Estimation of Annual Average Daily Bicycle Traffic Using Adjustment Factors

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ABSTRACT

The purpose of this research is to investigate the estimation accuracy of annual average daily bicycle (AADB) traffic volumes when using both daily and monthly adjustment factors. A full-year of daily bicycle volume data was collected at twelve permanent count stations during 2010 in the City of Vancouver, Canada and were used to calculate adjustment factors for bicycle traffic. The factors were applied to estimate the annual average daily bicycle (AADB) traffic volumes at other count stations where data was available for most of the year. A comparison was made between the use of monthly factors and seasonal factors where the results supported the superiority of using monthly factors. Detailed error analyses showed that the lowest errors were attained when applying the developed factors to the volume data of 2010, which is the same year of development data. To estimate the AADB using only one day of bicycle volume data, daily bicycle volumes were multiplied by both daily and monthly adjustment factors. A disaggregate error analysis was undertaken to estimate the amount of error attributable to the use of daily factors versus monthly factors. It was found that almost 15% of the estimation error of the AADB could be attributed to the use of daily factors while 11% is attributed to the use of monthly factors. Nevertheless, the overall error of using the two factors together was in the range of 23%. The paper also provides insights on the selection of data collection days/months, which could improve the design of data collection programs of bicycle traffic.

Key Words: bicycle volumes, monthly adjustment factors, AADB.

INTRODUCTION

With the increasing demand for sustainable transportation, more agencies have become interested in encouraging the use of non-motorized modes of travel such as bicycles. Facility design improvement is one attractive option to increase bicycle ridership though shifts from other motorized travel modes. Information on bicycle demand and current ridership has to be available to enable better design of different bicycle facility types (e.g. trails, shared lanes, etc.). As was suggested by the National Bicycle and Pedestrian Documentation Project (*1*), "*without accurate and consistent demand and usage figures, it is difficult to measure the positive benefits of investments in these modes, especially when compared to the other transportation modes such as the private automobile*".

The annual average daily traffic (AADT) volume is one of the fundamental traffic engineering metrics that is often used for planning and design purposes. The equivalent measure for bicycle traffic is usually referred to as the annual average daily bicycle (AADB) (*2*,*3*). An actual estimate of the AADB at a particular location requires the availability of all-around-the-year data of daily bicycle volumes (DBVs). As the number of cycling facilities increase, it becomes infeasible to install permanent counters on each single location for continuous data collection. Additionally, even with the availability of permanent counters at some locations, it is common to have data gaps due to counters malfunction along with other reasons. Accordingly, and similar to state-wide data collection programs, short-period bicycle counts (SPBCs) of one to few days are usually collected and factored up by daily and monthly/seasonal adjustment factors to estimate the AADBs. Daily and monthly adjustment factors are developed using available data from permanent count stations where daily volume data are collected automatically throughout the year.

Despite their significance, little research has been devoted to address questions related to the accuracy of the estimated AADBs when using daily and monthly adjustment factors. In a previous research (*3*), the accuracy of estimating the monthly average of daily bicycle volumes (MADB) using daily factors was explored. This research is more comprehensive as it considers the use of both daily and monthly adjustment factors to estimate the annual averages. In the current analysis, monthly factors are used only when full month of daily bicycle volume data are available. On the other hand, both daily and monthly factors are used only when one day of bicycle volume data is collected. A comparison is also carried out between the estimation accuracy of AADBs when using monthly factors versus seasonal factors. Finally, the temporal transferability of the developed factors to estimate AADBs of a previous, and subsequent year, is also explored.

This paper is structured as follows: the first section is an introduction that provides an overview of the research theme and objectives. The second section includes a brief description of previous similar work. The third section describes the general methodology adapted in conducting the current study. Section Four describes the available bicycle volume data. The development of daily and monthly adjustment factors are discussed in Section Five. The results of the analysis are introduced in Section Six, followed by a discussion and concluding remarks in Section Seven.

PREVIOUS WORK

Most of the current developments of daily and monthly adjustment factors are mainly devoted to vehicular traffic (*4*,*5*,*6*). Only a few studies have attempted to develop daily and monthly adjustment factors for the exclusive use of bicycle traffic. For example, Nordback et al. (*2*) addressed several questions related to the design of bicycle counting programs such as the timing and frequency of the counts required for reliable estimation of annual average daily bicycle traffic. The authors analyzed a large dataset of cycling counts from Colorado to study the estimation accuracy when using data of different quantity and temporal resolution to estimate the annual average of daily bicycle traffic. The estimation errors ranged between 15% when using four weeks of continuous count data to 54% when only one hour of data was used. The authors recommended that weekly cycling counts should be used in the estimation of the AADB volumes. In case such data is unavailable, counts for at least twenty-four hours should be used instead.

Another study by Miranda-Moreno et al. (*7*) analyzed a large dataset of cycling volumes collected at 40 different locations in five North American cities. The authors found that four cycling volume patterns could exist at any bicycle facility; utilitarian, mixed utilitarian, recreational and mixed recreational. Hourly and daily expansion factors for cycling traffic were calculated according to the defined volume patterns. Nevertheless, due to seasonal variations from one city to another, monthly adjustment factors were developed separately for each city. No testing or evaluation of the developed factors was carried out in this study. In addition, the analysis lacked a full year of cycling volume data for calculating an annual average of bicycle volumes, where only data from April to November was used to calculate the "overall" average of daily cycling volumes.

