




# Investigation of the factors affecting the consistency of short-period traffic counts

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**Abstract** The main intent of this study is to investigate the accuracy of short-duration traffic counts conducted during winter months. The investigation is based on 11-year sample data collected using permanent traffic counters at various locations in Alberta, Canada. Four types of road sites: commuter, regional commuter, rural long-distance, and recreational sites are studied. The sample data constitute six different durations of counts (12-, 24-, 48-, 72-, 96-h, and 1 week) taken during summer and winter months. The coefficient of variation (CV) is used as the relative measure of deviation for counts of different durations to measure the accuracy of short-period traffic counts. The study results indicate that 48-h count seems to be the most cost-effective counting interval during both summer and winter months. It is also found that the lowest values of CV result for counts taken at commuter sites, and the highest values are observed for recreational sites. Frequent changes in temperature and other weather events cause

significant variation in traffic volume, which results in an increase in CV values for counts taken during winter months. The application of an adjustment factor to remove the effect of cold and snow from short-period counts is also included in this study. Introduced adjustment factors can reduce the values of CV for all counts taken during winter months. The findings of this study can lead highway agencies to improve the cost-effectiveness of their short-period traffic counting programs.

**Keywords** Short-period traffic counts · Average annual daily traffic · Design hourly volume

## 1 Introduction

Highway agencies allocate a significant amount of their resources to traffic counting programs. The traffic volume data collected are used for studying temporal and spatial variation of traffic and estimating important traffic parameters such as average annual daily traffic (AADT), design hourly volume (DHV), and average daily vehicle distance traveled (DVDT). Estimation of these parameters is needed for design, planning, control, operation, and management of the highway infrastructure. The most commonly implemented counting programs by highway agencies are: (1) Continuous counting programs by permanent traffic counters (PTCs) record traffic volume every hour of everyday throughout the year, and (2) Sample counting programs by short-duration counts (SDCs) are conducted periodically (e.g., seasonally) or sporadically every year for durations ranging from a few hours to several weeks.

Permanent counts without missing or erroneous data provide actual temporal distributions of traffic and accurate

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estimates of parameters such as AADT. Since it is not feasible to have continuous traffic counters on every road segment for the entire year, short-period traffic counts are performed using portable counters for the roads without PTCs. Short-period counts ensure the geographic diversity of traffic counts, but they contain sample information and, therefore, yield only estimates of AADT after appropriate adjustment factors are applied. The data from PTCs are used to develop daily, hourly, and monthly expansion factors (DF, HF, and MF, respectively), which are then applied to short-term counts in order to estimate AADT [1].

Weather conditions have been shown to be among the primary contributing factors to seasonal variations in traffic volume [2–6]. Reduction in traffic volume and traffic flow speed, increased number of accidents, and trip delays or cancellations are among potential effects of adverse weather on traffic. Due to adverse weather conditions, short-period counts are mostly conducted in spring/summer months. Many agencies limit short-duration counting to summer months (i.e., from May to September) because of the difficulties in operating the counting devices during severe weather conditions in the winter season. With the availability of modern counting devices (radar or video recorders and passive infrared recorders), it is now possible to conduct SDCs in winter months. Short-duration counts (SDCs) are very important to the state and national transportation agencies as it supports AADT estimation. Winter SDCs are equally central as summer SDCs for planners and designers for conducting mechanistic empirical pavement design analysis. In a typical situation where the deteriorated pavement during winter requires to be redesigned either for rehabilitation or for new construction, designers or highway project managers need not to wait till summer for SDCs. The winter SDCs can be considered for the pavement rehabilitation design, and this process can expedite the execution of pavement construction. However, there has been a very limited amount of research done on the accuracy and reliability of short-period traffic counts that could potentially be carried out during winter months. The precision and bias of short-duration traffic counts have wide-reaching implications for transportation planning and facility design. For example, AADT and DHV will directly affect the functional classification of highways, roadway geometry, material selection, and pavement structure. Therefore, it is important to study the accuracy of SDCs taken during adverse weather conditions. Hence, cold, snow, and rainfall are the weather conditions of concern in this research. Previous research [7] used the factor method [1] to measure the accuracy of the estimates of the computed AADT based on sample short-period counts against the actual AADT calculated based on PTC data. However, measuring the accuracy of SDCs is not studied well. We did not find any evidence related to analyzing the SDCs

accuracy in cold regions in particular. Investigating the accuracy of the SDCs will help in developing a cost-effective schedule for traffic data collection during any season of the year. Therefore, the main intent of this study is to investigate the accuracy of short-duration counts taken during winter months.

Although technological development has made it possible to conduct SDCs in winter months, the reliability of these counts is a problem that requires further research. Datla and Sharma [8–11] developed a traffic–weather model in which the percentage reduction in traffic counts due to adverse weather can be adjusted using percentage reduction factors. Therefore, estimates of AADT based on short-period counts taken in the winter season can be as reliable. The applicability of short-period counts in winter after applying such percentage reduction factors is also studied in this research.

## 2 Literature review

SDCs contain only sample information. Therefore, they need to be adjusted using appropriate factors to yield reliable estimates of traffic parameters which are used in evaluating the classification of vehicles as well as temporal and spatial distribution of traffic [8, 12, 13]. The problem of precisely estimating the parameters associated with yearly traffic volume at a count site where traffic counts are available for only a limited part of the year has been the focus of a number of past studies. Several methods have been used in the literature to estimate AADT from short-duration counts. Gulati [7] studied the statistical precision of AADT estimated from samples of different durations of short-period traffic counts (24-, 48-, and 72-h) taken during the months of May to September. The factor approach has been the traditional method for computing traffic parameters from short-period counts. Other methods, such as neural network approach or methods based on regression modeling, have also been used in the past [14–16]. Aldrin [14] adopted multivariate regression-based models to estimate AADT and compared them to traditional factor method. In this study, the so-called basis curve method, in which basis curves for specific short-duration count sites were established based on iterative computation using site-specific parameters, was used. The method was shown to have slightly better results compared to the factor approach with more than a 2% reduction in the error of estimation.

Jiang et al. [17] proposed a method that incorporates aerial image data with ground-based data to improve the accuracy of AADT estimates from short-period counts on 122 highway segments in Florida and Ohio. The method was intended to reduce errors in estimating AADT from two consecutive 24-h counts and error in estimating the

increase in AADT between a future year for which AADT is to be estimated and the year in which the coverage counts were taken. The results showed that there was progressive reduction in relative errors of AADT estimates when growth factors were considered that were even more significant when image-based AADT estimates were added. Gadda et al. [18] studied the relative magnitudes of errors in estimation of AADT from extrapolating short-period local traffic counts using samples collected from automatic traffic recorder (ATR) sites in four states on weekdays of the spring and summer months of 1984–2004.

