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Using Pedestrian Count Models to Estimate Urban Trail Traffic

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Abstract. Many cities are developing multiuse urban greenway trails to be used for recreation, exercise, and transportation. Analysts need many kinds of data about these new trails, but especially trail traffic because of its implications for the efficient allocation of resources for trail management. This paper addresses this need by presenting new information about the use of trails. We adapt and test the validity of a previously reported model that predicts hourly pedestrian crosswalk volume from shorter sampling intervals, and we apply the model to greenway trails. Based on 166 hours of data collection on an Indianapolis, Indiana trail system, we develop expansion equations for sampling intervals of five, ten, fifteen, and thirty minutes. We find that both the equations from the previous study and our new equations provide reasonably accurate hourly predictions. Trail managers can use these findings to make decisions about current trail maintenance and promotion.

1. Introduction

Many cities are developing multiuse urban greenway trails to be used for recreation and exercise, and to a lesser extent, transportation. To encourage these developments, as well as other methods of non-motorized transportation, Congress enacted the Transportation Equity Act for the Twenty-First Century in 1998. In it, Congress authorized $270 million for the U.S. Department of Transportation for the fiscal years 1998-2003 to provide and maintain recreational trails. The Act also allowed for the “consideration of bicyclists and pedestrians in the planning process and facility design” (FHWA 1999). Over time, the FHWA has funded nearly 4,000 trail projects. Trail advocates note that more than 12,500 miles of trails have been established in the U.S. (Rails-to-Trails Conservancy, no date).

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Public officials and trail managers need information about trail traffic to allocate resources for existing and potential trails and evaluate possible new trail sites. There are, however, few available and efficient methods for estimating trail traffic. Although models for predicting for crosswalk pedestrian traffic have been developed, these methods generally have not been applied to multiuse trails (Pushkarev and Zupan 1971; Behnam and Patel 1977; Davis, King and Robertson 1991). It is important that predictive models be developed for trail traffic. Managers can use them to identify areas where traffic is greatest and to make development and maintenance activities more cost-effective.

This paper has several objectives. The first is to describe patterns of use, such as mode of travel, gender, group use, and time of day use, from field observations of two greenway trails in Indianapolis, Indiana. The second is to adapt a modeling procedure developed by Davis, King, and Robertson (1991) for estimating pedestrian crosswalk volume to greenway trails. Our new models developed from trail traffic counts are compared with their models for crosswalk volume and tested for accuracy. Another purpose is to compare the estimates from count models with estimates of traffic from infrared counters that are in place on the trails. The final purpose is to discuss the study's implications for planning.

The paper is structured in five sections, including this introduction. The next section discusses the background behind the study. The third concerns the study's methodology, and the fourth presents the results. The fifth presents conclusions and describes the implications of the study.

2. Background

Multiuse trails have been studied by researchers in the fields of transportation and recreation, among others. Recent studies in the transportation literature have documented the need for research on traffic patterns on greenway trails. In a comprehensive review of studies of trail traffic, for example, Hunter and Huang (1995) found wide variation in their detail and quality and concluded that many of them have not provided representative information that can be used in other applications or locations to estimate traffic. More recently, the Bureau of Transportation Statistics concluded that data about the "number of bicyclists and pedestrians by facility or geographic area" is "poor" and the "priority for better data" is "high" (U.S. Department of Transportation, 2000, p. 45).

Several approaches may be used to obtain data about trail traffic. Continuous manual counts historically have been used to count vehicles, and they have proven very helpful in determining maximum flow rates, capacity limitations, and peak hour volumes. Although continuous counts are highly accurate, they also can be time-consuming, tedious, and inefficient. These counting methods can be adapted to trail traffic, but the same limitations apply.

As part of its effort to address this need for better information, the Federal Highway Administration published the *Guidebook on Methods to Estimate Non-Motorized Travel* (FHWA 1999). The Guidebook describes a variety of approaches, including several Pedestrian Sketch Plan Methods. Pedestrian Sketch Plan Methods are used to estimate existing and future pedestrian volumes. Some of these methods use pedestrian counts and regression analysis to predict these volumes as a function of variables in and around the area in which the study is being conducted. Examples of such variables include adjacent land use, transit volumes, surrounding population and employment, and traffic movements (FHWA 1999). Variables such as trip purpose, trail availability and accessibility, seasonal and temporal travel patterns, weather, and safety also may be important in explaining trail traffic.