The last study that addressed adjustment factors of cycling traffic is that by Lindsey et al. (*8*). Data from six off-street trails were used to compute daily and monthly adjustment factors for non-motorized traffic including bicycles. The authors demonstrated the application of the developed factors using an example. An assessment of the accuracy of the developed factors was not carried out. The authors suggested that the factors presented in their study could give useful insights into the patterns of non-motorized traffic on shared use paths in Minnesota where the data were collected. Nonetheless, the factors will not be transferable to other geographic locations where weather conditions may differ.

Apart from these recent studies, most of the previous work on cycling models has been mainly directed to analyze the relationship between weather conditions and cycling ridership (*9-20*). A study by Lindsey et al. (*21*) explored the relationship between weather conditions and trail traffic volume, including bicycles among other users. Many studies focused on the behavioural differences of cyclists in response to variant weather conditions at utilitarian and recreation facilities (*9*,*10*,*12*,*13*,*14*,*18*). Some of these studies also analyzed daily, monthly, or seasonal variations of cycling ridership (*5*,*6*,*9*,*10*,*14*,*20*).

METHODOLOGY

The estimation of annual average daily bicycle (AADB) volume at a particular location is carried out in two stages. In the first stage, one day of actual bicycle volume data must be available and is factored by a daily adjustment factor (DF) to estimate a monthly average daily bicycle (MADB) volume. In the second stage, the estimated MADT is multiplied by a monthly/seasonal adjustment factor in order to estimate the AADB. This can be expressed mathematically as:

$$MADB_{kj} = DBV_{ikj} \times DF_{ik} \quad (1)$$

$$AADB_j = MADB_{kj} \times MF_k \quad (2)$$

Where:
$MADB_{kj}$: Monthly average of daily bicycle traffic of month *k* and link *j*,
DBV_{ij} : Daily bicycle volume for day of week *i* of month *k* and link *j*,
$AADB_j$: Annual average of daily bicycle traffic of link *j*,
DF_{ik} : Daily adjustment factor for day of week *i*, of month *k*, and
MF_k : Monthly adjustment factor of month *k* as calculated from other count stations.

Daily and monthly adjustment factors were calculated from count stations where data was available for months or years. These factors were then used to estimate the MADBs and the AADBs at other count stations where cycling volume data were available only for few days. The development of daily and monthly factors is computationally easy, yet data intensive. In our approach, for a particular day of the week *i*, a particular month of the year *k*, and facility *j*, a DF is calculated as the ratio between the monthly average daily traffic of bicycles (MADB) and the daily bicycle volume (DBV) such that:

$$DF_{ikj} = \frac{MADB_{kj}}{DBV_{ikj}} \tag{3}$$

Noteworthy is that this method of calculation is different from the approach usually adapted in the development of DFs in statewide data collection programs, where a DF is computed as the ratio between the AADB and the annual average volume for a particular day (*22*):

$$DF_{ikj} = \frac{AADB_j}{AADB_{ij}} \tag{4}$$

Where:

$AADT_{ij}$: Annual Average daily bicycle traffic of day of week *i* at location *j*

Monthly factors (MFs) were computed at count station where at least one full year of bicycle volume data was available. A MF represents the ratio between the annual average daily bicycle (AADB) volume at location *j* and the monthly average daily bicycle (MADB) volume at the same location:

$$MF_{kj} = \frac{AADB_j}{MADB_{kj}} \tag{5}$$

As monthly data becomes available at more than one count station, more than one daily factor can be computed. Hence, an overall daily factor for any day should be estimated to represent daily factors of all count stations. Two different methods of calculating the "overall" daily factors can be applied: harmonic mean and average. This can be expressed mathematically as:

$$DF_{ik} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{DF_{ikj}}} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{DBV_{ikj}}{MADB_{kj}}} \tag{6}$$

$$DF_i = \frac{1}{n}\sum_{i=1}^{n} DF_{ij} \tag{7}$$

Where *n* is the number of count stations with full month of daily bicycle volume data.
In a similar manner, when annual bicycle volume data become available at more than one count station, an average of all the calculated monthly factors could be computed either as the harmonic mean or as the average of all calculated monthly factors:

$$MF_k = \frac{1}{\frac{1}{m}\sum_{i=1}^{m}\frac{1}{MF_{kj}}} = \frac{1}{\frac{1}{m}\sum_{i=1}^{m}\frac{MADB_{kj}}{AADB_j}} \tag{8}$$

$$MF_k = \frac{1}{m}\sum_{i=1}^{m} MF_{kj} \tag{9}$$

Where *m* is the number of count stations with a full year of bicycle volume data.

