**Pedalling Forward: The Evolution of Dedicated Cycling Infrastructure in Canadian Cities from 2010 to 2022**

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**INTRODUCTION**

Recognizing the significance of sustainable mobility, Canadian municipalities are intensifying efforts to enhance active transportation infrastructure due to its relative cost effectiveness, accessibility, and positive impact on users' health (1). Among various active transportation initiatives undertaken by local governments, the development of cycling infrastructure has emerged as a key strategy to meet urban mobility needs (2). This approach to mobility has the potential to alleviate transportation demands and align with broader environmental targets (3,4). Consequently, many large Canadian cities have made considerable progress in building new bikeways and upgrading infrastructure to create active spaces for individuals of all ages and abilities.

In line with these urban planning initiatives, the Vision Zero road safety strategy stands as a crucial guiding principle. Originating in Sweden in 1997 and adopted by many municipalities worldwide, Vision Zero strives to eliminate all severe and fatal road transportation injuries while promoting healthy and equitable mobility for all (5). Despite investments in cycling infrastructure to meet these goals for cyclists, the challenge of road safety persists as a pressing public health concern as transport injuries continue to have an immense human and economic burden (6). In addition to having direct public health impacts, the perceived risk of injury associated with on-street cycling may also deter its adoption as an alternative transportation option (2). From an equity standpoint, the lack of safe infrastructure may disproportionately discourage this mobility choice for certain groups based on age and gender (7).

Given the importance of on-street cycling infrastructure in enhancing safety and comfort, a detailed examination of infrastructure trends is necessary to better understand how cities are accommodating the needs of their diverse communities. Particular attention needs to be focused on the implementation of high comfort cycling routes, including cycle tracks, which are physically separated from vehicle traffic (8). This form of on-street infrastructure can be contrasted with painted lanes, which are perceived as less comfortable due to the lack of a protective barrier. A past study found that only 15% of cyclists perceived mixed traffic routes as being safe; however this perception increased to 77% for painted lanes, and was as high as 91% when physical barriers were part of the infrastructure (9).

This evaluation of trends becomes even more critical in the context of the COVID-19 pandemic, which required municipalities to respond to shifting mobility patterns and emerging public health needs (10). Notably, as cycling ridership surged nationwide, there were approximately 43,700 cycling-related emergency visits in Canada from April 2020 to March 2021, reflecting a 36% increase from the previous year (11,12). With the anticipation that increased ridership will persist in the coming years (13), municipalities must take proactive steps to design active transportation networks that can not only safely accommodate higher volumes, but also foster equitable access. In addition, the accuracy and verification of city open data needs to be considered as there is possibility of inconsistent, misclassified, or missing cycling infrastructure data (14,15).

In light of these considerations and the unique challenges presented by the COVID-19 pandemic, the focus of our research was to describe the trend in the implementation of manually-verified on-street cycling infrastructure within Vancouver, Calgary, and Toronto from 2009 to 2022. Understanding these trends is crucial in determining how large Canadian municipalities adapted to evolving public health needs, particularly during a time of increased reliance on active transportation. This study is part of the RECOVR initiative (**R**oad-safety **E**valuation during **CO**VID-19 among **V**ulnerable **R**oad Users in Canada), a broader research effort funded by the Canadian Institutes of Health Research which aims to explore emerging challenges related to active transportation safety in several urban centres across Canada. Although there have been past studies evaluating cycling infrastructure data in Canada (14–17) and their associations with cycling safety (18–20), accessibility (21,22), and demand (23–27), none, to the best of our knowledge, have focused on the verification and changes of dedicated cycling infrastructure across Canadian cities to date. Thus, we make the following research contributions: (1) a case study comparing changes in dedicated cycling infrastructure trends across three Canadian cities (Vancouver, Calgary, and Toronto) and (2) an approach for manual verification and correction of data containing cycling infrastructure installations and upgrades across time.

**METHODS**

***Data Sources***

Cycling network data, represented by street centrelines, were acquired from open data repositories maintained by the municipalities of Vancouver, Calgary, and Toronto in January 2023 (28–30). Within these datasets, cycling routes are divided into individual segments, representing city blocks (Vancouver & Calgary), or corresponding to entire installations (Toronto).

***Inclusion and Exclusion Criteria***

In line with the study's emphasis on dedicated cycling infrastructure located on public roadways, infrastructure classifications pertaining to painted lanes, buffered lanes, and cycle tracks were eligible for inclusion. To ensure methodological consistency and account for potential disparities in the inclusion of decommissioned infrastructure within municipal data, only infrastructure that was permanently installed and active at the time of dataset acquisition was eligible for inclusion.

Segments of cycling infrastructure categorized as off-street paths, shared roadways, or mixed-use paths were excluded from the analysis. Moreover, any segments classified as a temporary installation were removed, ensuring the study's findings reflected long-term planning and policy decisions within the evaluated municipalities. Duplicate entries with the same polyline coordinates were identified and removed. Lastly, street imagery was used to review each segment’s classification, leading to the removal of infrastructure consistent with the specified exclusion criteria.

***Infrastructure Classifications***

This retrospective study centered on describing trends in on-street infrastructure, designated for the exclusive use by cyclists (*dedicated infrastructure*). As each municipality has their own individual classification systems (see ***Appendix 2*** for details), a standardized classification criterion was applied across cities, based on the Can-BICS classification system (8). For the purpose of this analysis, the Can-BICS painted lane classification was further subdivided into two distinct types: painted lanes and buffered lanes. This distinction facilitated a more detailed analysis of infrastructure trends, and was influenced by previous research from Australia that observed an increased passing distance between motorists and cyclists when infrastructure consisted of buffered lanes as compared to painted lanes (31), potentially improving perceived safety and reducing the risk of collisions.

Based on this approach, three categories of infrastructure were considered, including painted lanes, buffered lanes, and cycle tracks. Painted lanes were characterized by solid or dashed lines separating cyclists from vehicle travel lanes, accompanied by signs or pavement markings to distinguish them as cycling routes. Buffered lanes shared similar features; however, were distinguished by a wider painted area marked with diagonal or chevron patterns. Cycle tracks were defined based on the presence of a permanent vertical barrier such as bollards or raised curbs. In situations where different infrastructure was present on opposite sides of a roadway, the segment’s classification was determined by the most protective element. Detailed information on the classification criteria is listed in ***Appendix 2***.

