Classification of bicycle traffic patterns in five North American Cities

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ABSTRACT

This paper analyses bicycle ridership patterns using a unique database of automated bicycle counts from approximately 40 locations in five North American cities and along the *Route Verte* in Quebec. The cities involved in this study are Montreal, Ottawa, Portland, San Francisco, and Vancouver. Count data show that the bicycle volume patterns at each location can be classified as utilitarian, mixed utilitarian, recreational and mixed recreational. Study locations classified into each of these categories are found to have consistent hourly and weekly traffic patterns, despite important differences between these cities in terms of factors such as weather, size, and urban form. Expansion factors for each location type are presented by hour and day of the week. There were differences in seasonal patterns of bicycle activity between the study locations, so different monthly expansion factors are presented for each city. Finally, some traffic volume characteristics are presented for comparison purposes.

1. INTRODUCTION

As bicycle usage and networks grow in size and complexity, there is a need to monitor and evaluate the characteristics of bicycle ridership at different locations over time. A full understanding of temporal cyclist ridership patterns can help municipalities:

(i) Monitor the evolution of bicycle ridership on specific facilities (e.g., bicycle lanes or cycle tracks) or along corridors. Municipalities are often interested in quantifying the attractiveness of the bicycle infrastructure and how ridership is evolving over time.

(ii) Evaluate the impact of new bicycle infrastructure, programs or policies to encourage cycling.

(iii) Collect data for traffic safety studies to identify design characteristics that can pose safety issues.

(iv) Identify current ridership patterns and predict future demand. This can help with operating and maintaining bicycle facilities. Knowing the distribution of hourly traffic can be useful for timing traffic signals, assigning traffic patrols to certain times of day, and scheduling maintenance work.

(v) Generate expansion factors to extrapolate manual short-term counts into average annual daily traffic as is typically done for motor vehicle traffic. This is useful for a broad range of studies that require estimate of cyclist exposure in locations that lack permanent data collection.

(vi) Prioritize funding for new facilities based on predicted demand.

In response to these and other bicycle data needs, several North American cities and bicycle organizations have installed automated data collection technologies to collect continuous counts in specific locations. Despite the increase in data collection efforts in the last years, there is still little published work on the analysis of bicycle ridership patterns in North America. Practical experience and very few studies suggest that bicycle ridership patterns might vary across cities and location types. For example, urban areas may have typical commuting patterns with distinct morning and afternoon peaks or cold-climate cities may have lower ridership during winter months. However, previous research on these patterns has been limited (1, 2).

According to their use and ridership characteristics, bicycle facilities are often classified as either *utilitarian* (which includes any cycling not done mainly for fitness and/or recreation but as a means of transport) or *recreational* (leisure, social and/or fitness activities). This classification may be overly simplistic, given that in most cases ridership is composed of a mix of users with utilitarian and recreational purposes, independent of facility design. For instance, cycle tracks can be mainly utilitarian during the week but also be heavily used on the weekend for recreational purposes, as has been documented in previous works (1,2). Multiuse paths serve recreational bicyclists but are also used for trips to work, school, and many other utilitarian purposes (3). Bicycle volumes may also exhibit different types of patterns based on the characteristics of a location rather than the specific facility type.

Classification is necessary for the generation of expansion factors for different types of facilities, as has been done for many years in freeways and rural roads (4 - 7). Expansion factors are critical for extrapolating short-term counts into average annual daily traffic which are useful in different applications in transportation such as bicycle safety, demand analysis and pollution exposure (8 - 10). Classification will also help for carrying on comparative analysis across facilities as well as monitoring and detecting bicycle demand changes over time (11, 12). The justification of bicycle infrastructure is always easier when performance towards goals is demonstrated, in particular when funding is questioned (13, 14). Being able to have a point of references (e.g., average annual daily traffic) from similar facilities in other cities can help municipalities to fix their goals and evaluate their performance.

In this regard, the objectives of this paper are three-fold:

- Analyze bicycle traffic patterns using a unique database containing automatic hourly counts from locations in five North American cities (San Francisco, Portland, Montreal, Vancouver and Ottawa) and along the *Route Verte*, a bicycle facility network spanning the Canadian province of Quebec.
- Present a general classification scheme for bicycle traffic patterns according to automated count data.
- Calculate expansion factors based on location type and region, and a set of simple performance measures for comparative analysis. Permanent locations with similar traffic patterns are grouped together and expansion factors are generated for expanding short-duration counts.

By including different cities with a variety of bicycle facilities and location characteristics (such as weather, urban environment, and size), this paper is expected to reach more generalized conclusions for the cycling conditions in North America. This paper shows that bicycle traffic patterns can be classified into four groups: primarily utilitarian, mixed-utilitarian, mixed-recreational, and primarily recreational.

2. STUDY LOCATIONS AND DATA

This section introduces the urban areas (cities) where locations are located. This is followed by a description of the data.

2.1 Description of Study Areas

This study utilizes a unique cyclist-count database from a large set of automatic counting stations in five North American cities, as well as along the *Route Verte* in Quebec, operated by Velo Quebec (VQ). There are four locations in Montreal (refereed as Mon1-Mon4), two in Ottawa (denoted as Ott1-Ott2), one in Portland (refereed as Port), eight in San Francisco(denoted as SF1-SF8), six in Vancouver (Van1-Van6), and sixteen along the *Route Verte*, in cities and towns from Montreal to Quebec City (refereed as VQ1-VQ16). The locations chosen for this study have some of the most extensive sets of automated bicycle count data in North America General characteristics of the cities and the *Route Verte* are described below, and **Table 1** presents a brief description of each specific counter location involved in the analysis.

Montreal: Montreal experiences warm, often humid, summers, as well as cold, snowy winters. Average daily high temperatures range from 27°C in July to -9°C in January. Montreal receives roughly 980mm of precipitation per year, 220 mm of which is snow. Several of its bicycle facilities have been in use since the 1970's, and Montreal has recently constructed several new bicycle lanes and physically separated cycle-tracks. For these, as well as many km of multiuse paths in and around the city, Montreal has received accolades as a cycling city. (15)

Ottawa: Like Montreal, Ottawa experiences hot, humid summers and cold, snowy winters. Ottawa experiences similar temperatures to Montreal, and Ottawa receives 944 mm of precipitation per year, 212 mm of which is snow. (15) Although Ottawa has only recently begun to construct bicycle facilities, it now boasts an expanding network of cycle tracks and bicycle lanes.

Portland: Portland is characterized by a temperate climate, with mild, wet winters and dry summers. Average high temperatures range from 8°C in January to 26°C in July. Rainfall averages 950 mm per year in downtown Portland (17). Portland's bridges act as feeders to carry commuters and students from neighborhoods east of the Willamette River into the downtown area and beyond, with the Hawthorne bridge carrying more bicycle traffic than any other bridge in the city. Portland was described by one researcher (16) to be “the American city that comes closest to implementing a truly comprehensive, well-integrated, long-term package of infrastructure, programs, and policies to promote cycling.”

San Francisco: San Francisco is known for mild temperatures year-round, hilly topography, and frequent fog. Average high temperatures range from 14°C in December to 22°C in September in downtown, with average annual precipitation of 600 mm (17). San Francisco has the lowest rate of precipitation and the highest winter temperatures of the locations under study. Bicycle infrastructure in San Francisco currently includes roughly 37 km of separated bicycle paths and 72 km of on-street bicycle lanes (18). These facilities, as well as designated bicycle routes without any dedicated bicycle lanes, serve most of the spatially constrained city.