Two Pedestrian Sketch Plan Methods that do attempt to predict traffic volumes from neighborhood characteristics first were reported in papers by Pushkarev and Zupan (1971) and Behnam and Patel (1977). Both teams predicted pedestrian volumes in high-density urban areas based on existing land use. Pushkarev and Zupan (1971) used aerial photography to determine total pedestrian volume in Manhattan during various parts of the day, and then used regression analysis to estimate total pedestrian volume per block. Adjacent land use, distance to transit entrances, and sidewalk and plaza space per block were the independent variables. Similarly, Behnam and Patel (1977) used regression analysis and land use data to predict pedestrian volume per hour per block in Milwaukee. Sidewalk pedestrian counts were used in each study to validate the results. These models allow existing pedestrian volumes to be predicted based on current land use, and future volumes based on future land use. Each of these models, however, is site-specific and difficult to adapt to other locations, partly because significant effort is required to obtain the data required to estimate and validate the models.

More recent studies that address these issues include those by the City of Portland, OR (1994) and Han and Lindsey (2004). City of Portland (1994) developed two indices, the Pedestrian Potential Index and the Deficiency Index, to identify pedestrian trail projects in areas of high-demand and to pinpoint existing areas with serious deficiencies. The former index used three variables – policy factors, proximity to “pedestrian generators” (e.g., schools, parks, commercial areas), and pedestrian potential factors (e.g., mixed use / density and street connectivity) – to determine the likelihood of use (FHWA 1999). Han and Lindsey (2004) present several models for forecasting daily traffic volumes at four locations on the Monon Trail in Indianapolis, Indiana with explanatory variables such as neighborhood demographics, month, day of week, and deviation from long term average weather conditions. They found that month, day of week (i.e., weekday vs. weekend), and weather variables explained approximately 41 percent of the variation in daily trail use, and that location and demographic variables accounted for an additional 47 percent of the variation (Han and Lindsey 2004). The effects were generally in the expected directions: weekend days were correlated with higher levels of traffic, while trail sections in lower income neighborhoods were correlated with lower trail use. Deviations from long term weather conditions had opposite effects depending on the season (e.g., temperatures above normal decreased daily traffic in July and August but increased daily traffic in other months).

One Sketch Plan Method that provides good estimates of trail traffic, can be adapted to other cities, and potentially can provide data to be used in the development of more sophisticated causal models is based on study in Washington D.C. by Davis, King, and Robertson (1991). They found it was possible to predict hourly pedestrian crosswalk volume with relatively high accuracy using expansion models based on short-term manual counts. Specifically, they estimated equations to predict hourly pedestrian volumes in crosswalks from short-term field counts of five, ten, fifteen, or thirty minutes. They found that the middle thirty minutes of an hour provided the greatest accuracy in predicting the value for the entire hour, although sampling the middle five minutes proved the most efficient. The five-minute count was the most efficient because it could produce a rough, but relatively accurate, estimate of total volume in a very short amount of time. The mean hourly percent error for the five-minute intervals was 31.2%, while for the thirty-minute intervals it was 11.9%. Davis, King, and Robertson (1991) recommended a four-step procedure for applying their method and that their method be tested in other cities. Their procedure involves selection of the type of application, selection of count interval, collection of data, and computation of estimated values. They posed the question "Are these models valid in other cities that have different characteristics?" (p. 29), and suggested, "To test the validity of the models developed in this study, data should be collected at several sites for several cities throughout the country" (p. 30). Researchers are developing causal models for forecasting trail traffic, but it remains necessary to develop efficient approaches to obtaining traffic counts as part of field observations.

In addition to researchers in the field of transportation, a number of researchers in the recreational field also have reported on urban trail use (Furuseth and Altman 1991; Moore, Graffe, Gitelson, and Portert (1992), PFK Consulting (1994), Gobster 1996; Lindsey 1999, Lindsey and Nguyen forthcoming). PFK Consulting (1994) reported estimates of annual and monthly use of the Northern Central Rail Trail near Baltimore, Maryland for 1984 to 1994 based on counts of cars in parking lots. They reported an overall increase in attendance from 9,820 in 1984 to 457,540 in 1994 (*8*, p. IV-27). Survey respondents reported walking / hiking (46.6 percent) and biking (40.9

percent) as their primary activities. Gobster (1996) studied 13 multiuse trails in northern and central Illinois and used visitor distance decay functions developed from surveys of users to classify trails as state, regional, or local based on the proportion of users that traveled different distances to use the trails. Activity patterns varied along with type of trail, with local trails attracting more pedestrians and fewer bicyclists than regional trails or state trails.

