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Guidance on **Signal Control** Strategies for Pedestrians **to Improve Walkability**

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Walking as a transportation mode is associated with a number of benefits ranging from reductions in congestion and emissions levels to improvements in personal health. Therefore, many communities across the United States are eager to increase walk mode shares. Yet, the traffic signal timing and optimization models we use continue to focus only on automobile traffic. These legacy signal timing policies at intersections have prioritized vehicular movements, leading to large and sometimes unnecessary delays for pedestrians. Because pedestrian trips are short, delays at signalized intersections can affect pedestrians disproportionately and are a key factor in pedestrian non-compliance.[1]

Historically, there has been limited research focus on control strategies for pedestrians at signalized intersections. Generally, control strategies can be divided into two categories: safety or efficiency-related. A safety-related signal timing strategy may seek to improve pedestrian safety by reducing pedestrian-vehicle conflicts. Examples include leading pedestrian interval (LPI) and exclusive pedestrian phase (aka, the Barnes Dance). Efficiency-related control strategies aim to reduce delays for pedestrians. Examples of efficiency control strategies include reductions in cycle length during coordinated operation, free operation, permissive period changes, and actuated coordination. Historically, these have received less attention in pedestrian focused literature.

The choice of a control strategy depends on the operational objectives with no one solution that fits all scenarios. Hence, the objective of this article is to provide the practitioner with a toolkit of pedestrian control strategies, along with safety and efficiency impacts, so that an informed decision can be made.

Pedestrian Signal Timing Strategies

Safety Focused Strategies

Leading Pedestrian Interval

Leading pedestrian interval (LPI) refers to a signal control strategy where pedestrians are provided with a walk indication for a few seconds prior to the onset of the concurrent vehicular green indication, allowing pedestrians to establish themselves in the intersection before conflicting vehicles are released. Figure 1 shows the ring-and-barrier diagram, where pedestrian phases 2 and 6 have an LPI.

The advantages of an LPI are primarily safety related, with evidence of reduced conflicts between pedestrians and turning vehicles.[2] Efficiency impacts have been less studied, but authors agree on an increase in delays due to lost time for vehicles.[3,4,5] The magnitude of increase in delay depends on a number of factors such as the length of the leading pedestrian interval, whether the intersection is in coordination, cycle length, and whether the LPI has been implemented for pedestrian phases on the major, minor-street, or both. Saneinejad and Lo developed a worksheet tool to assess the suitability of a location for LPI implementation and recommend conducting a before-after analysis to understand the impacts.[5]

Exclusive Pedestrian Phase (Barnes Dance)

An exclusive pedestrian phase is a type of phasing in which pedestrians have exclusive use of the intersection including lateral and diagonal crossings while all vehicular traffic is stopped, with the WALK signal displayed simultaneously for all crosswalks. Figure 2 shows the ring-and-barrier diagram for the Barnes Dance (phase 12).

While this phasing eliminates conflicts for pedestrians and is effective in reducing pedestrian-motor vehicle crashes, it increases both vehicular and pedestrian delays due to increased cycle length, especially if pedestrians are only allowed to cross during the

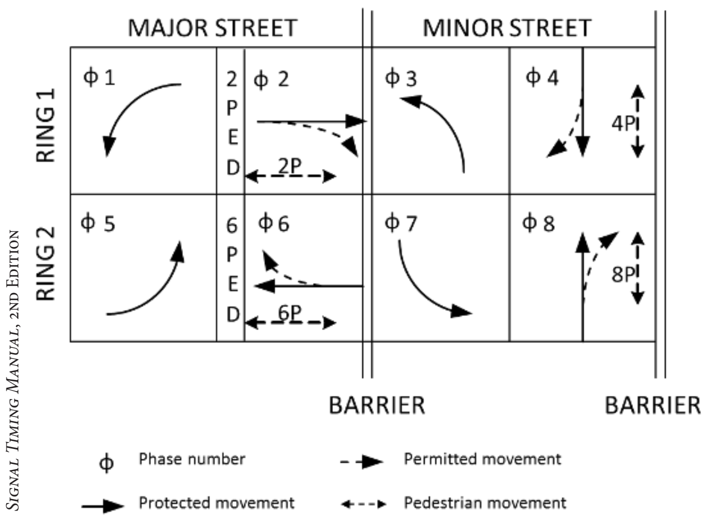

Figure 1. Leading Pedestrian Interval

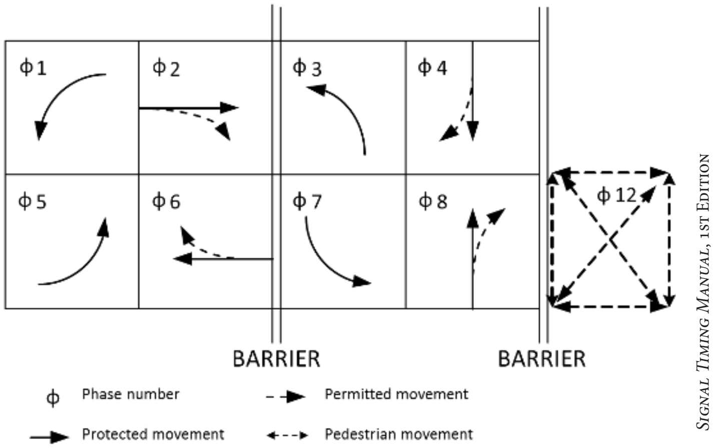

Figure 2. Exclusive Pedestrian Phase (Barnes Dance)

exclusive phase.[6] Increased pedestrian non-compliance due to the higher delays because of exclusive pedestrian phase implementation has also been observed.[6]

This strategy is best suited for intersections with high volumes of pedestrians and turning vehicles, at locations where traditional pedestrian accommodation does not work well. However, costs associated with this strategy, namely increased delays and non-compliance by pedestrians should be carefully weighed before implementation.