The estimation accuracy of the AADBs when using daily and monthly/seasonal factors have not been yet well documented. In some studies, adjustment factors were computed without any testing or application. In some other studies, only the aggregate (i.e. total) error that resulted from estimating an AADB from one or few days of bicycle data was calculated. To the best of our knowledge, no attempt has been yet carried out to decompose the estimation error when applying daily and monthly factors for estimating AADBs. The main objective of the current research is, therefore, to estimate the error component at each stage of the estimation of AADB. To elaborate, it is desired to estimate the magnitude of error when calculating the MADT from a daily volume as well as calculating the magnitude of error when using an actual monthly volume to estimate an annual average of the daily bike volumes. Monthly and annual bicycle volume data have to be available to enable an assessment of the accuracy at each stage. For the first stage, estimation of the MADTs, daily bicycle volumes are multiplied by daily adjustment factors and the estimated MADTs are compared against the actual MADTs. The daily factors used in this study were developed and tested in a previous research (*3*). In this study, monthly and seasonal factors are developed and furthermore used to estimate the AADBs of count locations where a full month of bicycle volume data is available. Seasonal factors are calculated as the average of the three monthly factors of each season. The rationale behind using seasonal factors is that bicycle ridership might exhibit similar trends during different months of the same season. Hence, it could be acceptable to use only one representative factor for each season. In our analysis, the AADBs estimated from both monthly and seasonal factors are compared against the actual AADBs and the errors are computed. Comparing the errors at each stage, one could get insights into the magnitude of error for both the estimation of AADB from MADBs, as well as from the DBVs. This would help in choosing the best data collection scheme that would allow reducing the estimation error to a minimum. The Mean Absolute Percent Error (MAPE) is used as the evaluation criterion to assess the accuracy of the estimated MADBs and AADBs. The MAPE is calculated as:

$$MAPE_{Daily\ Factors} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{MADB_{Actual} - MADB_{Estimated}}{MADB_{Actual}}\right| \tag{10}$$

$$MAPE_{Monthly\ Factors} = \frac{1}{M}\sum_{i=1}^{M}\left|\frac{AADB_{Actual} - AADB_{Estimated}}{AADB_{Actual}}\right| \tag{11}$$

Where:

$MADB_{Actual}$ = Actual monthly average of daily bicycles,
$MADB_{Estimated}$ = Estimated monthly average of daily bicycles,
$AADB_{Actual}$ = Actual annual average of daily bicycles,
$AADB_{Estimated}$ = Estimated annual average of daily bicycles,

N = Number of validation days for MADT estimation, and
M = Number of validation months for AADT estimation

Other evaluation measures are also computed including the Root Relative Squared Error (RRSE), and the Normalized Root Mean Square Error (RMSN). Finally, the scatter plot of the actual versus the estimated volumes is visually inspected with respect to a 45° line representing a perfect fit.

DATA DESCRIPTION

The City of Vancouver maintains and operates approximately 470 km of bicycle routes throughout the city within its network of 2,400 kilometres of streets, as well as off-street pathways. The City's existing bicycle network includes a variety of types of bicycle facilities, including separated bicycle lanes, local street bikeways, arterial street bike lanes and off-street pathways. The available dataset comprised more than 810,000 hours of bicycle volume data that were collected using permanent inductive loop counters installed at several locations in the city between 2005 and 2011. Hourly volumes were aggregated and resulted in an initial dataset of 32,170 daily volume records for 325 different links after the removal of suspicious records; those marked by a flag indicating unreliable data collection. Most of the available daily volume records, 16,467, were for the year 2011 followed by 2010 which comprised 11,842 days of bicycle volume data. The fewest number of daily counts available per year, 693 records, were for the year 2008. No full day of bicycle data were available for the years 2005-2007. As the current analysis is considered with the development and application of monthly adjustment factors, a full year of daily bicycle volume data is desired to enable the optimal calculation of these factors. Having a closer look at the available data, it was found that annual daily bicycle volumes were only available at twelve count locations during 2010. Data from other years were incomplete due to counters multifunction during some periods of the year or simply because the counters had been installed after the start of the year. Table 1 shows the monthly and annual averages of the daily bicycle volumes at the twelve count locations.

In addition to the calibration/development data, another set of data has to be reserved for validating and evaluating the accuracy of the developed factors. As the available data covered only twelve locations, it was difficult to split these data into two sets for development and evaluation purposes. Alternatively, it was decided to use data from all locations where daily bicycle volumes were available for at least 335 days, which is equivalent to eleven months. Furthermore, the missing days of data could be distributed over more than one month. The assumption here is that an equivalent one month of missing data would not have so much impact on the true value of the AADB, especially if the missing volume data are distributed over different months. Although the assumption might be debatable, it became almost a common practice to accept less than a year of daily volumes in calculating the annual average daily bicycle volumes and estimating monthly adjustment factors (*7,8*). This is mainly attributed to the problems associated with the quality of the collected data as well as automatic counter malfunction problems, which make it very difficult to have a complete year of daily volume data at any location. After filtering out count locations that have data for less than 335 days, only thirteen count stations were left.

The available data was distributed over three different years; 2009, 2010, and 2011, which was advantageous, as it enabled exploring the temporal transferability of the developed factors. Table 2 presents a summary of the number of available days of data as well as the average

AADB at each validation location. Figure 1 shows the locations of the analyzed bicycle facilities in the City of Vancouver and well as the public road network of the city.

DEVELOPMENT OF ADJUSTMENT FACTORS

Different issues related to the development and application of daily adjustment factors were explored in previous work (*3*). These included grouping factors by weekdays/weekends versus developing factors for each day of the week, developing factors for different road classes, the method of calculating daily factors, and finally developing weather-specific factors. Two types of weather conditions were identified: wet and dry. For our purposes, a precipitation level of 5 mm or more per day was considered as “wet weather” where any value that is less than 5 mm/day was considered to represent dry conditions. This value is arbitrary and was selected based on local knowledge and engineering judgement. The results of the previous analysis indicated that developing factors for each day of the week provided slightly better estimation accuracy compared to grouping the factors by weekdays and weekends.

