Preliminary Development of Methods to Automatically Gather Bicycle Counts and Pedestrian Delay at Signalized Intersections

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Submitted for presentation and publication to the 91st Annual Meeting of the Transportation Research Board January 22-26, 2012

July 2011

7, 385 words [4, 635 + 9 figures x 250 + 2 tables x250]

ABSTRACT

The increase of bicycle and pedestrian traffic in many urban areas has led to growing interest in multimodal performance measures. Traditionally, counts of pedestrians and bicycles have only been collected for short durations at spot locations. The lack of reliable long-term data precludes systematic performance monitoring and analysis of trends. This paper summarizes preliminary efforts to develop a long-term monitoring and collection system that leverages existing infrastructure to monitor bicycle and pedestrian activity. Communication and logic protocols have been implemented to gather bicycle counts and pedestrian delay using existing hardware (loop detectors, signal controllers) and software at select intersections within the City of Portland, Oregon. Bicycle counts are being gathered using advance loops in bike lanes. Two novel methods for collecting pedestrian delay at signalized intersections are proposed in this paper. One method uses transit priority logging feature in the signal controller software to track individual pedestrian phase actuations and corresponding delay. The other method uses internal logic commands to capture pedestrian delay estimates in relevant bins. Both methods provide delay and number of pedestrian actuations which can be used to characterize the pedestrian LOS at an intersection. The results from the study reveal that automation of data collection techniques for generating multimodal performance measures can assist in analyzing performance and long-term trends. The methods developed in this study can benefit other regions in understanding the effects of signal timing settings on multimodal performance.

INTRODUCTION

There has been a growing emphasis on multimodal transportation due to the numerous benefits of walking and bicycling: improvements in personal health, decreases in congestion, reductions in pollution levels and greenhouse gas emissions. The Federal Highway Administration (FHWA) has recently adopted ambitious goals to double the percentage of total trips made by bicycling and walking in the US and concurrently reducing the number of bicyclist or pedestrian injuries and fatalities by 10% (*1*). In addition, FHWA's Office of Human and Natural Environment administers a Bicycle and Pedestrian program with the objective of promoting "bicycle and pedestrian transportation use, safety and accessibility" (*2*). As such, bicycle and pedestrian data are critical components in the evaluation of system performance and operating efficiency. In addition, this data also be used to understand current demand, forecast future infrastructure and operational needs, prioritize investments and improve safety (*3*).

Quantifying bicycle and pedestrian demand is important and yet, there are huge gaps in the data collection methods for non-motorized modes. Traditionally, bicycle and pedestrian data have been collected on a short-term basis using tube counters, video data or manual methods. Recently, there has been an effort invested to establish the National Pedestrian and Bicycle Documentation Project to collect consistent nationwide data that could be used by engineers and planners for operational and planning purposes (*4*).

BACKGROUND

There has been limited research on bicycling counting methods. An FHWA sponsored research study looked at the effectiveness of various technologies for pedestrian and bicycle detection *(5)*. Intrusive (loop detectors) and non-intrusive technologies (ultrasonic, infrared, microwave and video) were tested on pedestrians and bicyclists. The results from the study indicated that detection errors were within 10% when compared to manual counts for all technologies. While this study evaluated the efficiencies in detection across technologies, their accuracy for counting bicycles and pedestrians was not evaluated. Kidarsa et al. compare the performance of circular loops to octagonal loops for bicycle detection. No difference in detection performance was detected between the two loop designs. They also found that the loops connected independently provided larger detection zones than those connected in series (*6*). Nordback et al. studied the long term accuracy of loop detectors for counting bicycles along multiuse trails in Denver, CO. They found that the loop detectors underestimated bicycle counts by 4% on average compared to manual counts (*7*). Some of the errors were due to the inability of the loops to distinguish between groups of cyclists.

Research on pedestrian demand is emerging. A number of studies have looked at technologies for counting pedestrians (*8-14*). Models estimating pedestrian demand using land use and socioeconomic characteristics have also been developed (*15-16*). While these models estimate demand, they do not estimate delay nor provide any long-term monitoring capabilities. There has been limited research linking pedestrian delay to signal timing. Research by Hubbard et al. indicates that a number of factors such as pedestrian direction of travel, right turn traffic volume, number of pedestrians crossing and location of crosswalk, affect the likelihood of a pedestrian service quality being compromised (delayed, altered path or speed) (*17*). Day et al. propose using the rate of pedestrian phase actuation as a proxy measure for quantifying pedestrian demand at an intersection (*18*). The effort monitored the number of pedestrian phase actuations at intersection near the Purdue University campus. While, the study was able to show seasonal and special event trends in pedestrian actuations and appeared to be a reasonable proxy for demand, it did not correlate actuations to numbers of pedestrians and did not capture performance characteristics such as delay.

This paper reports on an effort to automate the collection of bicycle counts using inductive loop detectors at signalized intersections and proposes two novel methods for measuring pedestrian delay at pedestrian actuated intersections. Bicycle counts are being collected at three intersections and pedestrian delay data at eight intersections in Portland, OR as shown in Figure 1.

