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Assessing pedestrian and cyclist safety through exposure-adjusted crash risk in Greater Sydney

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1 Introduction

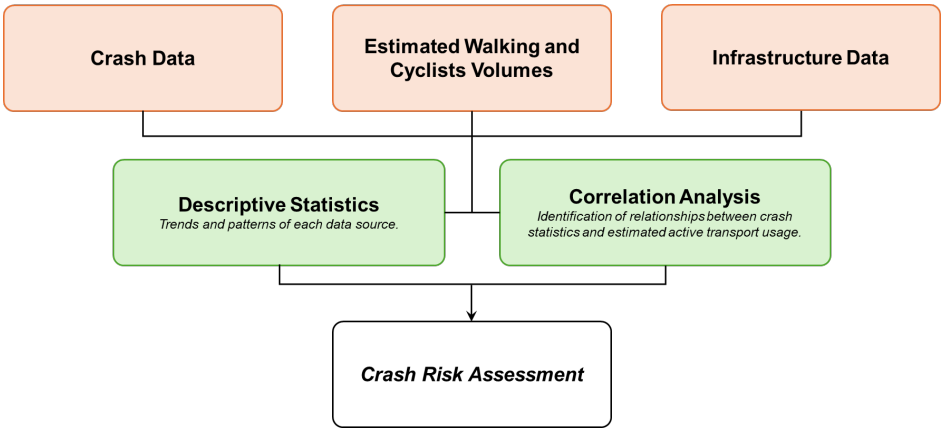
Active transport options, such as walking and cycling, are increasingly recognised as sustainable solutions for easing road congestion and reducing vehicle emissions (Pucher and Buehler, 2017, Anciaes et al., 2025). A recent literature review highlights that policies enhancing active and public transport options while limiting vehicle ownership are among the most effective strategies for mitigating traffic congestion (Anciaes et al., 2025). Despite clear evidence supporting active transport modes, ensuring uptake presents challenges. Pedestrians and cyclists, classified as 'vulnerable road users,' are exposed to heightened crash risks due to limited physical protection (Austroads, 2010). In Australia, pedestrians represent 17% of serious transport-related injuries and 13% of road fatalities, while cyclist deaths consistently account for 2%-3% of total road crash fatalities since the 1990s (Scarano et al., 2023, Bureau of Infrastructure and Economics, 2012, Senserrick et al., 2014). These alarming statistics highlight the need for enhanced safety measures and targeted analyses to reduce risks for these groups.

Efforts to promote walking and cycling are constrained by the lack of reliable behavioural data, which is essential for evidence-based infrastructure planning (Saberi and Lilasathapornkit, 2024). While crowdsourced options like Strava and mobile phone data offer broad coverage, they often suffer from biases, particularly overrepresenting recreational users and underrepresenting short utilitarian trips (Battiston et al., 2023, Venter et al., 2023). Researchers have attempted to overcome these limitations by integrating such data with observed counts and geographic variables to improve accuracy (Nelson et al., 2021). Building on these approaches, this study applies machine learning methods, proposed by Saberi and Lilasathapornkit (2024), to generate refined estimates of pedestrian and cyclist activity, which are then overlaid with NSW crash data (2022–2023) to identify LGAs with elevated risk. The novel exposure-adjusted analysis reveals spatial disparities linked to infrastructure gaps, offering actionable insights for targeted safety interventions.

2 Methodology

A macroscopic analytical framework is used to evaluate crash risk for active transport modes (walking and cycling) through the integration of safety data and estimated utilisation at a Local Government scale across the Sydney Metropolitan area. **Figure 1** presents a flow diagram of the methodology. This research combines crash data sourced from state government authorities (Transport for New South Wales) with robust estimates of pedestrian and cycling volumes. The volumes are estimated using a method proposed by Saberi and Lilasathapornkit (2024) and serve as the key exposure indicators for the analysis. Infrastructure data regarding cycling lanes and low speed environment road segments (less than or equal to 40 km/hr) are also incorporated as critical contextual factors that define the demand for walking and cycling as well as the associated safety. Descriptive statistics of each data set and a correlation analysis across the data are conducted to identify key patterns and form a crash risk assessment across each Local Government Area (LGA).