It was also found that developing factors for different road classes did not improve the estimation accuracy of MADBs. Finally, calculating the harmonic mean of all daily adjustment factors over different locations was shown to improve the estimation accuracy of monthly average volumes compared to using the straight average of daily factors. In general, the best estimation results of the MADBs were achieved when using daily factors that were disaggregated by day of week and weather conditions.

In the current research, we build upon our previous findings where we used year-specific daily adjustment factors that were computed by considering day of the week, month of the year as well as weather conditions. The daily factors from 2011 were used to estimate MADBs for any month in 2011, whereas the factors of 2010 were used for the estimation of MADBs of any month in 2009 and 2010. The hypothesis that daily factors from 2010 are better determinants of the monthly volumes of earlier years was previously tested and the results were presented in El Esawey et al. (*3*).

Monthly adjustment factors, on the other hand, were calculated at each count station for each month as in Equation (5). An overall average factor was then calculated using all factors, as in Equations (8), and (9). Monthly factors that were ±25% from the general average monthly factor were removed and considered outliers. A similar approach was proposed in McShane et al. (*22*) where the aim was to ensure the reliability of the estimated factors and the removal of any suspicious factors that could negatively affect the estimation results. Figure 2 shows the calculated monthly adjustment factors before and after the removal of outliers.

As shown in the figure, some points are clear outliers (e.g. factors of station 77601 for the three months of October, November, and December). After the removal of these outliers, all of the computed factors became very close to the average value. The typical range of monthly adjustment factors was 0.5 in July where the demand peaks, and 2.5 in December where the demand for cycling is minimum. Table 3 shows the final monthly factors as well as the number of control count stations used in the calculation of each factor.

RESULTS

Estimation Accuracy of AADBs from MADBs

The validation dataset included thirteen different count stations where each month of data at each station was used to estimate the AADB of that station (i.e. a total of 156 validation records). The AADB at each count station was calculated by multiplying the actual MADT of a particular month by the corresponding monthly/seasonal factor. Figure 3 depicts the estimated AADBs as well as the actual AADBs for different monthly and seasonal adjustment factors. As Figure 3 shows, all points are well clustered around the 45º line (solid line) for different monthly and seasonal adjustment factors. The dotted lines show the best-fit linear regression lines between the actual and the estimated values. In all of the figures, the regression line almost coincides on the 45º line showing a strong agreement between the actual and estimated values. Further inspection of Figure 3 reveals better clustering around the 45º line for the AADBs estimated using straight average-monthly factors. The finding of the visual inspection is also supported by the value of the coefficient of determination of the regression model which is slightly higher than all other models. These results indicate that monthly factors are better determinants of the AADBs compared to seasonal factors. Furthermore, applying monthly factors that are computed as the straight average of the factors was shown to provide better results than using the harmonic mean method.

A more quantitative analysis was carried out where different error measurements were calculated. In general, all error measurements clearly showed satisfactory estimation accuracies of AADBs when using either monthly or seasonal factors, with the use of monthly factors being always superior. The average value of the MAPE as calculated from the 156 validation records was about 11.5% and 12.4% when using straight average- and harmonic mean- monthly factors, respectively. Similarly, the MAPE was 17.0% and 17.2% when applying seasonal factors computed in the two methods. This minor difference shows no significant influence of the calculation method (i.e. average or harmonic mean) on the estimation results of the AADBs. The reason is perhaps the small sample size that was used in the calculation of factors which led to almost equal factors.

All other error measurements were consistent with the MAPE and supported the same outcomes. For example, The Root Relative Squared Error (RRSE) was about 15.2% and 16.4% when using straight average- and harmonic mean- monthly factors, respectively. Similarly, the RRSE was 22.4% and 22.7% when applying seasonal factors computed in the two methods.

Further analysis of the MAPE was carried out to estimate the error magnitude for each of the three years as well as for each month of the year. As stated previously, the monthly factors were shown to provide lower estimation errors of the AADBs compared to seasonal factors. Furthermore, the factors calculated by the straight average method were shown to be more accurate compared to the factors computed through the harmonic mean method. Accordingly, our detailed error analysis focused only on straight average-monthly adjustment factors.

As shown in Figure 4, the lowest estimation errors were attained for the year 2010; with an average MAPE of about 4%. This is logical as the data used in developing the monthly factors belonged only to 2010. The other two years showed reasonable estimation accuracy with an average MAPE of 15% and 12% for 2009 and 2011, respectively. These results indicate the feasibility of the temporal transferability of the monthly factors (i.e. applying the factors of one year to estimate the AADB of another year), keeping in mind that the attained accuracy levels will be significantly lower compared to using factors of the same year. More disaggregate error analysis was undertaken to determine which months of the year would provide the highest estimation accuracy and hence could be considered favorable when designing data collection programs for bicycle volume data.

As Figure 4 shows, the average MAPE error ranged between 2% for August, October, and December of 2010 and 28% of April, 2009. Even the highest error can still be considered reasonable taking into account the gains of cost and effort savings. The estimation accuracy indicates that the developed factors are robust and reliable in estimating the AADBs. Furthermore, it indicates that one month of actual data could significantly improve the estimation accuracy of annual average daily cycling volumes. In general, In general, the summer months (May to August) consistently provided the best estimation results with June being the month with the lowest MAPE error of 7% (i.e. average of all stations and three years). This indicates that the factors developed from these months are stable and representative of the annual average daily bicycle volumes of other bicycle facilities. It was also interesting to find out that the same four months provided the minimum absolute error difference when temporally transferred to other years. On the other hand, the months of October to February exhibited the highest MAPE and therefore were considered to be the most difficult to predict and not as favorable for data collection for purposes of developing monthly factors.