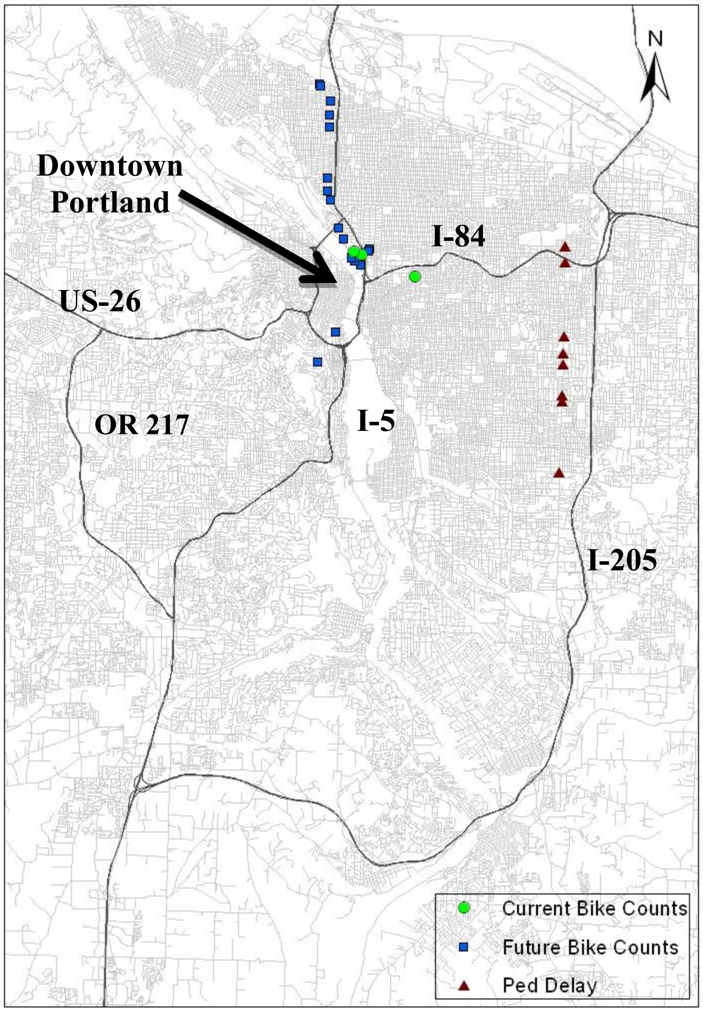


FIGURE 1 Bicycle Count and Pedestrian Delay Locations.

The green markers show current bicycle count locations, blue markers show future bicycle count locations and red markers show current pedestrian delay data collection locations. The remainder of this paper is divided in three sections. First, we present the methods for bicycle counting with existing advance loops in the bicycle lane in Type 170 and Type 2070 controllers. Minimum requirements for successful implementation are presented as well as some preliminary validation efforts. Next, methods to capture pedestrian delay using existing infrastructure, in locations with pedestrian push buttons and Type 2070 signal controllers are described. Some sample performance measures are presented. Finally, we present the conclusions and next steps.

BICYCLE COUNTS

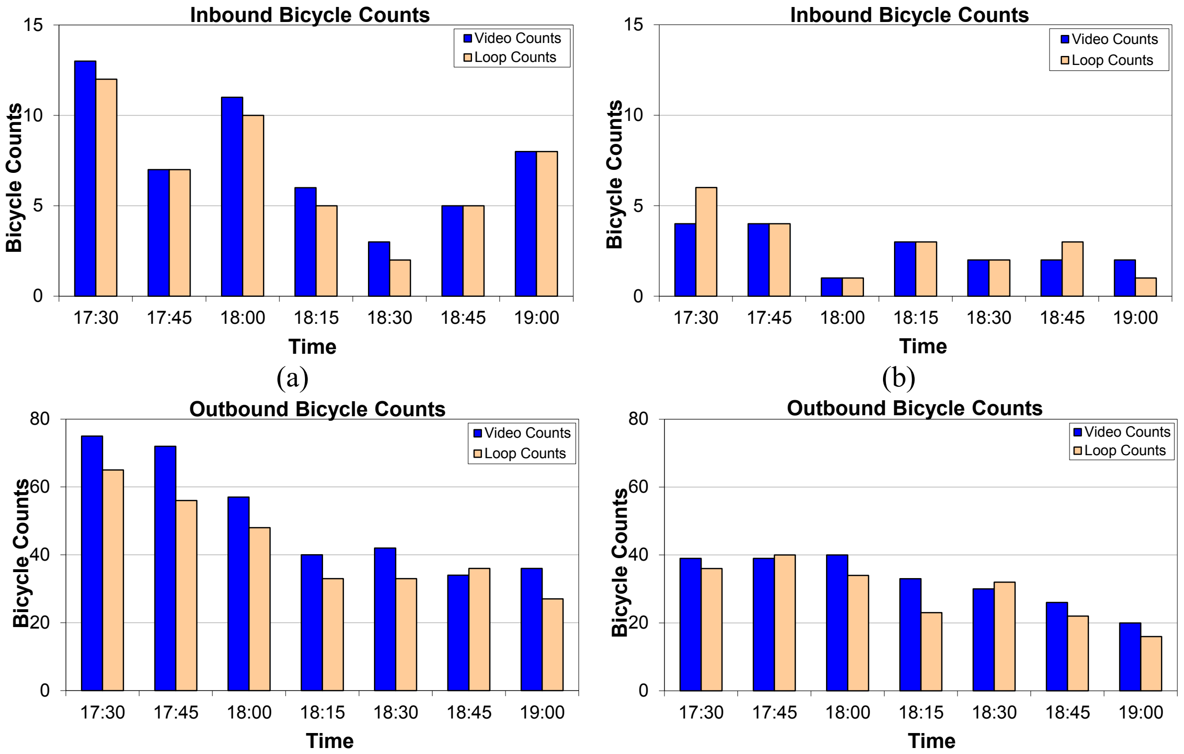
The most common form of sensors used for detection and counting of vehicles are induction loop detectors. These devices work on the principle of electromagnetic induction and are typically embedded in the pavement. Detection and counts are recorded by measuring the change in inductance when a vehicle travels over them. Multiple loops are placed in each lane while approaching the stop bar at a signalized intersection to allow for vehicle detection for phase changes. Advance loops are typically installed 300-400 ft from the stop bar to gather vehicle counts, occupancy and speed and can also be used for yellow extension. For bicycles, there are two sensors in the bicycle lane. The stop bar loop is typically used for phase actuation and commonly connected in series along with the vehicle loops. Therefore, counts cannot be obtained from the stop bar loops. These loops may also measure right turning traffic that is near to the loop due to the sensitivity settings of these sensors. Bicycle counts can be collected from advance loop detectors that are typically set back 40 - 60 ft from the stop bar.

