My title*

My subtitle

Ziheng Zhong

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My abstract

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*Code and data are available at: https://github.com/iJustinn/Toronto_Cycling_Network

1 Introduction

You can and should cross-reference sections and sub-sections. We use R Core Team (2023).

The remainder of this paper is structured as follows.

2 Data

2.1 Source

The data used in this paper was collected by the OpenDataToronto Library (Gelfand 2020). OpenDataToronto provides a platform for the public to access various datasets related to Toronto's civic operations and urban infrastructure. The specific dataset used in this research is the 'Cycling Network' (Data 2024), which provides detailed information on Toronto's bicycle infrastructure, including dedicated lanes, multi-use trails, and shared roadways. This dataset plays a crucial role in promoting active transportation and urban sustainability efforts within the city. It is frequently updated to reflect ongoing expansions and modifications to the cycling infrastructure, aligning with Toronto's broader efforts to reduce congestion, enhance mobility, and support environmental goals. This dataset not only informs local decisions but also contributes to broader discussions on urban transportation planning and sustainability in growing cities around the world.

Data used in this paper was downloaded, cleaned and analyzed with the programming language R (R Core Team 2023). Also with support of additional packages which will be talked about in the Section 2.3.

2.2 Measurement

The 'Cycling Network' dataset from Open Data Toronto tracks various aspects of Toronto's cycling infrastructure, such as installation dates, upgrades, street names, and the type of infrastructure (e.g., sharrows, multi-use trails). Each entry represents a segment of the cycling network, where real-world phenomena, such as the construction or upgrading of cycling paths, are documented. For example, when a cycling path is installed or upgraded, the responsible authorities collect information such as the installation year (e.g., 2001) and any subsequent upgrades (e.g., 2021). This data is then digitized into structured entries in the dataset.

To go from a physical event (e.g., the installation of a bike lane) to a dataset entry, detailed records are maintained by the city's transportation department. These records are geospatially coded (column geometry in this dataset), allowing each cycling path to be mapped precisely in relation to other city infrastructure. Thus, the phenomena of constructing or updating a bike lane becomes an entry with attributes such as the street name, road class, and installation

Table 1: Raw Coordinates

Simplified Geometry
{'type': 'MultiLineString', 'coordinates': [[[-79.4035069136297, 43.6952595244941], [-79.403
{'type': 'MultiLineString', 'coordinates': [[[-79.4036386937994, 43.6349938275931], [-79.403
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{'type': 'MultiLineString', 'coordinates': [[[-79.4677191149987, 43.7720763078272], [-79.467
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{'type': 'MultiLineString', 'coordinates': [[[-79.5430542283657, 43.58695658908], [-79.54307

Table 2: Extracted and Cleaned Coordinates

Longitude	Latitude	ID
-79.40351	43.69526	1
-79.40309	43.69535	1
-79.40240	43.69549	1
-79.40364	43.63499	2
-79.40355	43.63519	2
-79.40346	43.63535	2

history. This allows researchers to analyze trends in cycling infrastructure and its expansion over time.

2.3 Method

Data used in this paper was cleaned, processed, modeled and tested with the programming language R (R Core Team 2023). Also with support of additional packages in R: `sf` [], `readr` (Wickham, Hester, and Bryan 2023), `ggplot2` (Wickham 2016), `osmdata` [], `tidyverse` (Wickham et al. 2019), `jsonlite` [], `dplyr` (Wickham et al. 2023), `here` [], `knitr` [], `kableExtra` [], `[],` [], .

In the first data cleaning process, the focus was on extracting and cleaning geographical coordinates from the 'geometry' column, which contains location data in JSON-like format, Table 1 displays how the data was like. A custom function was created to parse the coordinates, filter out invalid entries, and extract the longitude and latitude values. The extracted coordinates were combined into a new dataset shon in Table 2, with unique IDs to match the original entries. Any rows with missing coordinate data were removed, and the cleaned data was saved into a separate file for further analysis.

The second cleaning process dealt with the 'UPGRADED' column, which contains information

Table 3: Number of Lane Upgrades by Year

Year	Number of Upgraded Lanes
2018	9
2019	14
2020	46
2021	28
2022	15
2023	12

Table 4: Number of Bikeways Installed by Year

Year	Number of Installed Bikeways
2001	539
2002	12
2003	15
2004	20
2005	65
2006	75

about the years when cycling lanes were upgraded. Invalid or missing years were filtered out, and the remaining valid data was converted to a numeric format. The dataset was then grouped by the year of upgrade, with a summary created to count the number of lanes upgraded in each year. This summarized data, Table 3, was saved for use in analyzing trends in lane upgrades over time.

In the third cleaning process, the focus was on the 'INSTALLED' column, which records the years when cycling infrastructure was first installed. Similar to the 'UPGRADED' column, invalid or missing years were removed, and the data was converted to numeric format. The installation data was grouped by year to count the number of bikeways installed each year. The resulting summary, Table 4, was saved for further trend analysis on the growth of the cycling network.

