Development of Pedestrian Recall versus Actuation Guidelines for Pedestrian Crossings at Signalized Intersections

Burak Cesme
Senior Engineering Associate
Kittelson and Associates, Inc.
Washington, D.C., 20003
bcesme@kittelson.com

Peter G. Furth
Department of Civil and Environmental Engineering
Northeastern University, Boston, MA, 02215
pfurth@coe.neu.edu

Ryan Casburn
Transportation Analyst
Kittelson and Associates, Inc.
Tampa, FL, 33602
rcasburn@kittelson.com

Kevin Lee
Principal Engineer
Kittelson and Associates, Inc.
Cincinnati, OH, 45202
klee@kittelson.com

Corresponding Author: Burak Cesme
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ABSTRACT

At signalized intersections, pedestrian phases can be configured as recall or push-button actuated. While pedestrian recall results in a moderate reduction in pedestrian delay, because with recall, a pedestrian arriving during the time nominally reserved for the Walk interval will be served immediately rather than waiting to be served in the next cycle, it can also lead to longer cycle lengths, increasing delay for all users, including pedestrians. This research explores the impact of pedestrian recall along a coordinated-actuated arterial for pedestrians crossing the mainline (i.e., crossing the coordinated phase) to provide pedestrian recall versus actuation guidelines for agencies. The guidance was developed with the aim of balancing pedestrian delay with operational efficiency for vehicles. Two criteria were considered while developing the guidance: (1) pedestrian demand, and (2) vehicular green time duration for the concurrent vehicle phase that is parallel to the pedestrian crossing. VISSIM microsimulation software was utilized using a real network in Fairfax County, Virginia to model the effects of pedestrian recall and actuation. Results showed that pedestrian recall should be considered when pedestrian demand is large enough that there is a pedestrian call in most cycles (pedestrian probability in a given cycle is greater than 0.6 or pedestrian volume per cycle is greater than 0.9). The guidance also suggests setting pedestrian phases on recall when the length of the vehicular green for the concurrent phase is long enough in most cycles that a pedestrian phase would fit without constraining the signal cycle length.

Keywords: Pedestrian Recall, Pedestrian Push-Button Actuation, Pedestrian Demand, Recall versus Actuation

INTRODUCTION

At signalized intersections, pedestrian phases can be configured as recall or pushbutton-actuated. With pedestrian phases on recall, a call for pedestrian service is placed automatically every cycle, resulting in the controller timing its Walk and pedestrian clearance interval, which begins with the Flashing Don't Walk (FDW) interval and can include several seconds of additional buffer time before a green signal is displayed to conflicting traffic. With pedestrian actuation, the pedestrian phase is omitted from a cycle unless a pedestrian manually places a call to the controller.

Pedestrian recall yields a moderate reduction in pedestrian delay, because with recall a pedestrian arriving during the time nominally reserved for the Walk interval will be served immediately, while with pushbutton actuation, pedestrians may not be served until the next cycle. This effect is not recognized in the *Highway Capacity Manual*'s pedestrian delay formula [1]. Lower pedestrian delay in turn improves pedestrian safety because it tends to improve pedestrian compliance [2] [3]. Kothuri also found that pedestrian recall led to greater pedestrian compliance than pedestrian actuated crossings [4]. In addition, with pedestrian actuation, pedestrians who are not the first to arrive may not push the button, thinking that others already have. Then, if the concurrent vehicular phase receives a green display without the pedestrian signal since no one pushed the button, they may start crossing without the protection of the pedestrian signal, which may leave them partway through their crossing when a conflicting movement receives a green display. Pedestrian recall eliminates this type of conflicts and therefore improves safety.

However, pedestrian recall also has drawbacks. By forcing a pedestrian phase to occur in every cycle, even when no pedestrians are present, pedestrian recall can reduce intersection capacity and increase delay for conflicting traffic – not only vehicles, but also pedestrians on other crosswalks. The delay impact is most pronounced when the crossing has a long pedestrian clearance (e.g., crossing a wide arterial), pedestrian demand is low, and the intersection is operating close to (or above) capacity. In addition, with long pedestrian crossings and low pedestrian demand along coordinated arterials, some agencies do not incorporate minimum pedestrian timings into the timing plan to keep cycle lengths as short as possible along the corridor and let transitions occur when a pedestrian call is registered (which is typically not too frequent due to low pedestrian demand). For those intersections, pedestrian recall requires embedding minimum pedestrian timings within the ring-barrier structure, which may lead to longer cycle lengths and can increase delay to both vehicles and pedestrians [5].

Agencies are looking for more specific guidance on when to set pedestrian phases on recall. Available guidance tends to be qualitative, calling for engineering judgment on a case-by-case basis. For example, the Signal Timing Manual (STM) indicates that pedestrian recall may be used at locations and/or times with high pedestrian volumes [6]. The National Association of City Transportation Officials (NACTO) Urban Street Design Guide recommends using pretimed signals in urban areas, which results in pedestrian phases being on recall [7]. Some cities and states have developed their own guidelines regarding pedestrian recall. For example, the City of Boston, Massachusetts recommends that pedestrian actuation be considered at intersections where pedestrians are present for less than 50% of the cycles during peak hours and at intersections designed to operate with vehicle detection that is actuated [8].

Existing guidance recognizes the obvious conclusion that pedestrian recall is appropriate in high pedestrian volume areas where pedestrian demand is present virtually every cycle. Likewise, for crossings with very low pedestrian demand (e.g., pedestrians are present less than 10% of all cycles), existing guidance clearly supports pedestrian actuation. For crossings with an intermediate level of pedestrian demand, however, agencies are interested in guidance as to whether the pedestrian phase should be on recall.

One of the main limitations of current guidance is that it generally considers only pedestrian volume without comparing it to the concurrent vehicular volume – or, more precisely, without considering green time demand for the concurrent vehicular phase in comparison with the demand imposed by a pedestrian phase. If the green time required to serve the concurrent vehicular phase in most cycles is longer than the minimum green duration needed to serve pedestrians, setting the pedestrian phase on recall will have almost no impact on the signal cycle. Under those conditions, pedestrian recall may be appropriate even with low pedestrian volumes.

