Day-of-Year Scaling Factors and Design Considerations for Non-motorized Traffic Monitoring Programs

Steve Hankey
Department of Civil Engineering, University of Minnesota
500 Pillsbury Dr. SE, Minneapolis, MN 55455
Email: hank0126@umn.edu
Phone: 612.625.2397
Fax: 612.626.7750

Greg Lindsey*
Humphrey School of Public Affairs, University of Minnesota
130 Humphrey School, 301 19th Ave. S, Minneapolis, MN 55455
Email: linds301@umn.edu
Phone: 612.625.0669
Fax: 612.625.3513

Julian Marshall
Department of Civil Engineering, University of Minnesota
500 Pillsbury Dr. SE, Minneapolis, MN 55455
Email: julian@umn.edu
Phone: 612.625.2397
Fax: 612.626.7750

*Corresponding author

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ABSTRACT

Background: General procedures for non-motorized traffic monitoring programs, including estimation of annual average daily traffic (AADT) from short-duration counts, have not been established.

Methods: Year-2011 continuous counts of non-motorized traffic were collected at 6 locations on the off-street trail network in Minneapolis, MN. We demonstrate a new approach – use of day-of-year factors – for estimating AADT from short-duration counts and illustrate how analyses of variability in count data can be used to design a monitoring program using both continuous and short-duration counts of non-motorized traffic.

Results: We have 5 core results that may be useful for developing non-motorized monitoring programs:

1. Day-of-year scaling factors have smaller error than the standard method (day-of-week and month-of-year) in estimating AADT, especially from shorter-duration (<1 week) counts.
2. Extrapolation error decreases with short-duration count length, with only marginal gains in accuracy for counts longer than one week.
3. Error in estimating AADT is lowest when short-duration counts are taken in summer (or spring-summer-fall) months (April-October).
4. The impact of sampling on consecutive (e.g., 5 successive days) vs. non-consecutive days (e.g., 5 separate days) on AADT estimation is minimal but may reduce labor requirements.
5. The design of a traffic monitoring program depends on the acceptable error, equipment availability, and monitoring period duration. Tradeoffs in length of short-duration counts and accuracy of estimates will depend on resource constraints.

Policy implications: Analysts can use day-of-year factors to improve accuracy of AADT estimation. Analyses of variability in traffic counts can strengthen the design of monitoring programs.

1. INTRODUCTION

Traffic counts are the foundation of transportation planning programs. Over the past several decades, the Federal Highway Administration (FHWA), state departments of transportation (DOTs), and local governments have established and funded comprehensive networks for counting motor vehicles in each state. These agencies have also developed standard procedures for monitoring, analyzing counts, identifying traffic patterns, extrapolating short-duration counts, and estimating traffic volumes at locations where counts have not been taken (*1*). The estimates of traffic volumes from these monitoring programs are used for many purposes, including planning, guiding investments, and establishing maintenance priorities.

In North America, similar monitoring networks have not been established for non-motorized traffic. Despite efforts to understand non-motorized traffic that date back to the 1970's (*2, 3*) or earlier, planners still lack the tools and data necessary to plan for non-motorized travel (*4*). Most research to date has focused on site-specific effects on non-motorized traffic such as weather (*5, 6*) as well as neighborhood demographic and built environment characteristics (*7-9*); relatively less research explores traffic patterns on networks (*10*). Since efforts to develop non-motorized transportation are growing (*11, 12*), the need for robust, local programs that count cyclists and pedestrians across networks is also increasing. For planners interested in non-motorized travel, consistent methods of data collection and analysis that enable better descriptions of non-motorized traffic patterns (e.g., estimates of bicycle miles traveled) are needed.

In Europe and other countries outside of North America, where non-motorized mode share is higher, research on non-motorized travel has focused on similar topics. For example, researchers in Berlin, Germany have counted bicycles continuously since at least 1983 and have shown that daily bicycle traffic varies systematically with temperature, precipitation, and duration of sunshine (*13*). Studies from Australia, the U.K., and New Zealand also focus on how weather and neighborhood characteristics affect non-motorized traffic volumes (*14-16*). Studies in the Netherlands (*17*) and Sweden (*18*) have shown that bicycle crashes are inversely correlated with bicycle volumes. Surveys are a tool frequently used to estimate mode share and explore travel behavior (*19-22*). A report from the Swedish National Road and Transport Research Institute recommends use of both surveys and traffic counts to track two common policy goals: (1) mode share of bicycles and pedestrians and (2) trends in non-motorized traffic volumes over time (*21, 22*).

Although research in non-motorized traffic monitoring is growing, standard methods have not been adopted in the US by federal, state, or local agencies (*23*). Key questions remain on best practices for virtually all elements of monitoring, including methods to scale short-duration non-motorized traffic counts to estimates of Annual Average Daily Traffic (AADT) (*24-28*). The FHWA recently published the first chapter on non-motorized traffic monitoring in its authoritative Traffic Monitoring Guide (TMG) (*1*). This chapter, which is based on standard procedures for monitoring motor vehicle traffic, recommends a combination of permanent reference sites and mobile short-duration sites to characterize spatial patterns in traffic. Automated, continuous counts from the reference sites are classified into factor groups and used to develop scaling factors. Two scaling factors for motor vehicles are typically constructed: (1) month-of-year (ratio of average monthly traffic to AADT) and (2) day-of-week (ratio of average day of week traffic to AADT). The scaling factors are applied to a larger number of short-duration counts to estimate traffic on a street network. The State of Colorado and a number of cities, including San Diego, San Francisco, and Portland, have initiated non-motorized traffic monitoring programs based on this approach, but general factor groups and procedures for factoring have not been validated. Because non-motorized traffic varies more in response to weather than does motorized traffic and since weather varies regionally within states, extrapolation factors specific to different municipalities or regions will be needed.