Methodology

There are specific criteria for obtaining bicycle counts from the advance loop detectors: presence of bicycle lane, availability of advance loop detector in bicycle lane, presence of individual loop wire to the advance loops and availability of communication to the signal controller. The presence of a bicycle lane is important because it ensures that only bicycles travel in that lane and are counted by the loop detectors. The presence of advance loop detectors in bicycle lanes ensures that bicycles can be counted while in motion, which typically generate more accurate counts as compared to stop bar counts. The presence of an individual wire allows exclusive bicycle counts from the loop detectors and the availability of communication to the signal controller is necessary to view and retrieve counts.

In Portland, the counts from the advance bicycle loop detectors are routed to a detector channel and can be directly viewed using TransSuite® (the Advanced Traffic Management System (ATMS) software used by the City of Portland). Bicycle counts can be obtained from loop detectors that are connected to either Type 170 or Type 2070 signal controllers. Legacy Type 170 controllers with a 332 cabinet have 28 channels, with only 12 available for counting purposes. With Type 170 controllers, the advance bicycle loops have to be connected to counting channels that are unused so as to not hinder the operation of the intersection. Type 2070 controllers offer more functionality and channels that can be used for operations (detection) and keeping track of counts. There are 32 channels (inputs) available in 2070 controllers that can be used for counting purposes. These controllers have the ability to gather bicycle counts from multiple bicycle detectors (if available) at an intersection due to the availability of a larger number of inputs.

At this preliminary stage, the bicycle counts from intersections are manually downloaded and archived for future analysis. In the future, these count files will be archived in the Region's archived data user service (PORTAL). For this study, three intersections were chosen to collect bicycle counts. These intersections met all criteria previously outlined. One intersection (N Wheeler Ave and N Williams Ave) had Type 170 controller and two intersections (N Broadway and N Benton, NE Glisan St and NE Sandy Blvd) used Type 2070 controllers. Bicycle counts collected from advance loop detectors were compared to those obtained from video data using manual counts to test the accuracy of the loop detectors. The video data was collected for a 1.5 hour peak in the afternoon (17:30 – 19:00) period on 2 days (5/10/11 and 5/11/11) using video cameras mounted at the intersection for traffic surveillance.



(a) (b)

(c) (d)

FIGURE 2 (a), (b), (c) and (d) Comparison of Loop and Video Bicycle Counts.

This verification was performed at the intersection of N Wheeler Avenue, N. Williams Avenue and N. Winning Way. The test location was a three legged intersection, with advance loops present on N Wheeler Avenue in the north and south bound bicycle lanes respectively. 15-minute bicycle counts obtained from the loops were compared to the 15 minute counts obtained from video data. A time sync was performed to ensure that counts were compared during the same time period. Figures 2 a-d show the comparisons between the loop and video counts. Figures 2 a-b show the southbound (inbound) counts while figures 2 c-d show the northbound (outbound) counts on 5/10/11 and 5/11/11 during the PM peak. The plots show expected trends; bicycle counts are lower in the inbound direction and higher in the outbound direction during the PM peak period. The plots also show that counts produced from the loop counts are underestimated when compared to video (manual) counts, confirming a similar finding by prior research (*7*). The mean absolute percent error (MAPE) was calculated as ((video count – loop count)/ video count) *100. Taking the absolute values prevents the positive and negative values from canceling each other out. MAPE was estimated as 14.15 percent and 14.75 percent for the inbound and outbound directions respectively. There are two possible reasons for underestimation: lower sensitivity setting of the advance loops and bicycles not riding over the detector in the bicycle lane. The sensitivity parameter setting allows a loop to distinguish between bicycles and vehicles. Adjusting the sensitivity to a higher value could possibly enable the detection of more bicycles. The other source of error could be attributed to the position of cyclist in the bicycle lane. The advance detector can only detect bicycles that go over the detector and therefore will not be able to count any bicycles that do not travel in the lane and/or are not positioned correctly over the detector. A site visit to this intersection confirmed the hypothesis that some bicyclists do not ride in the bicycle lane and therefore do not get counted.

Results

Collecting bicycle counts systematically over time also allows engineers and planners to study time-of-day, seasonal, and long-term trends. Differences pertaining to time of day, day of week or seasonal ridership numbers can be explored with the bicycle count data. Figures 3 (a) and (b) show plots of bicycle counts obtained from the southbound (inbound) and northbound (outbound) detectors on N Wheeler Avenue on six Tuesdays between October 2010 and July 2011.