The most obvious example is for pedestrian crossings that are concurrent with a coordinated phase. With the coordinated phases, there is almost always enough green time to fit the pedestrian phase without the need to extend the cycle length. As a result, agencies often use controllers' Rest in Walk feature (i.e., the pedestrian signal displays Walk while the concurrent vehicular phase is green, changing to FDW at the moment when the necessary pedestrian clearance will end simultaneously with the scheduled end of vehicular green) for the coordinated phase, which places an automatic call for the pedestrian phases. For example, the City of Portland, Oregon has a policy to implement pedestrian recall on the mainline phases to ensure that pedestrian crossings concurrent with the mainline gets served each cycle [4], however having a similar policy for the non-coordinated phases is a lot more challenging since recall for pedestrian phases crossing the mainline can reduce intersection capacity. On the other hand, there are non-coordinated phases whose vehicular demand is high, resulting in long phases in most cycles, for which providing pedestrian recall would have little impact on the signal cycle.

Research is therefore needed to address the following questions related to the recall-actuation tradeoff:

- What would be the impact on traffic if pedestrian phases crossing a major street are put on recall?
- How to judge when setting pedestrian phases on recall would impose costs on other users that can outweigh its benefit to pedestrians?
- Is there a pedestrian volume threshold (or threshold for fraction of cycles in which there is a pedestrian call) to determine when to set pedestrian phases on recall vs. actuation?
- How can knowing the green time distribution for the concurrent vehicle phase help determine whether the pedestrian phase can be put on recall with little impact to traffic operations?

The objectives of this research were to seek answers to these questions, assess pedestrian recall versus actuation tradeoffs both for pedestrians and vehicles, and balance pedestrian delay while maintaining operational efficiency for vehicles. The outcomes of this research can provide guidance for agencies to help them identify pedestrian crossings where pedestrian recall opportunities are likely to exist with little or no impact on traffic operations.

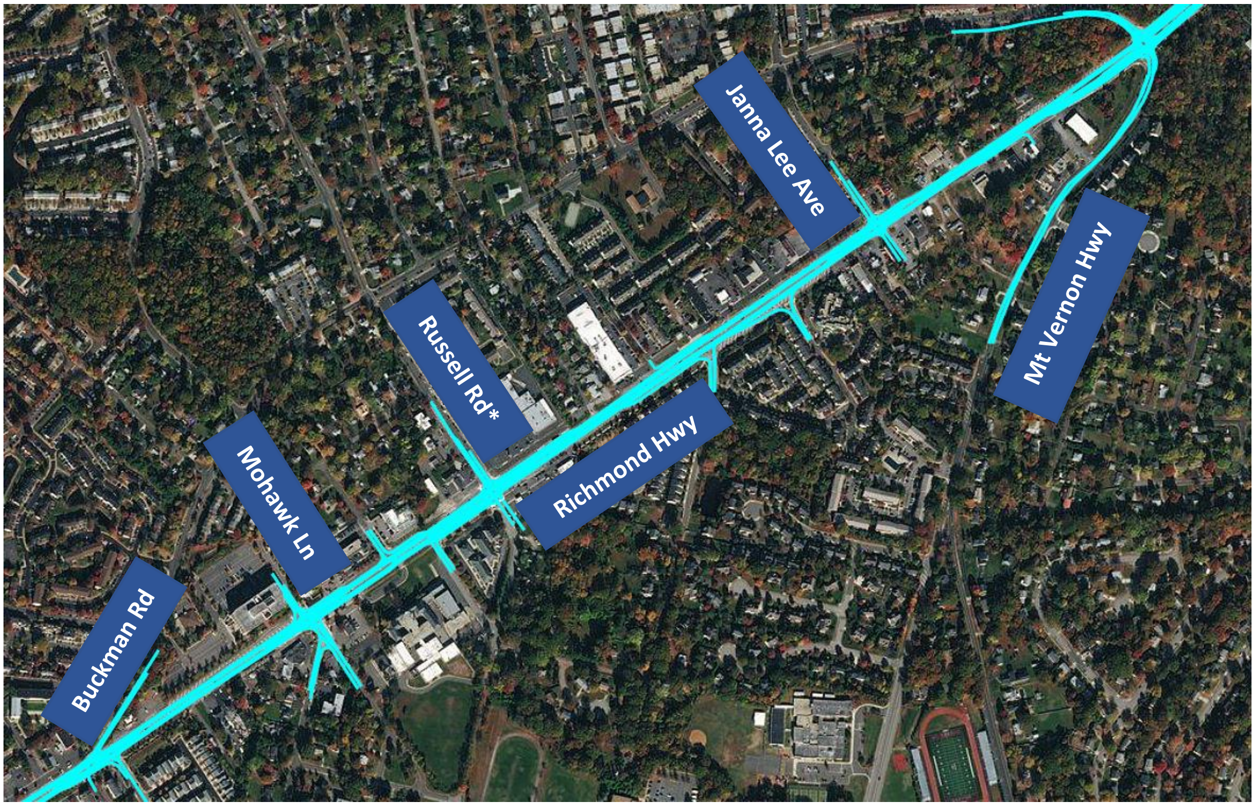
This research focused on the effects of pedestrian recall for pedestrians crossing the main arterial (i.e., running concurrently with the side street) since the impact of putting a side street on pedestrian recall has more impacts on traffic operations due to the longer crossing times required. With coordinated-actuated operation, a traffic signal control strategy that is commonly used in the U.S., setting the mainline phases on pedestrian recall usually has no impact on intersection performance as previously discussed since the coordinated phases are served every cycle and are usually guaranteed enough green time to serve the pedestrian phase.

METHODOLOGY

In this research, VISSIM microsimulation software was utilized to model the impacts of pedestrian recall versus actuation for a pedestrian phase crossing an arterial with coordinated-actuated control. A base model was developed using a real network in Fairfax County, Virginia. All the data required for the development of the model were gathered from the field. Maintaining the same roadway geometry, vehicle and pedestrian volumes were adjusted to create and test various scenarios (see below for details). The following sections provide a detailed description of our methodology.