Due to extreme cold and heavy snowfall events, there are reduction and fluctuation in traffic volume during the winter season. Datla and Sharma [8–11] developed percentage reduction factors using a traffic–weather model in order to compensate the reduction that resulted from each cm of snowfall and temperature drop below 0 °C at a scale of 5 °C. The study showed that the difference between the precision of estimation of AADT from short-period counts taken during the winter and summer seasons was reasonably small. The study compared AADT estimates using the traditional factor method for sample counts taken during summer months (May–September) and those using a method that applies the traffic–weather model for sample counts taken during winter months (November–March). The sample counts were taken at a commuter and a recreational site during both seasons, and the estimated AADT errors were produced using a similar method to that used by Gulati [7]. The reported AADT estimation errors for the proposed method, which was applied to sample counts taken in the winter, were 22.87% for recreational roads and 13.86% for commuter roads, whereas for traditional factor method (for sample counts taken in the summer), they were 18.11% and 12.57% for recreational and commuter roads, respectively.

Using advanced technologies such as video- or radar-based traffic detection techniques [19], it is possible for short-period traffic counts to be taken even in winter months. However, the estimation of annual traffic parameters such as AADT based on these counts has to take into account the fact that, in addition to the reduction in volume, traffic volume in the winter season fluctuates to a large extent. Therefore, if and when short-period traffic counts are to be taken during winter months, an insight into the nature of the traffic volume pattern in these months and the effects of winter weather conditions on traffic volume has to be gained. However, limited information is available in the literature on the estimation of AADT using short-duration counts taken during winter months. Only a limited number of the past studies among those mentioned above address these issues to a certain extent. None of these studies discuss the variation of the short-period counts over the study periods, and they are mostly limited to short-period counts taken during ideal weather conditions. Past

studies also did not discuss the effects of weather conditions on the variation of short-period counts. A systematic investigation is needed to understand the consistency or degree of variability in short-duration counts taken during winter months. An understanding of the effect of rain on summer short-duration counts is also important to decide the need for weather related adjustment factors for the accurate estimation of AADT from SDCs. This study analyzes, in detail, the variations of different durations of short-period traffic counts taken during both summer and winter seasons and association of such variations with different types of roads and weather conditions.

### 3 Study data

#### 3.1 Traffic data

The study uses sample data collected from hourly traffic data taken from 15 selected permanent traffic counter sites in the province of Alberta, Canada, over a period of 11 years from 1995 to 2005. The sample data constitute six different durations of short-period traffic counts (12-, 24-, 48-, 72-, 96-h, and 1 week) taken during summer and winter months. Summer includes the months of May, June, July, and August, and winter includes the months of December, January, February, and March. These months were considered because of the extreme nature of the weather conditions during these seasons and their tendencies to affect driver population. The traffic data collected on holidays and the weeks surrounding them were not considered. The literature [20] shows that “holiday period” days and weekend days contribute more to the variability of traffic volume than “non-holiday” days and weekdays. There is a substantial increase in traffic volume during statutory holidays [20]. Due to unique travel characteristics during holidays, the data for the week before and after statutory holidays were also excluded. The total numbers of weeks during summer and winter months are 9 and 11, respectively, which are included in the analysis.

#### 3.2 Weather data

The weather data associated with selected weather stations are obtained from Environment Canada. The weather data associated with each study site contain daily temperature (minimum, maximum, and average) (°C), daily rainfall (mm), and daily snowfall (cm). Data for other weather parameters such as wind speed, fog, pavement conditions were not available. Weather conditions during only two seasons, summer and winter, were considered for this study. The months considered for summer were May, June, July, and August and for winter, December, January, February, and March were considered. The rest of the

months were not included in the analyses because the effect of weather conditions on traffic volumes was insignificant.

## 4 Methodology

The key objective of this research is to analyze the accuracy of SDCs. The methodology to achieve this objective is as follows: (1) selection of PTC sites; (2) grouping of PTC sites; (3) data sampling; and (4) data analysis. These four steps are discussed in subsequent paragraphs.

### 4.1 PTC site selection

The 15 PTC sites investigated in this study are selected based on: (1) completeness of the data and (2) closeness to weather station. PTCs with  $\geq 99\%$  or less than 88 h of missing data out of annual hourly counts were selected for this study. GIS proximity analysis [10, 11] was performed using TransCAD to correlate spatially the PTC sites with the paired weather station. PTC sites with at least two weather stations within a radius of 16–24 km were selected as the weather conditions remain similar within the stated aerial distance. The closest weather station was given preference as the source of weather data for a particular PTC site and the data from the second one were used to fill in for the missing data from the first station.

### 4.2 Grouping of PTC sites

The selected PTC sites were grouped using hierarchical grouping method proposed by Sharma et al. [21]. This

method classifies and groups road types based on temporal variations in volume and driver population characteristics, such as trip purpose and trip length distribution. As a result of hierarchical grouping analysis, four types of road groups were identified. These groups were: commuter (COM), regional commuter (RCOM), recreational (REC), and rural long-distance (RLD) roads. Table 1 shows the list of study sites selected for this study, including their groups, functional classes, highway numbers, lanes, and the closest weather stations. Among 15 sites, commuters (COM), regional commuters (RCOM), and rural long-distance (RLD) sites are four each and recreational (REC) sites are three.

### 4.3 Data sampling

Table 2 shows the details of the sample data, including the day-of-the-week and time-of-day during which the sample counts were taken and the sample sizes per week for summer and winter seasons.

### 4.4 Data analysis

One way of measuring the quality of short-duration traffic data is testing the consistency (statistical dispersion) of the short-duration count data by itself. This study examines the consistency of different short-duration traffic counts in terms of their deviation from what the actual traffic volume in that period is most likely to be. The coefficient of variation ( $V_C$ ) can be used as the relative measure of dispersion of the various durations of traffic count data [13]. For a type of short-duration count at a particular study site,  $V_C$  is defined as follows:

**Table 1** Detailed information of PTC sites selected for study

Road group	PTC No.	Class	Highway	Type	Closest weather station	
COM	60021810	Freeway	Hwy 2	Multilane	C3031093	C303C642
COM	60023210	Freeway	Hwy 2	Multilane	C3012205	C3012206
COM	50011010	Expressway	Hwy 1	Multilane	C3031093	C3031094
COM	50161860	Freeway	Hwy 16	Multilane	C3012710	C3014922
RCOM	50011850	Expressway	Hwy 11	Multilane	C3030QLP	C3030862
RCOM	60021060	Expressway	Hwy 21	Multilane	C3033240	C3036099
RCOM	50160650	Arterial	Hwy 16	Multilane	C3062246	C3062242
RCOM	60200260	Major Arterial	Hwy 20	Two lanes	C3022159	C3025441
RLD	50030610	Arterial	Hwy 3	Two lanes	C3034596	C3032624
RLD	60221610	Major Arterial	Hwy 22	Two lanes	C303AFGF	C3031678
RLD	60221850	Major Arterial	Hwy 22	Two lanes	C3024920	C3026KN2
RLD	50270670	Major Arterial	Hwy 27	Two lanes	C3026KNQ	C3024920
REC	50010050	Freeway	Hwy 1	Multilane	C3050519	C3050526
REC	50010250	Freeway	Hwy 1	Multilane	C3050778	C3050533
REC	50010610	Freeway	Hwy 1	Multilane	C303F0PP	C3031676

