road rules*. Retrieved 15-January-2024 from https://www.mylicence.sa.gov.au/roadrules/e-scooter-trial

National Conference of State Legislatures. (2023). *Traffic safety state bill tracking*. Retrieved 15-January-2024 from https://www.ncsl.org/transportation/traffic-safety-state-bill-tracking

New South Wales Government. (2022). *E-Scooters*. Retrieved 16-January-2024 from https://www.transport.nsw.gov.au/roadsafety/road-users/e-scooters

Northern Territory Government. (2023). *Exemption from Motor Vehicles Act 1949, Traffic Act 1987 and Motor Vehicles (Standards) Regulations 2003*. Retrieved from https://nt.gov.au/__data/assets/pdf_file/0015/1203027/g4.pdf

Northern Territory Government. (n.d.). *Electric scooters and bikes*. Retrieved 29-January-2024 from https://nt.gov.au/driving/safety/electric-scooters-and-bikes#:~:text=Rules%20for%20riding%20your%20own,unregistered%20and%20uninsured%20motor%20vehicle.

O'Keeffe, B. (2019). Regulatory challenges arising from disruptive transport technologies—The case of e-scooters.

Ojea, S. (2018). *Madrid bans electric scooters from city's sidewalks*. Reuters. Retrieved 29-January-2024 from https://www.reuters.com/article/idUSKCN1MY1SY/

Pace, R., Pollard, M., Bunker, J., & Baczynski, J. (2021). Evaluating the impacts of personal mobility devices (e-scooters) in Central Brisbane. Australasian Transport Research Forum 2021 Proceedings,

Queensland Government. (n.d.). *Rules for personal mobility devices*. Retrieved 29-January-2024 from https://www.qld.gov.au/transport/safety/rules/wheeled-devices/personal-mobility-devices

Riggs, W., Kawashima, M., & Batstone, D. (2021). Exploring best practice for municipal e-scooter policy in the United States. *Transportation research part A: policy and practice*, *151*, 18-27.

Serra, G. F., Fernandes, F. A., Noronha, E., & de Sousa, R. J. A. (2021). Head protection in electric micromobility: A critical review, recommendations, and future trends. *Accident Analysis & Prevention*, *163*, 106430.

Sexton, E. G., Harmon, K. J., Sanders, R. L., Shah, N. R., Bryson, M., Brown, C. T., & Cherry, C. R. (2023). Shared e-scooter rider safety behaviour and injury outcomes: a review of studies in the United States. *Transport Reviews*, 1-23.

Shaheen, S., & Cohen, A. (2019). Shared micromoblity policy toolkit: Docked and dockless bike and scooter sharing.

Singapore Land Transport Authority. (2019). *E-Scooters to Be Prohibited on All Footpaths Following Safety Review*. Retrieved 29-January-2024 from https://www.lta.gov.sg/content/ltagov/en/newsroom/2019/11/1/e-scooters_tobe_prohibited_on_allfootpaths_following_safety_review.html

Singapore Land Transport Authority. (2022). *E-Scooter Official Handbook for Mandatory Theory Test*.

Sokolowski, M. M. (2020). Laws and policies on electric scooters in the european union: A ride to the micromobility directive? *European Energy and Environmental Law Review*, *29*(4).

Statista. (2023). *E-Scooter sharing - Worldwide*. https://www.statista.com/outlook/mmo/shared-mobility/shared-rides/e-scooter-sharing/worldwide

Topham, G. (2020). *UK rides the wave of micromobility by embracing e-scooters*. The Guardian Retrieved 29-January-2024 from https://www.theguardian.com/global/2020/aug/25/uk-rides-the-wave-of-micromobility-by-embracing-e-scooters

Transport Canberra. (2021). *Transport Canberra and City Services (TCCS) - Review of Shared Micromobility*. https://www.transport.act.gov.au/__data/assets/pdf_file/0007/1882240/Micromobility-Review-Final-Accessible.pdf

Transport Canberra. (n.d.-a). *E-scooter rules* Retrieved 29-January-2024 from https://www.transport.act.gov.au/travel-options/e-scooters/e-scooter-rules

Transport Canberra. (n.d.-b). *E-scooters and other similar devices FAQs*. Retrieved 29-January-2024 from https://www.transport.act.gov.au/travel-options/e-scooters/frequently-asked-questions

Transport Canberra. (n.d.-c). *Shared e-scooters*. Retrieved 29-January-2024 from https://www.transport.act.gov.au/travel-options/e-scooters/shared-e-scooters