Vancouver: Vancouver has a temperate climate that is similar to Portland’s. Located in the region with the warmest winters in Canada, Vancouver has high temperatures ranging from 6°C in January to 22°C in July. Also like Portland, Vancouver experiences rainy winters and relatively dry summers, averaging 1155 total mm of precipitation per year. (15) Vancouver has a network of bicycle facilities that serve downtown, residential neighborhoods and recreational destinations in and out of the city. In recent years, Vancouver has implemented bicycle-oriented traffic calming measures and constructed new bicycle facilities.

Route Verte (“Green Route”): The *Route Verte* is an extensive bicycle network spanning Quebec, made up of over 4, 900 km of bikeways. This vast bicycle route, considered the most extensive in North America, includes a variety of facilities, such as multiuse paths, designated shared roadways, and paved shoulders. All *Route Verte* counting stations analyzed in this study are located on pathways in suburban or rural areas. (19) The climate in each location is much like that of Montreal and Ottawa (15).

Table 1. Bicycle Counter Locations

Region	Facility	Location	Facility Type	Average Daily Volume[1]	# Observations (Days)[2]
Montreal	**Mon1**	Maisonneuve at Peel	Cycle Track	2200	183
	Mon2	Maisonneuve at Berri	Cycle Track	4324	191
	Mon3	Brebeuf at Rachel	Cycle Track	3736	228
	Mon4	Berri at Maisonneuve	Cycle Track	3735	197
Ottawa	**Ott1**	Ottawa River Path	Multiuse Path	1637	240
	Ott2	Colonel By Pathway	Multiuse Path	832	240
Portland	**Port**	Hawthorne Bridge	Separated Bikeway	4869	244
San Francisco	**SF1**	Northpoint at Polk	Paired Bicycle Lanes	421	322
	SF2	Polk at Grove	Unidirectional Bicycle Lane	404	328
	SF3	Potrero at 23rd St.	Paired Bicycle Lanes	259	147
	SF4	Valencia at 14th St.	Paired Bicycle Lanes	2475	182
	SF5	Seventh Ave. at Kirkham	Paired Bicycle Lanes	156	482
	SF6	Panhandle at Masonic	Multiuse Path in Park	3452	175
	SF7	Lake at Arguello	Paired Bicycle Lanes	188	172
	SF8	Arguello at Lake	Paired Bicycle Lanes	511	172
Vancouver	**Van1**	Cambie St. Bridge	Separated Bikeway	3004	335
	Van2	CV Greenway at Rupert	Bicycle Path	336	383
	Van3	CV Greenway at Victoria	Bicycle Path	990	332
	Van4	Ontario at 11th St.	On-Street Bicycle Boulevard	543	345
	Van5	Burrard St. Bridge	Bicycle Lane Separated Path	805	344
	Van6	Canada Line Bridge	Bike/Ped Bridge	788	332
Velo Quebec ***Route Verte***	**VQ1**	Métabéchouan, QC	Asphalt Bicycle Path	232	492
	VQ2	Duschesnay, QC	Gravel Bicycle Path	154	500
	VQ3	Québec, QC	Asphalt Bicycle Path	1015	457
	VQ4	Lennoxville, QC	Gravel Bicycle Path	207	458
	VQ5	Lévis, QC	Asphalt Bicycle Path	1034	444
	VQ6	Cabano, QC	Gravel Bicycle Path	144	466
	VQ7	St-Jean-sur-Richelieu, QC	Asphalt Bicycle Path	200	518
	VQ8	Longueuil, QC	Asphalt Bicycle Path	413	223
	VQ9	Cushing, QC	Asphalt Bicycle Path	112	361
	VQ10	Laval, QC	Asphalt Bicycle Path	590	492
	VQ11	Granby, QC	Asphalt Bicycle Path	267	492
	VQ12	Mont-Rolland, QC	Gravel Bicycle Path	359	448
	VQ13	Trois Rivières, QC	Asphalt Bicycle Path	542	442
	VQ14	Victoriaville, QC	Asphalt Bicycle Path	62	382
	VQ15	Gatineau, QC	Asphalt Bicycle Path	34	496
	VQ16	Blainville, QC	Asphalt Bicycle Path	135	399

[1] Average daily volume during study months (April to Novmber)
[2] Observation days are only during study months (April to November)

2.2 Cyclist Count Data Collection

The data for the 37 permanent locations consist of disaggregated automatic hourly bicycle counts collected with automatic inductive loop detectors embedded in the pavement of bicycle facilities. Past studies have shown that this equipment achieves high levels of accuracy (96% and more) (20, 21) The data were collected by the municipal planning departments of the cities under study, as well as by Velo Quebec (VQ), a non-profit cycling advocacy and research organization. All data were collected between 2008 and 2011, and each facility had at least one season of data. Some bicycle facilities in Montreal, Ottawa, and along the *Route Verte* are not maintained during winter, so in order to be consistent, this analysis only incorporated data from April through November (inclusive).

Before analysis, each dataset was reviewed thoroughly to identify missing values, which can be caused by routine maintenance, counter malfunction, construction, or other factors. In addition, an effort was made to identify extreme values. For instance, large bicycle races or group rides on the *Route Vert*e result in days with abnormally large total counts. Days with missing data or extreme values were excluded from the analysis of bicycle traffic patterns. Note that despite the high levels of accuracy, in-pavement loops do not count bicyclists with 100% accuracy. While the count data presented here are not adjusted for undercounting, the counter technology used at all locations in this study is similar and comparisons between sites are assumed to be consistent. However, if future validation studies show that accuracy varies by location, time, activity level, or other factors, some of the patterns identified in the analysis should be adjusted slightly.

3. METHOD OF ANALYSIS OF TRAFFIC PATTERNS

3.1 Definition of standardized indices

The bicycle traffic patterns are analyzed using hourly and daily indices, which express the average cyclist count for a given hour, day or month as a percentage of the seasonal daily average (**equations 1-5**). Because they are standardized with respect to the seasonal average, the indices facilitate comparisons of temporal profiles across facilities that exhibit different absolute ridership levels. In the vehicular traffic literature, these indices are typically referred to as expansion factors, and they can also be used to convert brief manual cyclist counts into overall yearly averages, as explained later.

Standardized Hourly, Daily, and Monthly Indices

$$I_h = (\bar{v}_h / \bar{V}_{24}) \quad (1)$$

$$I_d = (\bar{v}_d / \bar{V}_{24}) \quad (2)$$

$$I_m = (\bar{v}_m / \bar{V}_{24}) \quad (3)$$

Where:

I_h, I_d, I_m = standardized hourly, daily and monthly indices, respectfully.

$\bar{v}_h$, $\bar{v}_d$, $\bar{v}_m$ = seasonal (from April to November) averages for a given hour *h*, day of the week *d*, or month *m*, respectively.

$\bar{V}_{24}$ = average daily volume (ADV) over a biking season or year.

Traffic Distribution Indices

Traffic distribution indices are used to quickly summarize the distribution of bicycle traffic throughout the day, week or year, and are defined in equations 4 – 5.

$$I_{we/wd} = (\bar{v}_{we} / \bar{v}_{wd}) \quad (4)$$

Where:

$I_{we/wd}$= relative index of weekend vs. weekday cycling traffic (WWI).