**Table 2** Details of sample data of short-period counts studied

Counting durations	Days-of-week and time-of-day included	Number of samples per week	Total no. samples in a season from all sites	
12 h	Monday 7:00 a.m. to 7:00 p.m.	4	Summer	540
	Tuesday 7:00 a.m. to 7:00 p.m.			
	Wednesday 7:00 a.m. to 7:00 p.m.		Winter	
	Thursday 7:00 a.m. to 7:00 p.m.			
24 h	Monday 12:00 p.m. to Tuesday 12:00 p.m.	3	Summer	405
	Tuesday 12:00 p.m. to Wednesday 12:00 p.m.			
	Wednesday 12:00 p.m. to Thursday 12:00 p.m.		Winter	
48 h	Monday 12:00 p.m. to Wednesday 12:00 p.m.	2	Summer	270
	Tuesday 12:00 p.m. to Thursday 12:00 p.m.		Winter	
72 h	Monday 12:00 p.m. to Thursday 12:00 p.m.	1	Summer	135
			Winter	
96 h	Monday 12:00 a.m. to Friday 12:00 p.m.	1	Summer	135
			Winter	
1 week	Monday 12:00 a.m. to Sunday 12:00 p.m.	1	Summer	135
			Winter	

$$V_c = \frac{\sqrt{\left\{ \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2 \right\}}}{\bar{X}} \times 100 = \frac{\sigma}{\bar{X}} \times 100, \quad (1)$$

where, for a particular site,  $X_i$  is the  $i$ th volume count of a particular duration at site,  $n$  represents the number of the short-duration counts taken at site,  $\bar{X}$  is the average volume of the  $n$  short-duration counts taken, and  $\sigma$  is standard deviation. In this context,  $V_c$  is explained as the expression of standard deviation as the percentage of the mean value of a particular duration of short-period traffic counts. A low value of  $V_c$  is associated with less dispersion in a particular volume of count data from their mean, which reflects high accuracy in estimating the actual traffic volume.

## 5 Analysis and results

In this study, hourly traffic volume factors (the ratio of hourly volume to AADT) were used rather than the hourly volume to remove the effect of monthly and yearly trends in traffic volumes from the analysis. It may be noted that the 12-, 24-, 48-, and 72-h traffic counts were limited only to weekday (Monday–Thursday) traffic. This was done to avoid the effect of weekend traffic on such counts. However, weekly counts included weekend traffic as well.

All of the short-duration count samples were included in such a way that data from the  $n$ th week of one year are grouped together with every  $n$ th week's data from all other available years of the study period. Week numbers were chronologically assigned as week 1–9 in the summer and week 1–11 in the winter. The CV of all short-duration counts in that group

was then calculated in order to measure the apparent similarity among them. For example, every 12-h count taken at a study site in the second week of July of 1995 is grouped together with every other 12-h count taken at the same site during the same week in July for the remaining years. The CV of 12-h counts collected on the weekdays of the second week in July of every year was then calculated for the study site.

### 5.1 Consistency of SDCs taken during summer and winter months

The comparison of the variation of traffic patterns of short-period counts during the summer (S) and winter (W) is shown in Table 3. The maximum and minimum CV values are presented for all SDCs considering 9 weeks in summer season and 11 weeks in winter season. The coefficients are shown in the form of range to indicate how far apart they are for summer counts as compared to winter counts. Some counters display significant fluctuation in their coefficients during both seasons. Even though it is expected that variability in traffic volume is inevitable during the winter months, some counts were different in this respect from the others. Counts from RCOM60200260 had the highest fluctuations in traffic volume factors for all duration counts in the winter months (Table 3). The highest coefficients (12%–15%; see Fig. 1a) were seen in the counts during the first week of the winter season. This fluctuation in traffic volume factors could be mainly due to extremely cold temperatures on most days in the first and second weeks of every winter in the study period. 49% of the daily average temperatures recorded during these weeks were less than  $-15^\circ\text{C}$ , and

**Table 3** Traffic pattern of short-period counts during summer (S) and winter (W)

Road group	Counter	Season	Ranges of CV (%)					
			12 h	24 h	48 h	72 h	96 h	1 week
COM	60021810	S	2.4–4.8	1.7–4.1	1.1–3.9	0.8–3.8	0.7–3.7	1.1–4.3
		W	4.2–9.8	3–7.6	2.4–7	1.6–7.1	1.7–7	1.6–8.6
COM	60023210	S	2.3–3.3	2–3.8	2–3.3	1.2–3.3	1.1–3.3	0.6–3.5
		W	3.9–8.2	4–7.8	3–7.8	2.5–7.4	2.7–6.8	2.5–7.5
COM	50111450	S	3.7–6.2	3.6–6.8	3.1–6.9	3–6.7	2.3–6.8	1.3–5.6
		W	5.7–12.8	6.1–13	5.8–13	5.9–13.1	6.3–13.2	5.9–12.6
COM	50161860	S	1.9–4.2	1.9–4	1.7–3.7	1.7–3.7	1.8–4.1	1.1–3
		W	2.6–8.4	2.8–6.9	2.4–6.3	2–6.2	1.7–6.2	2.1–6.5
RCOM	50011850	S	3.8–6.7	2.5–6.4	1.8–6.1	1.6–5.9	1.9–4.9	2.3–4.2
		W	5.6–11.9	4.2–10.9	2.5–10.8	1.5–11	1.9–10.5	1.3–9.9
RCOM	60021060	S	3.5–5.0	2.5–4.5	1.6–4	1.1–3.8	1.2–3.4	1.8–3.2
		W	5.6–10.3	4.1–11.1	2.8–9.3	2–8.7	1.9–8.6	1.7–7.7
RCOM	50160650	S	4.1–6	3.6–5.2	3.3–4.8	3.2–4.7	2.9–4.8	3.2–5
		W	6.6–10.7	6.1–9.6	5.6–9.3	4.9–9.3	5–9.3	3.6–8.4
RCOM	60200260	S	2.9–8.6	3–7	2.9–6.9	1.6–6.6	1.9–6.1	1.7–10.4
		W	4.6–15.0	4.9–15.3	3.6–15.5	3.4–14.6	3.4–14.1	2.3–12.6
RLD	50030610	S	3.4–9.6	2.3–6.3	1.8–4.2	1.5–4.1	0.9–5.5	1.4–4.1
		W	6.6–11.8	5.6–11.4	4.5–11.6	3.9–11.4	4–10.3	2–9
RLD	60221610	S	4.5–6.4	3.8–5.7	2.7–5.6	2.2–5.1	2.4–4.9	2.5–4.2
		W	5.7–12.2	5.5–10.8	4.3–9.9	3.9–9.1	3.8–9.7	5.3–10.3
RLD	60221850	S	4.8–8.1	3.4–6	2.8–5.4	2.6–5.1	2.6–5.8	2–4.8
		W	7.2–12.6	6.5–12.5	5.5–12.3	6–12.7	5.4–13.2	6.5–12.3
RLD	50270670	S	3.3–7.1	2.7–6.5	2.0–6.4	1.8–6.5	1.6–6.4	1.7–4.4
		W	4.9–12.8	4.4–11.4	3.8–10	3.8–10.2	3.8–10.1	2.7–8.4
REC	50010050	S	4.0–6.0	3–4.6	2.1–4.1	1.9–4	1.7–4.2	1.4–4.4
		W	5.2–13.4	4–12	2.9–12.3	3.1–11.9	3.1–10.8	3–11.7
REC	50010250	S	4.8–7.6	2.9–5.9	1.7–5.2	1.4–5.2	1.3–4.8	1.6–4.9
		W	7.6–16.1	5.4–14.4	3.7–13.8	2.5–14.5	3.2–12.8	2.1–14.8
REC	50010610	S	5.1–7.1	3.4–5.4	1.8–4.6	1.5–4.3	1.1–4.1	1.5–3.7
		W	7.9–15.2	6.4–13.2	5.7–12.4	5.2–12.5	6.1–11	7.1–11.6