Figure 1: Macroscopic analysis methodology



3 Main findings

3.1 Descriptive statistics

Summary of collected crash data is presented in **Table 1**. This table highlights that while pedestrians and cyclists account for a relatively small share of total crashes (5% and 4% respectively), they experience disproportionately high rates of severe outcomes. The fatality rate for pedestrian-involved crashes is three times higher than the overall average, and both groups show significantly elevated rates of serious and moderate injuries, nearly double those seen across all transport modes, underscoring their vulnerability in the road network.

Table 1 - Summary of collated crash statistics

Year	User Mode	Number of Crashes	Fatality Rate (%)	Serious Injuries Rate (%)	Moderate Injuries Rate (%)
2022 - 2023	**All modes**	36,859	1.5	21.5	28.0
	Pedestrians	1,920	4.5	41.6	32.7
	Cyclists	1,389	1.2	35.5	38.1

An initial examination reveals a consistent spatial pattern of pedestrian crashes over the two years. Within Greater Sydney, four LGAs emerged as particularly concerning: the City of Sydney, Canterbury-Bankstown, Inner West, and Cumberland recorded the highest numbers of pedestrian-involved crashes. Most notably, the City of Sydney and Canterbury-Bankstown significantly outpaced other areas, each experiencing more than 80 pedestrian crashes annually, a substantial disparity that underscores these areas as critical zones for pedestrian safety interventions. An initial review indicates some differences in the patterns of cyclist crashes and changes in the ranking of LGAs when comparing the total number of cyclist crashes between 2022 and 2023. Nevertheless, the City of Sydney, Northern Beaches, Randwick, and Inner West consistently feature among the top five high-risk LGAs for cyclist crash risks across both years. The City of Sydney, in particular, stands out with a substantial gap compared to other LGAs, recording over 100 cyclist crashes in 2022 and more than 50 in 2023.

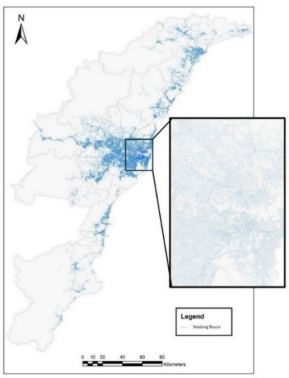
3.2 Crash risk indicator estimation

Evaluating safety based on aggregated crash statistics ignores the exposure and the infrastructure context of each LGA. Accordingly, estimates of walking and cycling were made using the machine learning method proposed by Saberi and Lilasathapornkit (2024). To apply the methodology, initially the walking and cycling networks had to be defined for the study area. The walking network was constructed using the Geoscape PSMA network, encompassing 188,999 links. The cycling network, on the other hand, was developed using OpenStreetMap and Transport for NSW Bicycle Infrastructure Network data, which includes

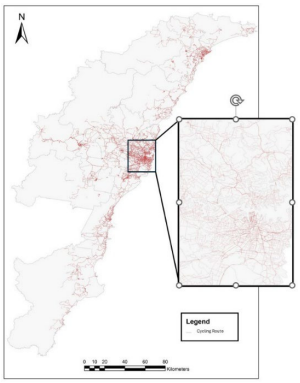
114,885 links. These links represent streets within the network, **Figure 1**, plot (a and b). The number of trips was then estimated using equations (1) and (2). The findings suggest that the study region accommodates approximately 7.1 million walking trips per weekday and 6.7 million walking trips per weekend. For cycling, the estimates indicate 260,000 trips per weekday and 406,000 trips per weekend across the NSW Six Cities Region. **Figure 1**, plots (c) and (d), visually represent the aggregated number of trips for walking and cycling at the LGA level, respectively.