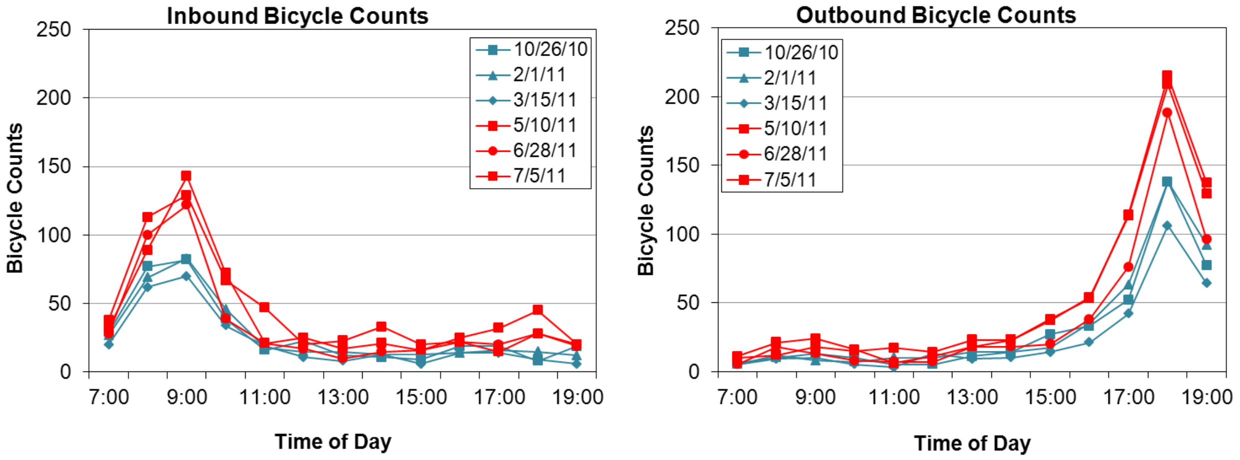


FIGURE 3 (a) and (b) Inbound and Outbound Bicycle Counts.

Figure 3 (a) shows higher bicycle traffic in the AM peak in the inbound direction as expected and the reverse trend is seen in Figure 3 (b) with higher outbound PM peak bicycle counts. It is also apparent that the outbound direction shows higher counts in the PM peak than the inbound direction in the AM peak, suggesting that more bicyclists use this facility during the evening commute. A seasonal trend is also at play, with bicycle counts in the spring and summer months trending higher than fall and winter months. Comparing the average of the highest peak hour counts during the summer and winter months, ridership increases during summer are 76 percent for the AM peak in the inbound direction during summer and 60 percent for the PM peak in the outbound direction. Comparing the directional counts during the summer months, bicycle ridership is greater by 55 percent for the outbound PM peak counts compared to the inbound AM peak counts. During the winter months, the difference between the outbound PM peak counts and the inbound AM peak counts is 70 percent.

Inductive loop detectors allow for cost-effective bicycle data collection, which could then be used for operational and planning purposes. Important considerations when loops are used for counting appear to be sensitivity parameter setting, placement of loop in bicycle lane and regular calibration and maintenance.

PEDESTRIAN DELAYS

The City of Portland operates more than 1,050 signalized intersections, with a mix of Type 170 and 2070 controllers. Type 2070 controllers are newer and are operated using Voyage controller software provided by Northwest Signal Supply, Inc (*19*). Voyage software can be used at isolated intersections or as a larger part of the central control system (*19*). In addition, another program called NWSCentral is also available to access the Voyage software from a Windows-based computer. Two methods were developed in this study to automate the process for pedestrian delay data collection using Voyage software. Both the methods relied on pedestrian push button actuations to capture delay. In this paper, we define pedestrian delay as the difference between the time when a pedestrian activates the push button and the time that the pedestrian phase is served. Previous research has shown that the delay calculated using Highway Capacity Manual (HCM) methods does not accurately reflect the delay observed in the field *(17)*.

Methodology

The pedestrian delay data in this study can only be collected for phases that are pedestrian actuated with push buttons. The National Electrical Manufacturers Association (NEMA) has adopted specific phase numbering standards (1-8) for defining phase movements. Through and left turning movements are represented by even and odd numbers respectively. Along major arterial corridors in the City of Portland, vehicle and pedestrian recall is implemented on the mainline phases (2 and 6), which ensures that these movements get served each cycle. Thus, the relative importance of measuring delay on these movements is less than the highly variable cross street travel. Figure 4 shows the phase diagram for the intersection of SE 82nd Avenue and Tillamook Street in Portland, OR. This intersection operates as a 6 phase intersection, with phases 2 and 6 serving the mainline through movements (SE 82nd Avenue south and north bound).

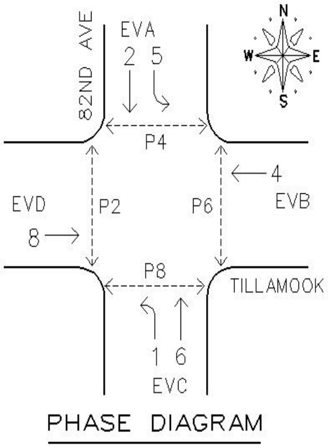


FIGURE 4 Phase Diagram for SE 82nd Avenue and Tillamook Street.