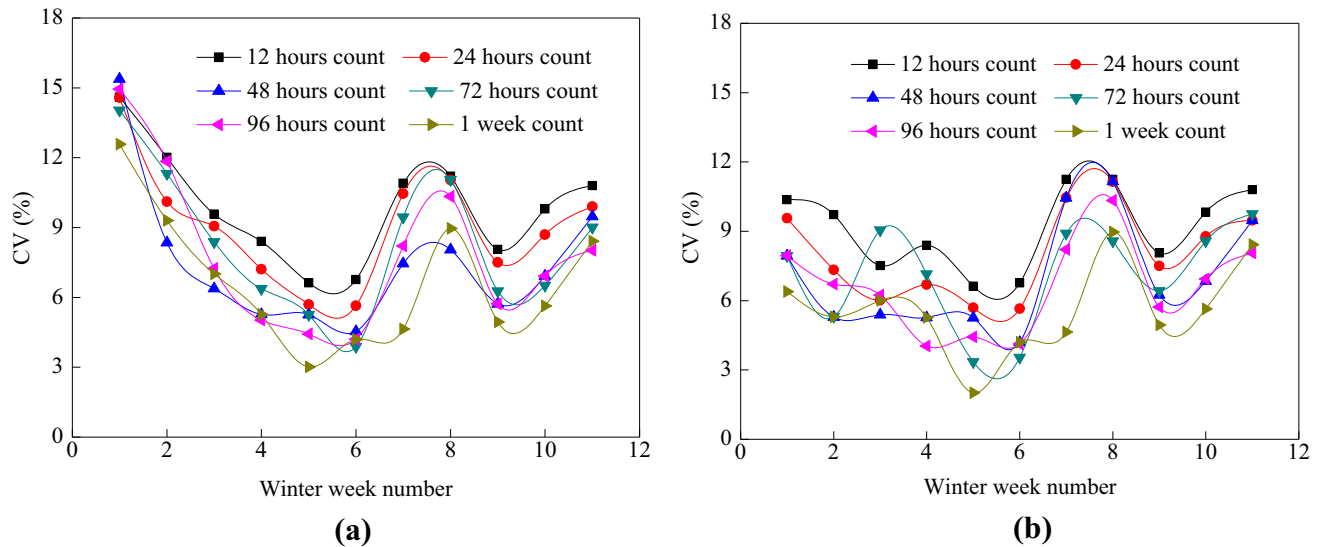
35% were below  $-20$  °C. The average daily temperature varied from  $-30.3$  to  $7$  °C and from  $-35.8$  to  $0$  °C in the first and second weeks of the available study period, respectively. Similarly, for RLD-50030610, the CV rose up to 11% from 6% (see Fig. 1b) due to a heavy snowfall (20 cm) and consequent extremely cold temperatures in the eighth week of the winter in 1998. The average values of the CV for all SDCs are presented in Table 5 of Appendix 1.

Summer counts showed a relatively steady pattern of weekly traffic, whereas winter counts showed many significant troughs and peaks of coefficients from the same study site. Figure 2 shows the variations in CV values during summer and winter, accounting all the SDCs for RLD60221850 site. It is clear that the summer counts are more stable than the winter counts (significant rise and falls). For this site, the variation in coefficients for summer

counts did not go beyond 6%, and for winter counts it was more than 12%. The CV values for most of the cases considering all the study sites were well within 4% for summer counts; however, for winter counts, the coefficients increased to as high as 15.5%.

## 5.2 Effects of counting interval

The average CV values were determined from all the weeks for different durations of counts taken during the summer and winter seasons at each study site. The variations of CV values for all SDCs at COM60023210 are presented in Fig. 3. It is obvious from Fig. 3 that the coefficients of variation for 12- and 24-h counts are appreciably higher than those for 48-h counts for both the commuter (COM60023210) and regional commuter



**Fig. 1** CV values for all SDCs during winter for **a** RCOM60200260 and **b** RLD50030610

(RCOM60200260) sites. Thus, 48-h counts seem to be the most cost-effective duration of count. The same results were noted for the remaining sites.

### 5.3 Effects of road type

It is shown in Fig. 2 that the lowest value of CV results from counts taken at the commuter site. For example, 48-h counts taken during summer months result in CV values of 2.25% and 4.1% for the commuter and regional commuter site, respectively. It was found that the CV value resulting from 48-h count is the lowest at all the commuter sites. The highest values are observed for recreational sites. Intermediate values of CV result for counts taken at regional commuter and rural long-distance sites. It was also observed that the 12- and 24-h counts taken at commuter sites produce CV values, which are only slightly higher (less than 1%) than those for longer duration hours. For recreational sites, this difference could be more than 3%. The average values of CV for counts taken at commuter sites and regional commuter sites with durations longer than 24-h do not exceed 5% and 6.5%, respectively, during winter months. For this reason, highway agencies might find it acceptable to carry out counts during the winter at commuter and regional commuter roads.

### 5.4 Effects of season

The CV values for the short-period counts taken during the summer season are considerably less than those for counts taken during the winter season for all sites and duration of counts. The differences between the values of CV for traffic counts taken during the summer and winter seasons are different from site to site. However, these gaps are not

affected by the duration of counts. The higher values of CV for the winter season are indicative of a larger temporal variation in traffic volume due to changing weather conditions. There is a higher variation in CV values for the recreational study sites than the commuter study sites, whereas the rural long-distance and regional commuter sites have intermediate variations in CV values. This is most likely because recreational roads serve a larger portion of discretionary trips, which have a high tendency for trip adjustment (the avoidance or postponement of trips) due to weather conditions during winter months; this is unlike commuter roads, which serve unavoidable (non-discretionary) trips most of the time.