***Data Collection***

Changes to the infrastructure that occurred within the study period were documented, including details about the year of modification and the subsequent classification following those changes. An installation was defined as the introduction of dedicated cycling infrastructure on a roadway where no prior dedicated infrastructure existed within the study period. In cases where dedicated infrastructure was already present at the study period’s outset, the installation year was designated as the initial year of the study period (2009). Conversely, an upgrade was defined as the modification of existing dedicated cycling infrastructure, resulting in the reclassification of the segment. Following the identification of eligible segments from municipal data, a combination of imagery services and grey literature sources (municipal government briefs, construction notices, news articles, and posts from community organizations) was utilized to determine infrastructure installation or modification during the study period (2009-2022). Segments were first examined at specific time points using Google Street View and Google Earth to classify both existing infrastructure and any facilities that preceded an upgrade. Moreover, this examination of infrastructure for each city allowed for the exclusion of misclassified infrastructure that did not meet the predefined eligibility criteria.

***Descriptive Analysis***

Based on the collected data, the total length of each infrastructure type at the end of each study year was computed. Using the shapefiles downloaded from each municipality open data portal(28–30), the length of each route segment was calculated in in R using the sf package version 1.0-16 (32). The combined information on length, infrastructure types during the study period, and their associated years of implementation were analyzed in using R Version 4.3.3 (33). A series of functions were developed to calculate the yearly trends in the total length of each bikeway type across each municipality. The code used to perform this analysis are available in the ***Supplementary Files***. A secondary analysis involved exploring yearly trends in bikeway infrastructure by road type. Utilizing ArcGIS Pro Version 3.1.2 software (32) , a spatial join was carried out between bikeway segments and street centreline information for each municipality, enabling the collection of street classifications associated with each cycling route. Yearly trends in infrastructure were then analyzed in a similar manner as above, considering road types, which were classified as either arterial, collector, or local. Finally, we mapped the segments identifying the location of new installations and infrastructure since 2020.

**RESULTS**

***Descriptive Characteristics of Each Municipality***

Using open data sources from each municipality (28–30) and Statistics Canada (34), ***Table 1*** below presents an overview of each city’s demographics, roadway infrastructure, and bikeway network. Vancouver leads in population density with 5,758 individuals per square kilometer (sq km) and has 84% of its roadways designated as local streets. Notably, 11.9% of roadway-km within the municipality have cycling routes, including dedicated cycling infrastructure, local street bikeways, and shared roads.

Calgary follows with a population density of 1,583 individuals per sq km, 65% of its roadway network being local streets, and 7.2% of roadway-km having cycling routes. A standout feature of Calgary’s active transportation infrastructure is its extensive network of paths, with a total length of 1,012 km, as compared with Vancouver’s 77.5km and Toronto’s 365.9km of off-street paths.

Finally, Toronto, the most populous municipality in the study, has a density of 4,434 individuals per sq km, with 66% of its roadways designated as local streets, and only 7% of roadway-km with cycling routes.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Municipal Attributes** | | **Municipality** | | |
| **Category** | **Measure** | **Vancouver** | **Calgary** | **Toronto** |
| **Demographics**  **(2021)** | Population (2021) | 662,248 | 1,306,784 | 2,794,356 |
| Area (km²) | 115 | 825.3 | 630.2 |
| **Density** (Pop. per km²) | **5,758** | **1,583** | **4,434** |
| **Municipal Roadways** a  (2022, cen-km) | Arterial | 221.6 | 1,402.1 | 1153.7 |
| Collector | 132.7 | 1331.9 | 767.1 |
| Local | 1869.4 | 5197.3 | 3658.6 |
| **Roadways, Total** | **2,223.7** | **7,931.3** | **5,579.4** |
| **Municipal Bikeways and Pathways** b  (2022, cen-km) | Path *(Off-Street)* | 77.5 | 1,012 | 365.9 |
| Cycle Track *(On-Street)* | 27.4 | 31.7 | 73.9 |
| Painted Lane *(On-Street)* | 43.8 | 57.0 | 131.5 |
| Shared Route *(On-Street)* | 193.3 | 481.0 | 184.4 |
| Local Street Bikeways (On-Street) |  | N/Ac | N/Ac |
| **On-Street Routes, Total** | **264.5** | **569.7** | **389.8** |
| **All Routes, Total** | **342.1p** | **1,581.7** | **755.8** |
| **Cycling Route Coverage** (by cen-km) | **% Roadway-km with routes** | **11.9%** | **7.2%** | **7.0%** |
| cen-km: centreline-kilometers, length of a route measured along its central axis.  *a: Total Centreline-km of Public Roadways in Vancouver, Calgary, and Toronto. Excluding Highways, Skeletal Roads, and non-municipally operated roads. Local roadways denote residential streets and lanes.*  *b: Total centreline-km of municipally operated bikeways and pathways, excluding planned infrastructure, temporary infrastructure, and decommissioned infrastructure. Analyzed directly from municipal data, prior to the exclusion of misclassified segments.*  *c: Local Street Bikeways are not included in totals. Based on the Can-BICS classification, Calgary does not have infrastructure fitting the defined Local Street Bikeways. Similarly, Toronto does not have Local Street Bikeways according to the Can-BICS definition.* | | | | |

**Table 1: Comparison of Municipal Roadway and Bikeway Infrastructure in Vancouver, Calgary, and Toronto (Canada), 2022.** Information downloaded from municipally maintained open datasets, with records last downloaded between June 2022 and August 2023. Analysed prior to the exclusion of misclassifications. Methodology and detailed download dates available in ***Appendix 2***.