Base Model Development

Five signalized intersections were chosen from the Richmond Highway (U.S. Route 1) corridor in Fairfax County, Virginia, as shown in **Figure 1**. Russell Road was selected as the analysis intersection in which pedestrian recall and actuation were tested under various scenarios. The test intersection is a noncritical intersection with slack capacity whose cycle length is controlled by another intersection on the arterial; therefore, providing pedestrian recall here will not cause oversaturation or affect the cycle length.



(*indicates the subject intersection that was analyzed)

Figure 1: Simulation Network

Base signal timings were obtained from Virginia Department of Transportation (VDOT). Because only a 5-intersection segment was considered for this analysis, cycle lengths and splits were re-optimized using Synchro, maintaining the existing phase sequences and the coordinated-actuated operation mode. This led to a corridor cycle length of 110 seconds (lower than the existing cycle length of 180 seconds). At the test intersection (i.e., Russell Road), two crosswalks were modeled and analyzed:

i. Pedestrians crossing the mainline (i.e., Richmond Highway), concurrent with the side street vehicular movement. This crossing was tested with recall and with actuation. The Walk interval lasts 7 seconds and Flashing Don't Walk (FDW) 20 seconds. By Virginia DOT policy, pedestrian clearance interval, based on a crossing speed of 3.5 ft/sec, has to be completed before the yellow interval begins. Therefore, the yellow and red clearance intervals are considered as part of the phase end buffer time.
ii. Pedestrians crossing the side street (i.e., Russell Road), concurrent with the coordinated mainline movement. This crossing was set to Rest in Walk and therefore to recall. No experimentation was done with this crossing; it was modeled only to measure the effects of pedestrian recall on the other crossing for pedestrians crossing the site street.

Scenario Testing and Variables

Sensitivity runs were performed at the test intersection/crosswalk by varying pedestrian demand, and thus the probability of pedestrian calls in a given cycle. The side street volume, and thus average green time required to serve side street demand, was also varied. Side street volume was expressed in terms of the average green time needed per cycle to serve that demand as a fraction of minimum green time needed to serve a pedestrian phase (calculated as Walk + FDW). A total of 60 scenarios were modeled and analyzed in VISSIM – for 2 pedestrian mode settings (pedestrian recall and pedestrian actuation), we considered 5 pedestrian probability scenarios and 6 side street scenarios, shown in **Table 1**.

Table 1: Simulation Scenarios Considered for the Analyses

Probability of pedestrian demand (PP) in a given cycle (pedestrian volume)
0.1 (4 peds/hr)
0.3 (12 peds/hr)
0.5 (24 peds/hr)
0.7 (42 peds/hr)
0.9 (80 peds/hr)

Side street green time (SSG) required as a fraction of minimum pedestrian green time needed
0.5
0.6
0.7
0.85
1.0
1.2

The probability of pedestrian demand in a cycle (PP) is related not only to pedestrian volume, but also to the Walk interval and cycle length. For the experimental site, pedestrian volumes for each PP scenario were calculated assuming a Poisson arrival process for pedestrians, which leads to the following equation:

$$Hourly\ Pedestrian\ Volume = \frac{-\ln(1-PP)}{[C-(PP*W)]} * 3600 \qquad (1)$$

where PP = probability of pedestrian demand in a given cycle, C = cycle length in seconds, and W = Walk interval length in seconds.

To convert SSG values into hourly vehicular volumes that can be entered as an input to the VISSIM experimental setup, the following formula was first utilized using the lost time concepts identified and described in Furth et al., for the actuated approaches [9].

$$Hourly\ Vehicular\ Volume = \frac{\left[(Walk + FDW) * SSG - L_{start\ up} - L_{end}\right] * SatFlow}{Cycle\ Length} \qquad (2)$$

where $L_{start\ up}$ is the start-up lost time, assumed as 2 seconds, L_{end} is the end lost time, assumed as 3 seconds, and *SatFlow* is the saturation flow rate, assumed as 1,800 vehicles per hour per lane. After initial volumes calculated using equation (2) were entered into the simulation, actual green times were obtained from VISSIM and compared to SSG values given in **Table 1**. Where there were differences, hourly vehicular volumes were slightly adjusted in VISSIM to match the SSG values.

Base Signal Timing

Cycle length was 110-seconds throughout the corridor. For SSG values below 1.0, the side street maximum green was fixed to 27 seconds to meet the minimum pedestrian green requirements (7 seconds Walk plus 20 seconds of FDW). For SSG values of 1.0 and 1.2, the side street maximum green was increased to accommodate side street vehicle demand, with the additional green time taken from the coordinated phases in order to maintain the same cycle length.

Selected Performance Measures

The following performance measures were used:

- Average pedestrian delay for pedestrians crossing the arterial,
- Average pedestrian delay for pedestrians crossing the side street,
- Average intersection vehicle delay,

- Average network vehicle delay, and
- Phase green time distribution, including average green times, for the side street as well as the coordinated phase.

Pedestrian delay measures assume full pedestrian compliance. Reported results are averages of ten simulation runs performed for each scenario, each with different random seeds. Delay effects associated with each scenario are reported using the measure *Delay Change*, given by:

$$Delay\ Change = Delay\ with\ Ped\ Recall - Delay\ with\ Ped\ Actuation \quad (3)$$

Therefore, a positive delay change indicates that pedestrian recall increases delay, while a negative value indicates that pedestrian recall reduces delay.

RESULTS

Figure 2 shows delay change for pedestrians crossing the main arterial. Delay change varies with PP, and is otherwise the same for all SSG values. Results indicate that when PP is close to zero, the delay change is nearly equal to the length of the Walk interval (7 seconds), because the low probability of pedestrian demand in the previous cycle makes it unlikely that a pedestrian arriving in the first 7 seconds of a cycle will be greeted by a Walk interval. With high values of PP, delay change is close to zero, because there is a high chance that another pedestrian arrived earlier in the cycle and pushed the button, making it almost the same as if the pedestrian phase were on recall.