### 5.5 Effect of rainfall on summer SDCs

The strength of the correlation between short-period traffic counts and the amount of rainfall on the days the counts were taken was tested using Pearson correlation test [22]. Only 24-h counts on weekdays were considered because the precipitation data were made available on a daily (24-h) basis, and 24-h counts were taken only during regular weekdays (Monday–Thursday). Rain events were not considered as they occurred in the confinement of a particular duration of the day in which they occurred, but the day as a whole is considered to be a “rainy day” due to that event or events. Figure 4 shows scatter plots of 24-h traffic volume factors (daily traffic volume divided by AADT) versus daily precipitation (rainfall) during summer months for commuter and recreational road types.

The graph in Fig. 4a suggests no clear evidence ( $r = -0.023$ ) of an impact of rainfall on weekday’s traffic volume for commuter site. The same interpretations were observed for regional commuter and rural long-distance

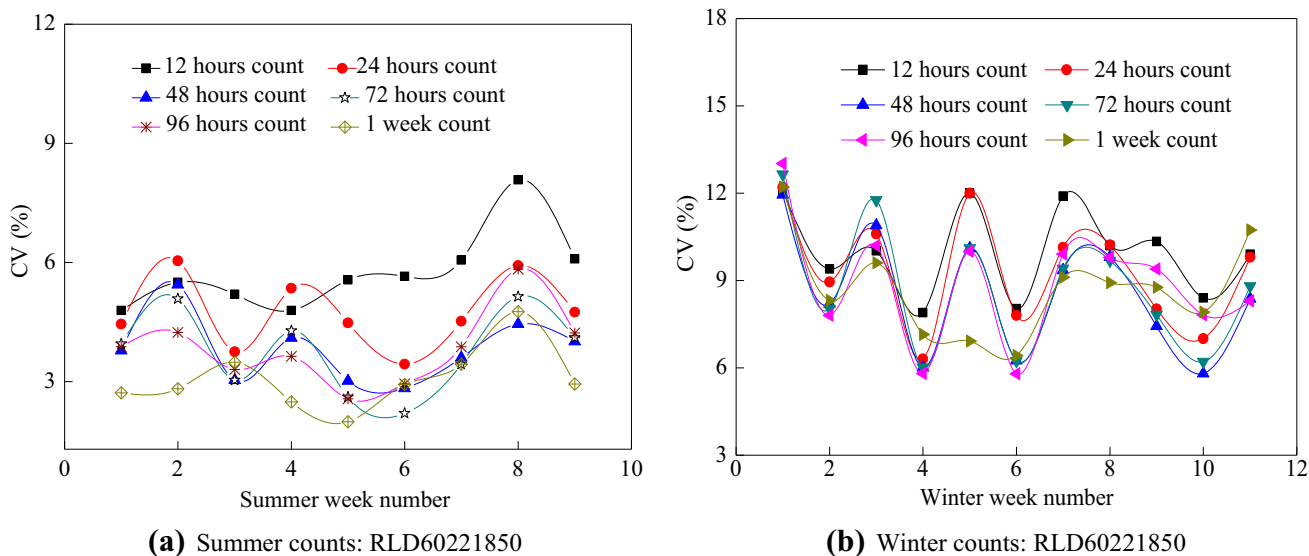


Fig. 2 CV values for all SDCs during summer and winter for RLD60221850

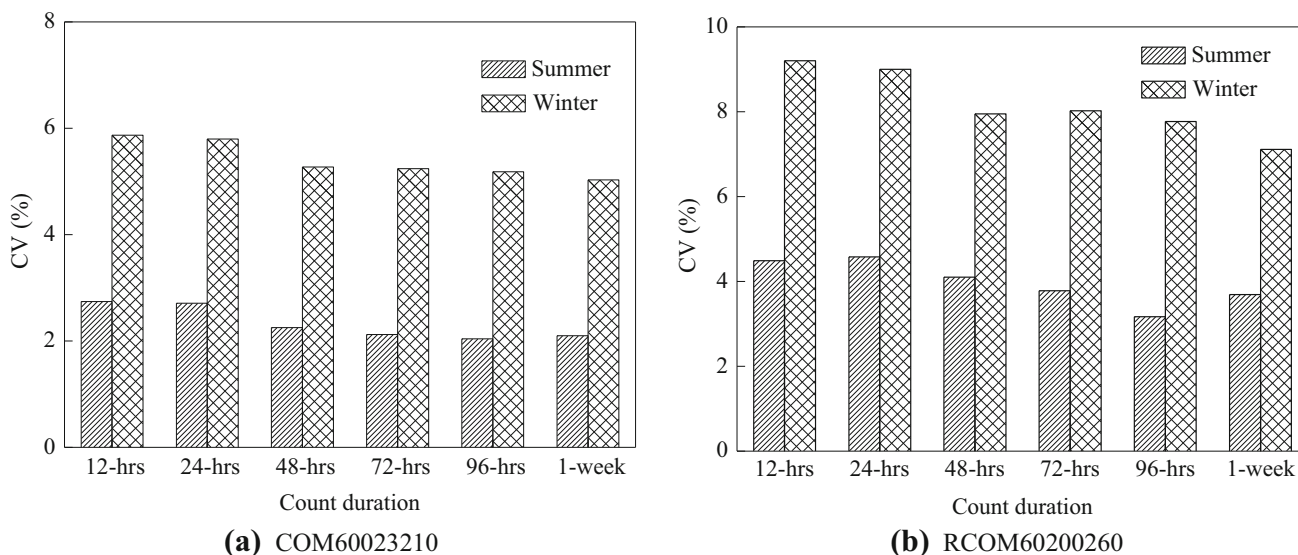


Fig. 3 Average CV values for all SDCs during summer and winter months

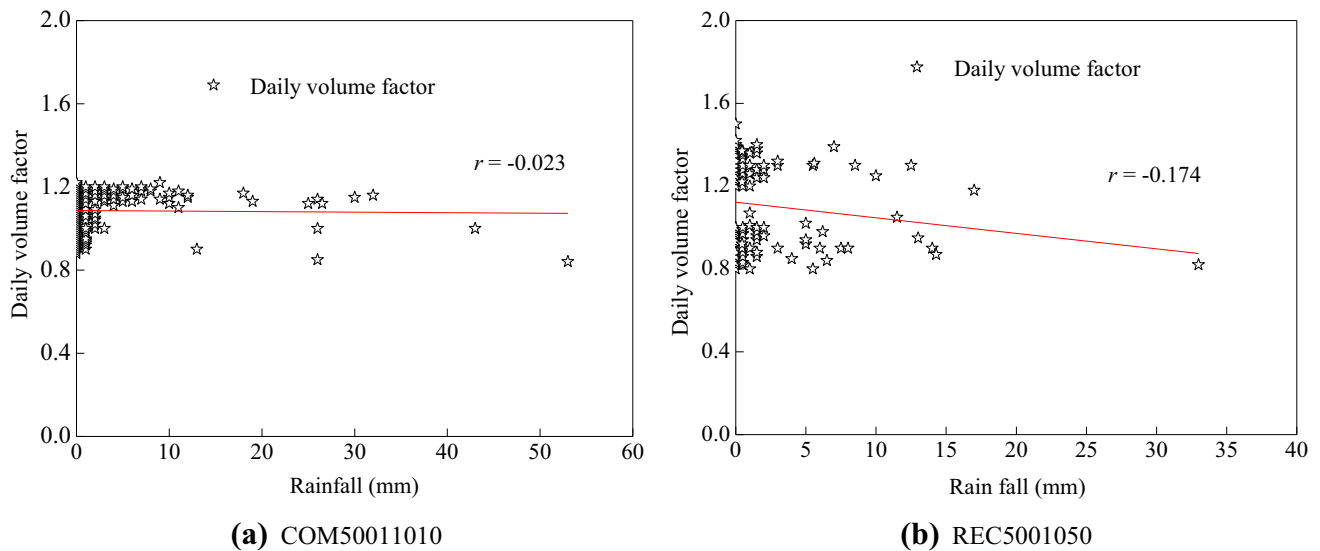
road types. The recreational site shows (see Fig. 4) a slightly negative correlation between traffic volume and rainfall events because rainfall events have a tendency of affecting discretionary trips more than non-discretionary trips.

### 5.6 Effect of snowfall and temperature on winter SDCs

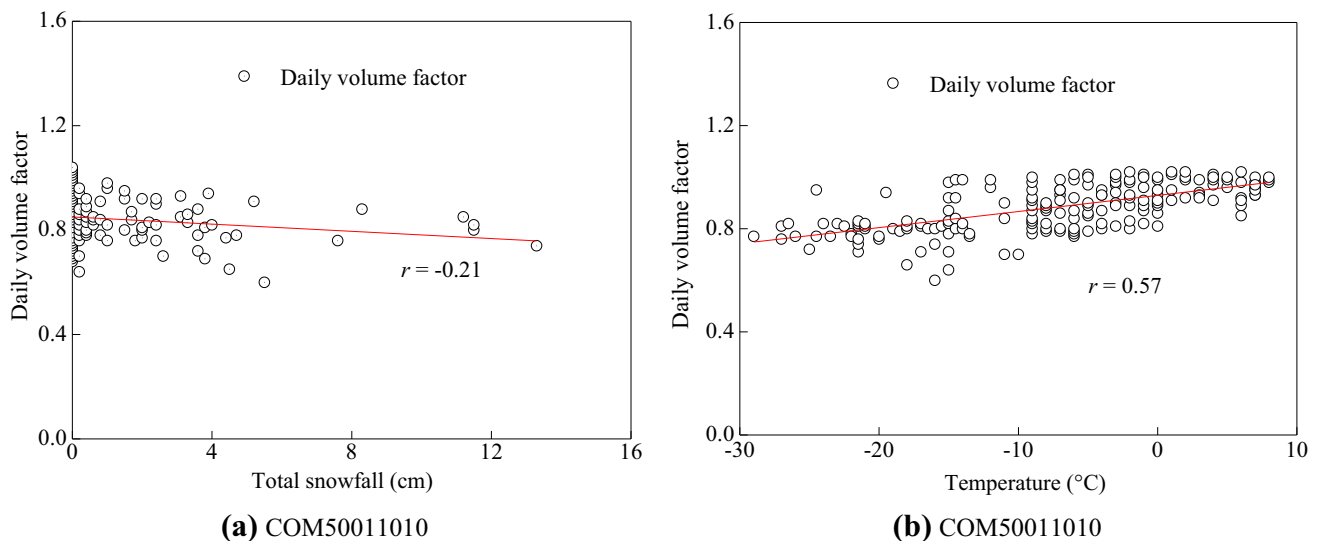
The effects of snowfall and cold temperature on the short-duration counts taken during winter months are also examined. It should be noted that no attempt was made in this research to identify particular snowstorm events (or

events of a severe nature) in this period. Similar to the analysis of rainfall impact on SDCs, the relationship of total (24-h) snowfall or average daily temperature versus corresponding 24-h counts for each road type was studied. Figure 5a shows that the effect of snowfall on winter 24-h count is stronger than the effect of rain on summer count for the commuter site. Figure 5b reveals the strength of correlation between the average daily temperature and daily traffic count for the same site. Similar results were found for all other study sites. The degree of correlation may vary from site to site, but it was observed that generally cold weather tends to have a similar effect on all study sites.