$\bar{v}_{we}$, $\bar{v}_{wd}$= seasonal average daily weekend and weekday traffic, respectively.

$$I_{AM/Mid} = \frac{\delta_i^{AM}}{\delta_i^{Mid}} \quad (5)$$

Where:

$I_{AM/Mid}$= relative index of morning (hours 7:00 to 9:00) to midday (hours 11:00 to 13:00) cycling traffic (AMI).

$\delta_i^{AM} = \sum_{h=7}^{9} \bar{V}_h$

$\delta_i^{Mid} = \sum_{h=11}^{13} \bar{V}_h$

3.2 Classification of Bicycle Traffic Patterns

The bicycle traffic patterns were classified using the following procedure.

1. *Identification of locations with utilitarian and recreational patterns.*
   The hourly, daily and monthly indices were computed for each counter location using equations 1 and 2. The values for each facility were plotted to graphically portray the hourly and daily profiles. Locations with either standard utilitarian or recreational traffic patterns were identified. For instance, typical utilitarian patterns consist of two peak traffic periods on weekdays (during the AM and PM commuting hours) and a higher proportion of traffic during the week than on the weekend. Standard recreational patterns consist of one midday or PM peak traffic period on weekdays, and a higher proportion of traffic on weekends than during the week. This has been documented in recent bicycle studies (1, 2, 22). These patterns again are similar to those in highways (4, 6). The locations without typical utilitarian or recreational patterns were identified as mixed facilities.
2. *Determination of confidence intervals (CI) for utilitarian and recreational groups.*
   Using the data from the locations with standard utilitarian and recreational patterns, 95% confidence intervals were constructed using the mean and standard deviation of each hourly and daily index across all facilities in each group. For instance, the lower (LL) and upper limits (UL) for the hourly profile were estimated as $\bar{v}_h \pm 1.96(\sigma_h/\sqrt{n})$, where *h* ranges from 0 to 23. The CI's were then superimposed on the hourly and daily profiles and used to validate the initial classifications made in step 1. An iterative process was used to refine the CI's and groups; if a location's hourly and daily profiles did not fit within the upper and lower limits of the CI for utilitarian or recreational locations, that location was moved to the mixed category and the CI's were recalculated with the remaining locations. This was repeated until all facilities remaining in the utilitarian or recreational groups fit within the respective CI's.

3. *Classification of mixed facilities*.

   The patterns of the facilities that had been classified to the mixed category as an outcome of the previous step are further analyzed in this step. Many of these locations still exhibit similar patterns to the utilitarian or recreational locations, despite not fitting completely into either. For instance, certain locations did not exhibit higher ridership during the week than on the weekend, but still exhibited AM and PM commuting peaks. Other locations also did not exhibit higher ridership during the week than on the weekend, but exhibited one weekday peak, like recreational facilities. CI's were constructed for these two subgroups and again, the upper and lower CI limits was then used to identify those locations with uncommon patterns. If the patterns of a location fell within the defined CIs, it was classified as either "mixed-utilitarian" or "mixed-recreational". If not, the location was classified as an outlier with an anomalous classification. Locations that do not fall in any of these four categories were excluded from the calculation of the expansion factors.

The procedure outlined above is illustrated in **Figure 1** for the utilitarian and mixed utilitarian classifications. The same procedure was applied to arrive at the recreational and mixed recreational classifications.

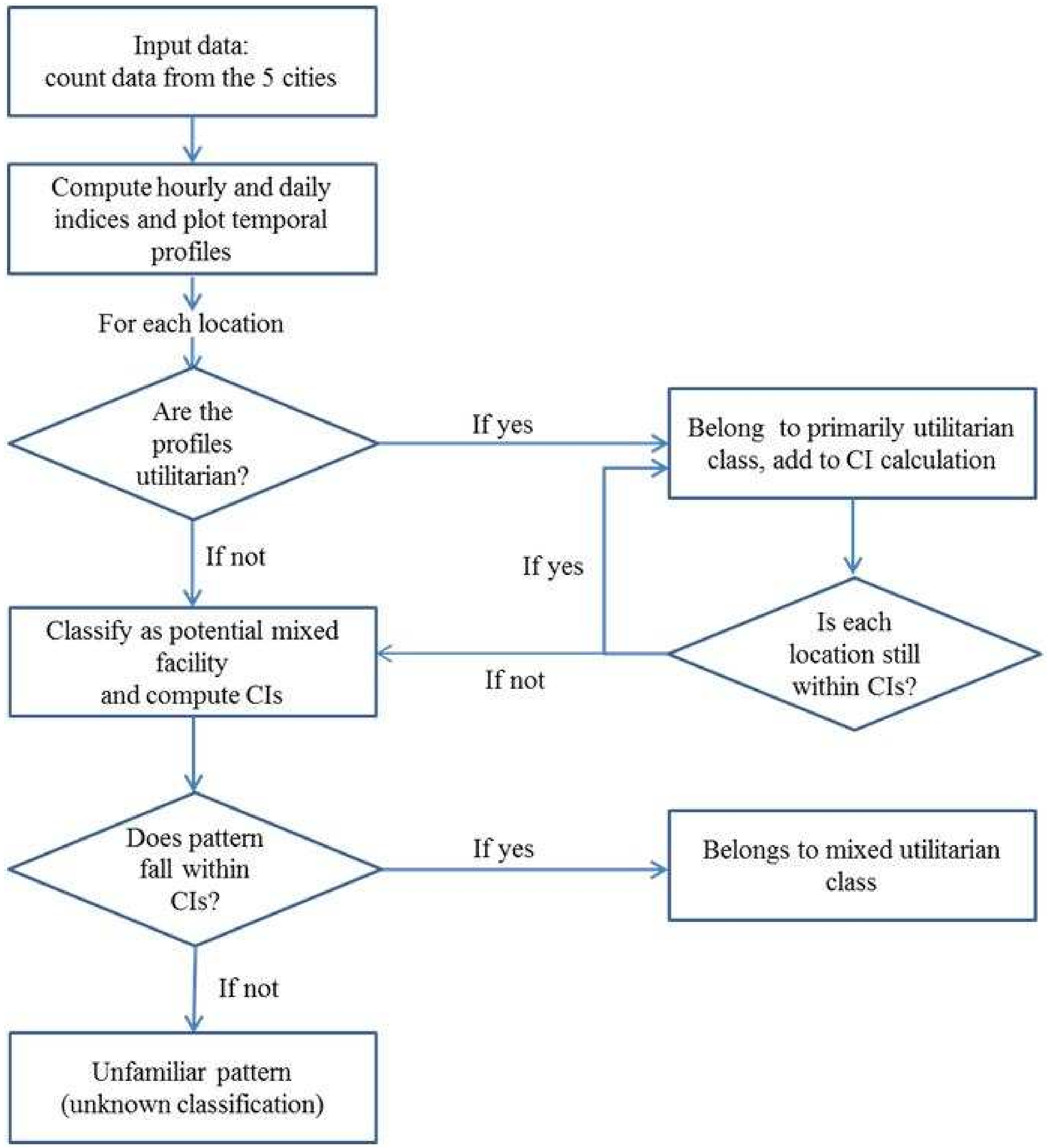


Fig. 1. Classification of the city counting locations

4. RESULTS

This section provides the results of the location classification using the procedure described above. In addition to a discussion of the bicycle traffic classifications in the five study cities and the *Route Verte*, this section presents expansion factors for use in practice.