***Eligibility and Inclusions***

As seen in ***Figure 1***, from a total of 3666 segments in Vancouver's cycling network (total length: 341.7 km), 3152 segments (251.6 km) were extracted by filtering for local street bikeways (Vancouver only), painted lanes, buffered lanes, and cycle tracks within the existing data. After verifying infrastructure classifications, 3118 segments (247.1 km) were confirmed for inclusion in subsequent analyses, while 34 were found to be ineligible. Of these 34 excluded segments, 49% were mixed-use pedestrian paths, 20% were local shared paths, and 31% were off-road cycling paths.

Calgary’s data, limited to on-street routes, included 4169 segments (571.8 km), from which 784 (87.1 km) met the eligibility criteria. Following the same process of data collection and confirmation through street imagery, 752 segments (85.5 km) were eligible for inclusion. Of the 32 segments excluded following screening, 47% were on-street routes shared with motor vehicles, 25% were mixed use routes, and 28% were inactive temporary infrastructure.

Lastly, for Toronto, the data consisted of 1323 segments (755 km), of which 331 segments (205.3 km) met the eligibility criteria. Utilizing street imagery to verify classifications, 326 segments (204.3 km) were confirmed for inclusion, with all five excluded segments being on-street routes shared with motor vehicles.



**Figure 1: Flow diagram of inclusion criteria for bikeway segments in Vancouver, Calgary, and Toronto**. This flowchart provides a high-level overview of the segment inclusions and exclusions for each municipality. Data from Calgary were specific to on-street routes only. For detailed flow diagrams specific to each municipality, please refer to the***Appendix****.*

***Classification of Installation and Upgrade Years***

Installation years were verified for all segments, revealing that 66% of segments in Vancouver, 8% in Calgary, and 41% in Toronto had dedicated cycling infrastructure established by 2009 or earlier. A comparative assessment was then conducted between the verified installation years and those in the original municipal datasets. In Vancouver, among segments installed or updated during the study period (n = 251), 83.3% accurately matched the city's provided installation years, and 97.2% were within a ±1-year range. For Calgary, among a similar subset of segments (n = 668), 42.1% matched with the city's recorded installation years, and 62.7% were accurate within ±1 year. Finally, in Toronto, among 188 eligible segments meeting this criterion, 74.5% accurately matched with the city's provided installation years, and 78.2% were accurate within a ±1-year span.

During the data collection phase, discrepancies emerged in the recording of recent infrastructure changes among the cities. Consequently, the results for Calgary and Toronto reflect infrastructure changes until the end of the 2022 calendar year, while Vancouver's results describe modifications up to 2021. Through the exploration of street imagery, it was revealed that several changes made in 2022 in Vancouver were left undocumented. Overall, this adjustment ensures the accurate representation of infrastructure changes occurring up until the end of each calendar year. The study period for Vancouver was then adjusted accordingly.

***Classification of Infrastructure***

The standardized criteria enabled a detailed comparison between cities. For Vancouver, by December 2021, there were 41.19 km of painted infrastructure (*37.19 km painted lanes + 9.0 km buffered lanes*) and 30.58 km of cycle tracks following the verification of infrastructure classifications (***Appendix 1***). When contrasting these results with the original classifications (the one provided by the city), the standardized data comparatively had 3.18 km more cycle tracks and 2.39 km more painted infrastructure (***Table 1***). In Calgary, verified data for 2022 included 60.28 km of painted infrastructure (*55.7 km painted lanes + 4.8 km buffered lanes*) and 24.5 km cycle tracks. Accordingly, the verified data had 3.5 km more painted lanes and 7.2 km fewer protected lanes when compared to the administrative data. In Toronto, the review found 135.8 km of painted infrastructure (*123.6 km painted lanes + 12.2 km buffered lanes*) and 67.6 km of cycle tracks, with 4.3 km more painted infrastructure and 6.3 km fewer cycle tracks compared to the original municipal records.

***Trends in Infrastructure Installations***

An examination of the cycling infrastructure implementation trends across Vancouver, Calgary, and Toronto reveals significant large growth in dedicated on-street cycling networks since 2009. At the beginning of the study, these cities had 43 km, 8 km, and 103 km of such infrastructure, respectively. By the conclusion of the study period, Vancouver added 27 km (64% increase), Calgary 77 km (1014% increase), and Toronto 101 km (98% increase) of dedicated cycling infrastructure to their roadways. Moreover, a growing proportion of infrastructure is composed of cycle tracks. While in 2009, only 4% of Vancouver's dedicated cycling facilities were cycle tracks and none existed in Calgary or Toronto, this changed dramatically by the end of the study period, with cycle tracks constituting 39% of Vancouver's, 29% of Calgary's, and 33% of Toronto's dedicated on-street infrastructure (***Figure 2***). This increase in cycle tracks has partly been driven by upgrades of existing painted lane infrastructure(***Figure 3***). This is particularly salient in Vancouver, which has consistently seen decreases in painted cycle lanes since 2016 in favour of upgrades to protected infrastructure.

. In particular, Calgary and Toronto showed an upward trend in the installation of dedicated on-street cycling infrastructure since the pandemic’s onset. As illustrated in ***Figure 3***, the growth in Toronto’s infrastructure was at it highest in 2020, with 4.7 km of new infrastructure per 1000 cen-km of roadway, while Calgary’s peak occurred in 2021, with 1.0km of new infrastructure built per 1000 cen-km of roadway. For both cities, this growth of on-street cycleways is primarily attributed to the increase in cycle track infrastructure, as depicted in ***Figures 2 and 3***. In contrast, the installation of infrastructure within Vancouver peaked in 2016, with its post-pandemic infrastructure growth remaining in line with previous levels.

A spatial depiction of each city’s infrastructure trends following the start of the pandemic is shown in ***Figure 4***. In Vancouver, N(4%) of the existing infrastructure were upgraded and N was newly installed since the start of 2020. Calgary saw less than 1% of infrastructure upgraded, and instead had 23% of its current infrastructure newly installed since 2020. Finally, in Toronto 9% of current infrastructure was upgraded during this time and 24% was newly installed.

A secondary analysis was conducted to identify the type of roads that experienced the most significant increase in infrastructure since the start of the pandemic. Much of this increase stemmed from the introduction of cycling tracks on arterial roads. In contrast, less attention has been given to building protected facilities on collector roads, not only since the start of the pandemic, but throughout the entire study period. These results underscore the need for investments in infrastructure across all road types in order to foster a more inclusive and connected cycling network.