Pedestrian delay is captured for phases 4 and 8 (crossing the major arterial SE 82nd Avenue), which are not on recall and are equipped with push buttons. A description of the two methods used for collecting pedestrian waiting times is provided below.

Transit Priority Logging

Among the various advanced features present in the Voyage software is the ability to implement transit priority. At various signalized intersections, the City of Portland implements conditional transit priority if the bus is running late to either "extend the green phase" or "shorten the red phase" depending on the time in the cycle during which a bus arrives at an intersection (*20*). The transit priority log in the Voyage software records the time of the transit priority call and the time when the call was served for each event. Using the transit priority logging capability, logic was implemented in Voyage software to capture pedestrian delay. A pedestrian call is logged as a transit priority call. To record waiting time for pedestrians, we log the time when a pedestrian call is placed and when it gets served. At intersections, where transit priority for buses is active, a sequence is needed to inform the controller regarding the order of priority for the two events. Currently, priority is set equal implying that the calls are handled on a first come - first serve basis. Figure 5 shows a graphic of the logic used to capture delay for phase 4 pedestrian movement.

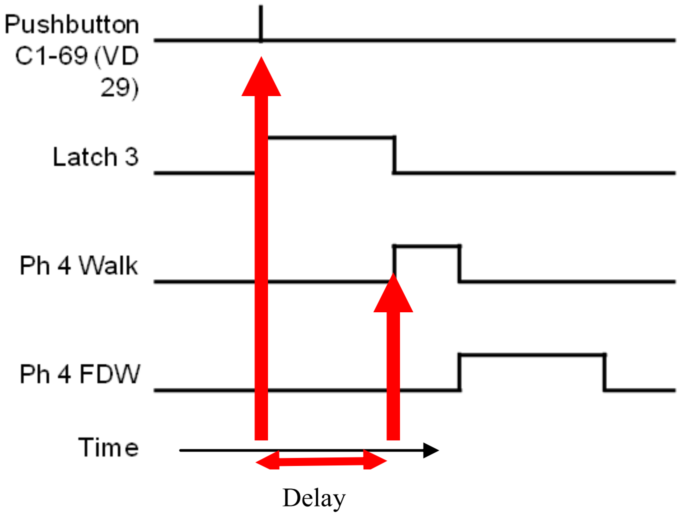


FIGURE 5 Pedestrian Delay using Transit Priority Logs.

The pedestrian push button is reassigned to a vehicle detector and the logic is set up in a way such that a latch is on if the pushbutton is activated and the walk phase is not active currently. The latch ensures that the transit priority input turns on and is only released when the walk is served. Additional pedestrian calls during the walk phase are ignored by the logging feature. This allows the system to keep track of the time the push button was activated and the time until that the walk phase was served. One primary limitation of this method is that only one transit priority event can be active at a particular time. This limitation can hinder the actual transit priority operation, if the priority sequence is not set correctly. In addition, at an intersection if there are two pedestrian actuated phases and if the push buttons corresponding to both phases are actuated at the same time, only one pedestrian actuation event will be active and recorded at a particular time (meaning that the total delay is twice what is measured).Future versions of Voyage software will mitigate this issue by collecting delay as a standard measure of effectiveness (MOE) in the controller.

Volume Bin Logging

In addition to the using transit priority logs, another method using internal timers in the controller was also implemented to record pedestrian delay, which is grouped into bins. Three bins are used for delay data collection: 0-20 seconds, 20-40 seconds and >40 seconds. Figure 6 shows the logic used in the implementation of this method. The red lines indicate bin boundaries and the blue line indicates when the walk is served for each case. When a pedestrian call is received, a latch is set using internal logic commands in Voyage software. Four (4) timers per each pedestrian phase are activated when the latch is set, the first timer counts down from 20 seconds to 0 (timers 5/6), the second timer counts down from 40 seconds to 0 (timers 7/8), the third timer counts down from 0.1 second to 0 when the walk is served (timers 1/2) and the fourth timer counts down from 1 second to 0 when the walk ends and the clearance interval begins (timers 3/4). While the first and second timers classify the delay into the respective bins, the third and fourth timers keep track of beginning and end of walk indication.