Estimation Accuracy of AADBs from DBVs

The aim of the previous analysis was to assess the estimation accuracy of AADB volumes when using the monthly averages of daily bicycle volumes along with monthly adjustment factors. The outcomes were that monthly factors are more robust than seasonal factors and the average method is more appropriate for developing the factors. Building upon these results, daily bicycle volumes were further used to estimate the AADB at each station. Each DBV was multiplied by the corresponding DF and MF following Equations (1) and (2). Recalling that both the actual MADT and AADB were available for each record, it was accordingly possible to calculate the magnitude of error attributed to the use of each factor. In total, 4555 validation records (i.e. daily bicycle volumes) were available and used to compute the MADTs and the AADBs. The MAPE of MADTs estimation was found to be 15.3% while the MAPE of estimating the AADBs was about 23.4% showing a significant increase from the average MAPE when using monthly averages (i.e. 11.5%). It is noteworthy is that the sum of the two error components, 15.3% and 11.5%, is not equal to the total error of AADBs. This is expected as some under/over estimation could take place while using one of the adjustment factors and is compensated by the use of other factors. This would lead to decreasing the overall estimation error of the AADB. In summary, it can be concluded that almost 15% of the estimation error in the AADB could be attributed to the use of DFs while 11% is attributed to the use of MFs. Nevertheless, the overall error of using the two factors together was in the range of 23%. For more detailed analysis, the error difference for each record was computed to determine the degree of error attributed to the use of the daily factors and the degree of error attributed to the monthly factors. A frequency distribution of that error difference was created and it showed that more than 70% of all the validation records had an error component of 15% or less that is attributable to the use of DFs which supports the previous results.

Another analysis was undertaken to identify the best combination of days/months where the collected daily bicycle volume data would lead to the lowest estimation errors of the AADBs. The MAPE of the estimated AADBs was found to be relatively low when using daily cycling volume data from weekdays, preferably Tuesdays to Fridays. This is intuitive and in agreement with the general rules for any volume data collection plan. Further analysis was carried out to estimate the MAPE errors for different combinations of months and days. The results showed that the estimation errors of AADBs could be as low as only 12% when using data from Wednesdays to Fridays in August. This is a significant improvement in the estimation accuracy compared to the overall error average of 23.4%. Hence, it can be concluded that for the best estimation accuracy of the annual average daily bicycle volumes, it is recommended to conduct short-count data collection during normal weekdays (i.e. Tuesdays to Fridays) in either July or August (in comparison to other days and months).

SUMMARY AND CONCLUSIONS

Traditionally, the annual average daily traffic (AADT) metric has been used to serve many purposes within the field of transportation engineering. A common approach to estimate AADT volumes is to factor up short-period traffic counts (SPTCs) of one to three days by daily and monthly/seasonal adjustment factors. Adjustment factors are usually developed using available data from permanent count stations where daily volume data are collected automatically throughout the year. Only a few studies were devoted to addressing questions related to the accuracy of the estimated AADT when using daily and monthly adjustment factors. The literature is further sparse when dealing with this issue for non-motorized traffic, especially for cycling. In a previous research study (*3*), the accuracy of estimating the monthly average of daily bicycle volumes (MADB) using daily factors was explored. This research was more comprehensive as it considered the use of both daily and monthly adjustment factors to estimate the annual averages. In the current analysis, monthly factors were used only when full month of daily bicycle volume data was available. On the other hand, both daily and monthly factors were used when only one day of bicycle volume data was collected.

One complete year of daily bicycle volume data at twelve count stations in Vancouver, Canada, was used in the analysis. Firstly, a comparison was carried out between the estimation accuracy of the AADBs when using monthly factors versus using seasonal factors. The results supported the superiority of using monthly factors where the average estimation error was about 11.5% compared to an average error of about 17.0% when using seasonal factors. Secondly, the temporal transferability of the developed monthly factors to estimate AADBs for a previous and sequent year was explored. The results showed that the lowest errors were attained when applying the developed factors to the volume data of 2010, which is the same year of development data. On the other hand, the errors were relatively high for the other years. It is recommended not to use the transferred factors from one year to another unless factors for the same year are unavailable. Thirdly, the average estimation error of the AADB was computed when using only one day of bicycle volume data. For that purpose, daily bicycle volumes were multiplied by both daily and monthly adjustment factors. The amount of error attributable to the use of daily factors versus monthly factors was computed. It was found that almost 15% of the estimation error of the AADB could be attributed to the use of daily factors while 11% can be attributed to the use of MFs. Nevertheless, the overall error of using the two factors together was in the range of 23%. In general, this research provides guidance on how to calculate the adjustment factors and the expected accuracy of transferability. As well, the results of this paper provide an overview on the magnitude of error that may result when using daily and monthly adjustment factors to estimate the annual averages of bicycle volumes. Finally, the paper provides insights on the selection of data collection days/months, which could improve the design of data collection programs of bicycle volumes.