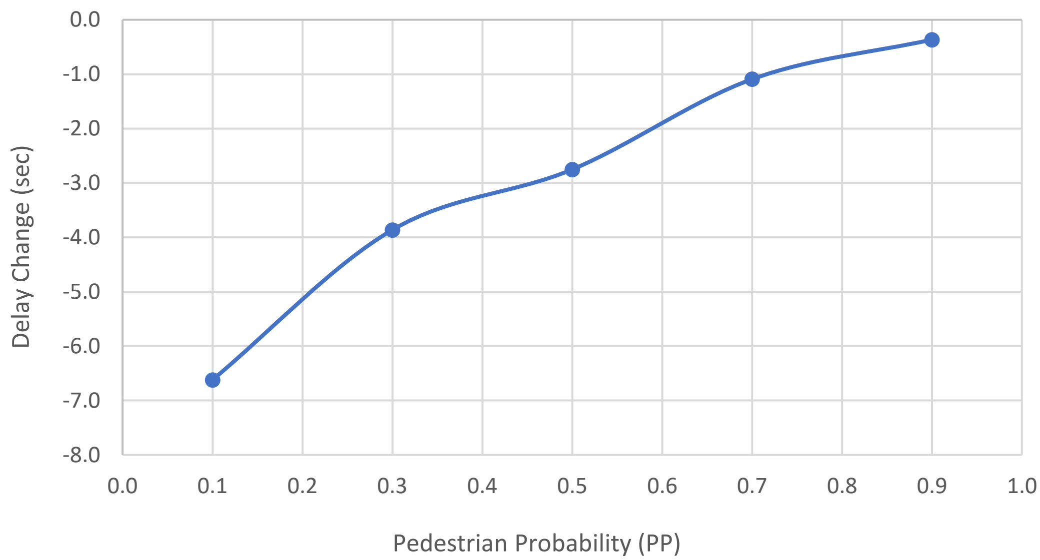


Figure 2: Average Pedestrian Delay Change for Pedestrians Crossing the Main Arterial under Various Probability of Pedestrian Call (PP) Scenarios

Figure 3 shows delay change for pedestrians crossing the side street. Recall that for this crossing, the pedestrian phase is assumed to be on recall with the Rest in Walk setting. Therefore, any increase in green duration for the mainline movement due to the side street ending early also increases these pedestrians' Walk interval correspondingly. Because pedestrian recall for the side street phase reduces green time for the mainline, it increases delay for pedestrians walking parallel to the mainline, indicated by a positive delay change. With PP = 0.1 (low pedestrian demand) and SSG = 0.5 (low side street vehicular volume), the highest impact scenario, average pedestrian delay for the side street crossing increases by almost five seconds if the other pedestrian phase has recall. Another important finding is that with high

SSG scenarios (SSG ≥ 0.85), regardless of the PP values, the impact of pedestrian recall is small because with high SSG, the side street phase consumes nearly all of its allowed green time regardless of whether the pedestrian phase is on recall.

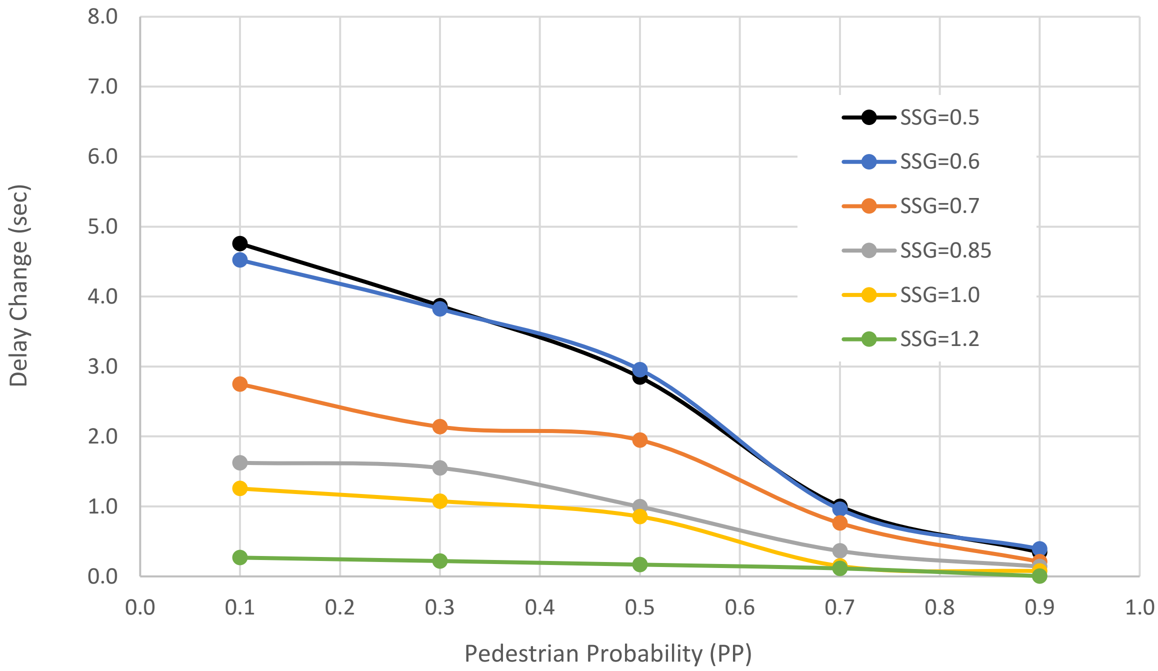
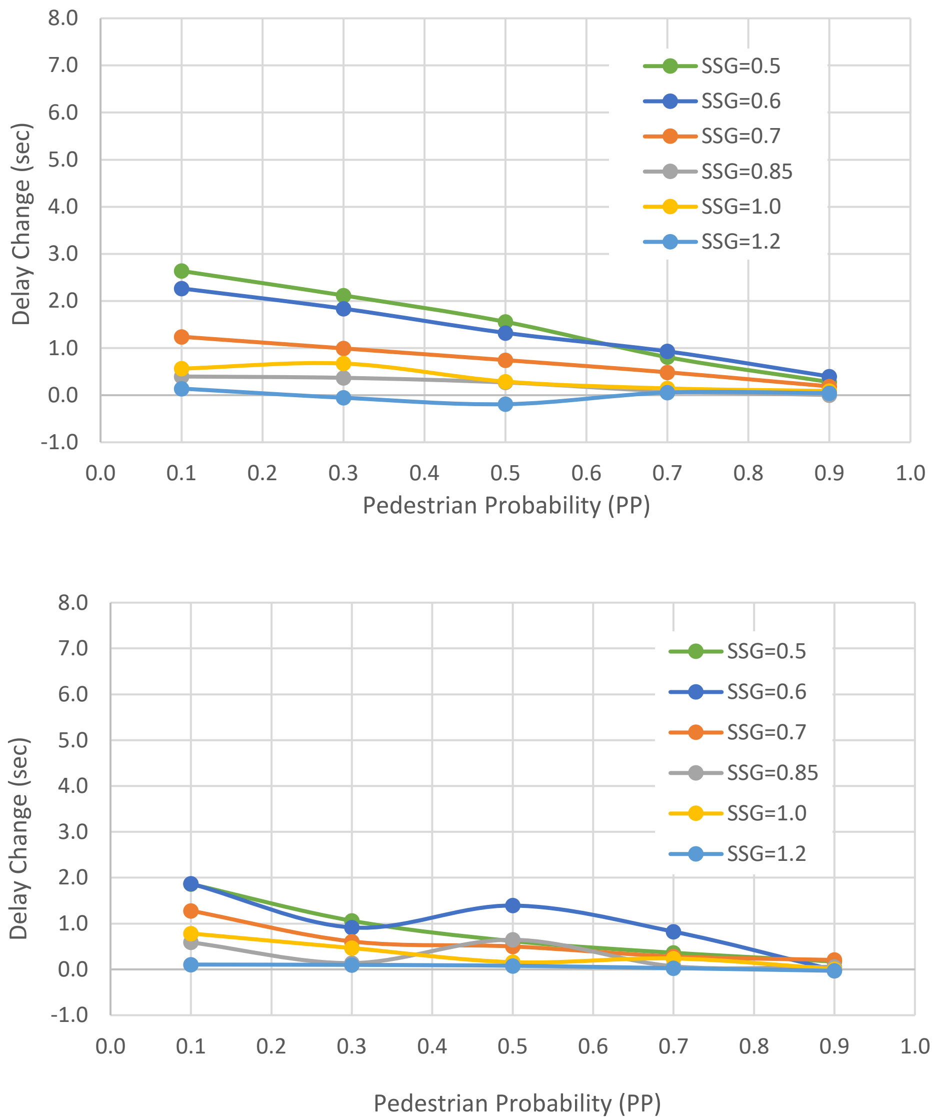