Researchers recently have addressed three key issues in non-motorized traffic monitoring: (1) the length of short-duration counts needed to minimize error in extrapolation, (2) the identification of factor groups based on hourly traffic patterns, and (3) the development of adjustment factors for bicycle traffic. Nordback et al. (*27*) used data from a monitoring network in Boulder, Colorado to develop guidance for short-duration monitoring. They show that short-duration counts of at least 1 week are satisfactory for minimizing the magnitude of error when using the standard scaling factor approach for motor vehicles (i.e., day-of-week and month-of-year factors) and that extrapolation error is minimized when monitoring occurs between April and October. They recommend that short-duration counts be at least 24 hours long, preferably one week or longer, and corroborated findings from the TMG that data from at least 5 reference sites be used to develop factors. Miranda-Moreno et al. (*29*) explored hourly bicycle traffic patterns at 37 locations in 5 cities and derived four classifications: (1) utilitarian, (2) mixed-utilitarian, (3) mixed-recreational, and (4) recreational. This classification scheme can be used to define factor groups for developing scaling factors. Using multiple years of monitoring data from Vancouver, Canada, El Esaway et al. (*10*) have shown that use of weekend and weekday factors produces results comparable to seven day-of-week factors, that integration of weather considerations in factors improves estimates, and that the reliability of factors degrades over time.

We expand on these findings by (1) illustrating a new method for scaling short-duration counts and (2) showing how a limited number of continuous count sites can inform efficient design of monitoring networks. Specifically, we introduce a day-of-year scaling factor (i.e., a scaling factor for each specific day of the year; applicable to that year only) as an alternative to the standard scaling factors (i.e., month-of-year and day-of-week). Following Nordback et al. (*27*), we explore the effect of the length and month of short-duration counts on estimation of AADT. We also demonstrate how taking short-duration counts on consecutive or non-consecutive days impacts AADT estimates. We then illustrate the implications for design of a comprehensive monitoring program for a 78-mile (126-km) trail network in Minneapolis, MN.

2. DATA AND METHODS

Since late 2010, continuous counts of non-motorized traffic have been collected at 6 locations on the off-street trail network in Minneapolis, MN using TrailMaster active infrared monitors. Procedures used to collect, adjust, validate, and aggregate counts are described by Wang et al. (*30*). Briefly, the monitors record a count any time the infrared beam is broken; therefore, counts reported here are for mixed-mode traffic (i.e., cyclists and pedestrians combined). Traffic volumes for 2011 varied by an order of magnitude across sites (Table 1).

[Insert Table 1]

2.1. Example Of Classifying Locations In Factor Groups

We classified our sites in factor groups using previously published indices (*29*). Here, we perform this classification as an example; in the analyses that follow in subsequent sections (e.g., length and month of short-duration counts) we present results based on pooled scaling factors (i.e., no factor groups) because our sample size is small (i.e., 6 count sites) and to be consistent with Nordback et al.'s (*27*) recommendation to use at least five continuous reference sites when calculating scaling factors. Furthermore, Miranda-Moreno et al. (*29*) defined locations based on bicycle traffic; here, we apply their method for mixed-mode trail traffic.

Following criteria established by Miranda-Moreno et al. (*29;* Table 2), we classified the sites by four factor groups: (1) utilitarian, (2) mixed-utilitarian, (3) mixed-recreational, and (4) recreational. The approach by Miranda-Moreno et al. uses two traffic indices: (1) relative index of weekend vs. weekday traffic (WWI) and (2) relative index of morning (7-9am) to midday (11am-1pm) traffic (AMI):

$$WWI = \frac{V_{we}}{V_{wd}} \quad (1)$$

$$AMI = \frac{V_{am}}{V_{mid}} \quad (2)$$

where V_{we} is mean daily weekend traffic volume, V_{wd} is mean daily weekday traffic volume, V_{am} is mean morning (7-9am) traffic volume, and V_{mid} is mean midday (11am-1pm) traffic volume. Both AMI and WWI are meant to identify sites where traffic is either utilitarian or recreational. For example, sites with a low WWI would likely be utilitarian since weekday traffic exceeds weekend traffic. Similarly, a location with a high AMI would also be classified as utilitarian since high morning peak-hour traffic (as compared to midday traffic) would indicate largely commute-based traffic. AMI uses the morning peak-hour rather than the afternoon peak-hour since the afternoon peak-hour likely includes post-work recreational traffic.

[Insert Table 2]

2.2. Month-Of-Year And Day-Of-Week Vs. Day-Of-Year Scaling Factors

The method used for extrapolating short-duration counts of motor vehicles typically involves using two scaling factors to estimate AADT: (1) month-of-year and (2) day-of-week. We propose a new scaling factor (day-of-year) to better account for the greater day-to-day variability in non-motorized traffic. Instead of averaging count data across the day-of-week and month-of-year, we calculate 365 separate scaling factors specific to each day of the year. Importantly, day-of-year scaling factors apply to one year only, and are not necessarily applicable across years. This approach accounts for peaks and lows specific to certain days (e.g., poor weather, holidays) that may be missed when data are averaged across longer time periods. This approach also should improve performance for shorter duration counts since the scaling factors are specific to each day. A limitation of scaling factors for non-motorized traffic is that they are only applicable to the city-region where the data are collected; differing weather patterns in various regions make it difficult to transfer scaling factors from one region to another. Figure 1 shows the day-of-year scaling factors (new method) along with the day-of-week and month-of-year scaling factors (standard method) for year-2011.