A graph of a number of people

Description automatically generated with medium confidence

***Figure 2: Changes in dedicated cycling infrastructure between 2009 and 2021 for Vancouver, Calgary, and Toronto based by infrastructure category****. Assessed using roadway centreline-km, with infrastructure classifications determined by the most protective element present along each road segment.*

*A screenshot of a graph

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***Figure 3: Yearly net change in cycle route infrastructure by municipality, standardized per 1000 centerline-km of roadway.*** *The net change considers both the installation of new facilities, and the removal of existing infrastructure, such as when an existing facility is upgraded. Cycle route infrastructure is defined by the most protective element along a street centreline. This reflects the overall modifications made within each municipality over the course of the study period (2009-2022).*

*A map of a city

Description automatically generated*

Downtown Region

Vancouver, CA

*A screenshot of a map

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Downtown Region

Calgary, CA

*A map of a city

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Legend

--- New Infrastructure Since Jan. 2020

--- Upgraded Infrastructure Since Jan. 2020

--- Unchanged Infrastructure

Downtown Region

Toronto, CA

***Figure 4: Changes in Dedicated On-Street Infrastructure Since January 2020 for Vancouver, Calgary, and Toronto****Mapped in ArcGIS Pro 3.0.1.*

**DISCUSSION**

The present study sought to describe the overall trends in the implementation of on-street cycling infrastructure across Vancouver, Calgary, and Toronto from 2009 to 2022. By using standardized criteria for classifying cycling infrastructure and leveraging street view imagery services, this work allowed for a comparison of trends and classifications between municipalities. Overall, a consistent increase of cycling network growth occurred in all three cities, with a shift towards protected cycling infrastructure. More recently, the onset of the COVID-19 pandemic revealed a divergence in municipal responses, with increased rates of infrastructure installations in Toronto and Calgary as opposed to…. In addition to new installations, Toronto also prioritized the upgrading of existing infrastructure, with 9% of its current network of dedicated cycling routes being upgraded during this time. In contrast, Vancouver’s change in cycling infrastructure was consistent with changes seen prior to the pandemic.

This belongs in the new paragraph., likely attributed to an already extensive network of cycling routes and numerous local roadways.

Overall, the expansion of on-street cycling routes over the past decade is a reflection of the growing popularity of cycling as a mode of transportation (35), and investments in infrastructure have played a key role in supporting this upward trend (36). Despite these advances, the adoption of cycling has not grown equally among all groups, with ridership levels among females and children often being lower (35). This emphasizes the need to address barriers to cycling, particularly through investment in high comfort cycling facilities. Research has found that women ride less – less protected…. (refs). This research reveals that municipalities have prioritized investments in safer and more infrastructure, yet the opportunity still exists to bridge remaining infrastructure gaps. In the context of the COVID-19 pandemic, the growth in cycling networks seen in Toronto and Calgary, particularly in protected facilities, is in line with the broader trends seen across North American and European cities (37). The need to accommodate increased ridership drove many local governments to develop local infrastructure during this period, but also brought forward permanent changes in favour of cycling. These trends may have signified a larger paradigm shift, reflecting efforts to embrace active transportation and to rethink the design of urban centers (38).

This study offers valuable insights into cycling infrastructure implementation trends, with key strengths including the use of standardized criteria for classifying infrastructure and an innovative visual approach to confirm changes over time. T The incorporation of information pertaining to infrastructure updates also ensures that the resulting trends accurately reflect the evolution of on-street cycling infrastructure. However, there are some limitations to consider. By defining infrastructure based on the most protective infrastructure, some finer details regarding infrastructure modifications may have been overlooked. Additionally, the exclusion of temporary infrastructure could limit the study's ability to fully capture how municipalities promoted active transportation, particularly during the pandemic.

The insights from this study set the stage for more in-depth research into cycling infrastructure trends, particularly as they relate to equity and road safety. Identifying how municipalities have responded to existing gaps in cycling networks, particularly in relation to factors such as population density and neighbourhood marginalization, is important to promote healthy and equitable mobility for all. This detailed exploration may shed light on the prioritization of these factors in urban planning and contribute to a better understanding of how cycling infrastructure is implemented across municipalities.

**CONCLUSION**

In summary, this extensive evaluation of on-street cycling infrastructure trends in Vancouver, Calgary, and Toronto from 2009 to 2022 provides insight into how municipalities have prioritised active transportation options. The study reveals anexpansion in dedicated cycling networks, particularly in the form of cycle tracks, reflecting a conscious shift toward safer and more comfortable cycling facilities. The COVID-19 pandemic has notably spurred an upward trend in infrastructure development, especially in Calgary and Toronto, in response to changing mobility patterns and evolving public health needs. Discrepancies and misclassifications within municipal cycling network data points to the fact that these data were not collected for the purpose of evaluation or research. This underscores the need for an effort to introducestandardized classifications for infrastruture to facilitate effective urban planning and policymaking. Despite some progress, the findings also point to a need for continued investment to address potential gaps in cycling networks, particularly as protected facilities were often less prioritized along medium-traffic roads. By investing in more inclusive and connected cycling networks that align with the Vision Zero road safety plan, municipalities can foster safer, more sustainable, and resilient mobility in cities.