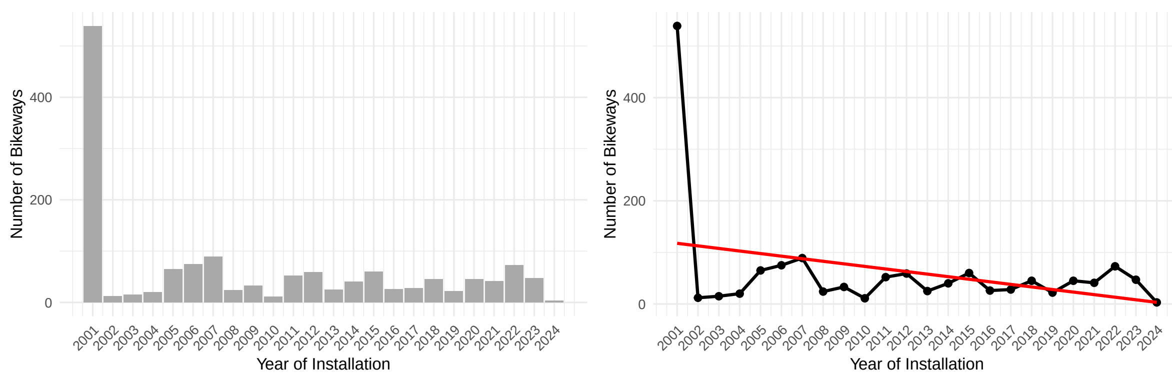
Finally, the fourth cleaning process involved classifying cycling lanes based on the type of infrastructure. Data from the 'INFRA_HIGHORDER' and 'INFRA_LOWORDER' columns was cleaned, and missing values were removed. The lanes were classified into three comfort levels: High Comfort, Moderate Comfort, and Low Comfort, depending on whether the infrastructure was protected or involved bike lanes. The classification, along with year data for installation and upgrades, was saved for analysis on the types of cycling lanes and their comfort levels. Table 5 shows how it looks like.

Table 5: Classification of Cycling Lanes by Comfort Level

Installed Year	Upgraded Year	Comfort Level
2001	2021	Low Comfort
2001	2009	High Comfort
2001	2011	High Comfort
2001	2011	High Comfort
2001	2012	High Comfort
2001	2012	High Comfort

3 Results

3.1 Data Trend



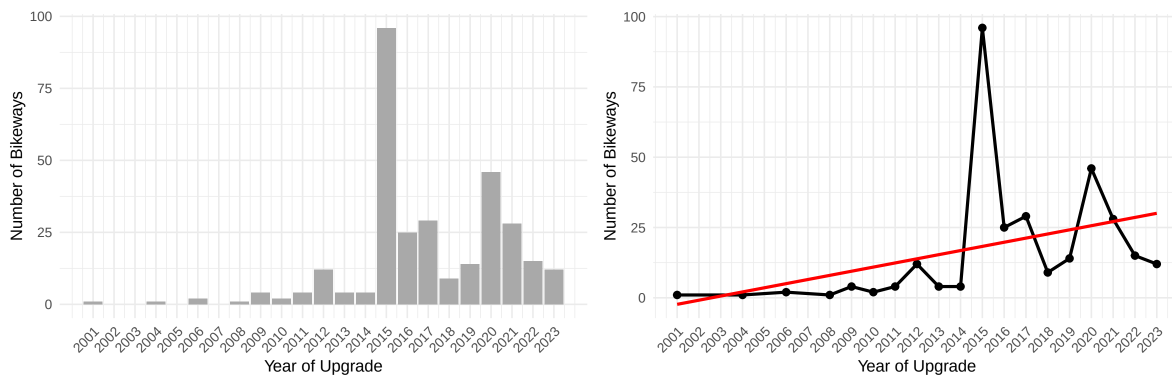
(a) Number

(b) Trend

Figure 1: Toronto Bikeways Installed by Year

Figure 1 consists of two panels depicting the number of bikeways installed in Toronto by year, alongside a trend analysis of the installation pattern over time. Figure 1a displays the raw count of bikeways installed per year from 2001 to 2024. A significant spike is observed in 2001, with over 400 bikeways installed in that year alone. This likely reflects a major investment in cycling infrastructure at the time. Following 2001, the number of installations drops sharply and stabilizes at much lower levels in subsequent years, with occasional small peaks around 2007, 2011, and 2021.