[Insert Figure 1]

2.3. Short-Duration Counts: Sample Duration And Month

Following Nordback et al. (*27*) we analyzed error in AADT estimates associated with various lengths of short-duration counts. Any given monitoring location will have day-to-day variability in traffic counts because of weather, individual traffic behavior, among other variables. In general, the error associated with extrapolating from short-duration counts should decrease as the length of the short duration count increases. Our analysis aims to find the point of diminishing return for estimation error as the length of the short-duration count increases. First, we randomly pulled count periods (n=50) from year-2011 counts as a basis for the analysis. We calculated an average scaling factor for each location and count period based on an average of the other 5 locations. We then scaled the short-duration counts to AADT and compared to the actual AADT for that location. Mean absolute error was calculated for comparison. We repeated this analysis for short-duration count periods of 1 day, 3 days, 1 week, 2 weeks, and 1 month. We performed this analysis for both the standard method of deriving scaling factors and the new day-of-year method.

We also explored the impact of taking short-duration counts during different months on estimation error. For each count period length we stratified our random sample by month to assess if some months seemed to be better for estimating annual traffic. Again, we repeated this analysis for all count period lengths (1 day, 3 days, 1 week, 2 weeks, 1 month) and both methods of scaling to AADT. We then estimated equipment needs associated with different short-duration count lengths.

2.4. Design Scenario: Planning a Short-Duration Count Campaign In Minneapolis

As a practical example of the decisions needed to implement a comprehensive monitoring program for any traffic network, we created a design scenario for a hypothetical short-duration monitoring program on the Minneapolis off-street trail network. The aim of the program is to estimate annual miles traveled for the entire trail network. We discuss the process of choosing monitoring segments and developing protocols for count length and scaling to estimates of AADT for each segment when monitoring must be completed in a specific amount of time. In this scenario counts will be collected over 7 months at 78 locations and 125 monitoring sites (because bike and pedestrian traffic is separated at some locations). Using these assumptions we calculated the number of counters necessary to complete the monitoring campaign for different short-duration count lengths.

We also explored whether sampling on consecutive or non-consecutive days had an impact on error in estimated AADT; for example, whether five (temporally separate) samples of duration one day would be preferable to one sample of duration five days. We present AADT estimation error and the additional labor needed to complete a sampling campaign where counters are relocated more frequently.

3. RESULTS

Our analysis is tailored to inform decisions on how to plan a monitoring program for the trail network in Minneapolis. As described next, we have five main conclusions:

1. Day-of-year scaling factors result in smaller error than the standard factors (day-of-week and month-of-year) in estimates of AADT, especially for shorter duration (< 1 week) counts.
2. Extrapolation error decreases with the length of the short-duration counts, with only marginal gains in accuracy for counts longer than one week.
3. Extrapolation error is lowest when short-duration counts are taken when volumes are highest; here, in summer (or spring-summer-fall) months (April-October).

4. The impact of sampling on consecutive vs. non-consecutive days on AADT estimation is minimal, but sampling on consecutive days likely reduces labor requirements and is more efficient.
5. The design of a traffic monitoring program depends on the acceptable error, equipment availability, and monitoring period duration. Tradeoffs in length of short-duration counts and accuracy of estimates will depend on resource constraints.

3.1. Example Of Factor Group Classification For Reference Sites

We calculated WWI and AMI for each location and found that our locations fall in two categories: Mixed-utilitarian and mixed-recreational (Table 3). Although we explored the feasibility of applying our methods separately for these two factor groups, we report here pooled results for all six locations because the AMI in these two categories overlap and separation of the reference sites into two groups would not meet the minimum number of locations for factor groups recommended by Nordback et al. (*27*). Although the variation in traffic across sites is comparable (see Figure 1), pooling factor groups may increase estimation error at some sites. As monitoring occurs at more sites, use of separate factor groups may be feasible. Because monitoring has not occurred on other segments, we are not able to determine whether any sites in Minneapolis fall in the other two categories (utilitarian, recreational). To establish a more robust reference site network, continuous counts should be added in five or more locations for all factor groups.

[Insert Table 3]

3.2. AADT Estimation Error And Short-Duration Count Length

As described above, we used 50 random count periods (1 day, 3 day, 1 week, 2 weeks, 4 weeks) to explore the impact of short-duration count length on AADT estimation error. We calculated mean absolute error among locations and count periods for both methods of scaling counts to AADT (Figure 2). We found that the day-of-year scaling factors had smaller AADT estimation error than the standard factors (month-of-year and day-of-week). This effect was especially pronounced for shorter count periods and attenuated as the count period approached 1 month. For example, the error in AADT when extrapolating from one day counts using the new method was slightly over 20%; the error using the standard method was nearly 40%. Similar to Nordback et al. (*27*) we also found that 1 week seemed to be the point of diminishing return for minimizing error from extrapolation.

To illustrate the greater need for resources to implement longer short-duration counts (or the limitations associated with the availability of portable counters for short-duration counts), we plotted the number of portable counters needed to complete the short-duration counts at 78 trail locations (assumptions: 125 monitoring sites [because of separated traffic]; one visit per site for each short-duration count length; relocation of monitors takes 1 day) within a monitoring period of seven months. For example, if only 2 counters are available, the maximum length of short-duration counts possible within the seven month limit would be three days. With this constraint, the expected estimation error in AADT would be 15% using the day-of-year factors and 27% using the standard factors. The plot in Figure 2 also illustrates how an analyst can estimate equipment needs to obtain desired levels of accuracy within fixed monitoring periods. For example, to achieve an error of 11%, short-duration counts would need to be 2 weeks in length, and 8 portable counters would be needed.

[Insert Figure 2]

3.3. Deploying Short-Duration Counts In Different Months

We explored the impact of sampling in different months on AADT estimation error by stratifying the results from our random sample by month (Figure 3). We repeated this analysis for both the standard and new methods of scaling to AADT. We found the day-of-year scaling factors performed better than the standard factors. The difference is larger for the shorter count periods; as the count duration increased, the difference between results using the standard and new scaling methods diminished. AADT estimation error across months was nearly equal for the two scaling methods for the multi-week count durations.