Figure 3: Average Pedestrian Delay Change for Pedestrians Crossing the Side Street under Various Probability of Pedestrian Call (PP) and Side Street Green Ratio (SSG) Scenarios

It is worth highlighting that for agencies that do not use the Rest in Walk feature, pedestrian recall would have no delay impact for pedestrians crossing the side street since the Walk duration would remain the same. And while the change in pedestrian delays for the low SSG scenarios are almost equal and opposite for the two pedestrian crossings (i.e., crossing the arterial versus the side street), from a safety perspective due to improved compliance, the impact is likely to be greater for pedestrians crossing the arterial. With PP = 0.1, the 7-second reduction in delay for crossing the arterial, from 59 seconds to 52 seconds, can be expected to have a significant safety benefit, while the 5-second increase in delay for crossing the side street, from 8 seconds to 13 seconds, can be expected to have very little safety impact because either way, average delay is very small and compliance will be very good. This likely safety benefit is also not captured in a simple "change in delay" measure.

Figure 4 displays overall intersection and network delay change for vehicles under various PP and SSG scenarios. As in previous cases, the impact of pedestrian recall is negligible when SSG ≥ 0.85. With lower SSG and PP scenarios, the increase in intersection delay becomes more pronounced, though still the increase is less than three seconds for all the scenarios. This is partly because the results are obtained from a scenario in which platoons from upstream intersections arrive at the study intersection towards the middle of the green phase. As a result, while pedestrian actuation allows returning to the coordinated phase early in the absence of a pedestrian call, the benefit is small since platoons arrive later during the green phase. In such a case, the main benefit of pedestrian actuation is for vehicles that turned onto the mainline at the upstream intersection, because starting the mainline green early would reduce their delay. To explore the effects of pedestrian recall on intersection delay under different coordination patterns and progression bands, additional sensitivity runs were performed, as discussed in the next section.



a. Intersection vehicle delay

b. Network vehicle delay

Figure 4: Vehicle Delay Change under Various Probability of Pedestrian Call (PP) and Side Street Green Ratio (SSG) Scenarios

Network delay change, which is average change in delay for all vehicles in the network, shows similar but smaller results. One reason for a smaller average delay change is that no impact is expected to through traffic on other cross streets. Another reason is that with coordinated control along an arterial, releasing vehicles early at the subject intersection may create a delay reduction at that intersection in which that delay reduction can be offset by a delay increase at the next intersection, if the signals are timed in such a way that those released early get stopped anyway at the next intersection.

Phase green time distributions for the side street provide further insights into the impact of pedestrian recall versus actuation. **Figure 5** presents side street green time distributions for each SSG scenario when there are no pedestrians crossing the mainline at the study intersection. For reference, the minimum pedestrian green duration (27 seconds) to serve pedestrians is also shown. With high SSG scenarios, it can be observed that phase green duration was longer than the minimum pedestrian green time in most cycles, indicating that setting pedestrian recall would have little or no impact. For example, when

SSG = 1.0, less than 30% of the cycles had a green duration that is less than 27 seconds and when SSG = 1.2, only about 18% of the cycles required green duration that is less than 27 seconds.