4.1 Traffic ridership analysis at city locations

Following the procedure defined in Section 3 and illustrated in **Figure 1**, the bicycle traffic patterns were calculated for each count location. **Figures 2** and **3** show the average hourly profiles across 24 hours for the city and *Route Verte* locations during weekdays and weekends, respectively. **Figure 4** shows the daily profiles over the week for both city and *Route Verte* locations.

With few exceptions, most of the locations in the five urban areas exhibit two very pronounced peaks during the AM and PM commute times on workdays (**Figure 2a**). In addition, they have higher ridership during the workweek than on the weekend (**Figure 4a**). Locations with such patterns are classified as "primarily utilitarian". To validate the correct classification of each of these facilities, hourly and daily CIs were also estimated as illustrated in **Figure 2** - **4**.

As explained in the previous section, facilities that do not fall within CIs were grouped as locations with mixed patterns. The temporal profiles of these locations are reproduced separately in **Figure 5,** along with the mean profiles of the primarily utilitarian facilities, for clarity. With the exception of SF8, these locations maintain relatively consistent ridership throughout the week. However, all of the hourly profiles of these locations still exhibit two distinct peaks during the workweek. This suggests that although the bicycle traffic on the weekend is as high as on the weekdays, these locations are still used heavily during the commuting hours, with two rush-peak periods. These facilities are labeled "mixed-utilitarian"**.**

The anomalous counter is SF8, which is located on the border of Presidio National Park, en route to the Golden Gate Bridge. Due to high tourist traffic to the bridge and park, SF8's daily profile is very similar to that of a recreational location. However, due to commuting traffic during the week, it still exhibits two distinct peaks during the workweek, with slightly higher noontime traffic. SF8 also exhibits a very recreational weekend hourly profile, with greater use occurring in the morning than the utilitarian average. Although this location is clearly mixed-use, it is not included in the mixed-utilitarian category for the sake of preserving consistency.

4.2 Traffic ridership analysis at *Route Verte* locations

With some exceptions, most of the suburban and rural count locations along the *Route Verte* exhibit only one midday or PM peak on both workdays and weekends (**Figures 2b** and **3b**), as well as lower ridership during the workweek than on the weekend (**Figure 4b**). Locations exhibiting these patterns were classified as "primarily recreational", as discussed in the methodology section. Again, following the procedure defined in 3.2, locations that deviated from typical recreational patterns were singled out. For clarity their traffic patterns are presented in **Figure 6.** Like the mixed-utilitarian locations, these also maintain relatively consistent ridership throughout the seven days of the week. However, although some may have a small AM peak, the hourly profiles do not exhibit two distinct peaks commuting peaks. This suggests that although they may be relatively mixed-use, they are still used more heavily for recreational purposes. These facilities are labeled "mixed-recreational"**.**

It should be noted that the mixed recreational locations have greater variability than the mixed-utilitarian category. **Figures 6a and 6b** present the profiles of MR locations that exhibit higher WWI values (ranging from 1.34 to 1.51), while **Figures 6c and 6d** display the profiles of the MR locations that exhibit lower WWI values (0.96 to 1.20). The MR locations with higher WWI values more closely resemble primarily recreational facilities. However, those with lower WWI values appear more irregular. Although they do not exhibit two distinct peaks like the PU or MU facilities, they tend to exhibit an AM peak, suggesting more mixed use. It is possible that the variations in temporal profiles across mixed-recreational locations can be explained by the locations characteristics, such as the surrounding land use, density, its proximity to attractions, town centers, and so on. For instance, two locations may be experiencing roughly the same proportion of recreational and utilitarian use, but because one is closer to a town, it may get used more during the week, whereas the more remote locations are visited only for longer rids on the weekend. More specific categories that include such characteristics might be necessary. Until this can be investigated with GIS based land-use characteristics, the recreational category was made to contain only those facilities with very high WMI values.

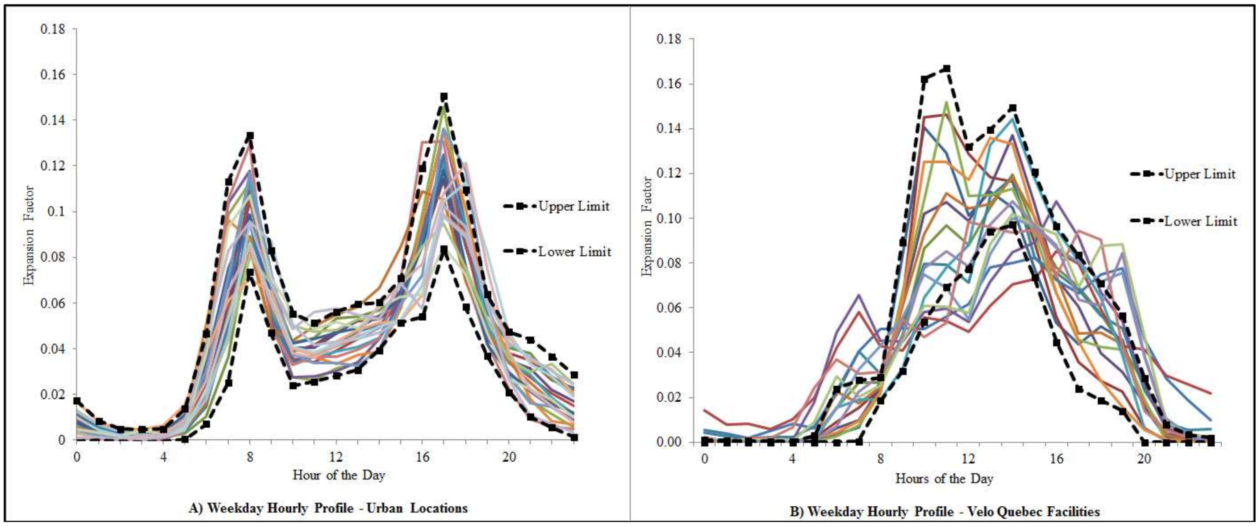


Figure 2. Weekday Profiles for Urban and *Route Verte* (Velo Quebec) locations

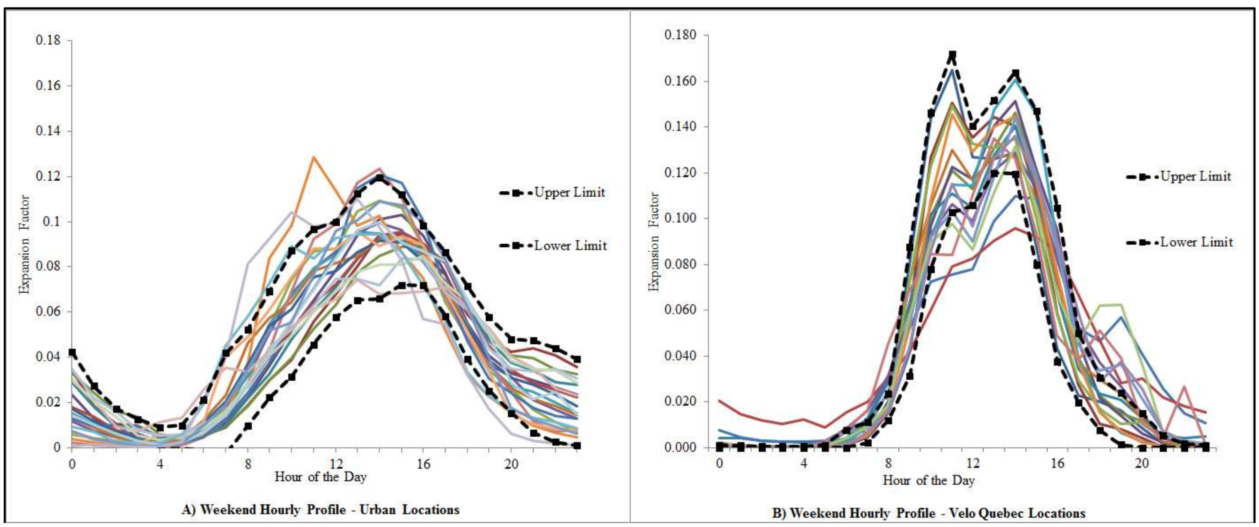


Figure 3. Weekend Hourly Profiles for Urban and *Route Verte* (Velo Quebec) locations