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**APPENDIX 1 – SUPPLEMENTARY RESULTS**

A map of a city

Description automatically generated

Legend

--- New Dedicated Infrastructure (2020-21)

--- Upgraded Dedicated Infrastructure (2020-21)

--- Unchanged Dedicated Infrastructure (2020-21)

***Supplementary Figure 1: Enlarged Map. Changes in Dedicated On-Street Infrastructure Between 2020-2021 for the Municipality of Vancouver, CA.*** *New installations of dedicated infrastructure are denoted in green, upgrades from a previous dedicated infrastructure type are denoted in orange. Mapped in ArcGIS Pro 3.0.1.*

*A map with green lines and red lines

Description automatically generated*

Legend

--- New Dedicated Infrastructure (2020-22)

--- Upgraded Dedicated Infrastructure (2020-22)

--- Unchanged Dedicated Infrastructure (2020-22)

***Supplementary Figure 2: Enlarged Map. Changes in Dedicated On-Street Infrastructure Between 2020-2022 for the Municipality of Calgary, CA.*** *New installations of dedicated infrastructure are denoted in green, upgrades of dedicated infrastructure are denoted in orange. Mapped in ArcGIS Pro 3.0.1.*

*A map of a city

Description automatically generated*

Legend

--- New Dedicated Infrastructure (2020-22)

--- Upgraded Dedicated Infrastructure (2020-22)

--- Unchanged Dedicated Infrastructure (2020-22)

***Supplementary Figure 3: Enlarged Map. Changes in Dedicated On-Street Infrastructure Between 2020-2022 for the Municipality of Toronto, CA.*** *New installations of dedicated infrastructure are denoted in green, upgrades of dedicated infrastructure are denoted in orange. Mapped in ArcGIS Pro 3.0.1.*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Total Length of Roadways with Dedicated Cycling Infrastructure by Year (2009-2022)**  *Measured by centreline-km of roadway* | | | | | | | | | | | | | | |
| **Vancouver** | | | | | **Calgary** | | | |  | **Toronto** | | | |  |
| Type | PL | BUF | CT | **TOTAL** | Change | PL | BUF | CT | **TOTAL** | Change | PL | BUF | CT | **TOTAL** | Change |
| 2009 | 39.81 | 0 | 2.84 | **42.65** |  | 7.63 | 0 | 0 | **7.63** |  | 101.91 | 1.03 | 0 | **102.94** |  |
| 2010 | 39.31 | 0 | 6.34 | **45.64** | *+2.99* | 12.28 | 0 | 0 | **12.28** | *+4.65* | 106.51 | 1.03 | 0 | **107.54** | *+4.60* |
| 2011 | 39.37 | 0 | 6.65 | **46.02** | *+0.38* | 19.18 | 0.55 | 0 | **19.73** | *+7.45* | 108.06 | 1.56 | 0 | **109.63** | *+2.09* |
| 2012 | 41.56 | 0 | 6.81 | **48.37** | *+2.35* | 23.90 | 0.55 | 0.56 | **25.02** | *+5.29* | 108.82 | 1.56 | 0 | **110.37** | *+0.74* |
| 2013 | 39.47 | 1.51 | 8.60 | **49.58** | *+1.21* | 26.35 | 0.55 | 0.70 | **27.60** | *+2.58* | 108.30 | 2.02 | 2.55 | **112.86** | *+2.49* |
| 2014 | 39.05 | 1.51 | 11.02 | **51.58** | *+2.00* | 34.52 | 0.73 | 1.25 | **36.50** | *+8.90* | 108.47 | 5.91 | 7.75 | **122.13** | *+9.27* |
| 2015 | 41.20 | 1.51 | 11.95 | **54.65** | *+3.07* | 34.82 | 0.73 | 6.62 | **42.16** | *+5.66* | 111.95 | 5.75 | 13.18 | **130.88** | *+8.75* |
| 2016 | 40.08 | 1.86 | 17.11 | **59.05** | *+4.40* | 40.41 | 0.75 | 7.89 | **49.05** | *+6.89* | 114.66 | 6.04 | 16.06 | **136.75** | *+5.87* |
| 2017 | 36.42 | 7.10 | 17.79 | **61.31** | *+2.26* | 49.83 | 0.75 | 8.04 | **58.61** | *+9.56* | 119.13 | 5.51 | 19.96 | **144.60** | *+7.85* |
| 2018 | 35.90 | 7.19 | 20.68 | **63.77** | *+2.46* | 54.76 | 0.75 | 8.04 | **63.55** | *+4.94* | 121.62 | 9.05 | 21.30 | **151.98** | *+7.38* |
| **2019** | 35.07 | 8.01 | 21.71 | **64.80** | *+1.03* | 55.38 | 0.75 | 9.30 | **65.43** | *+1.88* | 121.27 | 9.79 | 23.78 | **154.83** | *+2.85* |
| **2020** | 34.36 | 9.01 | 23.89 | **67.27** | *+2.47* | 55.86 | 0.75 | 12.87 | **69.48** | *+4.05* | 119.67 | 16.36 | 50.17 | **186.20** | *+31.37* |
| **2021** | 32.59 | 9.01 | 26.29 | **69.89** | *+2.62* | 55.98 | 4.77 | 21.08 | **81.83** | *+12.35* | 124.68 | 12.25 | 65.37 | **202.29** | *+16.09* |
| **2022** |  |  |  |  |  | 55.68 | 4.77 | 24.52 | **84.97** | *+3.14* | 123.66 | 12.25 | 67.57 | **203.48** | *+1.19* |

***Supplementary Table 1: Total Length of Dedicated On-Street Cycling Infrastructure between 2009 and 2022, for Vancouver, Calgary, and Toronto (Canada).*** *Each entry denotes the aggregated length of infrastructure existing at the conclusion the calendar year. Lengths are measured in roadway centreline-km, with cycling infrastructure classified according to the side of the road featuring the most protective element. Rows noted in light red denote infrastructure changes following the start of the COVID-19 pandemic. Geodesic lengths calculated in ArcGIS Pro 3.0.1.*

|  |
| --- |
| **A**S  A graph of a growing graph  Description automatically generated with medium confidence  **B**S  A graph of a number of people  Description automatically generated with medium confidenceA graph of a number of blue lines  Description automatically generated with medium confidenceA graph of a number of years  Description automatically generated with medium confidence |

***Supplementary Figure 4: Changes in dedicated cycling infrastructure between 2009 and 2021 for the Municipality of Vancouver, CA*** *by (A) roadway classification, and (B) infrastructure distribution within each road class. Assessed using roadway centreline-km, with infrastructure classification determined by the most protective element present along each road segment.*

|  |
| --- |
| A graph of a growing graph  Description automatically generated  **A**S  **B**S  A graph of a growing graph  Description automatically generatedA graph of a growing graph  Description automatically generatedA graph of a growing graph  Description automatically generated |