**Fig. 4** Effect of rainfall on 24-h traffic counts during summer months



**Fig. 5** Effects of snowfall and temperature on winter month 24-h traffic count

As discussed earlier, because of the severity of winter weather conditions, traffic volume during winter months fluctuates much more than that of the summer. From the study data, the traffic volume in each study site was found to be lower during winter months than summer months. Table 4 shows the percentage reduction in traffic volume of 24-h traffic counts on weekdays during winter months in comparison to the 24-h weekday traffic counts during summer months. It indicates that the largest reduction in traffic volume is at recreational sites, whereas the least reduction in traffic volume is noted for commuter sites. In spite of the possibility of taking traffic counts during winter, the accuracy in determining AADT based on these counts may not be as much as the accuracy of counts taken

during the summer months. Because of the snow and cold effect on winter counts, it is required to apply the adjustment factors to improve the accuracy of winter SDCs.

## 6 Application of adjustment factor to remove the effect of cold and snow from SDCs

To adjust the effects of cold and snow, two types of adjustment factors were used: (1) weather factors or percentage reduction (PR) factors and (2) hourly, daily, and monthly factors (HF, DF, and MF). The data from PTCs were used to develop daily, hourly, and monthly factors using Eq. (1), which are then applied to short-

**Table 4** Percentage reduction in 24-h traffic volume during winter months

Study site	Reduction (%)	Average reduction (%)	Study site	Reduction (%)	Average reduction (%)
COM50011010	27.52	19.64	RCOM50011850	27.56	26.58
COM50161860	17.11		RCOM50160650	25.28	
COM60021810	27.78		RCOM60021060	27.61	
COM60023210	15.33		RCOM60200260	25.88	
RLD50030610	32.55	30.44	REC	43.61	47.03
RLD50270670	24.83		REC	46.74	
RLD60221610	30.50		REC	50.74	
RLD60221850	33.89				

term counts in order to estimate AADT. Datla and Sharma [8] developed a multiple regression model (traffic–weather model) to estimate the reduction in traffic volume due to cold weather and snow during winter months. We applied their calibrated model by incorporating weather factors or percentage reduction (PR) factors along with hourly, daily, and monthly factors to accurately estimate AADT from short-period counts (12-, 24-, 48-, 72-, 96-h, and 1 week counts) taken during the winter season.