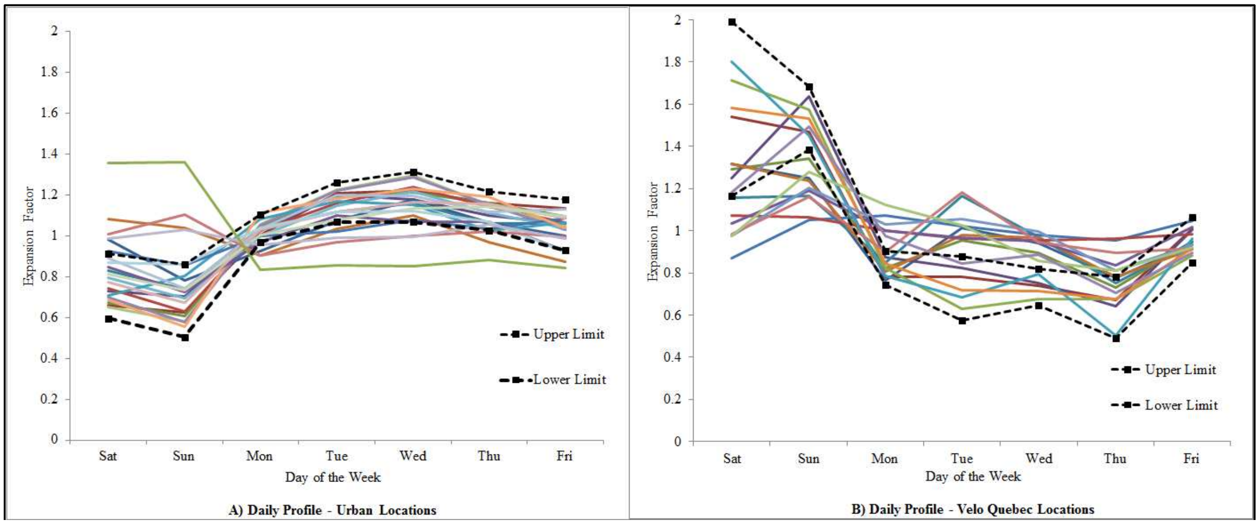


Figure 4. Daily Profiles for Urban and *Route Verte* (Velo Quebec) locations

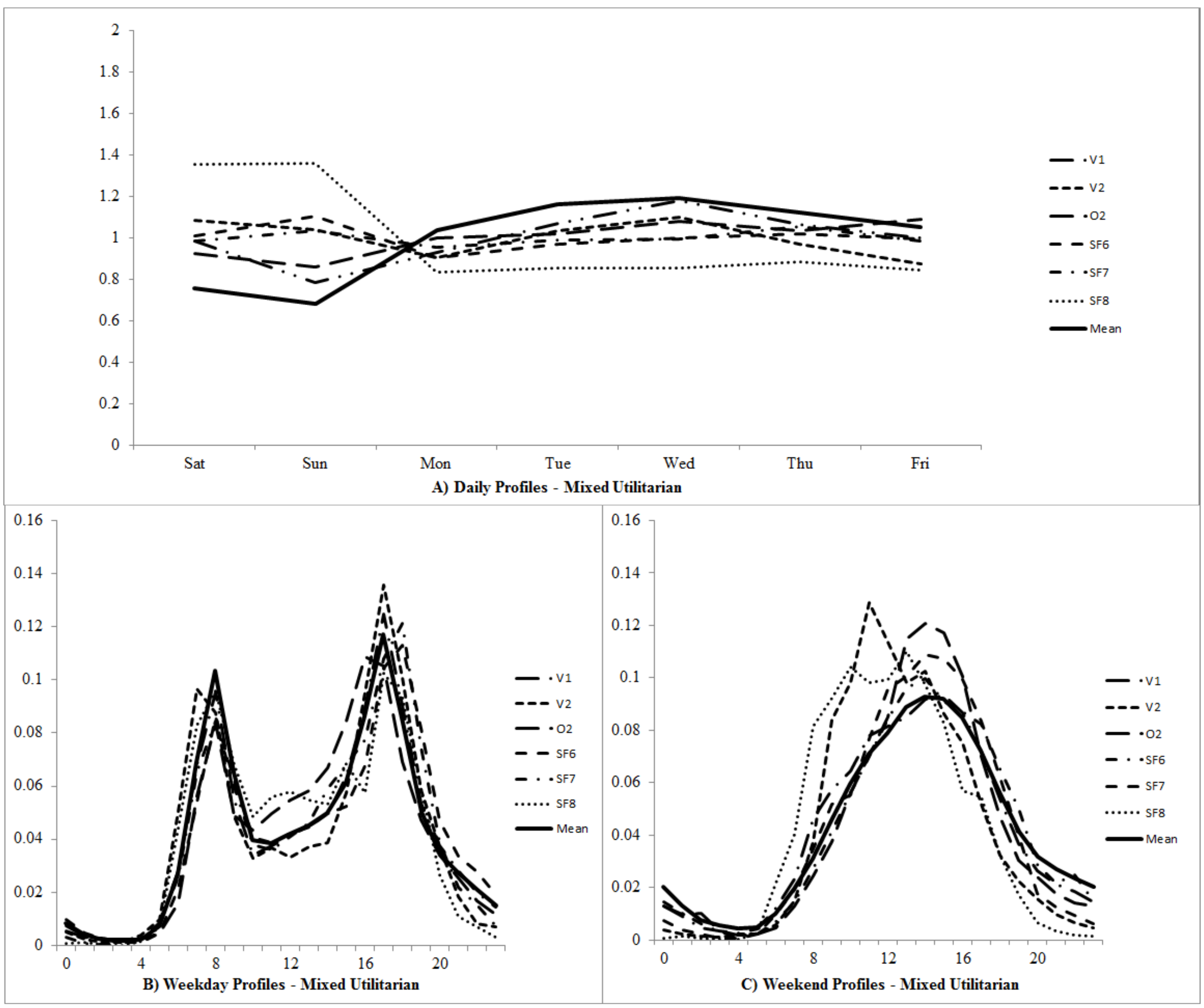


Figure 5. Mixed Utilitarian Daily and Hourly Profiles

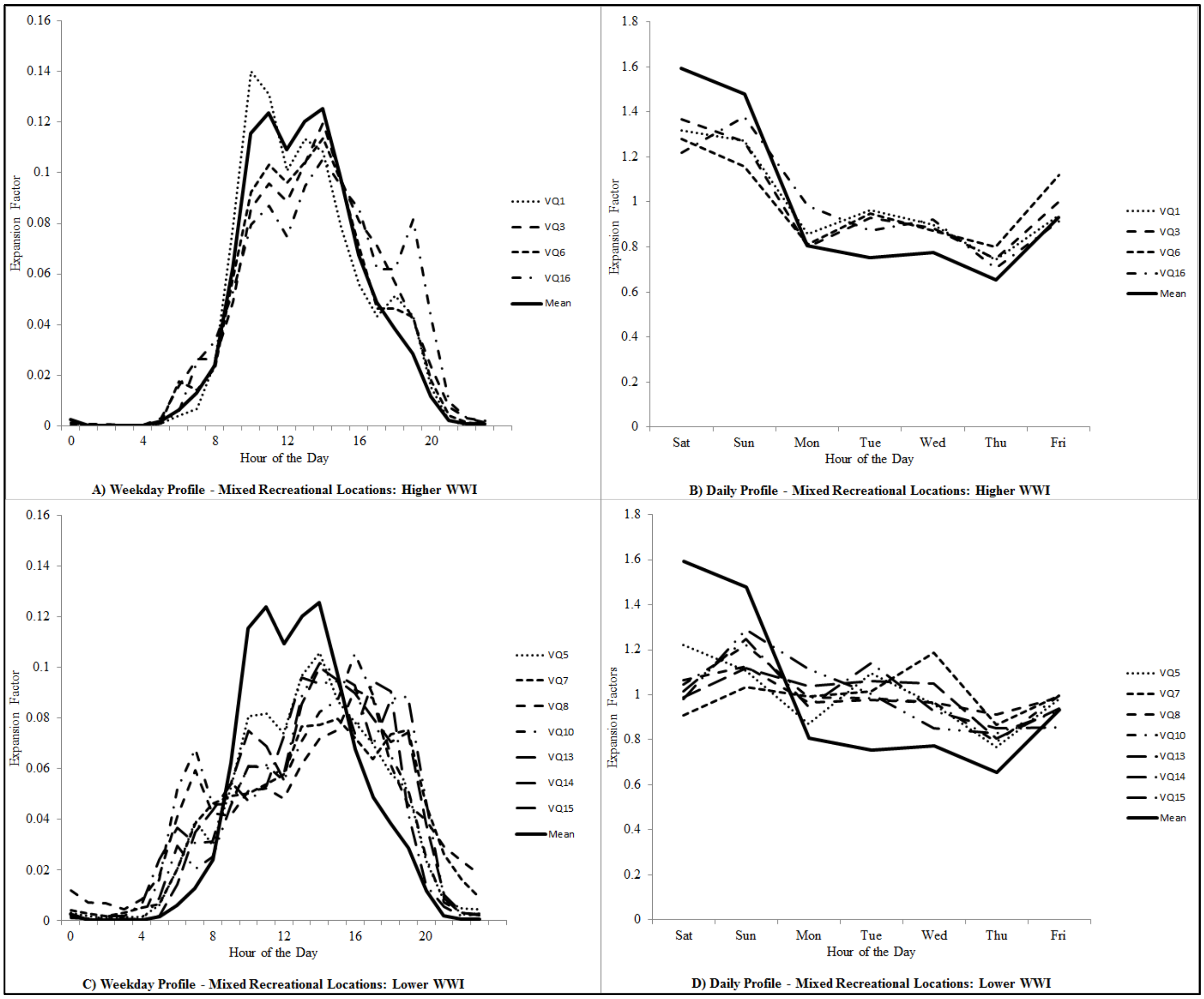


Figure 6. Traffic Profiles for Mixed Recreational Facilities

4.3 Seasonal (monthly) Patterns across Regions and Classifications

As seen before, hourly and daily patterns presented in **Figures 2 – 4** appear relatively consistent across regions; i.e. primarily utilitarian locations in Vancouver exhibit very similar hourly profiles to those of primarily utilitarian facilities in Montreal. However, monthly patterns vary considerably across both classifications and regions (**Figure 7**). For example, when examining seasonal data from April through November, Vancouver's utilitarian facilities retain higher ridership in November