***Supplementary Figure 5: Changes in dedicated cycling infrastructure between 2009 and 2022 for the Municipality of Calgary, CA*** *by (A) roadway classification, and (B) infrastructure distribution within each road class. Assessed using roadway centreline-km, with infrastructure classification determined by the most protective element present along each road segment.*

|  |
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| **A**S  A graph of a growing graph  Description automatically generated  **B**S  A graph of a number of blue and white lines  Description automatically generatedA graph of a number of roads  Description automatically generatedA graph of a blue line  Description automatically generated |

***Supplementary Figure 6: Changes in dedicated cycling infrastructure between 2009 and 2022 for the Municipality of Toronto, CA*** *by (A) roadway classification, and (B) infrastructure distribution within each road class. Assessed using roadway centreline-km, with infrastructure classification determined by the most protective element present along each road segment.*

*A graph of a number of data

Description automatically generated*

***Supplementary Figure 7: A comparative analysis between municipal data and verified data on the installation years for cycling infrastructure in Vancouver, CA.*** *Any data where a city provided installation year was missing or the verified year occurred earlier than the start of the study period (2009) has been excluded from analysis, yielding n = 252 segments. The graph shows that 83.3% of the included segments had the correct installation year as per the city's data, and 97.6% were accurate within a range of ±1 year.*

*A graph of a bar graph

Description automatically generated*

***Supplementary Figure 8: A comparative analysis between municipal data and verified data on the installation years for cycling infrastructure in Calgary, CA.*** *Any data where a city provided installation year was missing or the verified year occurred earlier than the start of the study period (2009) has been excluded from analysis, yielding n=670 segments. The graph shows that 42.1% of the included segments had the correct installation year as per the city's data, and 62.8% were accurate within a range of ±1 year.*

*A graph of a number of data

Description automatically generated*

***Supplementary Figure 9: A comparative analysis between municipal data and verified data on the installation years for cycling infrastructure in Toronto, CA.*** *Any data where a city provided installation year was missing or the verified year occurred than the start of the study period (2009) has been excluded from analysis, yielding n=192 segments. The graph shows that 75.5% of the included segments had the correct installation year as per the city's data, and 78.1% were accurate within a range of ±1 year.*

**APPENDIX 2 – METHODOLOGY**

**Segment Inclusion Criteria for Vancouver**

Shapefiles identified from: https://opendata.vancouver.ca/explore/dataset/bikeways/information

Downloaded: January 2023

N = 3664 Segments

**Identification**

Segments Excluded

(n = 2568)

Filter for Dedicated Cycling Infrastructure: bikeway\_type = “Painted Lanes” or “Protected Bike Lanes”.

(n = 1096)

Off-street Segments Excluded

(n = 315)

Filter for Infrastructure Located on Roadway: street\_segment != “Off-street”

(n = 781)

**Filtering**

Duplicates Excluded

(n = 1)

Remove Duplicates

Remove duplicates based on Starting XY AND Ending XY

(n = 780)

Segments Included for Data Entry and Screening

(n = 780)

**Eligible**

**Misclassifications: Offroad Cyclist Path (n = 11)**

**Misclassifications: Multi-Use Path (n = 17)**

**Misclassifications: Local Street Bikeway/Shared Road (n = 6)**

Misclassifications: Inactive Temporary Infrastructure: (n = 0)

**Duplicates: (n = 1)**

Exclusion of Misclassifications and Duplicates following Screening

(n = 745)

**Screening**

**Verified Inclusions:**

**(n = 745)**

**Inclusions**

**Segment Inclusion Criteria for Calgary**

Shapefiles identified from: https://data.calgary.ca/Transportation-Transit/Calgary-Bikeways/jjqk-9b73

Downloaded: January 2023

N = 4166 Segments

**Identification**

Segments Excluded

(n = 3371)

Filter for Dedicated Cycling Infrastructure: bicycle class = “Bicycle Lane” or “Cycle Track”.

(n = 795)

Ineligible entries removed

(n = 12)

Filter for Active Status: status != “INACTIVE”, “PLANNED”

(n = 783)

**Filtering**

No duplicates excluded

Null geometry: (n = 1)

Remove null geometries and check for duplicated segments

(n = 782)

Segments Included for Data Entry and Screening

(n = 782)

**Eligible**

Misclassifications:Offroad Cyclist Path (n = 0)

**Misclassifications: Multi-Use Path (n = 8)**

**Misclassifications: Local Street Bikeway/Shared Road (n = 15)**

**Misclassifications: Inactive Temporary Infrastructure: (n = 9)**

Duplicates: (n = 0)

Exclusion of Misclassifications and Duplicates following Screening

(n = 750)

**Screening**

**Verified Inclusions:**

**(n = 750)**

**Inclusions**

**Segment Inclusion Criteria for Toronto**

Shapefiles identified from: https://open.toronto.ca/dataset/cycling-network/

Current to: 2023-01-19, Downloaded July 2023

N = 1323 Segments

**Identification**

Filter for Dedicated Cycling Infrastructure: "Bi-Directional Cycle Track", "Bike Lane", "Bike Lane - Buffered", "Bike Lane - Contraflow", "Cycle Track", "Cycle Track - Contraflow"

(n = 331)

Segments Excluded

(n = 992)

**Filtering**

Check for Duplicates

None found, based on Starting XY AND Ending XY

Segments Included for Data Entry

(n = 331)

**Eligible**

Misclassifications:Offroad Cyclist Path (n = 0)

Misclassifications: Multi-Use Path (n = 0)

**Misclassifications: Local Street Bikeway/Shared Road (n = 5)**

Misclassifications: Inactive Temporary Infrastructure: (n = 0)

Duplicates: (n = 0)

Exclusion of Misclassifications

(n = 326)