The PR factors due to the effect of snow and cold were calculated for all study samples from each road type. The factors were applied to the daily volume factors to compensate for the positive or negative effect of cold weather and snowfall on traffic volume. The coefficients of variation were re-calculated after the application of adjustment factors for all short-period count durations. Figure 6 shows the coefficients of variation for COM50161860, RCOM50011850, RLD60221610, and REC50010050 sites for all count durations during the winter months before and after the adjustment factors for cold temperatures and snow were applied. The graphs show that there are differences between summer and winter coefficients of variation for all durations of short-period counts. It can be seen that the application of adjustment or percentage reduction factors narrows these differences. Similar results were observed for the remaining sites.

The change in the coefficients of variation after the applications of adjustment factors for all count durations during the winter months is presented in Table 6 of Appendix 2. It is evident from the table in Appendix 2 that the application of adjustment factors for snow and cold reduces the coefficients of variation by 8%–43%. However, in general, the actual reduction in the coefficient of variation depends on the type of road and a particular site within a road type. Such reductions in the values of CV may be attributed to site-specific conditions such as geometric features, the pavement conditions, winter maintenance operations, and the geographic location of the site.

## 7 Conclusions

Several research studies have been conducted in the past on the accuracy of AADT estimates resulting from short-period traffic counts during the spring and summer months. Short-duration counts (SDCs) are very important to the state and national transportation agencies as it supports AADT estimation. Winter SDCs are equally central as summer SDCs for planners and designers for conducting mechanistic empirical pavement design analysis. In a typical situation where the deteriorated pavement during winter requires to be redesigned either for rehabilitation or for new construction, designers or highway project managers need not to wait till summer for SDCs. The winter SDCs can be considered for the pavement rehabilitation design, and this process can expedite the execution of pavement construction. However, there is hardly any research conducted on the consistency and potential accuracy of such counts taken during any period of the year including winter months. For this reason, the present study focuses mainly on the effects of weather conditions on the accuracy of short-period traffic counts. The consistency of short-period traffic counts of different durations (12-, 24-, 48-, 72-, 96-h, and 1 week) is expressed in terms of CV. The study results indicate that the values of CV are affected by the duration of counts. It is obvious from the results of this study that 48-h counts result in the values of CV that are lower than the values for 12- and 24-h counts but are comparable to the values of CV for the higher duration of counts. In addition, the overtime wage rules in Canada at present will increase the personnel cost of the 72-h count by 1.7 times than 48-h counts. For 96-h the cost will increase by 2.4 times than the cost of 48-h counts. Therefore, surveys for short-duration counts for 48-h will be reasonably accurate and cost-effective [23].

In general, the lowest values of CV result from counts taken at commuter sites and the highest values are observed for recreational sites. Intermediate values of CV result for counts taken at regional commuter and rural long-distance

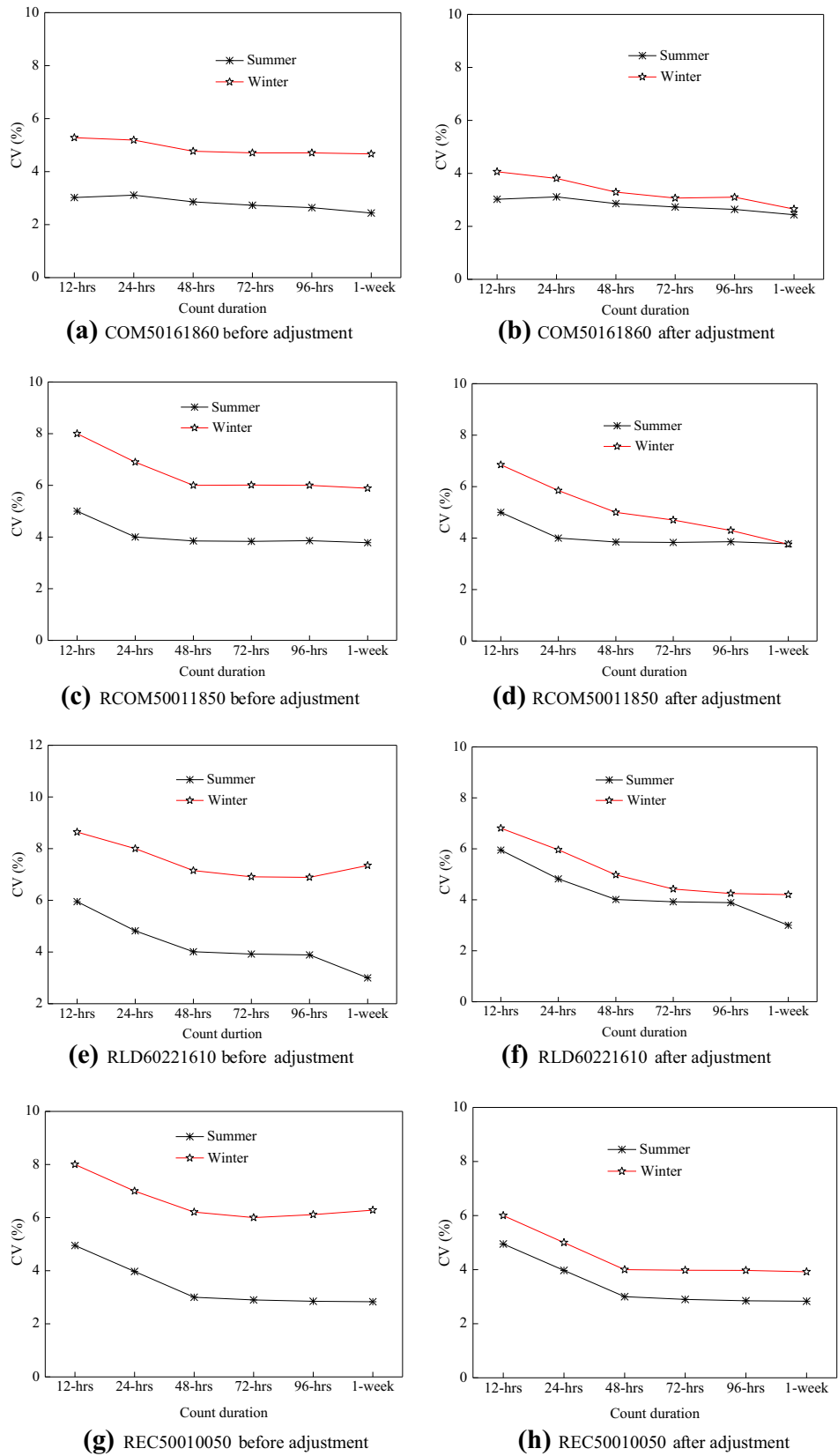


Fig. 6 Summer and winter CV values before and after adjustment

sites. There is an appreciable increase in the coefficient of variation for counts taken during winter months as compared to those for counts taken during summer months. The differences between the values of CV for traffic counts taken during summer and winter seasons are different from one site to another.