For both methods, error in estimated AADT was greater during times of year when weather patterns are most variable in Minneapolis (early spring and late fall). AADT estimation error was lowest in summer and near-summer months. Use of the day-of-year scaling factors seemed to stabilize the error during summer and near-summer months to a ~10% error for the medium to longer count durations. Based on these results, short-duration counts are best undertaken during April-October using the day-of-year factors. This finding corroborates results obtained by Nordback et al. (*27*) using the standard factors.

[Insert Figure 3]

3.4. Design Scenario: Planning a Count Campaign In Minneapolis

For this design scenario we discuss (1) choosing segments for short-duration counts and (2) exploring tradeoffs between short-duration count length and labor requirements. The design scenario shows that data from a small number of continuous count sites can inform decisions about how and where to develop larger-scale monitoring programs for non-motorized traffic.

3.4.1. Choosing Trail Segments For Sampling

To locate counters and estimate AADT and miles traveled, the network must be divided into distinct segments with consistent traffic flows. Since no counts currently exist on most of the network, segments for this example were chosen using local knowledge of trail traffic. We consulted staff members at the Minneapolis Park and Recreation Board (MPRB) and the City of Minneapolis and used our own knowledge of trail traffic to choose segments. Break points were typically assigned where there were feeder facilities (e.g., streets with bicycle facilities) or where there were natural generators of trail traffic (e.g., parks or beaches).

We identified 78 segments that averaged 1 mile (1.6 km) in length, including sites with the reference monitors (range: 0.28-1.8 miles [0.45-2.9 km]; Figure 4). Because users can access trails from informal access points as well as intersections, and because we have limited information on traffic levels between monitoring points, we do not know whether traffic flows on these individual segments are consistent, nor whether 78 segments is the optimal number. However, for Minneapolis available evidence suggests that mile-long segments are a reasonable starting place. Allocating count sites is likely best undertaken as an iterative process; future monitoring would provide more data and potentially a stronger basis for site selection. In motorized vehicle monitoring, traffic segments are determined iteratively through examination of variation of traffic flows through a network link. MnDOT has established criteria for determining traffic segment breaks (*31*) that consist of acceptable relative changes in traffic flow for ranges of motor vehicle AADTs (e.g., for AADTs between 1,000 – 4,999, increases in traffic along the segment of more than 20% call for a break). On the Midtown Greenway, given there is only a 2% variation in non-motorized AADT between the Cedar and Hennepin monitoring sites, it is reasonable to assume flow between the sites is consistent. Given the large (~120%) difference in flow between the W. River Parkway and Cedar sites, subdividing into one or more segments is appropriate. Future work could usefully include field validation by monitoring different points within a segment, to determine within-segment consistency in traffic flows.

[Insert Figure 4]

3.4.2. Estimating Feasibility Of Various Short-Duration Count Lengths Given Constrained Resources

We next performed a scenario analysis to explore how best to implement short-duration counts and what length of counts would be possible. Our calculations assume the following:

1. All 78 trail segments must be monitored at least once within a single monitoring period.
2. Sampling will occur during months with the lowest mean AADT estimation error (April-October [210 days]; Figure 3).
3. Six sets of monitoring equipment are available for short-duration counts in addition to the six reference locations.
4. Owing to separation of bicycle and pedestrian traffic, some segments will require multiple counters (1 counter: n=47; 2 counters: n =27; 3 counters: n=4) and a 10% sub-sample of the segments (1 counter: 5; 2 counters: 2; 3 counters: 1) will be re-sampled for internal validation. The total number of monitoring sites is 125.
5. We assume it takes one day to relocate monitors resulting in 21 days lost to relocation per count cycle (i.e., time to count all segments).
6. Relocation of portable counters requires 8 hours or one person-day.

Longer-duration, consecutive-day counts necessitate few samples per location; shorter-duration, non-consecutive counts allow more temporally-separate samples at each location. To test whether it is better to choose longer or shorter count periods, we constructed 9 scenarios. For each scenario we use day-of-year scaling factors to calculate mean AADT estimation error and the proportion of days used to relocate monitors. Count cycles (i.e., the length of time needed to sample all segments) were repeated until the 7 months expired. For example, for a 1-day count period, 5 count cycles could be completed in 7 months; for a 5-day count period, 1 count cycle could be completed in 7 months. To simulate the 1-day count period (Scenario 1) we randomly selected 5 days from each reference location between April and October and estimated AADT based on those observations. This process was repeated for each location and scenario (Table 4).

[Insert Table 4]

Figure 5 shows mean absolute AADT estimation error and time required for relocation in each scenario. There is little difference in the mean error among scenarios suggesting that the choice of sampling in consecutive or non-consecutive days is not significant. However, more labor is required with relocating the monitors multiple times when choosing to sample with shorter durations. For example, 50% of the days are spent relocating counters in Scenario 1 vs.

10% of days in Scenario 9 (Table 4). Furthermore, more count data are collected in Scenario 9 than in scenario 1 (Scenario 9: 1,121 count-days; Scenario 1: 623 count-days). This analysis does not include a margin for error that may be important for unexpected events such as lost data, vandalism, human error, or other problems that may arise. To account for contingencies, it may be best to choose a shorter count duration (e.g., 1 week) that allows for extra sampling time if needed and only slightly increases the time required to relocate monitors.

[Insert Figure 5]

4. DISCUSSION

Our analyses show that use of day-of-year scaling factors results in lower error in estimates of AADT than are obtained with standard day-of-week and month-of-year factors, especially for estimates from short-duration counts of one-week or less. Our analyses corroborate and generalize Nordback et al.'s (*27*) findings that errors in estimates of AADT are minimized when short-duration counts are taken between April and October and that short-duration samples of more than one week result in only marginal improvements in estimates of AADT. We also showed that short-duration counts taken on consecutive days rather than randomly selected days produce similar estimates of AADT when using the day-of-year scaling factors, indicating that analysts can minimize labor costs by conducting short-duration counts on consecutive days. Our results highlight the need to customize monitoring strategies for local monitoring networks. We illustrated an example of how this can be done for a 78-mile (126-km) trail network in Minneapolis.