**Screening**

**Verified Inclusions:**

**(n = 326)**

**Inclusions**

|  |
| --- |
| ***Criteria for Classifying Infrastructure*** |
| **Overview of Steps**  Infrastructure Classification Steps:   * Classify dedicated on-street cycling infrastructure types as either a painted lane, buffered painted lane, or cycle track based on the criteria listed below. Where dedicated on-street cycling infrastructure is absent for a specific segment, the segment will be classified as a shared road, and excluded if it did not receive a subsequent upgrade to a dedicated cycling infrastructure type. Where the cycling facility is located >10 m from a roadway or is denoted for shared use with pedestrians, the segment will be excluded. * If differing infrastructure types exist on either side of the road, categorize the segment based on the most protective element of dedicated cycling infrastructure: Cycle Track (most protective) > Buffered Painted Lane > Painted Lane > Shared Road. * When different infrastructure types are observed along one side of a roadway segment, the classification will rely on the predominant infrastructure type present along the majority of the route, with infrastructure present at intersections excluded from consideration. |
| **Criteria for Painted Lane, Modified from Can-BICS** (8)**:**  A cycling facility can be considered a painted bike lane if the design is consistent with the following features:   1. Lane Demarcation: Solid or dashed lane line(s).    1. Lane may be solid or dashed on the travel lane side. 2. Route Signage and Pavement Markings: Lane must include either of the following at the site or between the site and nearest intersection (≤ 250 m from the site):    1. Bicycle symbols painted on the road (reserved lane diamond optional).    2. Reserved lane sign (for bicycles) or bicycle symbols on signs (cycling route wayfinding signs).    3. Shoulders lacking any bicycle stencils or signage as outlined above are considered ‘paved shoulders’ and should not be considered cycling infrastructure. 3. Auto parking prohibited: Curbside motor vehicle parking is prohibited with 'no parking' or 'no stopping' signs or equivalent pavement markings.    1. Only applicable to painted bike lanes adjacent to the curb, without a designated parking lane. |
| **Criteria for Buffered Painted Lane:**  A cycling facility can be considered a buffered bike lane if the design is consistent with the following features of a painted lane, in addition to:   1. Lane Demarcation: Solid lines    1. Lane must be buffered on the travel lane side and may be unbuffered or buffered on parking lane side (if parking is available).    2. The buffered delineation measures a minimum width of 1 foot (> 30 centimeters) and exhibits diagonal striping or chevron markings. |
| **Criteria for Cycle Track, Selected from Can-BICS** (8)**:**  A cycling facility can be considered a cycle track if the design is consistent with the following features:   1. Physical Separation: The cycle track is physically separated from the roadway (the portion of the road that vehicles can travel) and this ***separation has a vertical component.***    1. Where automobile parking is the physical separation, permanent vertical elements such as bollards, a curb, raised median, planter boxes, or street furniture (e.g., bike share station) must also be present along the street segment (the area between intersections).    2. Where bollards provide the physical separation, bollard spacing must be ≤ 6 m (about the length of a passenger car/truck), otherwise, consider the facility a ‘painted bike lane’ (roadway lane designated for cyclists without physical separation).    3. The facility may bend-in toward the roadway upstream of the intersection, an unprotected distance not exceeding 10 m (about two car lengths), otherwise, consider the facility a ‘painted bike lane’.    4. If the facility is located between automobile parking and a travel lane, regardless of the physical separation used, consider the facility a ‘painted bike lane’. 2. Right-of-Way: Part of the road and located ≤10 m from the roadway (i.e., street buffer width cannot exceed ten metres). |

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| ***Criteria for New Installations, Upgrades, and Installation Periods*** |
| **Definition of a New Installation**   * A new installation refers to the introduction of dedicated on-street cycling infrastructure on a road where no prior dedicated on-street cycling infrastructure existed within the period of interest (2009-2022). * In cases where dedicated on-street infrastructure is already in place at the beginning of the study period, the installation year will be designated as the first year of the study period (2009).   **Definition of an Upgrade**   * An upgrade refers to the modification of a segment with existing dedicated on-street cycling infrastructure, resulting in a different classification. This study considers potential classifications as either a cycle track, buffered painted lane, or painted lane. While commonly associated with the installation of more protective infrastructure, this definition is not limited to such cases.   **Determining an Installation Period:**   * An installation period refers to a specific year, a time range within a year, or a precise date when a bikeway undergoing modifications that meet the criteria of a new installation or upgrade becomes available for cyclists to use.   + An installation period can be confirmed visually through historical imagery or through written sources such as construction notices, policy documents, news articles, or other forms of grey literature. When utilizing historical imagery to ascertain the installation period, a time range is defined between the most recent image displaying the previous infrastructure and the earliest image featuring the new cycling infrastructure.   + In cases where ambiguity between different sources arises, (1) priority will be given to sources that provide direct confirmation of completion, such as completion notices, news articles announcing cycling route openings, or imagery, over those that suggest intended, planned, or approximate dates, (2) if this criterion is met and there remains ambiguity, the installation period will be defined as the most recent or earliest date or time range when a bikeway was accessible for use by cyclists. All other factors considered, the source with the greatest precision will take precedence. |