than both Montreal and Ottawa, suggesting that because Vancouver has warmer winters, more of its utilitarian cyclists ride year-round. However, the Velo Quebec facilities, which share a climate similar to that of Montreal and Ottawa, retain far less ridership in the winter than both cities, presumably because recreational trips are more sensitive to cold weather.

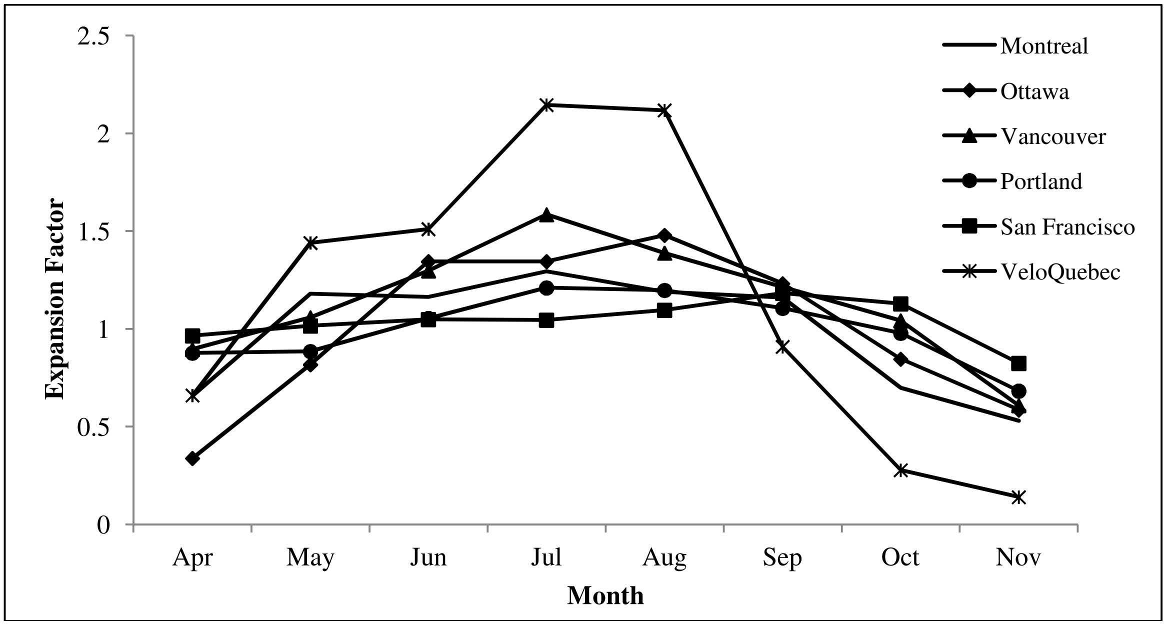
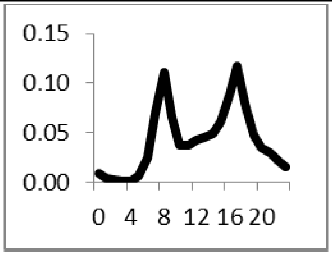
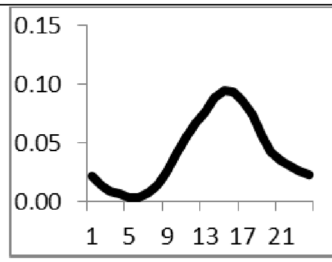
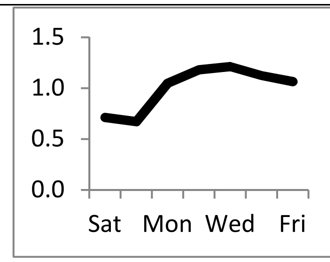
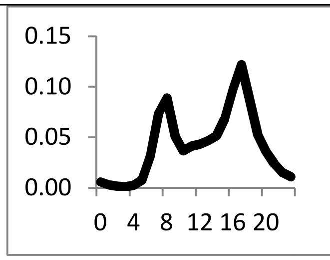
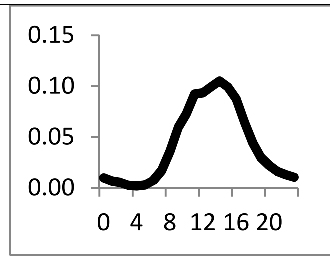
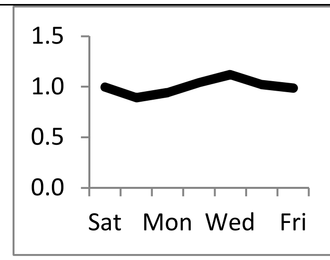
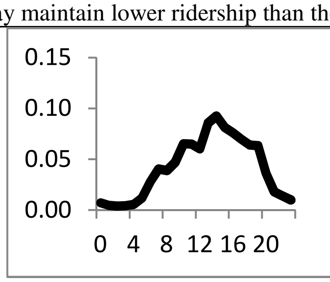
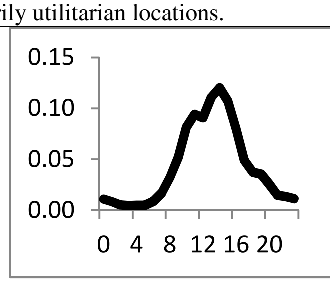
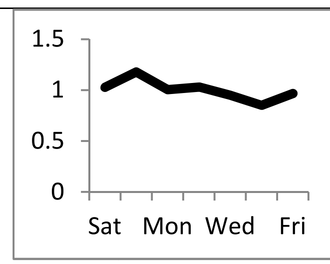
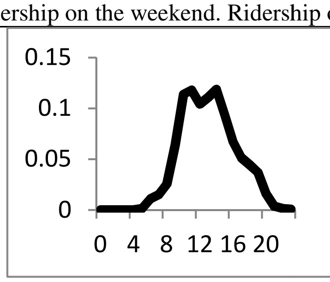
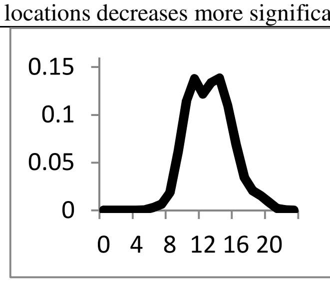
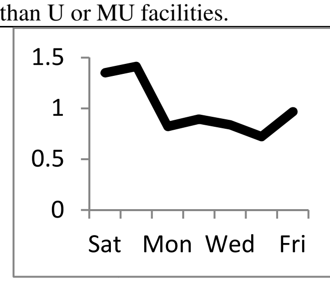