Researchers estimated total monthly and annual trail use from random, six-minute counts of users on seven greenway segments in Indianapolis in October 1996 and on three segments of another trail in October 1998 (Lindsey 1999). Monthly use on the 10 trail segments ranged from 2,500 to 41,500, while estimates of total annual use ranged from 27,500 to 456,600 (p. 151). Pedestrians (walkers and runners) accounted for 54 percent to 82 percent of respondents; bicyclists accounted for 15 percent to 46 percent. Like other studies (e.g., Furuseth and Altman 1991), surveys showed that trail users were more likely to be well-educated whites with above average incomes. In 2001, the Eppley Institute for Parks and Public Lands conducted a study to measure type of use and total use on six trails throughout Indiana using a combination of infrared trail counts and random user surveys. (Eppley Institute 2001; Lindsey and Nguyen (2004)). They found that walking was the most common type of use on five of the six trails, including the Monon Trail in Indianapolis, where more than 50 percent of named walking as their most common use of the trail.

These studies demonstrate the variability in trail use across sites and the need for additional studies of particular trails to document modes and patterns of use. In this paper we adapt and test procedures developed by Davis, King, and Robertson (1991) in a study of non-motorized traffic on multiuse urban greenway trails in Indianapolis, Indiana. Our findings include models for forecasting hourly traffic from shorter sampling intervals. Although we do not attempt to explain the differences in counts at different locations using land use, demographic, or other variables, our results potentially could be used in the development of more complex explanatory models.

3. Study Location and Methodology

The study location was Indianapolis / Marion County, Indiana. With 40 miles of existing trails and another 146 miles planned, the city is a good choice for a study of pedestrian traffic on greenways. In the early twentieth century, noted landscape architect George Kessler designed a master plan for a system of city parks and trails. The Kessler plan was only partially implemented, but many new parks and parkways were created because of the plan. Indianapolis then renewed its previous dedication to planning park corridors in the early 1990s, when it initiated a greenways planning process.

In 1994, the city adopted a new greenways master plan that since was updated in 1999 and 2002. The plan for the greenways system establishes six main objectives (Greenways Division 2002, p. 1):

- Provide opportunities for recreation and fitness trail activities;
- Protect important wildlife habitat and promote the conservation of open space, forests and wetland areas;
- Link Indianapolis neighborhoods with each other and with parks and other community assets;
- Educate the public about the importance of the natural environment of the Greenways System;
- Become an economic asset to the community by promoting economic development and by making Indianapolis a desirable place where new businesses can locate;
- Redevelop and manage the Marion County Bicycle Routes as part of the Indianapolis Regional Bicycle and Pedestrian Plan, which will connect the Greenways and Parks System to communities with the regional plan.

This study will focus on two of six existing trails: the Monon Trail and the White River Trail. Traffic counts have been taken with infrared counters on the Monon Trail since 2001 and on the White River Trail since 2002.

The study methodology involved four major elements. The first was to count the traffic at four sites on the Monon Trail and two on the White River Trail and to describe the activity patterns at these sites. The second, using data only from the Monon Trail, was to estimate expansion equations for predicting hourly traffic volumes from sample counts for shorter time intervals. The third element involved validating the equations estimated from the Monon Trail counts on the data from the White River Trail and comparing the results to the results from the application of the equations reported by Davis, King, and Robertson (1991). The final step was to compare the traffic estimates from expansion equations to estimates from counts taken by infrared counters.