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TABLE 1 Monthly and Annual Average Daily Bicycle Traffic of the Development Links

Location ID	Facility type	MADB												AADB
		1	2	3	4	5	6	7	8	9	10	11	12	
22901	Local Street Bikeways	196	268	267	332	398	485	576	498	457	385	261	177	359
22902	Local Street Bikeways	226	297	305	378	464	573	678	585	521	432	282	193	412
23701	Separated Bikeways	135	179	190	240	284	347	428	378	327	279	185	125	259
23702	Separated Bikeways	131	174	189	236	278	343	415	360	318	275	181	120	252
31601	Separated Bikeways	749	1281	1110	1288	1669	1993	2747	2257	1643	1623	828	582	1493
31602	Separated Bikeways	718	1246	1077	1268	1667	1895	2478	2237	1780	1555	684	591	1444
72601	Local Street Bikeways	203	273	269	315	386	467	543	486	407	338	239	175	342
72602	Local Street Bikeways	230	330	319	372	459	557	723	607	484	417	274	190	414
77601	Separated Bikeways	306	554	425	431	497	581	735	653	478	53	35	29	397
77602	Separated Bikeways	350	668	496	492	588	692	882	772	593	368	238	178	526
81201	Undeveloped Arterial Street	37	53	52	62	74	82	102	90	50	39	20	13	56
81202	Undeveloped Arterial Street	53	100	68	80	90	104	148	128	92	87	63	47	88

TABLE 2 Annual Average Daily Bicycle Traffic of the Validation Locations

Location ID	Year	# of days	AADB
72601	2009	339	394
72602	2009	349	412
65501	2010	356	166
65502	2010	357	152
22901	2011	359	375
31601	2011	362	1449
31602	2011	363	1421
44801	2011	348	642
44902	2011	341	597
95201	2011	335	305
95202	2011	342	578
102401	2011	350	780
102402	2011	354	583

TABLE 3 Final Monthly Adjustment Factors for Bicycle Traffic Volume in 2010

Month	MF	No. of stations used in the calculation	Max Difference from the average	Min Difference from the average
1	1.788	11	16%	-13%
2	1.279	9	17%	-13%
3	1.280	11	17%	-7%
4	1.067	12	15%	-9%
5	0.882	12	14%	-11%
6	0.742	12	8%	-14%
7	0.588	12	8%	-7%
8	0.675	12	10%	-7%
9	0.841	11	7%	-14%
10	0.950	8	4%	-6%
11	1.471	8	7%	-23%
12	2.150	9	13%	-19%