The approach proposed here, which employs day-of-year scaling factors, has several limitations, including the following:

1. Day-of-year scaling factors can be used only in metropolitan areas with similar daily weather patterns and not across larger regions or states. Additional research is needed to determine the geographic scale over which day-of-year factors can be used. That scale may vary across regions within states.
2. Day-of-year scaling factors are useful only for the year for which they are calculated. This means they are not as general as the factors used in the standard approach. From a practical perspective, whether this matters depends on the overall monitoring scheme and schedule for producing estimates of AADT. As long as continuous monitoring sites are operating, day-of-year factors that are year-specific can be produced. If short-duration counts are taken annually, then accurate estimates of AADT can be made. In many cases, the improvements in accuracy may warrant use of day-of-year factors. If resource shortages preclude taking continuous counts in a given year, use of standard factors may be necessary (though less accurate).
3. Day-of-year factors can only be applied ex-post, following the end of a calendar year when all daily reference site counts have been recorded. This aspect has practical implications. Use of the standard approach enables state DOTs to post estimates of AADT as soon as short-duration counts have been taken because the estimates reflect general or average traffic patterns. For example, if a state DOT verifies a 48-hour count of vehicular traffic taken in April, it can post the updated AADT immediately because the factoring calculations are embedded in its software. Whether delay poses a problem depends on the urgency of the need for estimates and their accuracy. In many cases, such

as allocation of resources for maintenance, the tradeoff may be warranted. In addition, it may be possible to combine use of day-of-year factors with the standard approach to produce estimates in a more timely way, and then revise those estimates after the end of the year. This type of hybrid approach would likely need multiple years of continuous data to estimate the proportion-of-year factor since there will be year-to-year differences in length of the non-motorized travel season.

A limitation of our example, but not our method, is that we estimated day-of-year factors for combined factor groups (i.e., mixed-recreational and mixed-utilitarian). We did so because there currently are only six reference monitoring sites for this network. In practice, the number of continuous reference sites needed to enable development of factors for different factor groups depends on the traffic patterns that exist at other locations in the network. Factor groups can only be determined iteratively, as data are obtained from short-duration counts and analyzed, and the variation in patterns across sites is determined. As data for short duration counts are obtained, it likely will be feasible to combine some segments and necessary to break others into shorter lengths. Given the criteria for classification adapted from Miranda-Moreno et al. (*29*) and Nordback et al.'s (*27*) recommendation of five continuous monitors per factor group, 15 reference sites would be needed if recreational locations also exist within the network, and 20 locations if both recreational and utilitarian sites exist. The effect of pooling factor groups likely is to overestimate the error associated with this method of extrapolation. Error can be reduced with refinement of factor groups.

Our scenario illustrates how analysts can work within both time and equipment constraints to maximize efficiency in data collection. This approach involves maximizing the length of short-duration counts, thereby increasing the accuracy of estimates of AADT derived from them. Our example included a seven-month window for short-duration counts, but the number of months or season of year appropriate for short-duration counts may vary regionally or for different weather patterns. Year-round short-duration counts may be feasible, for example, in places with arid or subtropical climates; or, the appropriate seasons for monitoring may be different in new locations. The time required to relocate portable counters is an important figure-of-merit, with the common goal of reducing that time requirement. We estimated person-hours required for relocation but did not include other resource requirements such as travel to monitoring sites, time addressing site vandalism, or time spent maintaining equipment performance; most (but perhaps not all) of these resource requirements may scale proportionally as the number of monitors used increases. Overall, our scenario demonstrated how, with a small number of reference sites and six portable counters, an agency could monitor a 78-mile (126-km) trail network within one year. As more agencies implement comprehensive monitoring programs, their results will add to understanding of program design.

5. CONCLUSIONS

Use of day-of-year scaling factors results in better estimates of AADT than use of standard day-of-week and month-of-year factors because day-of-year factors better account for variations in traffic associated with daily variations in weather and other factors. Analysts with responsibility for non-motorized traffic monitoring programs may want to consider the day-of-year factoring approach, to augment or replace existing approaches. For monitoring programs of pre-determined length (e.g., one year), analysts should monitor when volumes are highest (e.g., April-October in temperate zones) and preferably for a duration of at least one week (although results acceptable for some uses [e.g., ±20%] may be obtained with counts of just 24 hours). By increasing the number of portable counters for short-duration monitoring, analysts can increase the efficiency of monitoring programs. Future research should also focus on validating counting and scaling methods across regions; additional study of comprehensive monitoring programs in other regions is needed to confirm the implications of our design scenario.

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TABLE 1 Descriptive Statistics For Counts of Year-2011 Off-Street Trail Traffic

Location	Valid hours of counts	Annual traffic	AADT	Segment length in miles (km)	Miles traveled (km traveled)
Lake Calhoun Parkway	89%	1,308,643	3,585	1.2 (1.9)	1,583,458 (2,548,329)
Lake Nokomis Parkway	93%	538,448	1,475	1.2 (1.9)	667,676 (1,074,520)
Wirth Parkway	93%	116,765	320	1.5 (2.4)	171,645 (276,236)
Midtown – Cedar	91%	738,336	2,023	1.6 (2.6)	1,151,804 (1,853,648)
Midtown - Hennepin	96%	720,714	1,975	1.6 (2.6)	1,124,314 (1,809,407)
Midtown - West River Pkwy	91%	333,395	913	1.4 (2.3)	480,089 (772,628)

TABLE 2 Classification Criteria For Potential Factor Groups of Reference Sites[a]

Location type	WWI[b]	AMI[c]
Utilitarian	<0.8	>1.5
Mixed-utilitarian	0.8 - 1.25	0.75 - 1.5
Mixed-recreational	1 - 1.8	0.35 - 1
Recreational	>1.8	<0.35

[a]Adopted from Miranda-Moreno et al. (2013)
[b]Relative index of weekend vs. weekday traffic.
[c]Relative index of morning (7-9am) to midday (11am-1pm) traffic.