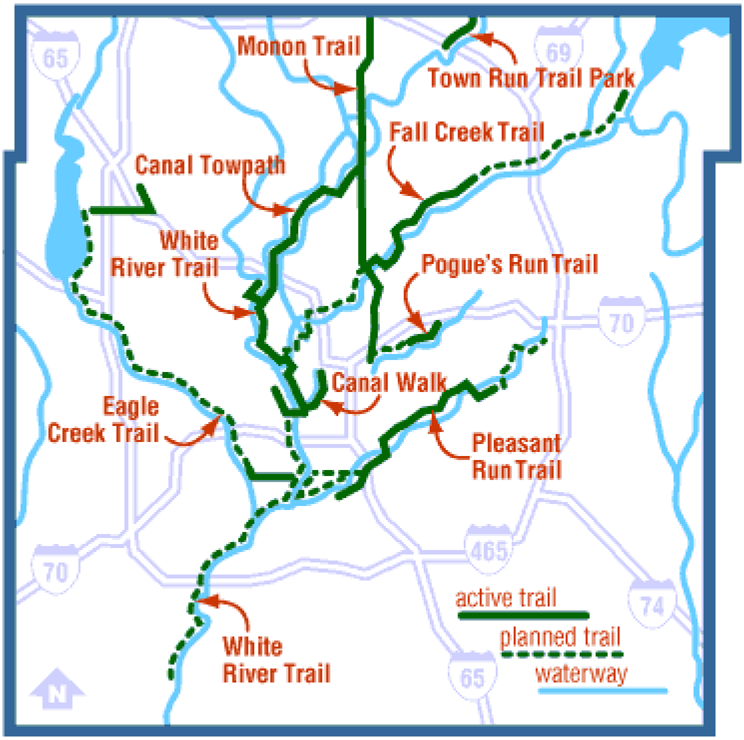

Figure 1. Indianapolis Greenway Trail System (Greenways Division, no date).

Counting Protocols

Key tasks in counting included site selection and determination of procedures and protocols for recording traffic information. Users were counted at the sites of already-existing infrared trail counters so that the accuracy of the infrared counters could be assessed. Data were collected at four locations on the Monon Trail on weekdays between June 12 and 27, 2003 from 7:00 AM to 7:00 PM (Figure 1). Three days of data were recorded at each site. One day on the Monon, however, only ten hours of data were collected because of severe weather conditions. Data to be used as control groups for testing the model equations were collected at two locations on the White River Trail. At the White River sites, counts were taken on both weekdays and weekends and the counting periods were only four hours long.

One or two people conducted the counting depending on previously recorded trail volume, with four people in total collecting data. Categories of data recorded included the number of users, mode of use, people in groups, and gender of users. The counters faced several problems in recording the data. At first, the sheets had included user race and direction of travel, but after trial counts, it was determined that the volume was too great to record all of this information accurately. The two categories mentioned above were eliminated because they were the least relevant to the study. Still, even with these categories eliminated, data collection during peak hours was difficult at most sites. Two counters were generally used at these sites to compensate for the problems presented by a single counter. Two counters were also used most of the time at the 38th St location because of concerns about safety. Female counters were always accompanied by another counter. When two counters were used, they were forbidden from comparing data in order to preserve the integrity of the counts and to obtain measures of counter reliability. Any inconsistencies that occurred had to be examined and reconciled to eliminate any discrepancies before it was officially recorded. Data were collected by hand on specially designed counting sheets and then transferred to a computer.

In sum, 142 hours of data for the Monon Trail were recorded, and 24 hours of data for the White River Trail were obtained. All of the data originally were recorded in five-minute intervals. Later, so that models could be developed for ten-, fifteen-, and thirty-minute intervals, the initial data were aggregated into these intervals. The first, middle, and last ten-, fifteen, and thirty-minute intervals in each hour were calculated, as well as an interval selected randomly within the hour. Two middle five- and fifteen-minute intervals were calculated because the counting sheets were designed in such a way that recording the exact middle five or fifteen minutes was not possible. Instead, the middle five-minute intervals were from 25:00 to 29:59 and from 30:00 to 34:59 and the middle fifteen-minute intervals were from 20:00 to 34:59 and 25:00 to 39:59.

Estimating the Expansion Equations

The second major element of the study was to estimate expansion equations for each of the time intervals. To do this, the data were normalized by applying the natural logarithm function to all of the individual counts. This procedure was done to reduce the skewness of the data. Some of these counts were zero (no people had come by in the time interval). Because the sample size was already small, the value 1 was added to each of these intervals in order to take the logarithm. If this number had not been added, 9.6% of the data would have been unusable.

After the data were normalized, a regression equation was estimated for each interval. Because of the log transformation of the data, the general equation for the line was $\ln y = m(\ln x) + b$. From there, a series of operations using logarithmic properties was performed to establish a general form of the equation that could be used for all of the data:

$$\ln y = m(\ln x) + b$$
$$\ln y = \ln(x^m) + \ln(e^b)$$
$$\ln y = \ln[(x^m)*(e^b)]$$
$$y = (x^m)*(e^b)$$

Testing the Expansion Equations

The equations estimated for each set of time intervals were applied to the White River dataset to validate them. The equations estimated by Davis, King, and Robertson (1991) also were tested on the White River data so that the two sets of equations could be compared. The sets of equations were compared based on each equation's mean hourly percent error and total percent error. The mean percent hourly error for each prediction equation is calculated as:

$$\overline{X} = \frac{\sum_{h=1}^{24} \frac{|P_h - A_h|}{A_h}}{h_{\max}} \tag{1}$$

where:

$\overline{X}$ = mean hourly percent error,
P_h = predicted hourly traffic, and
A_h = actual hourly traffic.