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| ***Table 1 Methodology and Classifications*** |
| **Census Populations:**  Data Source: Statistics Canada (2021): https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E |
| **Vancouver Street Centreline Calculation Methods**  ***Data Source(s):*** 2 Source Files  Public Streets (Last Updated July 24, 2023): <https://opendata.vancouver.ca/explore/dataset/public-streets/information/?location=16,49.24772,-123.19169>   * Filter: From public streets (n=17,032), select where streetuse != Closed (n=17,028)   Lanes (Last Updated June 13, 2022): <https://opendata.vancouver.ca/explore/dataset/lanes/information/?location=15,49.24423,-123.1524>   * Include all: (n=7,842)   ***Length Calculations:*** Calculate Geometry Attributes – Geodesic Length (km) in ArcGIS Pro 3.0.1  ***Classifications:***  Arterial Road: [from Public Streets – Filtered] streetuse == "Arterial"  Collector Road: [from Public Streets – Filtered] streetuse == "Collector", “Secondary Arterial”\*  Local Road: [from Public Streets – Filtered] streetuse == "Residential", "Leased", "Recreational", [from Lanes] all-included  (\*) The classification of secondary arterial roads as part of the collector category was determined through a random evaluation of several secondary arterial roads. These roads were frequently situated within residential areas, featured residential driveways, included a median divider with no additional lane markings, and hosted community facilities such as schools, recreational areas, and community centers. This decision helped maintain consistent classification practices across municipalities. |
| **Vancouver Routes Centreline Calculation Methods**  ***Data Source(s):*** 1 Source File  Vancouver Bikeways (Downloaded May 2023): <https://opendata.vancouver.ca/explore/dataset/bikeways/information>   * Include all: (n = 3666)   ***Length Calculations:*** Calculate Geometry Attributes – Geodesic Length (km) in ArcGIS Pro 3.0.1  ***Classifications:***  Cycle Track: Bikeway Type == “Protected Bike Lanes” & Subtype != “OSB”, “OSS”  Painted Lane: Bikeway Type == “Painted Lanes”  Off Street, Path: Bikeway Type == “Protected Bike Lanes” & Subtype == “OSB”, “OSS”  On Street, Shared: Bikeway Type == “Shared Lanes”, “Local Street” |
| **Calgary Street Centreline Calculation Methods**  Street Definitions: <https://www.calgary.ca/planning/transportation/road-classification.html>  ***Data Source(s):*** 1 Source Files  Calgary Centreline: Last Updated July 1, 2023 (from: <https://data.calgary.ca/Transportation-Transit/Street-Centreline/4dx8-rtm5>)   * Filter: From Calgary Centreline (n=115,948), select where ctp\_class != Skeletal Roads & Ownership != Private (n=87, 463)   ***Length Calculations:*** Calculate Geometry Attributes – Geodesic Length (km) in ArcGIS Pro 3.0.1  ***Classifications:***  [From Calgary Centreline – Filtered]  Arterial Road: ctp\_class == "Arterial Street", "Industrial Arterial", "Local Arterial", "Parkway", "Urban Boulevard"  Collector Road: ctp\_class == "Neighbourhood Boulevard", "Collector", "Primary Collector"  Local Road: ctp\_class == "Access Route", "Residential Street", "Activity Center Street", "Historic Road Allowance", "Lanes (Alleys)", "Industrial Street" |
| **Calgary Routes Centreline Calculation Methods**  ***Data Source(s):*** 2 Source Files  Calgary Bikeways (Downloaded January 2023): <https://data.calgary.ca/Transportation-Transit/Calgary-Bikeways/jjqk-9b73>   * Filter: From Calgary Bikeways (n = 4170), select where bicycle\_cl != “DECOMISSIONED”, “TEMPORARY” (n = 4161)   Calgary Parks Pathways (Last Updated August 2023): <https://data.calgary.ca/Recreation-and-Culture/Parks-Pathways/qndb-27qm>   * Filter: From Calgary Parks Pathways (n=15, 828) select where life\_cycle != PLANNED, maintained begins with “CALGARY”, material != TO BE IDENTIFIED (n = 15, 828)   ***Length Calculations:*** Calculate Geometry Attributes – Geodesic Length (km) in ArcGIS Pro 3.0.1  ***Classifications:***  Cycle Track: [from Calgary Bikeways – Filtered] bike\_cl == "Cycle Track"  Painted Lane: [from Calgary Bikeways – Filtered] bike\_cl == "Bicycle Lane"  On street Bikeway: [from Calgary Bikeways – Filtered] bike\_cl == "Neighbourhood Greenway", "On-Street Bikeway", "On-Street BIkeway", "Shared Lane"  Off-street paths: [from Calgary Parks Pathways – Filtered] include all |
| **Toronto Street Centreline Calculation Methods**  Definitions: https://www.toronto.ca/services-payments/streets-parking-transportation/traffic-management/road-classification-system/about-the-road-classification-system/  ***Data Source(s):*** 1 File  Toronto Centreline: Last Updated May 3, 2023 (from: <https://open.toronto.ca/dataset/toronto-centreline-tcl/>)   * Filter: From Toronto Centreline (n = 70,974), select where Jurisdi37 == “CITY OF TORONTO”, Feature36 != “Collector Ramp”, “Busway”, “Creek/Tributary”, “Expressway”, “Expressway Ramp”, “Ferry Route”, “Geostatistical Line”, “Hydro Line”, “Major Railway”, “Major Shoreline”, “Minor Railway”, “Minor Shoreline (Landlocked)”, “Pending”, “River”, “Trail”, “Walkway” (n – 45, 639)   ***Length Calculations:*** Calculate Geometry Attributes – Geodesic Length (km) in ArcGIS Pro 3.0.1  ***Classifications:***  [From Toronto Centreline – Filtered]  Arterial Road: FEATURE36 == "Major Arterial", "Major Arterial Ramp", "Minor Arterial", "Minor Arterial Ramp"  Collector Road: FEATURE36 == "Collector"  Local Road: FEATURE36 == "Access Road", "Other", "Laneway", "Local" |
| **Toronto Routes Centreline Calculation Methods**  ***Data Source(s):*** 1 Source Files  Toronto Bikeways (Downloaded January 2023): <https://open.toronto.ca/dataset/cycling-network/>   * Include all (n = 1323)   ***Length Calculations:*** Calculate Geometry Attributes – Geodesic Length (km) in ArcGIS Pro 3.0.1  ***Classifications:***  [From Toronto Bikeways]  Cycle Track: INFRA\_H20 == "Bi-Directional Cycle Track", "Cycle Track", "Cycle Track - Contraflow"  Painted Lane: INFRA\_H20 == "Bike Lane", "Bike Lane - Buffered", "Bike Lane - Contraflow"  On street Bikeway: INFRA\_H20 == "Sharrows - Arterial - Connector", "Sharrows - Wayfinding", "Signed Route (No Pavement Markings)", "Park Road", "Sharrows"  Off-street paths: INFRA\_H20 == "Multi-Use Trail", "Multi-Use Trail - Boulevard", "Multi-Use Trail - Connector", "Multi-Use Trail - Entrance", "Multi-Use Trail - Existing Connector" |

**SUPPLEMENTARY FILES**

Supplementary File: R Functions for Calculating Infrastructure Changes (https://osf.io/x9bv3/?view\_only=7a9291b77b914f8aa2eaedd9ac0722f7)