The initial analysis identifies the City of Sydney, Inner West, Randwick, Central Coast, and City of Ryde as the top five LGAs based on walking trip volumes. For cycling trips, the ranking shifts to the City of Sydney, Northern Beaches, Newcastle, Wollongong, and Randwick. Notably, LGAs such as City of Sydney, Randwick, Northern Beaches, City of Parramatta, Sutherland Shire, Central Coast, and Inner West consistently feature among the top 10 LGAs for both walking and cycling trips.

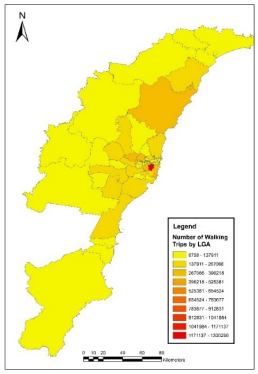
Figure 2: Cycling and Walking routes and Trips.



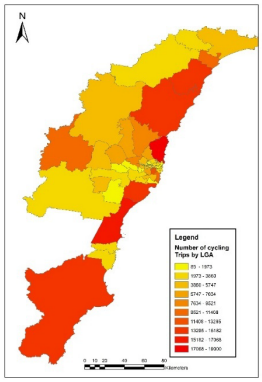
Plot (a): Walking Routes



Plot (b): Cycling Routes



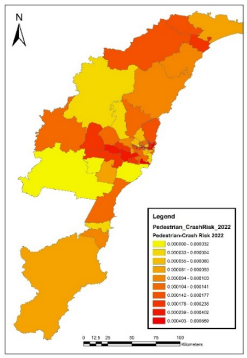
Plot (c): LGAs by number of walking trip



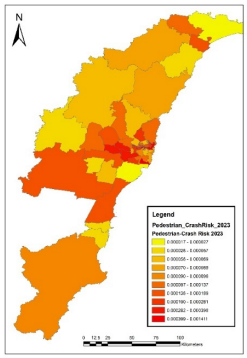
Plot (d): LGAs by number of Cycling trip

Crash risk indicators accounting for exposure were calculated to assess safety for both walking and cycling across LGAs. This indicator is determined by dividing the number of crashes by the estimated number of trips, offering a normalised measure of crash occurrence relative to activity levels.

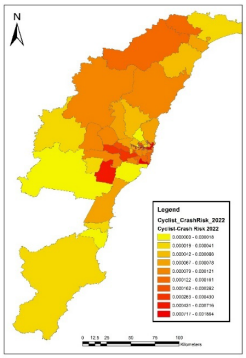
Figure 2: LGAs by pedestrians crash risk (plot a-b) cyclist crash risk (plot c-d) for 2022 and 2023.



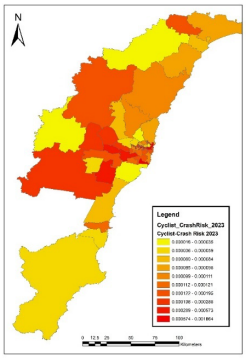
Plot (a): Pedestrian - 2022



Plot (b): Pedestrian - 2023



Plot (c): Cyclist - 2022



Plot (d): Cyclist - 2023

Figure 2, plots (a) and (b), illustrates the pedestrian crash risk across LGAs for the years 2022 and 2023. While the colours (categories) of some LGAs changed over time from 2022 to 2023 (indicating that some areas had changes in crash risk) a significant number of LGAs consistently remain categorised as high risk throughout the study period. This highlights persistent safety concerns that warrant further investigation and targeted interventions.

Figure 2, plots (c) and (d), illustrates cyclist crash risk across LGAs for the years 2022 and 2023. The results are similar in nature to the pedestrian crash risk maps, while the colours (categories) of some LGAs shifted over time from 2022 to 2023, many of the LGAs consistently remained in high-risk categories throughout the study period.