The total percent error is calculated as:

$$T = \frac{\sum_{h=1}^{24} (P_h - A_h)}{\sum_{h=1}^{24} A_h} \tag{2}$$

where:

T = total percent error for the 24 hours of counting on the White River Trail, and P_h, A_h as above.

Comparing Predicted Traffic with Traffic Estimates from Infrared Counters

The final objective of the study was to compare the manually counted values with the values recorded by infrared counters that have been used to count trail traffic on the Monon and White River trails. Protocols for operation of the infrared counters (TRAILMASTER 1500©) are described in Lindsey and Nguyen (2004). The infrared counters consist of a transmitter and a receiver mounted in aluminum utility boxes. The transmitter projects an infrared beam across the trail, and the receiver records an event when the beam is broken. The infrared counters are unable to distinguish among types of users, and traffic counts must be adjusted to account for systematic undercounts associated with users passing counters simultaneously. The adjustment equation, which was obtained by regressing the actual, observed count on the estimate obtained from the infrared counters, is: 1.55*(infrared counter hourly count)-5.22.

4. Results

Characteristics of Trail Traffic

Table 2 includes a summary of the traffic counts for both trails. At the Monon Trail sites, a total of 11,612 users was counted. The most common type of use was bicycling, followed by walking, running and roller-skating. Babies and other users (mainly wheelchairs) made up the remaining difference. On average, there were 82 users per hour, with the maximum and minimum totals being 469 and 5, respectively.

On the White River Trail, 716 users were counted. There were 30 users per hour; the maximum and minimum were 56 and 11, respectively. As on the Monon trail, cyclists made up the largest percentage of users, but at these locations they made up more than 80 percent of the total users.

Based on observations of trail use, it was known that trail traffic included many people traveling in groups, which were defined as two or more people traveling together. On the Monon Trail, observers found that 4901, or 42.2%, of the 11,612 users traveled in groups, usually made up of 2 or 3 people (Table 3). The percentage of people traveling in groups at each of the four locations on the Monon Trail was roughly the same. On the White River Trail, however, a majority of the users – more than 58 percent – traveled in groups.

Previous observations of trail traffic indicated that men were more likely to use the trail than women, especially during the evening. The results of the study confirm these observations. Of the 11,612 users on the Monon Trail, 56.7%, or 6,579, were men and 43.3%, or 5,033, were women. Women, however, outnumbered men during the early parts of the day (8:00-10:00 AM). The proportion of men at the 38th St location was even higher (71.6%), perhaps because of perceived safety or concerns about the area in which the trail is located. The 38th Street location is located in a very poor, racially segregated neighborhood (Lindsey, Maraj, and Kuan 2001). It is also possible, however, that higher proportions of men prefer trail use to other methods of recreation or fitness training.

Table 2. Trail traffic on the Monon and White River Trails.

	Total	Mean hourly traffic	Maximum hourly traffic	Minimum hourly traffic	% Total	Infrared Counter	
Monon Trail						Unadjusted	Adjusted
1 hr. observations	142	82	469	5		142	142
Walkers	2903	20	137	0	25.0		
Cyclists	5188	37	149	1	44.7		
Runners	2103	15	123	0	18.1		
Skaters	964	7	50	0	8.3		
Babies	347	2	15	0	3.0		
Other	107	1	14	0	0.9		
Total traffic	11,612					7875	12,144
White River Trail							
1 hr. observations	24	30	56	11			
Walkers	54	2	7	0	7.5		
Cyclists	592	25	52	6	82.7		
Runners	52	2	10	0	7.3		
Skaters	11	0.5	3	0	1.5		
Babies	3	0.1	1	0	0.4		
Other	4	0.2	4	0	0.6		
Total users	716						

Table 3. Group use of greenway trails.