Transport for NSW. (2023). *NSW E-scooter Shared Scheme Trial*. Retrieved 29-January-2024 from https://www.transport.nsw.gov.au/projects/current-projects/nsw-e-scooter-shared-scheme-trial

Transport Service Tasmanian Government. (n.d.). *Personal mobility devices*. Retrieved 15-January-2024 from https://www.transport.tas.gov.au/road_safety_and_rules/personal_mobility_devices

United Kingdom Department For Transport. (2015). *Electrically assisted pedal cycles (EAPCs) in Great Britain: information sheet*. Retrieved 26-January-2024 from https://www.gov.uk/government/publications/electrically-assisted-pedal-cycles-eapcs/electrically-assisted-pedal-cycles-eapcs-in-great-britain-information-sheet

United Kingdom Department For Transport. (2020). *E-scooter trials: guidance for users*. Retrieved 15-January-2024 from https://www.gov.uk/guidance/e-scooter-trials-guidance-for-users#:~:text=You%20must%20have%20the%20category,can%20use%20an%20e%2Dscooter.

United Kingdom Department For Transport. (2023). *E-scooter trials: guidance for local authorities and rental operators*. Retrieved 15-January-2024 from https://www.gov.uk/government/publications/e-scooter-trials-guidance-for-local-areas-and-rental-operators/e-scooter-trials-guidance-for-local-areas-and-rental-operators

Vallmuur, K., Mitchell, G., McCreanor, V., Droder, B., Catchpoole, J., Eley, R., & Smyth, T. (2023). Electric personal MObility DEvices Surveillance (E-MODES) study: Injury presentations to emergency departments in Brisbane, Queensland. *Injury*. https://doi.org/10.1016/j.injury.2023.04.036

Ventsislavova, P., Baguley, T., Antonio, J., & Byrne, D. (2024). E-scooters: Still the new kid on the transport block. Assessing e-scooter legislation knowledge and illegal riding behaviour. *Accident Analysis & Prevention*, *195*, 107390.

VicRoads. (2023). *E-scooter hire schemes - FAQs for Councils*. Retrieved 29-January-2024 from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjQnMHHh4KEAxWkgFYBHewSAl0QFnoECBIQAQ&url=https%3A%2F%2Fwww.vicroads.vic.gov.au%2F-%2Fmedia%2Ffiles%2Fdocuments%2Fsafety-and-road-rules%2Fe-scooters-in-victoria%2Flocal-government-faqs-on-e-scooter-share-schemes-november-2023.ashx&usg=AOvVaw01kpTmdK76IliYYj8TCPRZ&opi=89978449

VicRoads. (n.d.). *E-scooter trial extended over summer*. Retrieved 29-January-2024 from https://www.vicroads.vic.gov.au/safety-and-road-rules/e-scooters-in-victoria

Wainwright, O. (2023). *Love them or hate them, a UK government decision on e-scooters is well overdue*. The Guardian. Retrieved 26-January-2024 from https://www.theguardian.com/commentisfree/2023/nov/06/love-hate-uk-government-e-scooters-trials-regulation

Zhang, W., Buehler, R., Broaddus, A., & Sweeney, T. (2021). What type of infrastructures do e-scooter riders prefer? A route choice model. *Transportation Research Part D: Transport and Environment*, *94*, 102761. https://doi.org/https://doi.org/10.1016/j.trd.2021.102761

Appendices

Appendix 1: Camera equipment installation image

Appendix 2: Data validation scope

Appendix 3: Data collection sites

Site 1 - Adelaide St, west of Creek St (southern footpath)

Site 2A - Annerley Rd north of College Hl Dr (western footpath)

Site 2B - Annerley Rd north of College Hl Dr (eastern footpath)

Site 3A - Melbourne St, west of Manning St (northern footpath)

Site 3B - Melbourne St, west of Manning St (southern footpath)

Site 4A - Sylvan Rd, west of Earle Ln (southern footpath)

Site 4B - Sylvan Rd, west of Earle Ln (northern footpath)

Site 5A Dickson St, north of Price St (northern footpath)

Site 5B Dickson St, north of Price St (southeast footpath)

Site 6A - Elizabeth St, west of Edward St (southern footpath)

Site 6B - Edward St, south of Elizabeth St (western footpath)

Site 7A - Eagle St, south of Eagle Lane (eastern footpath)

Site 7B - Eagle St, south of Eagle Lane (western footpath)

Site 8A - Parkland Blvd (western footpath)

Site 8B - Parkland Blvd (eastern footpath)