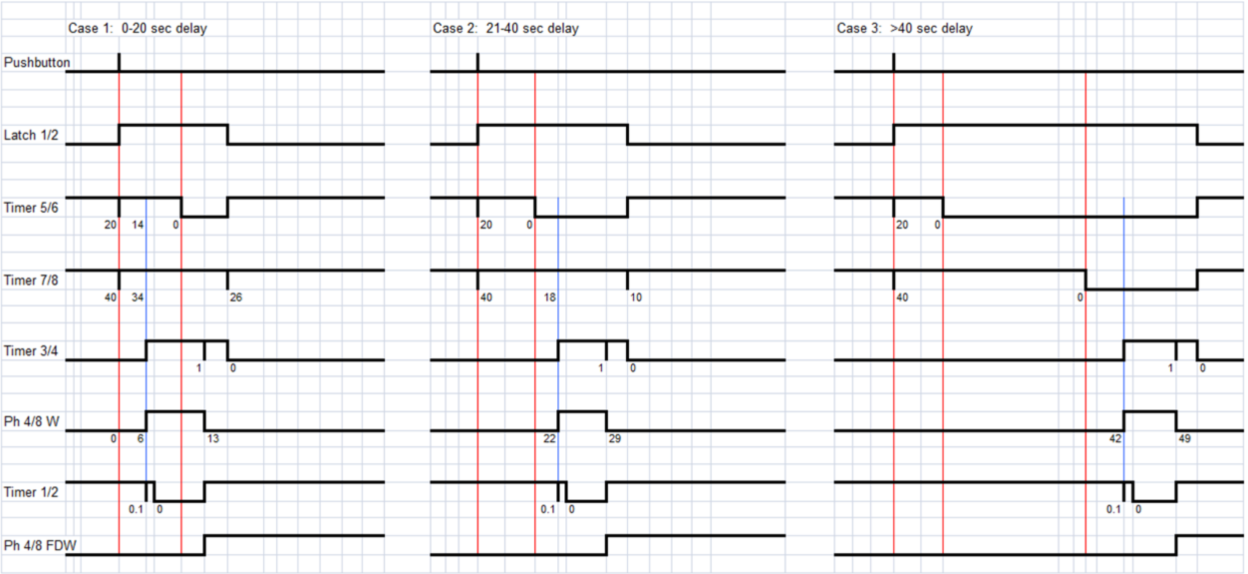


FIGURE 6 Pedestrian Delay Using Bin Method.

The logic for classifying delay into bins is shown below: For each bin, the criteria listed below have to be satisfied in order for the delay value to be placed in that bin.

Bin 1: Delay between 0 - 20 seconds

a. Latch 1 is set
b. Walk indication is active
c. Timer 1 ≠ 0
d. Timer 5 ≠ 0

Bin 2: Delay between 20 – 40 seconds

a. Latch 1 is set
b. Walk indication is active
c. Timer 1 ≠ 0
d. Timer 7 ≠ 0
e. Timer 5 = 0

Bin 3: Delay greater than 40 seconds

a. Latch 1 is set
b. Walk indication is active
c. Timer 1 ≠ 0
d. Timer 7 = 0

Each bin is reassigned to a vehicle detector, so that the counts (delay) from these bins can be obtained through the volume logs in TransSuite. While this method provides less detailed (delays are binned rather than reporting actual time) data than the transit priority log method, it is considered more accurate due to the inability of the transit priority log method to handle multiple pedestrian calls or the introduction of incorrect data when a bus transit priority event occurs at the same time.

Results

Pedestrian delay data was obtained using transit priority logging and volume bin logging methods. The transit priority logging was activated at three intersections. The volume bin method was employed at eight intersections, including the three where transit priority logging was employed. Table 1 shows raw data obtained from the transit priority log for 82nd Avenue and Tillamook Street. The transit priority column indicates the priority input at the intersection. At this intersection, bus transit priority is not active; transit priority inputs 2 and 4 indicate delay data logging for pedestrian phases 4 and 8 respectively. The status message "TP Input Active" indicates pedestrian push button actuation and "TP Phases Achieved" implies that the walk was served. The difference in times between these two indications is the delay experienced by the pedestrian. Other important data at the time of actuation such as the active phases, the active coordination plan, the cycle length, the reading of the cycle timer when the button was pushed, green indication was served and cycle timer reading when the phase terminates are also recorded.

TABLE 1 Transit Priority Log of the Delay Data from 82nd Avenue & Tillamook Street

Date	Time	Transit Priority	Status	Phases Active	Coord Plan	Cycle Length	On	Green	Off
7/12/2011	**17:57:38**	2	**TP Input Active**	26	3	80	33	0	0
7/12/2011	**17:58:29**	2	**TP Phases Achieved**	48	3	80	33	4	0
7/12/2011	17:58:29	2	TP Input Went Inactive In TP Green	48	3	80	33	4	4
7/12/2011	**18:01:52**	4	**TP Input Active**	26	3	80	47	0	0
7/12/2011	**18:02:29**	4	**TP Phases Achieved**	48	3	80	47	4	0
7/12/2011	18:02:29	4	TP Input Went Inactive In TP Green	48	3	80	47	4	4

The delay obtained from the volume bin data was less detailed. For a given time period, the count in each bin represented the number of times the delay was within that range. Summing the counts across all bins over the entire day provided the number of actuations for each intersection. Figure 7 shows pedestrian activity at the eight study intersections for one day. For each intersection, data for all the pedestrian phases that were not on recall were collected. While five intersections (SE Division, SE Flavel, SE Holgate, NE Tillamook and SE Woodward) had both phases 4 and 8 active, the other three intersections (SE Boise, SE Mill and NE Wasco) had only pedestrian phase 4 operational.

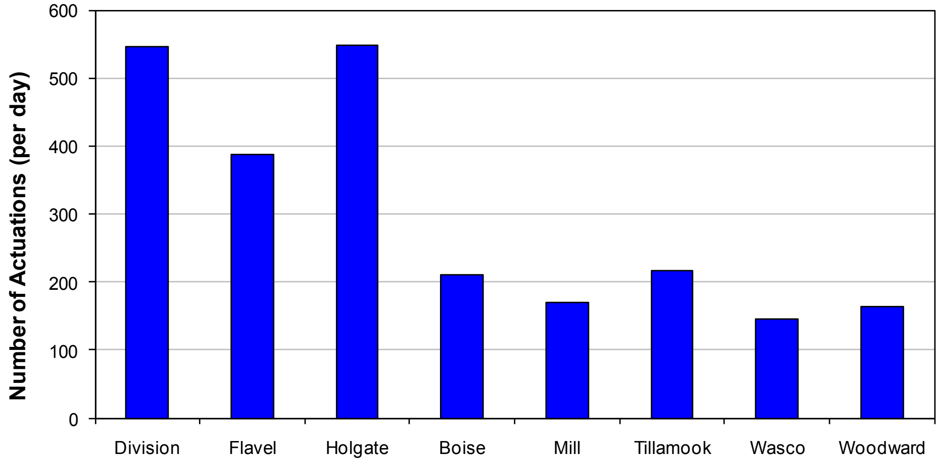


FIGURE 7 Number of Pedestrian Actuations Across Intersections.