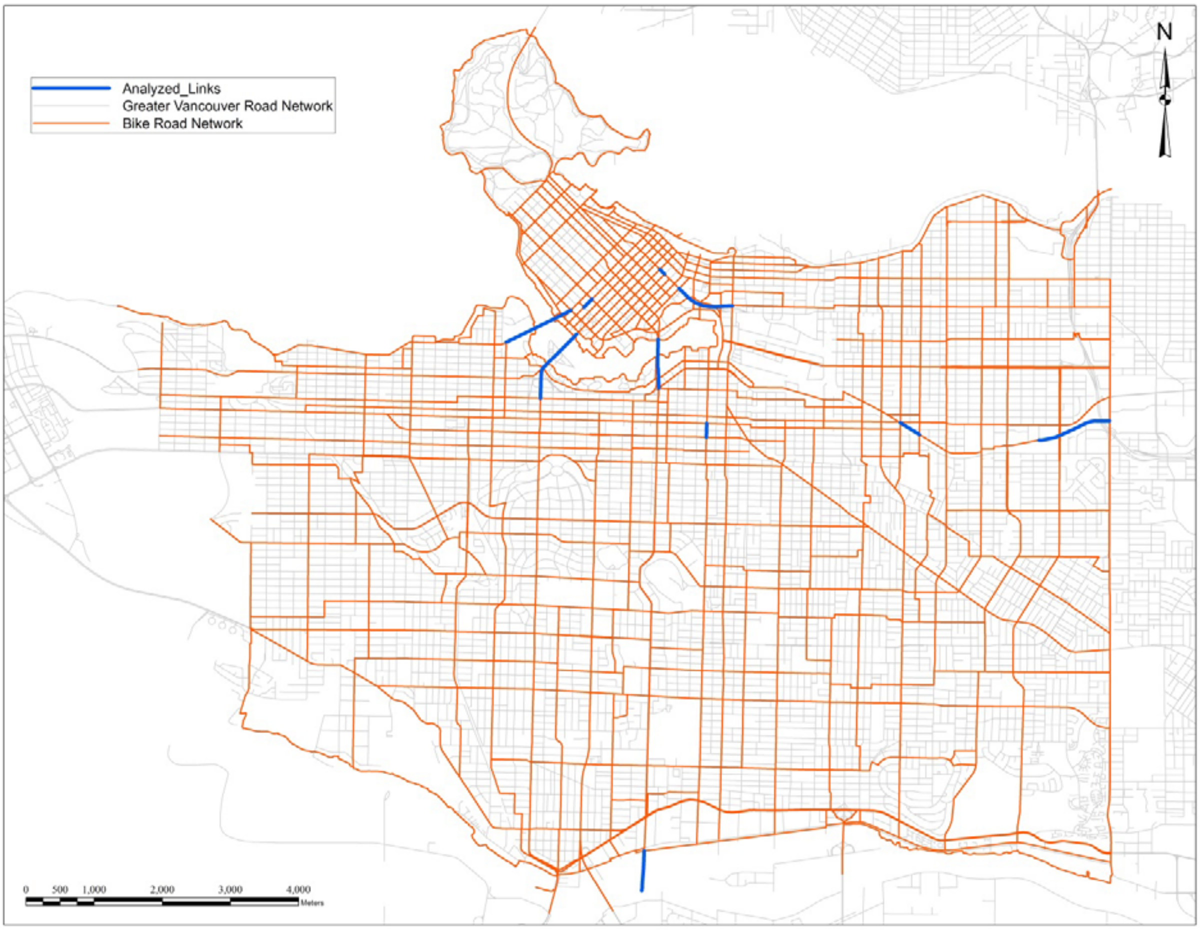

FIGURE 1 Analyzed Bicycle Facilities in the City of Vancouver

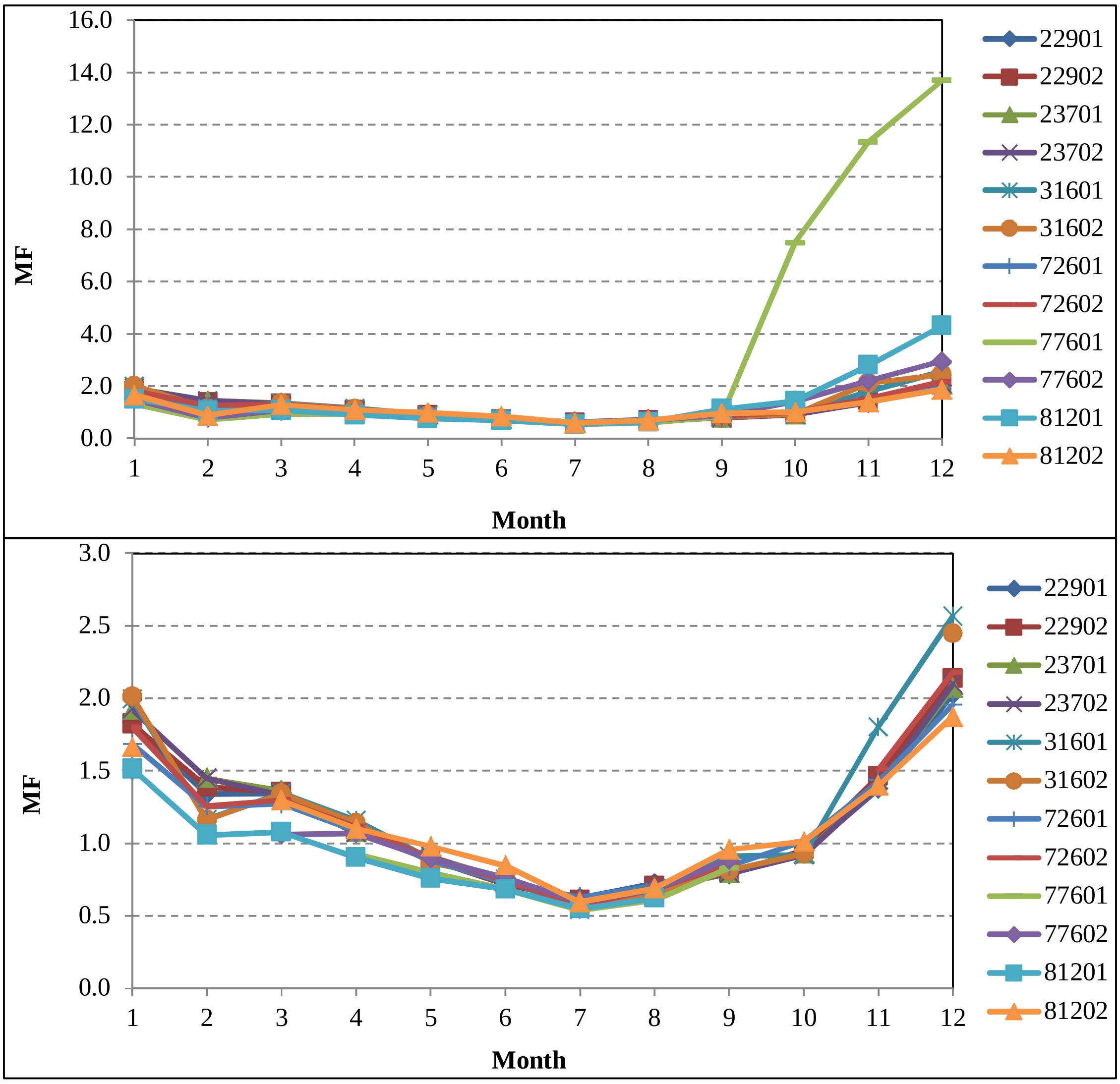

FIGURE 2 Monthly Adjustment Factors before and after the Removal of Outliers