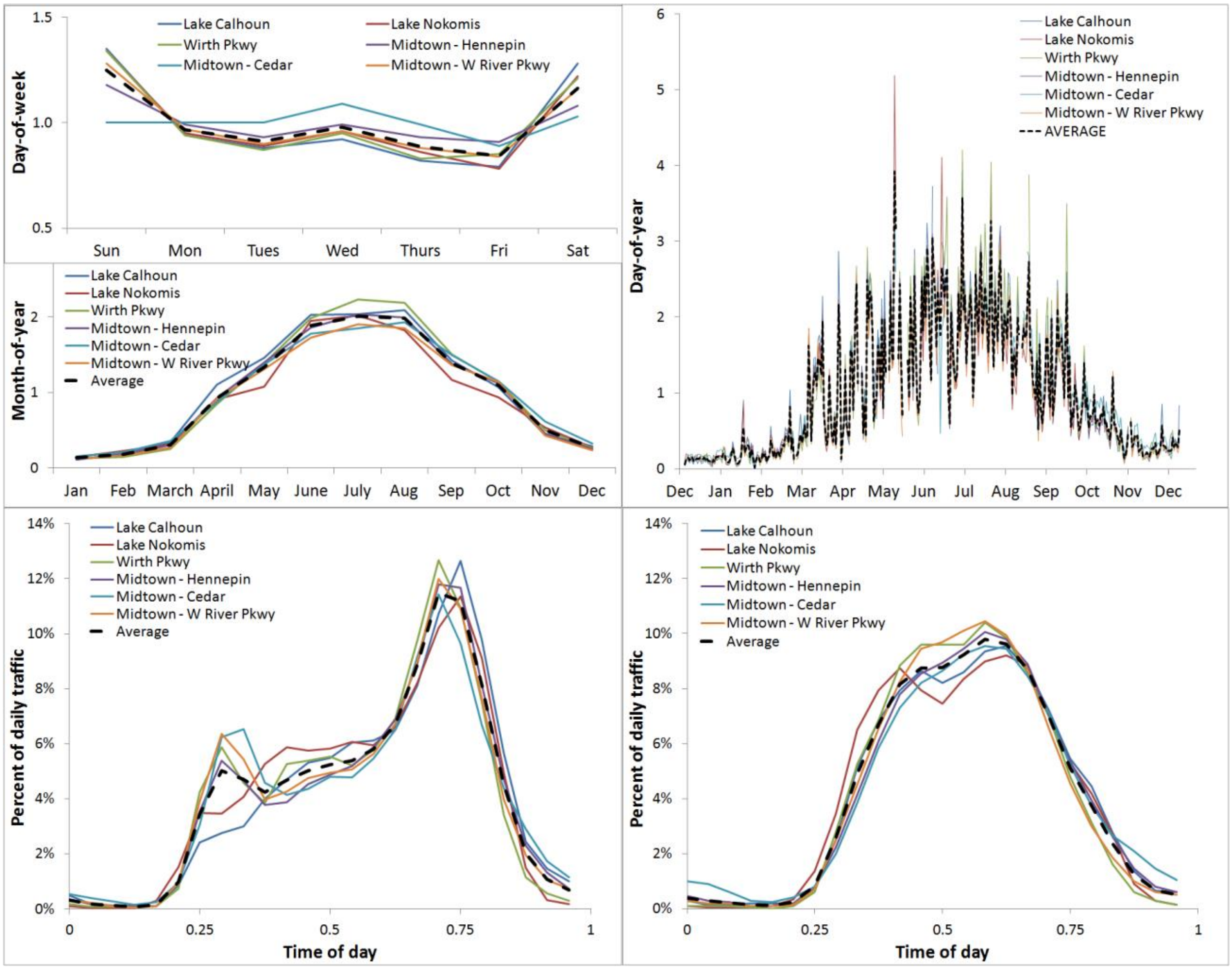
TABLE 3 Factor Groups Available at Current Sites

Location	WWI[a]	AMI[b]	Factor group
Midtown - Hennepin	1.19	0.77	Mixed-utilitarian
Midtown - Cedar	1.02	0.95	Mixed-utilitarian
Lake Calhoun	1.52	0.50	Mixed-recreational
Lake Nokomis	1.45	0.65	Mixed-recreational
Wirth Pkwy	1.44	0.74	Mixed-recreational
Midtown - W River Pkwy	1.34	0.84	Mixed-recreational

[a]Relative index of weekend vs. weekday traffic.
[b]Relative index of morning (7-9am) to midday (11am-1pm) traffic.

TABLE 4 Description of Design Scenarios (Total Available Sampling Days = 210)

	Count period (days)	Count-days per cycle	Days per cycle (w/ relocation)	Number of cycles possible	Relocation days	Total days	Person-hours for relocation
Scenario 1	1	125	42	5.1	105	208	840
Scenario 2	2	249	62	3.4	70	187	560
Scenario 3	3	374	83	2.5	53	166	420
Scenario 4	4	498	104	2.0	42	208	336
Scenario 5	5	623	125	1.7	35	125	280
Scenario 6	6	748	145	1.4	30	145	240
Scenario 7	7	872	166	1.3	26	166	210
Scenario 8	8	997	187	1.1	23	187	187
Scenario 9	9	1,121	208	1.0	21	208	168