3.3 Correlation analysis

A correlation analysis was conducted to examine the relationship between mode specific crash data, the number of walking and cycling trips, and the crash risk. The crash data was filtered specifically for walking and cycling modes to ensure the reliability of the analysis, with outcomes including total crashes, fatalities, and injuries of varying severity examined for each infrastructure type.

Table 2 presents the correlation between walking and cycling trips and the corresponding crash numbers for each year of analysis. Since, fortunately, the number of fatalities for pedestrian and particularly cyclist modes is low, conducting a correlation analysis based solely on fatality data may not be statistically meaningful, as many LGAs report either zero or very few fatal incidents. Therefore, we have opted to include a combined category of fatalities and serious injuries in the correlation analysis to provide a more robust assessment. For completeness, the correlation results based on fatalities alone are also presented in the table below.

Table 2: Correlations between walking and cycling trips and the categorised crash data

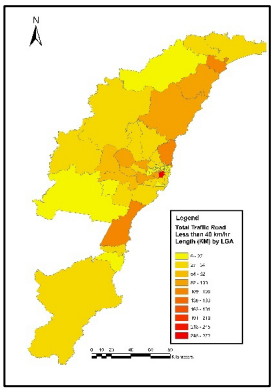
Pedestrian						
Year	Total No. Crashes	No. Fatality	No. Serious Injuries	No. Moderate Injuries	No. Minor Injuries	No. Fatality and Serious Injuries
2022	0.73	0.43	0.50	0.75	0.79	0.51
2023	0.71	0.37	0.47	0.73	0.76	0.48
Cyclist						
Year	Total No. Crashes	No. Fatality	No. Serious Injuries	No. Moderate Injuries	No. Minor Injuries	No. Fatality and Serious Injuries
2022	0.84	0.04	0.71	0.73	0.75	0.71
2023	0.81	0.24	0.72	0.79	0.73	0.72

Analysis of walking and cycling activity reveals a consistent trend: higher trip volumes are associated with increased crash and injury occurrences. For pedestrians, strong correlations were observed between walking activity and total crashes, moderate injuries, and minor injuries (ranging from 0.73 to 0.79 across 2022 and 2023), while correlations with serious injuries and fatalities were notably weaker. This suggests that greater pedestrian volumes lead to more frequent, but generally lower-severity incidents. In contrast, cyclists showed even stronger correlations across all crash categories, including serious injuries and combined fatality outcomes (up to 0.84 for total crashes). However, the link with fatalities alone remained weak, indicating that factors beyond exposure, such as infrastructure quality and helmet use, may play a more decisive role in fatal crash outcomes.

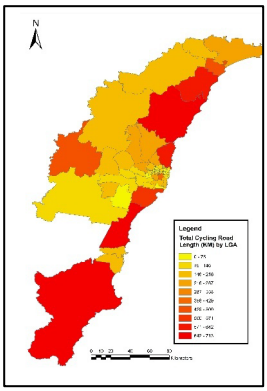
Lastly, a correlation analysis was conducted to explore the relationship between the length of infrastructure suitable for walking and cycling, cycling network, walking network, and low-speed road network (less than 40 km/hr), and crash data (Figure 3).

Crash risk values were estimated across all categorised crash data by dividing the number of crashes with the corresponding pedestrian and cyclist trip numbers for each LGA. Table 3 presents the correlations between the length of the low-speed environment road network and pedestrian and cyclist crash risk.

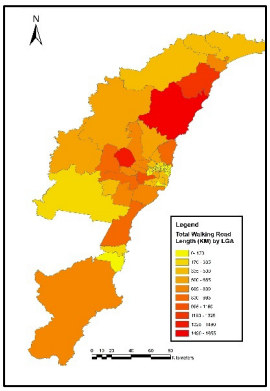
Figure 3: Total length of different infrastructure networks by LGA.