	Monon Trail	White River Trail
Total groups	2135	170
Total people in groups	4901	419
Total percent of users	42.2 %	58.5%
Average groups / hour	15	7
Max groups / hour	90	14
Min groups / hour	0	1
Average people / group	2.3	2.5
Maximum group size	14	6
Minimum group size	2	2

Expansion Equations for Trail Traffic

Expansion equations were developed for first, middle, last, and random five-, ten-, fifteen-, and thirty-minute counting intervals and compared to the equations developed by the previous study. Table 4 displays these equations. Each equation is given in the form (total hourly predicted value)=(constant)*(number of users per interval)^(constant). In each case, V_1 represents the total hourly predicted value, while the number of users per interval is denoted by an "I" with a subscript of the number of minutes in the interval (5, 10, 15, 30). Although Davis, King, and Robertson (1991) estimated equations for each of these periods, they report only the hourly expansion equations with the best statistical fit. In their study, the equations with the best fit were estimated from data from the middle 5, 10, 15, and 30-minute counting intervals. The percentage of variation in actual traffic explained by these sample counts ranged from 77% for the five-minute counts to 96% for the 30-minute counts.

Table 4. Expansion equations for pedestrian traffic

Counting Intervals (minutes of hour)	Davis, King, and Robertson (1991) Crosswalk Equations: Equations*	Davis, King, and Robertson (1991) Crosswalk Equations: Coefficient of Determination (R^2)	Greenway Equations: Equations*	Greenway Equations: Coefficient of Determination (R^2)
First 5			$V_1=19.274*I_5^{.7197}$	0.62
Mid 5a	$V_1=19.91*I_5^{.7862}$	0.77	$V_1=20.718*I_5^{.7234}$	0.62
Mid 5b			$V_1=19.603*I_5^{.7553}$	0.70
Last 5			$V_1=19.200*I_5^{.7409}$	0.68
Rand 5			$V_1=18.845*I_5^{.7429}$	0.66
First 10			$V_1=10.390*I_{10}^{.7766}$	0.76
Mid 10	$V_1=9.82*I_{10}^{.8465}$	0.86	$V_1=11.901*I_{10}^{.7533}$	0.77
Last 10			$V_1=11.747*I_{10}^{.7334}$	0.78
Rand 10			$V_1=10.577*I_{10}^{.7713}$	0.80
First 15			$V_1=7.593*I_{15}^{.7858}$	0.82
Mid 15a	$V_1=5.75*I_{15}^{.8996}$	0.91	$V_1=7.954*I_{15}^{.7983}$	0.84
Mid 15b			$V_1=7.282*I_{15}^{.8046}$	0.83
Last 15			$V_1=6.691*I_{15}^{.8193}$	0.88
Rand 15			$V_1=8.537*I_{15}^{.7624}$	0.86
First 30			$V_1=3.061*I_{30}^{.8890}$	0.91
Mid 30	$V_1=2.37*I_{30}^{.9625}$	0.96	$V_1=2.41*I_{30}^{.9517}$	0.94
Last 30			$V_1=2.624*I_{30}^{.9196}$	0.94
Rand 30			$V_1=2.82*I_{30}^{.9128}$	0.94

*V_1 = Estimated volume of hourly trail traffic
I_n = Number of users counted during the n-minute sampling interval

For both the crosswalk and the greenway equations, as the time interval increases, the constant term decreases and the coefficient (exponent) increases to approach the value of one. The thirty-minute equations with the best fit have exponents with values nearly equal to one and constant terms less than three. These values indicate that hourly traffic may be estimated from thirty-minute samples simply by doubling the sample count. We illustrate this approximation later.

The greenway equations estimated from the Monon Trail data consistently explained less of the variation in total traffic than the crosswalk equations reported by Davis, King, and Robertson (1991), and the counting interval for the model that fit best was different for each set (Table 4). For the five-minute intervals, the model (V_1=19.603*$I_5^{.7553}$) with the best fit (R^2 = 0.70) was estimated from the second middle five-minute interval. Among the 10-minute intervals, the random ten-minute interval explained the most variation. The equation (V_1=6.691*$I_{15}^{.8193}$) estimated from the last fifteen-minute interval had the best fit in its group (R^2 = 0.88). The middle, last, and random thirty-minute intervals were essentially equivalent, with R^2 values of 0.94.

Accuracy of the Expansion Equations

The Davis, King, and Robertson (1991) and the Greenway expansion equations were applied to the White River data, and the mean hourly percent error (equation 1) and the total percent error (equation 2) were calculated and compared (Table 5). In general, the mean hourly percent errors for the two sets of equations were comparable. For the Davis, King, and Robertson equations, the mean hourly percent error across the time intervals ranged from 26.1% to 101.3%, while the total percent error ranged from 11.6% to 21.6%. The Greenway equations resulted in a mean hourly percent error that ranged from 22.5% to 95.6%, and total percent error that ranged from 0.5% to 36.3%. For example, for the middle ten-minute interval during the 7:00 AM hour on June 13, the Davis et al. equation predicted a total of 51 users, and the equation developed by this study predicted a total of 52 users. The actual total was 25 users. Generally, the equations have limited accuracy when predicting trail traffic for a single hour; however, when the sum of the predicted hourly values was compared to the sum of the actual hourly values, the total percent error was much smaller.