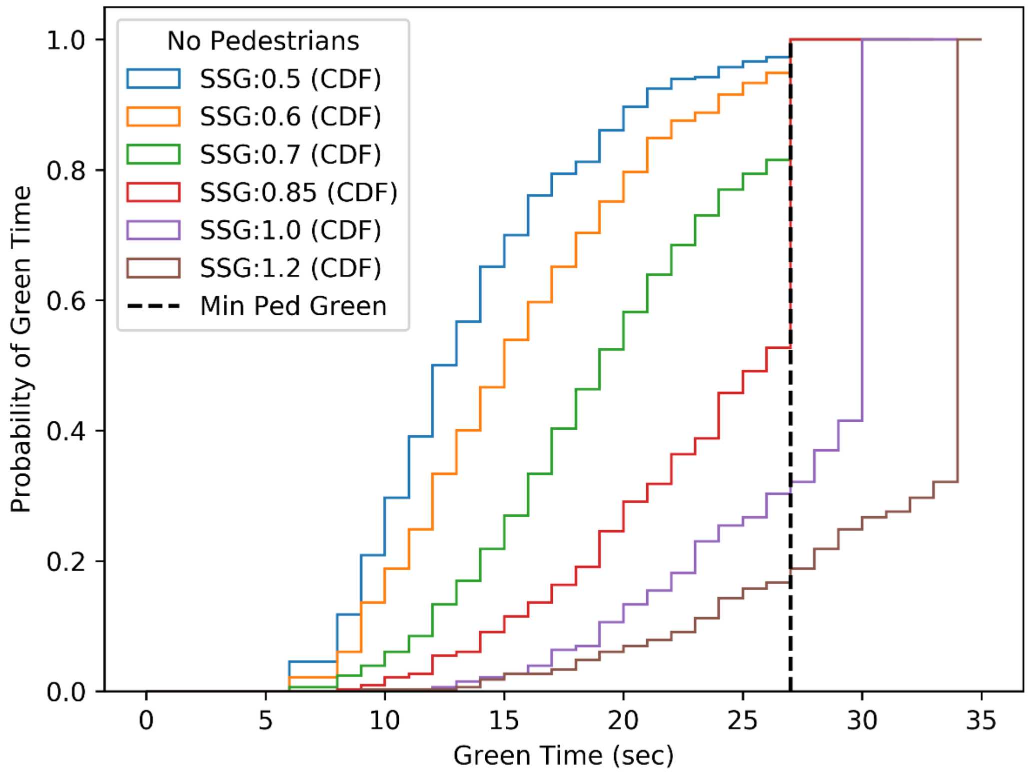


Figure 5: Side Street Green Time Distributions and Cumulative Distribution Functions (CDF) for each SSG Scenario When Pedestrian Volume Crossing the Mainline is Zero (i.e., No Pedestrian Call)

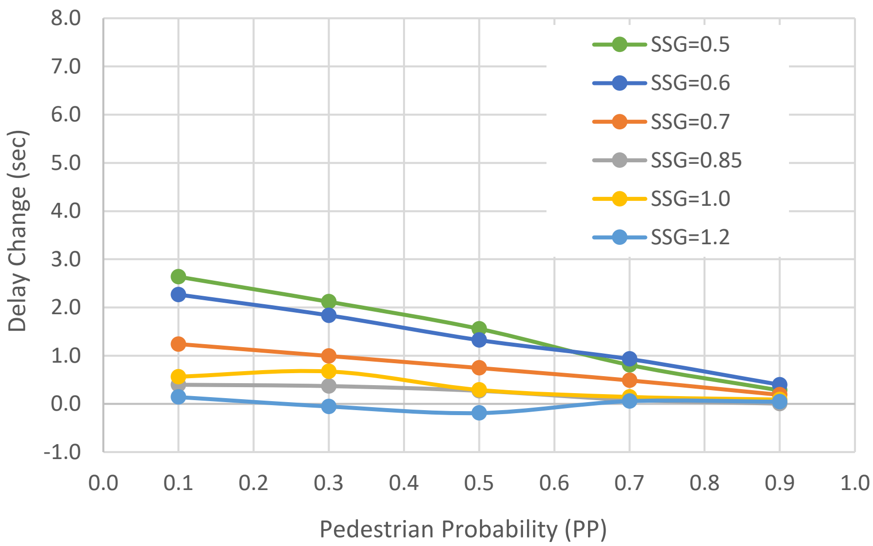
Progression Band Sensitivity Scenarios

Additional sensitivity scenarios were performed to measure the impacts of pedestrian recall on intersection delay under different coordination patterns and progression bands, which were achieved by changing the intersection spacing in the model. With the sensitivity runs, the cycle length and splits were maintained, but intersection spacing in both directions and offsets were adjusted such that platoons are arriving at different points of the mainline green phase at the subject intersection. **Table 2** describes the sensitivity runs performed.

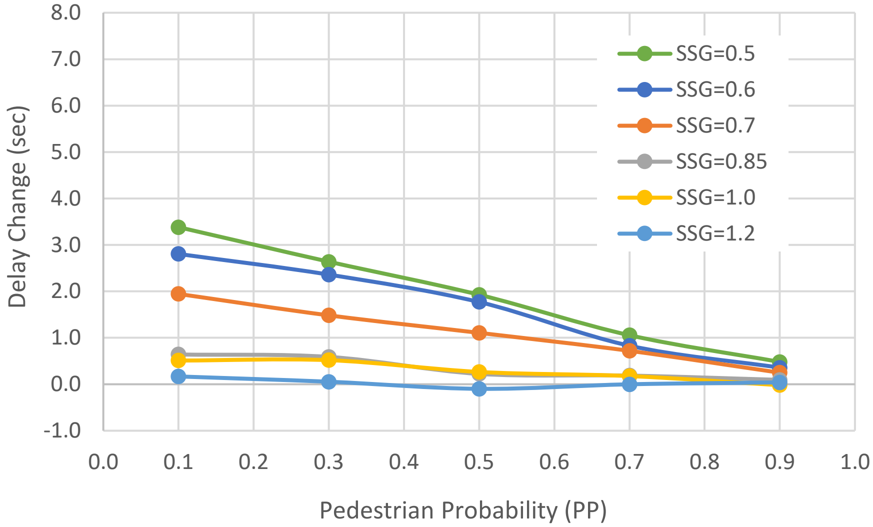
Table 2: Experiment Details for the Progression Band Sensitivity Scenarios