Figure 7. Daily Profiles for Urban and *Route Verte* (Velo Quebec) locations

4.4 Summary of Classification Groups

A summary of the classifications and their characteristics is provided in **Table 2**. The profiles presented in this figure are based off a subset of the data that is representative of each category. It is important to note that while many bicycle counter locations can be classified into one of these four categories, differences can still exist across locations in the same category (particularly within the mixed groups), and some may not fit well into any category.

Table 2. Summary of Bicycle Classifications

	Hourly Profiles[1]		Daily Profile[1]
Type	**Weekday**	**Weekend**	
Primarily Utilitarian			
	At the hourly level, these exhibit two distinct weekday peaks, much like automobile commuter patterns. Utilitarian facilities have their highest ridership during the workweek and drop off considerably on the weekend. The weekend profile builds smoothly to a single PM peak. Seasonally, they maintain higher ridership in the winter than rec. facilities.		
Mixed – Utilitarian			
	Mixed-utilitarian locations are often in urban areas but they may pass or connect to park/recreational areas. At the hourly level, they still exhibit two distinct peaks, but the ridership between the peaks may be slightly higher than on primarily utilitarian locations. They maintain a consistent level of ridership throughout the week, due to their dual commuter and recreational use. The weekly profile may still exhibit slightly higher ridership during the week.They may maintain lower ridership than the primarily utilitarian locations.		
Mixed-Recreational			
	Mixed-recreational locations are typically in parks or serve recreational areas while also connecting residential areas to commercial areas. They tend to maintain a consistent level of daily ridership throughout the week. However, unlike mixed-utilitarian, their hourly profiles do not exhibit two distinct commuting peaks. Still, their AM ridership during the workweek may be slightly higher than primarily recreational locations. The daily profile may exhibit slightly higher ridership on the weekend. Ridership on these locations decreases more significanlty than U or MU facilities.		
Primarily Recreational			
	Primarily recreational locations are typically in parks or serve recreational areas. They exhibit considerably higher ridership on the weekend than during the week. The workweek hourly profile closely resembles the weekend profile, which increases steeply to and decreases steeply from a mid-day plateau. A slight dip around noon may be present as well. The decrease in ridership due to winter is most significant at recreational locations.		

1. The pictured profiles are the mean values of the facilities belonging to each classification

4.5 Expansion factors for extrapolating manual counts

For their use in practice, hourly and daily level expansion factors for the four classifications are computed for the four types of facility locations. Expansion factors were calculated using the traditional approach, as done for highways (7):

1) Aggregate hourly volumes into daily totals and calculate the overall average daily volume.
2) Calculate average daily total for each day of the week and for each month of the year. Then divide each daily average by the overall average to obtain the daily expansion factors. Similarly, divide the monthly average by the overall average to obtain monthly expansion factors.
3) Calculate average hourly totals for each hour of the day. Compute hourly expansion factors by dividing each hourly average by the overall average.

The estimated hourly and daily expansion factors for each facility type are presented in **Table 3**. These values correspond to the graphical profiles presented in **Table 2**. While these values are representative of each category, individual facility locations may exhibit slightly different behavior, while still conforming to the overall patterns of a given classification. Because monthly expansion factors vary so heavily across regions, in addition to across classifications, general monthly expansion factors for the four classifications are not feasible. Monthly expansion factors must be specific to a given climate *and* classification. Therefore, monthly expansion factors for the utilitarian facilities in each city, as well for the recreational Velo Quebec facilities, are presented in **Table 4**.

Note that the expansion factors are most applicable to primarily utilitarian and primarily recreational locations, as these exhibit the greatest consistency. Great care must be taken to ensure that the factors are applied only to locations that exhibit the same patterns as the classification group being utilized. Mixed locations will require the greatest care, in particular mixed recreational.