Figure 1b adds a trend line to the same data, showing a gradual decline in the number of bikeways installed over time. The trend line, sloping downward, indicates that despite some fluctuations, the overall pattern is a decrease in annual bikeway installations. The early 2000s marked a high point for cycling infrastructure development, but after this surge, the rate of installation has steadily declined. This trend might reflect a shift in city planning priorities or the saturation of available spaces for bikeways in certain areas. The analysis highlights the need for renewed focus on expanding cycling infrastructure to sustain or increase the momentum of bike-friendly urban development.



(a) Number

(b) Trend

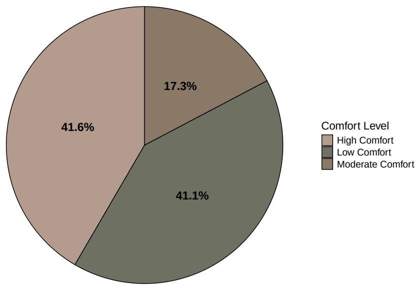
Figure 2: Toronto Bikeways Upgraded by Year

Figure 2 illustrates the number of bikeways upgraded in Toronto from 2001 to 2023, with panel (a) showing the raw counts of upgrades and panel (b) visualizing the trend. Figure 2a reveals that the most significant number of upgrades occurred in 2015, where nearly 100 bikeways were updated, marking a major peak. Outside of this spike, the number of annual upgrades remains relatively modest, typically fluctuating between 10 and 50 bikeways. Notable periods of increased upgrades are visible around 2012 and 2020, possibly reflecting concentrated efforts to modernize or expand existing cycling infrastructure in those years.

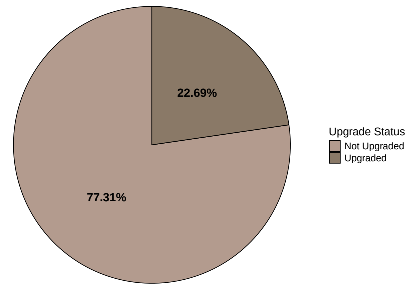
In Figure 2b, the overall trend is slightly upward, as indicated by the red trend line. Despite the notable peaks and valleys, the trend line suggests that, on average, the number of bikeway upgrades has increased over the years. The spike in 2015 significantly affects the trend, but even excluding that, the gradual rise suggests that more consistent efforts have been made to maintain and improve Toronto's cycling network. This trend aligns with broader urban planning strategies focused on making cities more accessible and environmentally friendly by supporting active transportation. The dips in recent years, particularly after 2020, might be influenced by resource reallocation or external factors, such as the global pandemic, which could have delayed infrastructure projects.

3.2 Distributions

Figure 3 provides a breakdown of Toronto's bikeway network by comfort level and upgrade status. Figure 3a shows the distribution of all bikeways based on comfort level, with the majority of bikeways classified as either Low Comfort (41.6%) or Moderate Comfort (41.1%), while High Comfort lanes constitute a smaller portion (17.3%). This indicates that while



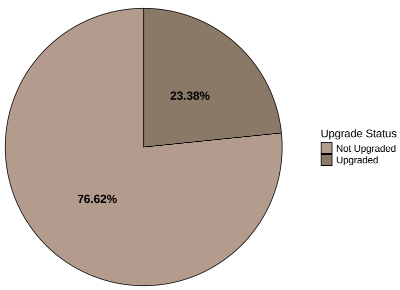
(a) Comfort Levels



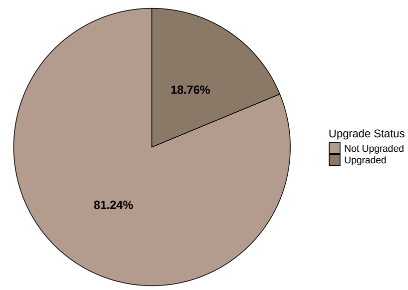
(b) Low Comfort

Figure 3: Toronto Bikeway Comfort Level Distribution

Toronto has invested in a significant number of bike lanes, most of them fall within lower comfort categories, suggesting that further improvements, particularly in upgrading existing lanes, are needed to promote safer and more comfortable cycling experiences.



(a) Moderate Comfort



(b) High Comfort

Figure 4: Toronto Bikeway Comfort Level Distribution

Figure 3b, Figure 4a, and Figure 4b offer a deeper look into the upgrade status for each comfort level. For Low Comfort lanes, only 22.69% have been upgraded, while 77.31% remain in their original state. Similarly, for Moderate Comfort bikeways, 23.38% have been upgraded, leaving 76.62% untouched. Interestingly, High Comfort lanes have the lowest proportion of upgrades, with only 18.76% improved, despite representing the most comfortable and potentially most desirable biking infrastructure. These trends highlight a potential gap in Toronto's focus on maintaining and upgrading its most comfortable and accessible cycling lanes, suggesting a need for more targeted investments in high-comfort bikeways to encourage broader use of cycling for transportation.