Sensitivity Scenario and Description	Platoon Arrival Pattern
Left-Skewed (i.e., the subject intersection is closer to Mohawk Lane intersection). This is the original scenario discussed above.	• Eastbound platoon arrives towards the middle of the green phase • Westbound platoon arrives towards the middle of the green phase
Un-skewed (i.e., the subject intersection is in the middle of Mohawk Lane and Janna Lee Avenue intersection)	• Eastbound platoon arrives towards the middle of the green phase • Westbound platoon arrives towards the start of the green phase
Right-Skewed (i.e., the subject intersection is closer to Janna Lee Avenue intersection)	• Eastbound platoon arrives before the green phase starts • Westbound platoon arrives towards the middle of the green phase

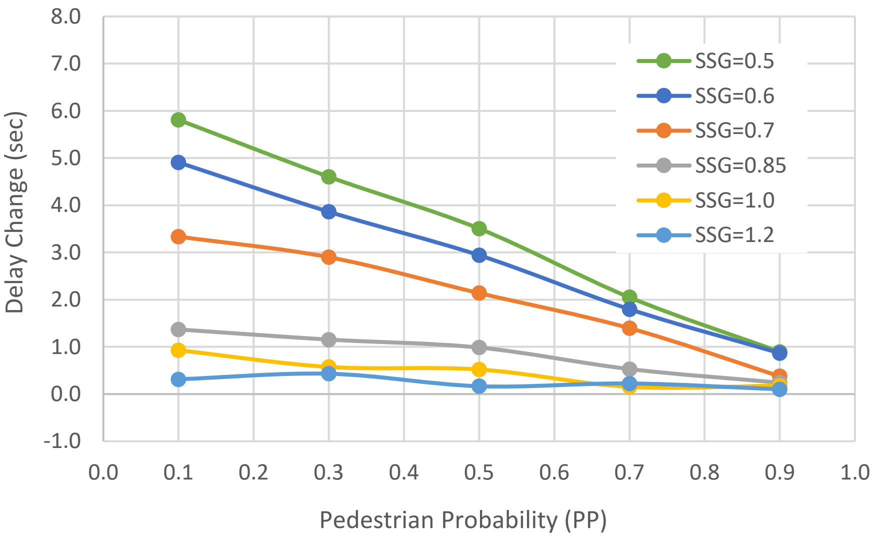
Average intersection vehicle delay impacts for the sensitivity scenarios are displayed in **Figure 6.** For the un-skewed scenario, the findings are almost identical to the left skewed scenario, with an increase in average intersection delay less than 0.5 seconds. This is because platoon arrival patterns for these two scenarios are similar. The impact of pedestrian recall on intersection delay for the right-skewed scenario, however, is considerably higher, because with the right-skewed scenario, the eastbound platoon arrives before the scheduled green start for the mainline. In such a case, the early return to green caused by pedestrian actuation substantially reduces delay, and therefore pedestrian recall has a higher impact on intersection delay.



a. Left-Skewed (Original) Results



b. Un-skewed Results



c. Right-Skewed Results

Figure 6: Progression Band Sensitivity Results: Intersection Vehicle Delay Change under Various Probability of Pedestrian Call (PP) and Side Street Green Ratio (SSG) when the Subject Intersection is Left-Skewed, Un-skewed, and Right-Skewed.

Network delay results for each sensitivity scenario are also provided in **Table 3**. Results are similar to the intersection vehicle delay findings. For the un-skewed scenario, the findings are almost identical to the left-skewed scenario (the original results) since platoon arrival patterns are similar and do not benefit too much from an early green start. For the right-skewed scenario, however, pedestrian recall results in a higher network delay due to the impact primarily on the eastbound platoon, as discussed above.

Overall, the sensitivity runs show that, for coordinated-actuated arterials, the specific impact of pedestrian recall on vehicle delay can be difficult to predict without detailed modeling since it depends on site-specific progression bands and arrival patterns.

Table 3: Progression Band Sensitivity Results: Network Vehicle Delay Change under Various Probability of Pedestrian Call (PP) and Side Street Green Ratio (SSG) when the Subject Intersection is Left-Skewed, Un-skewed, and Right-Skewed.

		Pedestrian Probability (PP)					
		0.1	**0.3**	**0.5**	**0.7**	**0.9**	
Side Street Green Ratio (SSG)	**0.5**	1.9	1.1	0.6	0.4	0.2	**Left-Skewed (Original) Results**
	0.6	1.9	0.9	1.4	0.8	0.0	
	0.7	1.3	0.6	0.5	0.3	0.2	
	0.85	0.6	0.1	0.6	0.1	0.1	
	1.0	0.8	0.5	0.2	0.2	0.0	
	1.2	0.1	0.1	0.1	0.0	0.0	
		Pedestrian Probability (PP)					
		0.1	**0.3**	**0.5**	**0.7**	**0.9**	
Side Street Green Ratio (SSG)	**0.5**	2.3	1.6	1.4	0.9	0.2	**Un-skewed Results**
	0.6	1.7	2.2	1.5	0.6	0.4	
	0.7	1.5	1.3	1.4	0.7	0.1	
	0.85	0.4	0.1	0.1	0.0	0.1	
	1.0	0.1	0.0	0.1	-0.1	-0.1	
	1.2	0.2	0.0	0.0	-0.1	0.0	
		Pedestrian Probability (PP)					
		0.1	**0.3**	**0.5**	**0.7**	**0.9**	
Side Street Green Ratio (SSG)	**0.5**	5.9	4.5	3.2	2.1	0.8	**Right-Skewed Results**
	0.6	5.6	3.9	3.4	2.2	0.8	
	0.7	3.7	2.8	2.2	1.1	0.3	
	0.85	1.7	0.9	1.1	0.6	0.3	
	1.0	0.5	0.2	0.6	0.6	0.1	
	1.2	0.6	0.5	0.1	0.2	0.1	

CONCLUSIONS

This research investigated the effects of setting pedestrian phases on recall along a coordinated-actuated arterial to identify situations in which providing pedestrian recall would have little or no impact on traffic operations. The research studied the effects of pedestrian recall for pedestrians crossing the main arterial because the impact of putting side street on pedestrian recall has more impacts on intersection capacity due to the longer crossings required. The impacts of pedestrian recall were analyzed by varying pedestrian demand and the green time required to serve the side street vehicular phase as a fraction of the minimum green time required to serve pedestrians.