Plot (a): Road Network (up to 40km/hr) Length by LGA



Plot(b): Cycling Network Length by LGA



Plot (c): Walking Network Length by LGA

Table 3: Correlations between the infrastructure lengths and crash risk

Correlation between Length of Road Network (less than 40 km/hr) and **Pedestrians Crash Risk**				
Year	Total Crash Risk	Fatality Crash Risk	Serious Injury Crash Risk	Moderate Injury Crash Risk
2022	-0.15	-0.25	-0.27	-0.10
2023	-0.26	0.05	-0.09	0.09
Correlation between Length of Road Network (less than 40 km/hr) and **Cyclist Crash Risk**				
Year	Total Crash Risk	Fatality Crash Risk	Serious Injury Crash Risk	Moderate Injury Crash Risk
2022	-0.33	0.06	-0.31	-0.36
2023	-0.32	-0.12	-0.32	-0.27

The analysis reveals a modest but consistent negative correlation between active transport infrastructure and crash risk for pedestrians and cyclists. For pedestrians, total crash risk declined from a correlation of -0.15 in 2022 to -0.26 in 2023, while cyclists showed a stable negative correlation around -0.33 across both years. Although associations with fatal crashes were weak or inconsistent, likely due to limited sample sizes, the overall trend suggests that increased provision of supportive infrastructure, such as lower-speed streets, shared zones, and dedicated paths, are linked to improved safety outcomes. These effects may stem from reduced vehicle speeds, lower traffic volumes, and better separation between vulnerable users and motor vehicles.

4 Discussion

Meaningful insights are offered into the relationship between infrastructure provision, travel demand, and risk for pedestrians and cyclists, thereby enriching the evidence base on active transport safety. Pedestrian and cyclist safety is a critical concern, as these groups represent vulnerable road users. By leveraging robust volume estimates and correlating them with crash data, the study conducts a macroscopic analysis of active transport safety across Local Government Areas (LGAs) within Greater Sydney. A novel machine learning methodology is employed to account for exposure indicators, such as walking and cycling trips, and to examine their relationship with various categories of crash data, including fatalities and injuries of differing severities.

The findings reveal critical insights into the relationship between active transport activity, infrastructure, and safety outcomes. LGAs with higher walking and cycling activity exhibit strong correlations with increased crash frequencies, particularly for less severe injuries. For

instance, the correlation between walking trips and total crashes is 0.73 in 2022 and 0.71 in 2023, with similar strong correlations for moderate injuries (0.75 in 2022 and 0.73 in 2023). This suggests that areas with higher active transport demand experience proportionally higher crash risks, likely due to greater exposure. Similarly, cycling activity exhibits even stronger associations, with total crashes showing correlation coefficients of 0.84 in 2022 and 0.81 in 2023, while serious injuries recorded correlations of 0.71 and 0.72, respectively. Weaker correlations for fatalities, implying that factors such as road infrastructure and traffic conditions significantly influence crash severity. This highlights the complex interplay between activity levels and safety, requiring strategies to address both exposure and severity factors. Correlating crash risk with low-speed environment road infrastructure, revealed an inverse relationship, particularly for total crashes involving pedestrians and cyclists. These findings reinforce the value of designing and expanding low-speed infrastructure as a policy tool to mitigate crash severity in high-risk areas. Fatal and moderate injury risks showed weak or inconsistent correlations most likely due to the small sample size of fatal and injury crashes. The overall trends suggest that expanded active transport infrastructure is associated with improved safety outcomes. From a policy perspective, these findings underscore the need to prioritise investment in infrastructure that not only encourages active transport but also mitigates its associated risks.

This study offers valuable insights into the relationship between active transport activity, infrastructure, and crash data, but its correlational approach limits causal interpretation. Expanding the analysis to include variables like road user behaviour, traffic dynamics, environmental conditions, and land use patterns, particularly residential, commercial, and recreational areas, may support a more comprehensive and targeted approach to improving pedestrian and cyclist safety.

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