3.3 Maps

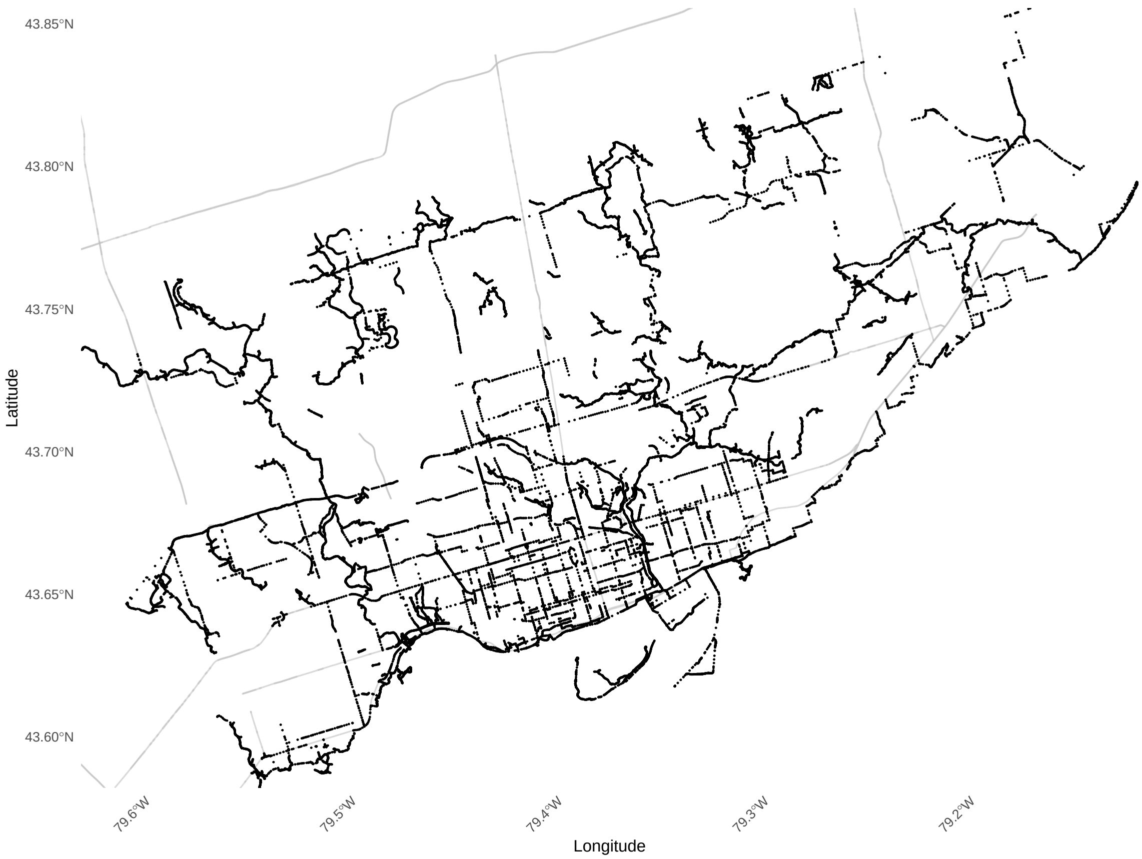


Figure 5: Map of Bike Lanes Locations in Toronto

Figure 5 provides a visual representation of the bike lane infrastructure across Toronto. The lines on the map correspond to various cycling paths, including dedicated bike lanes, multi-use paths, and shared roadways, which span different areas of the city. The geographic coordinates, ranging from around 43.60°N to 43.85°N in latitude and -79.6°W to -79.3°W in longitude, encompass most of Toronto's urban region. This map offers an important spatial perspective, illustrating the extensive network of cycling routes that connect different neighborhoods and areas within the city.

A key observation from the map is the dense concentration of bike lanes in the downtown core and along major roadways, indicating a well-established network in central Toronto. The downtown area's grid-like structure is particularly evident, showcasing a high density of lanes that facilitate easy cycling access within the city's busiest areas. As one moves further away from the city center, the map shows fewer bike lanes, suggesting that suburban regions may have less developed cycling infrastructure. However, there are notable multi-use paths extending toward the outskirts, particularly in parks and recreational areas, providing important cycling connections for those commuting or using bikes for recreational purposes.

This map highlights the importance of cycling infrastructure in promoting sustainable urban transportation. The wide distribution of bike lanes supports Toronto's efforts to enhance active transportation options, reduce traffic congestion, and improve accessibility for cyclists. The representation also provides a foundation for analyzing areas where future infrastructure developments could be prioritized, particularly in regions where cycling connectivity appears sparse.

4 Discussion

4.1 First discussion point

If my paper were 10 pages, then should be be at least 2.5 pages. The discussion is a chance to show off what you know and what you learnt from all this.

4.2 Second discussion point

4.3 Third discussion point

4.4 Weaknesses and next steps

Weaknesses and next steps should also be included.

A Appendix

References

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