As noted, the constants for the thirty-minute interval equations were slightly above two, and the exponents were nearly one, suggesting that hourly traffic may be estimated from 30 minute counts simply by doubling them. For instance, using the middle thirty-minute interval during the 3:00 PM hour on June 19, the crosswalk equation predicted 77 users, the Greenway equations predicted 75 users, and doubling the middle count predicted 74 users. The actual total was 70 users. The mean hourly percent error for simply doubling the 30 minute counts for the different counting intervals (i.e., the first, last, middle, and random thirty minutes) ranged from 7.5% to 33.9%, and the total percent error ranged from 0.8% to 4.0%.

Table 5. Mean hourly percent error for expansion equations

	White River			
	Davis, King, and Robertson (1991) Crosswalk Equations		Greenway Equations	
Counting Intervals (minutes of hour)	Mean hourly percent error	Total % error	Mean hourly percent error	Total % error
First 5			74.2	+15.2
Mid 5a	101.3	+21.6	95.6	+16.1
Mid 5b			60.3	+7.3
Last 5			68.3	+1.0
Rand 5			58.1	+7.5
First 10			60.9	+26.6
Mid 10	64.6	+15.7	65.9	+18.5
Last 10			49.5	+4.1
Rand 10			65.2	+28.2
First 15			48.4	+24.1
Mid 15a	45.5	+17.7	45.8	+24.1
Mid 15b			38.2	+3.7
Last 15			35.5	+0.5
Rand 15			51.3	+36.3
First 30			30.1	+21.1
Mid 30	26.1	+11.6	24.8	+10.0
Last 30			22.5	-4.3
Rand 30			27.4	+15.6

Accuracy of Infrared Counters

Raw and adjusted counts from the infrared counters on the Monon Trail are compared to estimates produced from both sets of expansion equations and to manual counts in Table 6. The raw total from the infrared counters were 3,737 users less than the manually counted data, a difference of 32.2%. After the predetermined adjustment equation was used to correct for error, the difference between the actual and predicted was an overestimate of 526 users, a difference of 4.5%.

Compared to the infrared counters, the estimates from aggregation of the predicted values using the David, King, and Robertson (1991) crosswalk equations are better. The percentage error for the infrared counters is comparable to the percentage error associated with estimates made from five minute sampling periods, but the error associated with longer sampling periods results in smaller percentage errors than the infrared counters.

5. Conclusions and Discussion

This paper has presented new descriptive information on traffic on two trails in Indianapolis, Indiana; a set of equations that analysts can use to predict hourly trail traffic from sampling intervals of 5, 10, 15, or 30 minutes; comparisons of the accuracy of these expansion equations with equations estimated for pedestrian traffic in crosswalks; and comparisons of the traffic volumes estimated with expansion equations with estimates from infrared counters on trails. Managers and researchers can use these procedures to describe traffic patterns on urban trails, produce information that can be used to improve the quality and efficiency of trail management, and develop causal models of trail traffic.

Table 6. Comparison of Estimates from Manual and Infrared Counts

	Total Users	Total % Error
Manual Counts	11,612	
Davis, et al. Expansion Equation Estimates		
• Best 5 minute interval	11,081	-4.6
• Best 10 minute interval	11,491	-1.6
• Best 15 minute interval	11,554	-0.5
• Best 30 minute interval	11,744	+1.1
Raw Infrared Counts	7875	-32.3
Adjusted Infrared Counts	12,144	+4.5

The information about patterns of trail use is useful, although limited because of small sample sizes, particularly for the White River Trail. While previous studies indicated that pedestrian traffic was greater than cycling traffic, the observations of trail traffic reported here indicate that cyclists account for the largest proportion of trail traffic. An accurate record of mode of use is important because it may affect future planning decisions. For example, a high-traffic area in which cyclists are the dominant users may require the trail to be widened. Mode of use may also be an indicator of the perceived safety of the trail. Previous research indicates that the population in the area around the White River Trail has a lower median income and is generally less educated than the rest of Marion County (Lindsey, Maraj, Kuan 2001). The trail is also located in a less residential area. Trail users may believe that the trail segment is less safe than segments in other neighborhoods. Additional research, however, is needed to provide more definitive information about mode of use.