Table 3. Hourly and Daily Expansion Factors by Classification

Hourly and daily factors	Hour	Utilitarian	Mixed Utilitarian	Mixed Recreational	Recreational
Hourly Expansion Factors by Classification	*0*	0.023	0.006	0.007	0.000
	1	0.015	0.003	0.005	0.000
	2	0.009	0.002	0.004	0.000
	3	0.007	0.001	0.004	0.000
	4	0.004	0.003	0.006	0.000
	5	0.004	0.008	0.012	0.002
	6	0.008	0.032	0.028	0.011
	7	0.014	0.074	0.040	0.015
	8	0.026	0.089	0.039	0.026
	9	0.042	0.051	0.047	0.064
	10	0.055	0.037	0.065	0.114
	11	0.067	0.041	0.065	0.118
	12	0.076	0.043	0.060	0.104
	13	0.088	0.047	0.086	0.111
	14	0.095	0.052	0.093	0.119
	15	0.094	0.069	0.081	0.093
	16	0.086	0.098	0.076	0.067
	17	0.075	0.122	0.070	0.051
	18	0.057	0.087	0.064	0.045
	19	0.043	0.053	0.063	0.037
	20	0.035	0.036	0.036	0.016
	21	0.031	0.024	0.018	0.004
	22	0.026	0.015	0.014	0.001
	23	0.023	0.011	0.010	0.001
Daily Expansion Factors by Classification	**Day**	**Utilitarian**	**Mixed Utilitarian**	**Mixed Recreational**	**Recreational**
	Sat	0.71	1.00	1.02	1.35
	Sun	0.66	0.89	1.18	1.41
	Mon	1.05	0.94	1.00	0.82
	Tue	1.18	1.04	1.03	0.89
	Wed	1.21	1.12	0.95	0.84
	Thu	1.13	1.02	0.85	0.72
	Fri	1.06	0.99	0.97	0.97

Table 4. Monthly Expansion Factors by Region and Classification

Month	Utilitarian					
	Ottawa	**Montreal**	**Vancouver**	**San Francisco**	**Portland**	**Vélo Québec**
Apr	0.34	0.66	0.71	0.96	0.88	0.66
May	0.82	1.18	0.90	1.02	0.88	1.44
Jun	1.34	1.16	1.06	1.05	1.05	1.51
Jul	1.34	1.29	1.30	1.05	1.21	2.15
Aug	1.48	1.19	1.58	1.10	1.20	2.12
Sep	1.23	1.16	1.39	1.18	1.11	0.91
Oct	0.85	0.70	1.21	1.13	0.98	0.28
Nov	0.59	0.53	1.04	0.82	0.68	0.14

4.6 Comparison of Bicycle Volume Patterns

In addition to the indices that were calculated for the classification, the average daily volume (ADV) was also computed for each facilities. These values are reported in **Table 5**, along with the relative indices of weekend vs. weekday (WWI), and the relative indices of AM to midday cycling (AMI).

From these comparisons, we can see that the traffic intensity can vary considerably between counting locations of the same type. For instance, the 2 top locations (Mont2 in Montreal and Port) present daily volumes that are 10 times higher than counting locations in San Francisco. Much less variability is observed in the recreational group, which present overall very low traffic intensity. Despite the large differences in volumes, there are consistent temporal patterns across these facilities and cities. The results of our classification can be evaluated based also the WWI and AMI indexes. Note that among facility groups, these indexes are very similar across facilities of the same group – this shows the heterogeneity of traffic patterns within locations of the same group.

Note that these simple indices can be also generated to monitor the evolution and performance of facility facilities and bicycle usage in general.

Table 5. Comparison of Bicycle Volume Patterns at Study Locations

Type	Study Location	AADT	WWI	AMI
The Utilitarian	**Port**	4869	0.54	1.68
	Mon2	4021	0.56	1.26
	Mon3	3553	0.65	1.66
	Mon4	3267	0.72	1.63
	SF4	2475	0.71	1.77
	Mon1	2200	0.56	1.62
	Ott1	1637	0.67	2.52
	Van3	990	0.61	2.05
	Van5	805	0.56	2.97
	Van6	788	0.72	2.17
	Van4	543	0.53	2.93
	SF1	421	0.77	2.62
	SF2	404	0.72	1.30
	SF3	259	0.65	1.53
	SF5	156	0.82	1.82
	Mean		0.65	1.97
Mixed Utilitarian	**SF6**	3452	1.08	1.62
	Van1	3004	0.84	1.76
	Ott2	832	0.85	1.16
	SF8	511	1.59	1.47
	Van2	336	1.1	2.17
	SF7	188	1.01	1.70
	Mean		1.08	1.64
Mixed recreational	**VQ5**	1034	1.25	0.48
	VQ3	1015	1.51	0.35
	VQ10	590	1.20	0.85
	VQ13	542	1.08	0.63
	VQ8	413	1.14	0.88
	VQ1	232	1.47	0.32
	VQ7	200	0.96	0.71
	VQ6	144	1.34	0.32
	VQ16	135	1.47	0.44
	VQ14	62	1.20	0.53
	VQ15	34	1.20	0.44
	Mean		1.26	0.54
Recreational	**VQ12**	359	2.13	0.24
	VQ11	267	1.81	0.33
	VQ4	207	1.77	0.32
	VQ2	154	1.88	0.27
	VQ9	112	2.26	0.26
	Mean		1.97	0.28

5. CONCLUSIONS AND FUTURE WORK

This paper studies the temporal bicycle traffic patterns at 37 automatic counting locations along bicycle facilities in Montreal, Ottawa, Portland, San Francisco, and Vancouver, as well as suburban/rural facilities along the *Route Verte* in Quebec, Canada. Based on the proposed classification procedure, this study shows that most of the study locations can be classified into one of four groups: primarily utilitarian, mixed-utilitarian, mixed-recreational, and primarily recreational. Locations with primarily utilitarian patterns have typical weekday morning and afternoon commute peaks and a single peak during weekends. These patterns are very similar to those observed in motor-vehicle traffic in urban arterials and highways. Mixed-utilitarian locations exhibit two distinct commute peaks at the hourly level, but the ridership between the peaks may be slightly higher than at primarily utilitarian locations. They also maintain a consistent level of ridership throughout the week – i.e. daily volumes on weekends are as high as on weekdays. Recreational locations exhibit their highest proportion of traffic volumes around midday during both weekdays and weekends. Moreover, they exhibit higher ridership on the weekend than during the week. Finally, mixed-recreational locations exhibit a consistent level of ridership throughout the week, like mixed-utilitarian facilities. However, they do not exhibit two distinct commuting peaks during the workweek. As bicycle facilities become more recreational in nature, the AM portion of the weekend hourly profile increases, whereas utilitarian facilities build to a gradual PM peak.

Within each of the four classifications, relative hourly and daily traffic patterns appear to be relatively consistent across regions. However, locale climate appears to have a considerable effect on the monthly profiles across cities. Utilitarian facilities in a city with colder weather retain lower ridership in the winter than those in warmer cities. However, different classifications appear to respond differently across seasons. Recreational locations retain far less ridership in winter than utilitarian ones.

The consistency of temporal profiles across locations in the same classification suggests that general expansion factors can be applied to some bike facility locations. This paper reports expansion factors for each type of bicycle traffic classification. The expansion factors are expected to be useful for practitioners and researchers to extrapolate manual counts, a common need in planning and safety studies. In addition, several indices were developed to compare overall bicycle volumes and patterns of bicycling activity across locations. These measures can be used for comparative studies.

Future studies should explore more detailed measures of the built environment in the vicinity of count locations. It is likely that some of the variations in bicycle volume patterns within each general category are associated with being located near a central business district, commercial zones, parks, or tourist destinations. This will help to further refine the comparison of bicycle ridership patterns across different built environment characteristics. In addition, winter data should be analyzed in a variety of locations to determine year-round bicycle volume patterns. Finally, changes in overall bicycle volumes and bicycle volume patterns over time can be investigated with a similar, rich database of continuous counts from locations throughout North America.

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