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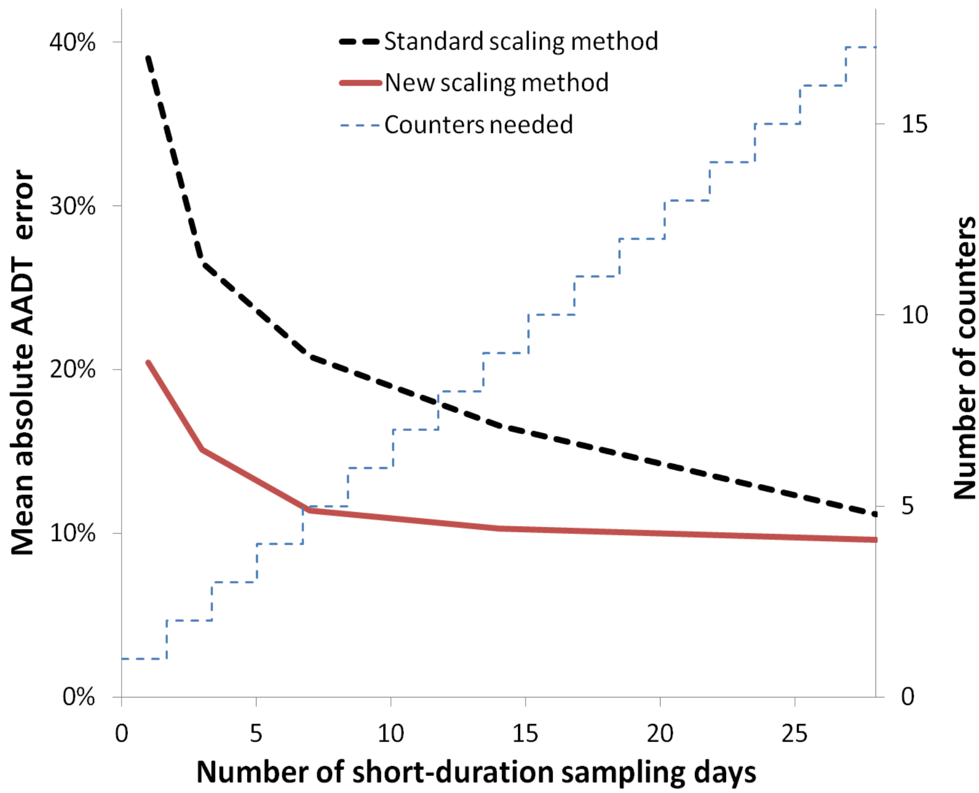

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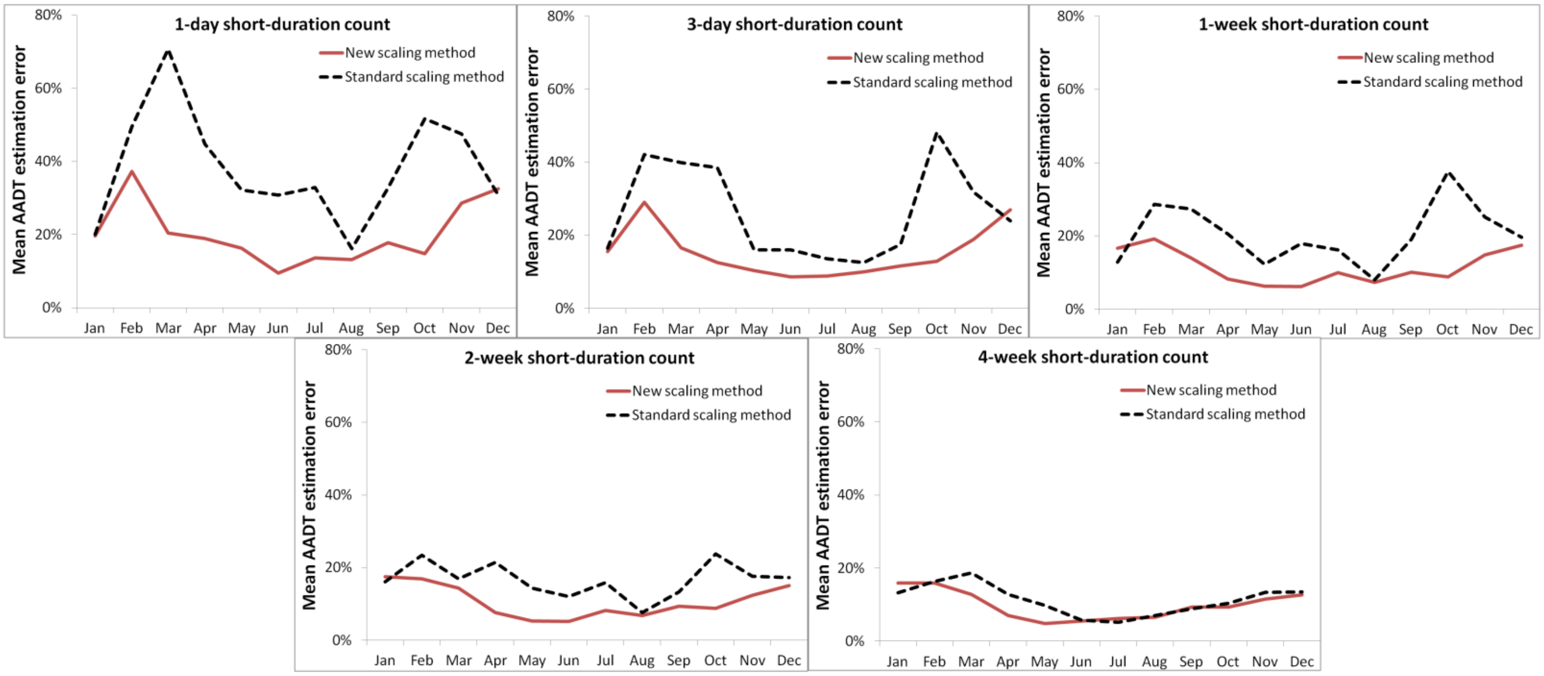