The study's results indicate that men are more likely to use the trail than women, in-particularly on the White River Trail where men make up over 70 percent of the users. This result may be additional indirect evidence about the perceived safety of the trail. Although previous studies on the greenway system indicate that crime is no more common on greenways than the rest of Marion County (Lindsey, Maraj, Kuan 2001) managers could survey trail users to see if women feel safe using this trail.

A useful finding not previously reported concerns group activity on trails. These observations indicated that between 42 percent and 58 percent of users may be in groups of two or more. This finding indicates there are social dimensions of trail use and has implications for marketing and management of trail systems. For example, managers, seeing the already existing tendency for users to travel in groups, could use this data to actively promote group events on the trail. Events could be targeted at families, and changes could be made to the trail to make it more accessible to large groups of users.

When the Davis, King, and Robertson (1991) crosswalk equations were tested on the data from the Monon Trail, it was found that they provided a reasonable estimate for the number of users. Their equations resulted in a total percent error that ranged from 0.5% to 4.6%. Mean hourly percent error for these equations on the greenways ranged from 16.8% to 52.3%, as compared to a range of 11.9% to 31.2% when they previously were tested on crosswalks. It appears that it is possible to predict greenway traffic using equations for crosswalk volume, although the larger range of error for crosswalk equations may indicate that there are differences in patterns of use on the types of infrastructure. The results clearly indicate that use of the crosswalk equations to predict total trail traffic over extended periods of time is more accurate than predicting data for a single hour.

The expansion equations estimated from field observations on the Monon Trail can be used to estimate trail traffic from samples collected for short time intervals, but the equations reported by Davis, King, and Robertson (1991) for pedestrians in crosswalks perform better. The likely explanation is that they are based on larger samples. When applied to the White River Trail observations, both sets of equations result in relatively large mean hourly percent error. The size of the mean hourly error potentially is a problem is situations where the information needed is an hourly traffic count. An hourly count is important because it allows managers to determine the peak hours of use on the trail. From this, planners can determine the level of congestion at a certain point on the trail and decide whether or not the trail is in need of expansion at that point. One strategy for dealing with this limitation is to take repeat samples at a given time and location.

In this study, total percent error is smaller than mean hourly percent error for both sets of equations. Total traffic counts may allow planners to determine where to allocate resources most efficiently. Highly traveled trails may need more maintenance than trails with less traffic. Conversely, less-traveled trails also may require attention because planners need to determine the best ways to promote an infrequently used trail. In situations where estimates of total traffic are needed, estimates from these equations can be used with greater confidence. Sensitivity analyses can be helpful for addressing issues related to the uncertainty of the estimates.

Comparisons of actual, observed counts with estimates made from expansion equations and infrared counters indicate that both approaches provide estimates that are reasonable and can be used in a variety of applications. The issue of whether it is more efficient to sample or to install infrared counters depends on the type of data needed and site specific factors that influence the difficulty of both approaches. Regardless of the type of data needed, however, it rarely will be necessary to count for more than thirty minutes at a time. Doubling thirty minute counts to predict hourly totals provides an estimate of total use that for practical purposes is equivalent to the values estimated from either the crosswalk or greenway equations. Unless very specific estimates are needed, this approach will be more efficient than continuous counting and sufficiently accurate to warrant its use. Despite these findings, however, more research is needed to determine optimal approaches to obtain data about trail traffic.

While the method of predicting greenway traffic developed in this study is relatively successful, there are ways in which it could be improved. First, more data is needed to improve the accuracy of the equations. An increased sample size will improve the quality of the data and the results. In addition, this approach needs to be validated on other greenway trails. This could occur either in Indianapolis or in different cities. If the results on other greenways are similar to that of this study, then the models developed here would have greater validity.

Another limitation of this approach is that it does not explain why trail traffic varies in different locations. Although these procedures for estimating hourly traffic are very basic and do not account for a number of variables that may influence users' decision to use a trail, this approach is relevant whenever actual counts are needed to develop new models or validate existing ones. Researchers need efficient methods for collecting the raw data from which causal models are developed.

The need for detailed information about traffic on multiuse urban greenway trails will increase in the future as more communities create greenway trails and managers seek to increase efficiency of management strategies. The approaches to data collection described here may be used in other communities to characterize traffic patterns on urban trails.

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