Only 24-h counts on weekdays could be investigated in relation to rainfall. The correlation between daily rainfall and 24-h traffic counts reveals that there is no clear evidence suggesting an effect of rainfall on short-duration traffic counts. The results indicate that total daily snowfall has little effect on short-period traffic counts taken on any type of road site. The reason could be the fact that the duration and time of occurrence of snowfall during the 24-h period may influence the hourly distribution of traffic volume rather than the total 24-h volume. Further investigations using detailed information such as the time, intensity, and duration of snowfall are needed to understand the effects of snowfall on winter SDCs. For example, a heavy snowfall during the night will have a different effect on a SDC than similar snowfall during peak hours of the day. Such detailed analysis is not in the scope of this study due to data limitations.

There is a large reduction in traffic volume during winter months. For example, the average reductions in 24-h counts for various types of roads are: 47.03% for recreational, 30.44% for rural long distance, 26.58% for regional commuter, and 19.64% for commuter study sites. As compared to the snowfall, there is a much stronger correlation between traffic volume and average daily temperature during winter months, which indicates that very low temperatures in the winter season can significantly affect traffic volume counts. It is for this reason that the CV is larger during winter months for all durations of counts. The differences between the values of CV for counts taken in the summer season and for those taken in the winter season are the highest for the counts taken at recreational study sites; they are the lowest for the counts taken at commuter sites. Intermediate differences result for the counts taken at regional commuter and rural long-distance study sites. The application of percentage reduction factors or adjustment factors for snow and cold, which are adopted from the traffic–weather model developed by Datla and Sharma [2, 18–20], can reduce the coefficients of variations for all counts taken during winter months. In general, 8%–43% reduction in the CV can be achieved by applying these percentage reduction factors. It is believed that the findings of this study can lead highway agencies to increase the cost-effectiveness of their short-period traffic counting programs.

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## Appendix 1

See Table 5.

**Table 5** CV for different durations of short-period counts at study sites

Road group	Counter	Season	Coefficient of variation (%)					
			12 h	24 h	48 h	72 h	96 h	1 week
COM	60021810	S	3.11	2.52	2.05	1.85	1.84	2.31
		W	7.31	5.93	5.11	4.87	4.83	5.24
COM	60023210	S	2.74	2.71	2.25	2.12	2.04	2.10
		W	5.87	5.80	5.27	5.24	5.18	5.03
COM	50011010	S	3.77	3.20	2.68	2.53	2.40	2.74
		W	6.89	6.52	5.97	5.77	5.72	5.79
COM	50161860	S	3.02	3.11	2.86	2.73	2.64	2.44
		W	5.28	5.19	4.77	4.71	4.71	4.67
RCOM	50011850	S	4.96	4.15	3.59	3.50	3.35	3.24
		W	8.02	6.76	6.06	5.88	5.90	5.63
RCOM	60021060	S	4.22	3.47	2.73	2.50	2.31	2.51
		W	7.88	7.45	5.90	5.61	5.43	5.44
RCOM	50160650	S	4.94	4.41	4.07	3.95	3.80	4.18
		W	8.43	7.90	7.51	7.39	7.32	6.47
RCOM	60200260	S	4.49	4.58	4.10	3.78	3.17	3.69
		W	9.20	9.00	7.95	8.02	7.77	7.11
RLD	50030610	S	5.02	3.74	2.85	2.59	2.78	2.71
		W	9.35	8.10	7.21	6.79	6.61	5.62
RLD	60221610	S	5.62	4.62	3.92	3.67	3.65	3.07
		W	8.77	7.93	7.07	6.88	6.83	7.33
RLD	60221850	S	5.76	4.75	3.91	3.83	3.80	3.07
		W	9.99	9.49	8.63	8.75	8.80	8.69
RLD	50270670	S	4.64	3.95	3.24	3.06	3.04	2.64
		W	8.39	7.65	6.94	6.79	6.89	5.91
REC	50010050	S	4.99	3.73	2.91	2.84	2.86	2.71
		W	7.99	7.04	6.42	6.21	6.24	6.77
REC	50010250	S	5.62	4.10	3.05	2.78	2.82	2.72
		W	10.83	8.55	7.58	7.37	7.96	7.70
REC	50010610	S	5.92	4.37	3.25	2.80	2.65	2.48
		W	11.48	9.96	8.83	8.38	8.87	8.85

## Appendix 2

See Table 6.

**Table 6** CV values for winter SDCs before and after the application of adjustment factors

Road group	Counter	Season	Coefficient of variation (%)					
			12 h	24 h	48 h	72 h	96 h	1 week
REC	50010050	Before	7.99	7.04	6.42	6.21	6.24	6.77
		After	6.20	5.01	4.22	3.96	3.92	3.85
REC	50010250	Before	10.83	8.55	7.58	7.37	7.96	7.70
		After	9.13	6.93	6.09	5.89	6.42	4.98
REC	50010610	Before	11.48	9.96	8.83	8.38	8.87	8.85
		After	10.58	9.07	7.91	7.42	7.83	7.61
COM	60021810	Before	7.31	5.93	5.11	4.87	4.83	5.24
		After	6.63	5.05	4.14	3.90	3.99	4.13
COM	60023210	Before	5.87	5.80	5.27	5.24	5.18	5.03
		After	4.37	4.18	3.60	3.47	3.40	3.11
COM	50111450	Before	8.77	9.80	9.23	9.54	9.59	8.71
		After	7.76	8.61	8.08	8.34	8.45	7.44
COM	50161860	Before	5.28	5.19	4.77	4.71	4.71	4.67
		After	4.06	3.81	3.29	3.07	3.10	2.65
RCOM	50011850	Before	8.02	6.76	6.06	5.88	5.90	5.63
		After	7.05	5.64	4.95	4.61	4.53	3.91
RCOM	60021060	Before	7.88	7.45	5.90	5.61	5.43	5.44
		After	6.85	6.23	4.58	4.24	4.06	3.96
RCOM	50160650	Before	8.43	7.90	7.51	7.39	7.32	6.47
		After	7.29	6.73	6.33	6.11	5.88	5.06
RCOM	60200260	Before	9.20	9.00	7.95	8.02	7.77	7.11
		After	7.91	7.58	6.41	6.39	6.21	5.28
RLD	50030610	Before	9.35	8.10	7.21	6.79	6.61	5.62
		After	8.09	6.43	5.45	4.94	4.89	3.95
RLD	60221610	Before	8.77	7.93	7.07	6.88	6.83	7.33
		After	6.92	5.88	4.92	4.56	4.54	4.65
RLD	60221850	Before	9.99	9.49	8.63	8.75	8.80	8.69
		After	8.32	7.63	6.61	6.57	6.54	6.01
RLD	50270670	Before	8.39	7.65	6.94	6.79	6.89	5.91
		After	6.88	6.09	5.34	5.11	5.13	3.97

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