From Figure 7, it is evident that certain intersections (SE Division, SE Holgate and SE Flavel) experience higher pedestrian actuations than the other intersections. The number of actuations per day ranged from a maximum of 548 for SE Holgate to a minimum of 146 at NE Wasco. At intersections where delay data for both pedestrian phases is collected, the actuations can also be studied separately by phase. Figure 8 shows the number of actuations for the intersection of SE 82nd Avenue & SE Division Street for one week (07/15 – 07/21) in July 2011. The plot shows an expected trend of higher weekday actuations and lower weekend actuations. Figure 8 indicates that the weekday actuations are consistent Monday through Thursday and trend lower on Friday, during the analyzed time period.

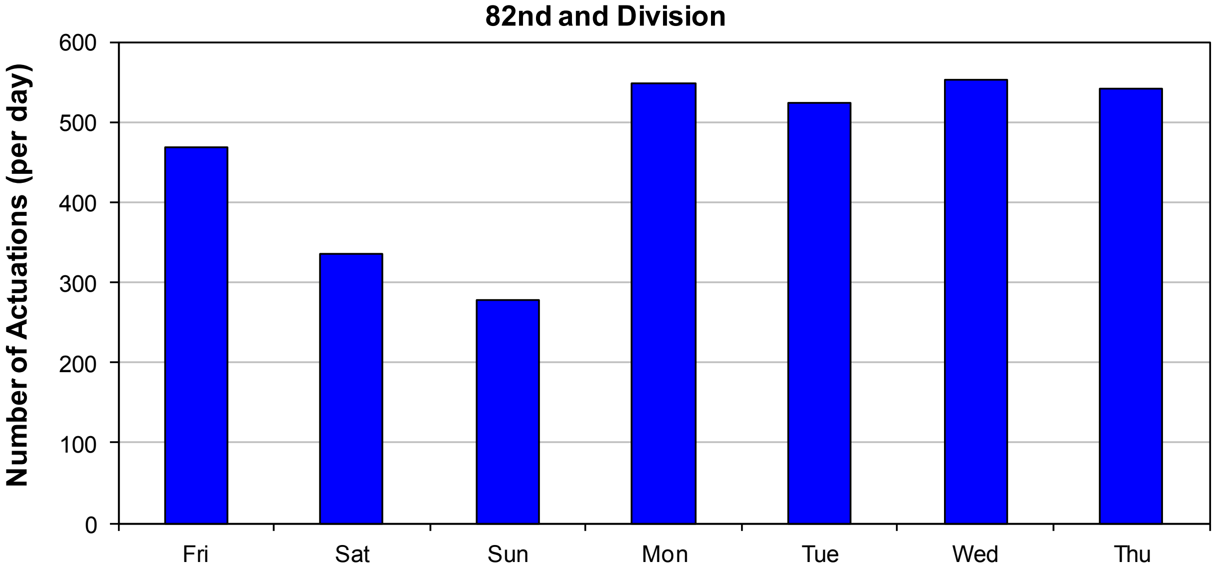


FIGURE 8 Weekly Pedestrian Actuations at 82nd Avenue and Division Street.

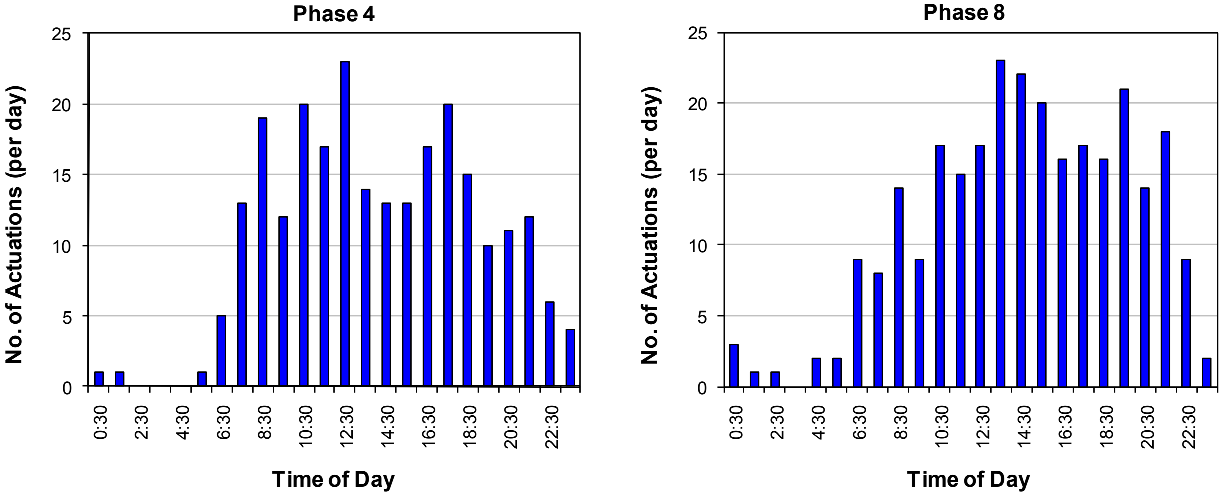


FIGURE 9 Pedestrian Actuations by Phase.