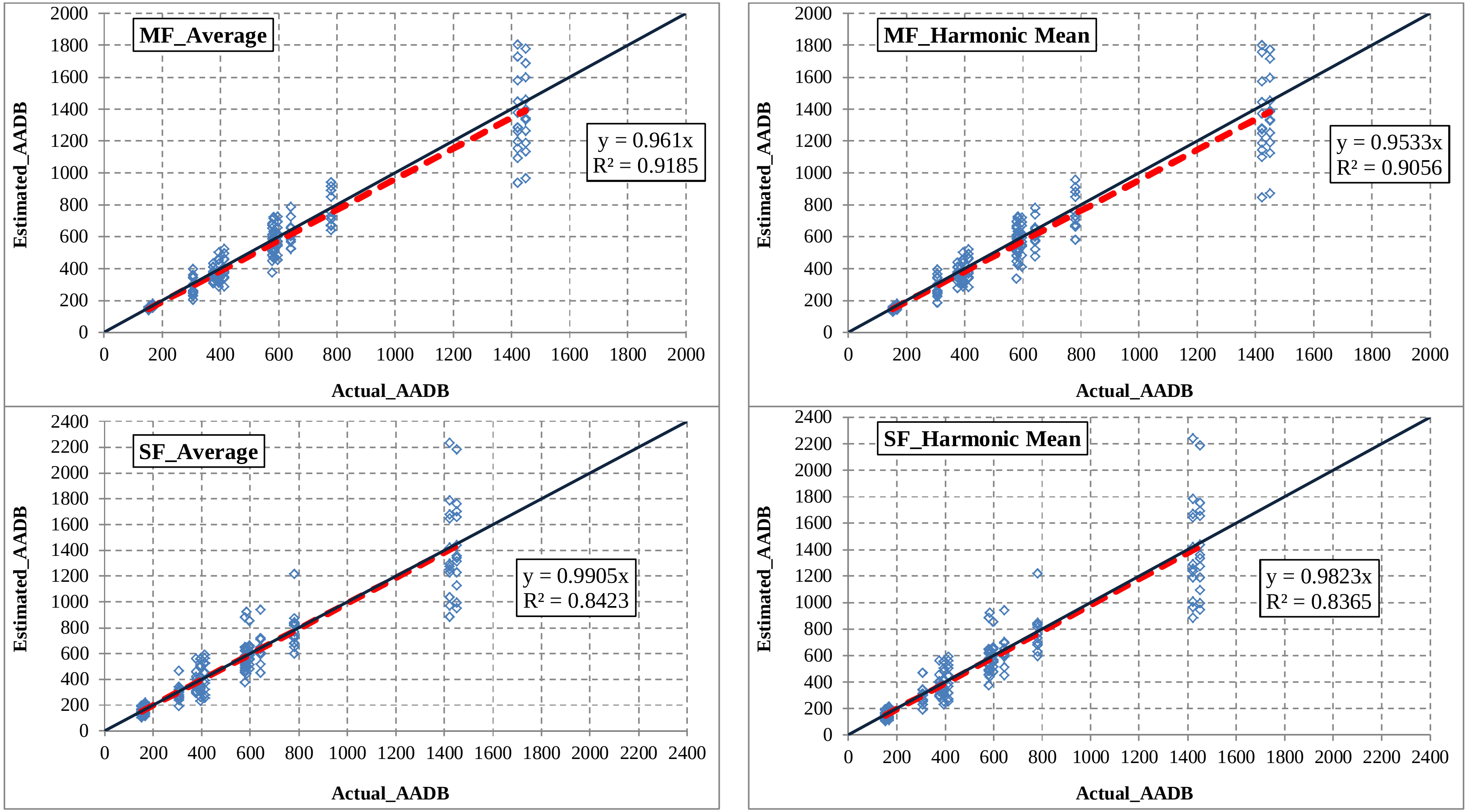

FIGURE 3 Scatter Plot of the Actual and the Estimated AADB Using Different Monthly and Seasonal Factors

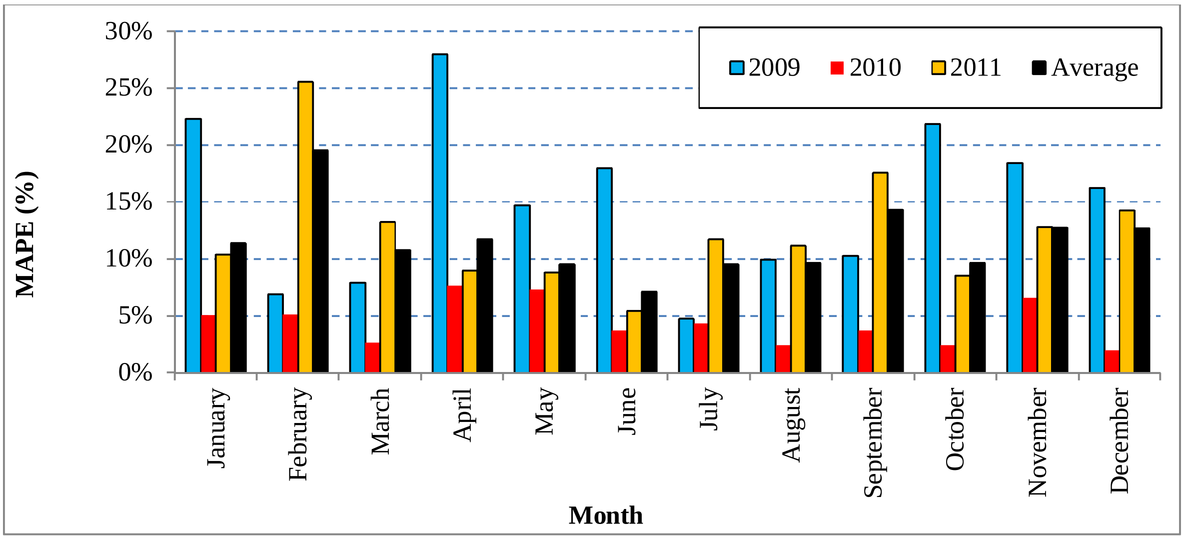

FIGURE 4 MAPE Errors for Different Months of the Year and Different Years