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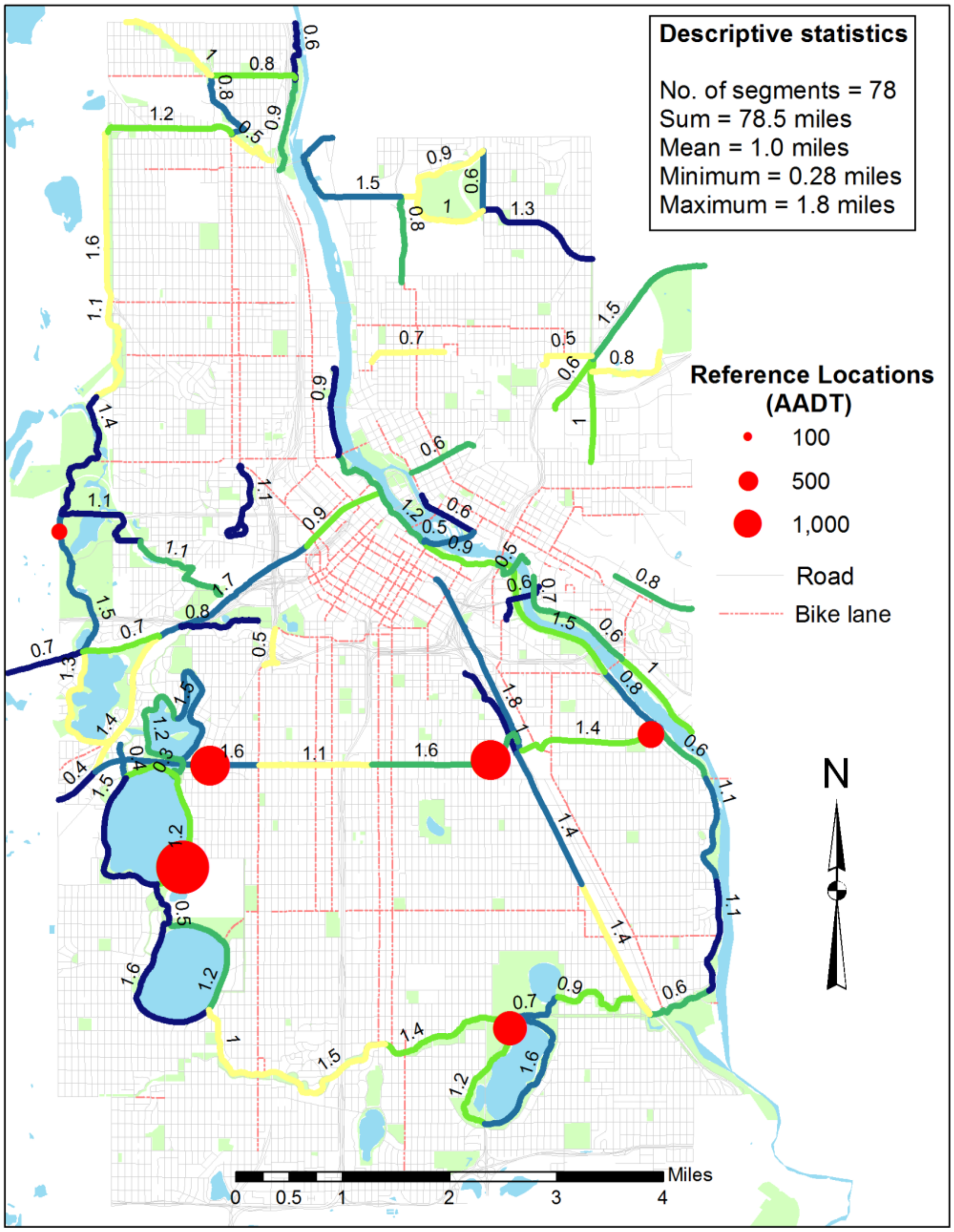

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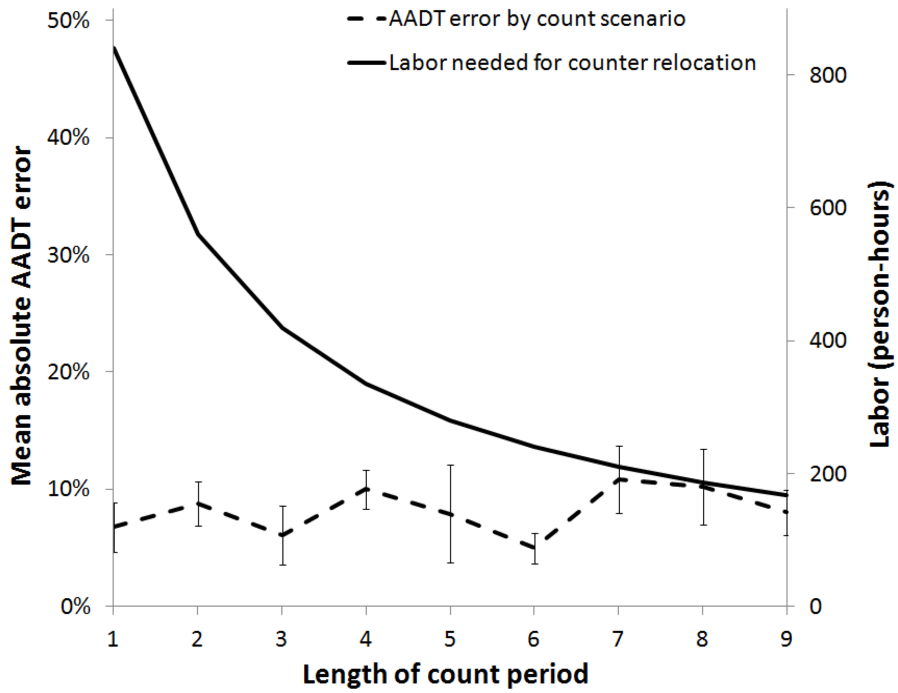

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