Figure 9 shows the pedestrian actuations separated by phases. The actuations are for pedestrian phases 4 and 8 for Tuesday, July 19th, 2011 at the intersection of 82nd Avenue and Division Street. The plot for phase 4 shows little or no activity at night, higher actuations during AM peak, midday and PM peak periods. The plot for phase 8 on the right shows highest actuations during midday followed by AM and PM peak periods.

Since the individual actuation data are not available with the bin method, an average delay value for each intersection cannot be estimated directly. However, with some simple assumptions it is possible to estimate the maximum and minimum ranges of the average delay per actuation. Assigning the binned counts to either the maximum or minimum delays possible and assuming the maximum delay is equal to the cycle length results in the following equations:

$$Total\ minimum\ delay = 0 * C_1 + 21 * C_2 + 41 * C_3$$

$$Total\ maximum\ delay = 20 * C_1 + 40 * C_2 + CL * C_3$$

$$Max\ Average\ Delay = \frac{Total\ Max\ Delay}{C_1 + C_2 + C_3}$$

$$Min\ Average\ Delay = \frac{Total\ Min\ Delay}{C_1 + C_2 + C_3}$$

$$Average\ Delay\ for\ Intersection = (Min\ Average\ Delay, Max\ Average\ Delay)$$

$Where$

$$Count\ in\ bin\ 1 = C_1$$
$$Count\ in\ bin\ 2 = C_2$$
$$Count\ in\ bin\ 3 = C_3$$
$$Cycle\ Length = CL$$

Table 2 shows the sample calculations for the ranges of delay for one day (7/25/2011) at five intersections as well as comparison of the two methods for three intersections. The delays obtained from transit priority logging method were classified into bins and compared to the delay from the volume bins. The results indicate that the TP method records fewer actuations compared to the volume bin method. The difference arises due to the ability of the transit priority logger to record only one event at a time, as described previously.

TABLE 2 Average Pedestrian Delay

Intersection	Counts						Delays per actuation (s)		
	Bin 1		Bin 2		Bin 3		TP	Vol	
	TP	Vol	TP	Vol	TP	Vol	Avg	Min	Max
NE 82nd & NE Tillamook	55	59	34	48	80	93	38.21	24.16	57.00
NE 82nd & NE Wasco	46	45	39	43	79	83	38.13	25.18	57.19
SE 82nd & SE Mill	33	32	34	34	99	104	49.69	29.28	72.21
SE 82nd & SE Boise	-	24	-	48	-	114	-	30.55	76.53
SE82nd & SE Holgate	-	97	-	123	-	315	-	28.97	72.36

Table 2 shows that the minimum average delay per actuation is similar for the five intersections listed above. However, the maximum average delay is higher at three intersections (SE Mill, SE Boise and SE Holgate). One clear limitation of these methods is that the number of pedestrians per actuation is unknown. Thus, delay calculations represent a lower bound. Long term ranges of average delay can be estimated and tracked over time to assess whether the average delay is trending upwards or downwards with time. The average delay can be used to calculate pedestrian LOS of each intersection and assess if changes need to be made to improve LOS.

A number of factors could affect average delay at an intersection. Clearly, longer cycle lengths will, on average, result in longer pedestrian delays. The City of Portland also follows a pedestrian friendly policy of letting the coordination phases rest in walk, if there is no call on the side streets. This policy ensures that pedestrians maximize their allowable walk time and minimizes delay for the coordinated phases. However, for the side street phases, delay could potentially increase since the cycle timer has to serve the pedestrian clearance time for the main phases, if there is a call on the side street instead of directly bringing up the yellow phase. Future work will evaluate the impacts on delay, of alternative pedestrian friendly strategies similar to those adopted by the City of Vancouver, B.C. such as use of permissive windows, removal of pedestrian holds, temporary removal of signals from coordination and shorter cycle lengths (*21*).

CONCLUSIONS

The objective of this paper was to report on efforts to use traffic signal controllers to collect data pertaining to people that walk and bike. The endeavor has resulted in the collection of bicycle counts and the development of a procedure to measure pedestrian delays at select intersections using existing hardware (loops) and software. Bicycle counts are collected on a continuous basis at three intersections in Portland, OR using inductive loop detectors in the bicycle lane (previously placed for presence detection). The pedestrian push-button actuation and delay data is gathered at eight intersections in Portland, OR using internal logic commands in the signal controller software.

This study has shown that existing technology and infrastructure can be used to collect valuable data in an automated manner. A limitation of this study is that the methods developed here are specific to certain hardware and software configurations. However, other areas can develop similar methods using existing infrastructure to gather similar types of data. Monitoring bicycle flow over time can help in measuring seasonal activity levels, estimating mode split, and incorporating bicycle considerations in transportation analyses. Similarly, the collection and evaluation of pedestrian delay enables monitoring of locations with high pedestrian activity and easier evaluation of the multimodal performance.

ACKNOWLEDGEMENTS

Funding for this study was provided by the Oregon Transportation Research and Education Consortium (OTREC) and the Signals, Street Lighting and ITS division of the Bureau of Transportation, City of Portland. The authors are grateful to Nelson Chi, Paul Zebell and Mark Haines from the City of Portland for their assistance with the data collection.

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