The findings of this research resulted in the following guidance suggested for agencies (**Figure 7**) to determine when to set pedestrian phases on recall versus actuated. For coordinated-actuated intersections, pedestrian recall for pedestrians crossing the main arterial should be considered under the following conditions. The thresholds provided in **Figure 7** for the pedestrian recall recommendation were determined such that the impact on intersection delay is approximately less than 2 seconds per vehicle for all the scenarios analyzed.

- When pedestrian demand is large enough that there is often a pedestrian call (number of pedestrians per cycle > 0.9), or

- When the side street vehicular green time concurrent to the pedestrian crossing is long enough in most cycles that a pedestrian phase would fit without constraining the signal cycle length. Results showed that when this fraction is higher than 0.85, there is negligible impact on intersection delay.

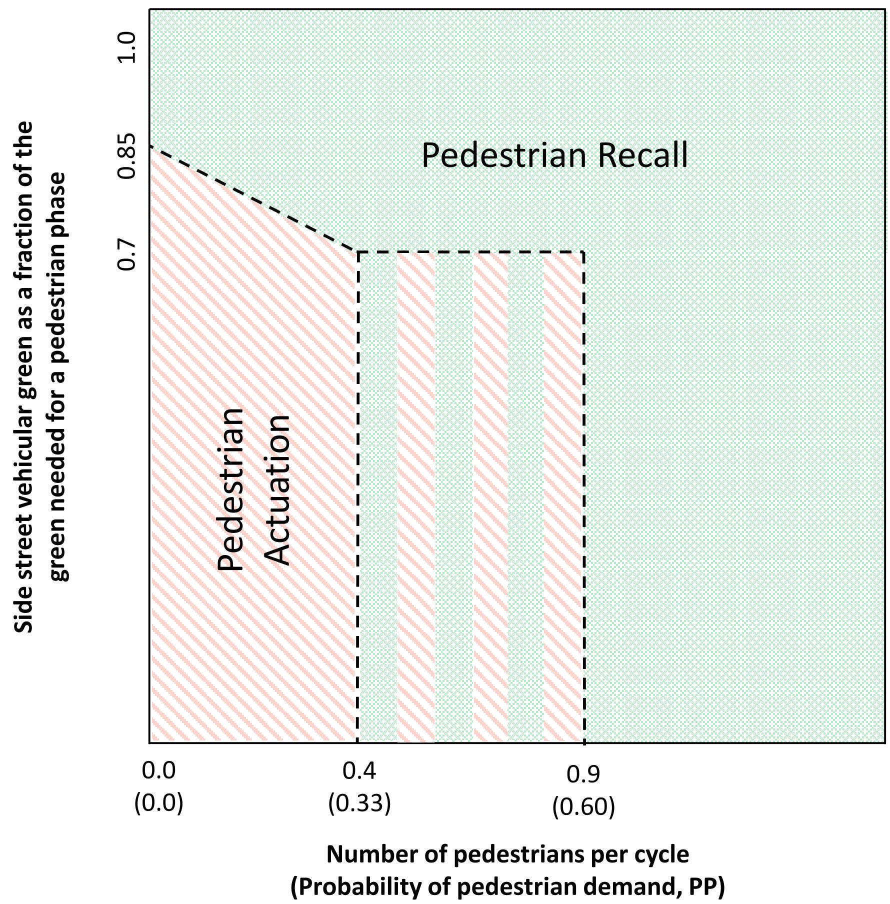


Figure 7: Suggested Guidance to Determine When to Set Pedestrian Phase (Crossing the Main Arterial) on Recall versus Actuated for Coordinated-Actuated Arterials

Note that there is an area in the suggested guidance in which no specific recommendation is provided (i.e., the number of pedestrians per cycle is between 0.4 and 0.9 and SSG is between 0.0 and 0.7). For intersections that fall under this area, the decision can be made based on the discretion of an agency depending on the users of an intersection and the established user and movement priorities.

An important finding of this research is that the pedestrian recall decision should be based not only on pedestrian demand (as recommended by existing guidance), but also on how green time duration for the concurrent vehicular phase compares with the green time needed to serve a pedestrian phase. For certain time periods, heavy vehicle demand on the side street can make it such that setting pedestrian phases on recall will have little impact on intersection delay.

At the same time, switching the pedestrian phase from actuated to recall based on time of day could be confusing for pedestrians. One good way to inform pedestrians whether or not they need to push the pushbutton for service is to use call indicators. Call indicators confirm that a call for pedestrian service has been registered (similar to elevators when a button is illuminated to indicate that the request has been received). If the operation is switched to pedestrian recall during a certain time of the day, the call indicator can be programmed to illuminate by default (automatically) when pedestrian phases are on recall, avoiding any confusion for pedestrians.

The sensitivity analysis shows that the impact of pedestrian recall on vehicles can depend on site-specific features. As a result, while the simple rules suggested here can provide important insights and help agencies determine when to set pedestrian phases on recall on coordinated-arterials, detailed modeling and analysis can lead to better decisions, especially when the results of the pedestrian volume and side street vehicular green duration do not lead to a clear decision.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: B. Cesme, P. Furth, and K. Lee; data collection: B. Cesme, R. Casburn; analysis and interpretation of results: B. Cesme, P. Furth, and R. Casburn; draft manuscript preparation: B. Cesme., P. Furth, and R. Casburn. All authors reviewed the results and approved the final version of the manuscript.

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