Efficiency Focused Strategies

Short Cycle Lengths

Cycle length in signal timing refers to the time taken for a complete sequence of signal indications.[7] Cycle length is an important signal timing parameter especially for coordinated signal systems. The *Highway Capacity Manual* (HCM) provides an equation to estimate pedestrian delay based on cycle length and effective green time for pedestrians.[8]

$$delay = \frac{(C - g_{walk})^2}{2C}$$

Where C = cycle length, g_{walk} = effective walk time

Research has shown that in general, shorter cycle lengths benefit pedestrians leading to lower delay.[1,4] The provision of shorter cycle lengths has also been recommended to encourage signal compliance and increase efficiency. While short cycle lengths reduce pedestrian delays and vehicular delays for the minor-street phases, delays for major-street phases may increase due to reduction in green time, possibly resulting in an overall increase in delay at the intersection.

This strategy is best suited for off-peak and other periods when vehicular demand is low, yet agencies want their signals to remain in coordination rather than setting them free, due to agency objectives. Ideally, this strategy is also applied during peak periods if possible, as keeping cycle lengths short does typically reduce overall delay.

Increasing Permissive Period

Permissive period refers to the period of time during the coordinated cycle in which calls on the conflicting (non-coordinated) phases will result in phase transition from coordinated to non-coordinated phase.[7] Previous research has shown that increasing permissive period length resulted in statistically significant lower pedestrian delay.[9] De Castro-Neto showed that for low volume conditions having the permissive period close later in the cycle was better for non-coordinated phases.[10]

Vehicular delays for the coordinated phases may be impacted depending on the magnitude of change in the permissive period, however, if the coordinated platoon arrives condensed and early in the coordinated green, any increase in delay should be minimal. More research is needed to fully understand these impacts. Pedestrian and vehicular delays for the non-coordinated phases may be reduced as a result of increase in permissive period. This strategy may be best suited for implementation on a time-of day basis as a tool to reduce pedestrian delay for the non-coordinated phases during the off-peak periods in a coordinated system.

Free Operation

Free operation is another strategy that can be used to reduce pedestrian delay compared to coordinated operation. By removing holds on coordinated phases, the traffic controller is able to serve whichever phase is requesting service based on the rules of actuated control, that of call and extend operation. Free operation generally results in the least amount of delay for all users, but many practitioners find it to be a less desirable option because it does not prioritize arterial corridor movement.

There is limited research on the impacts on pedestrians of operating the signal in free mode compared to traditional coordination. Kothuri et al. evaluated the impacts of coordination vs. free operation via micro-simulation and found that pedestrian delays are significantly reduced for minor-street phases during free operation. Using field derived inputs, volume to capacity ratios for the major-street and pedestrian phase actuations for the minor-street (proxy for pedestrian demand), Kothuri et al. proposed a methodology for determining if a signal should be coordinated or free, considering overall delay across all users at an intersection.[11]

Free operation may be best suited for intersections with long spacing (quarter mile or more) to adjacent signals especially when traffic v/c ratios are less than 0.5. It can also be applied at any intersection based on a time of day approach, in order to prioritize minor-street pedestrian movements. Free operation may be used during the off-peak periods to reduce pedestrian delays as well as during late-night hours when traffic volumes on the major-street are low, a strategy that has been followed by the City of Portland, OR, USA. It may also be best suited for intersections where the volumes on the intersecting streets are more balanced, presuming max times are set appropriately to prevent any movement from lengthening the cycle excessively.

Actuated-Coordination

Actuated-coordination is a signal timing treatment that allows the user to actuate a portion of the coordinated split.[2] This allows the coordinated phases to gap out if there is low demand during the actuated portion, thus allowing the signal to be more responsive to field conditions than traditional coordination. This additional time can be used by the minor-street or left turn phases. Figure 3 shows the ring-and-barrier diagram for actuated-coordination. In Figure 3, the latter portion of coordinated phases 2 and 6 are actuated and can terminate if there is low demand, while serving phases 3, 7, 4, and 8 earlier.

Research on the impacts of actuated-coordination showed a decrease in v/c ratios and fewer occurrences of split failures and a decrease in pedestrian delay.[12] Additionally, use of fully actuated-coordination and fixed force-offs also reduced minor-street delays.

This strategy may be most useful when agencies want their intersections to remain in coordination, even during off-peak periods. The greatest benefits may be seen during periods when the major-street demand is low and minor-street demand is high. However, presence of mainline detection is necessary for implementation. The increased cost of additional detection and maintenance, and the arrival of the major-street platoon should be carefully considered prior to implementing this strategy.

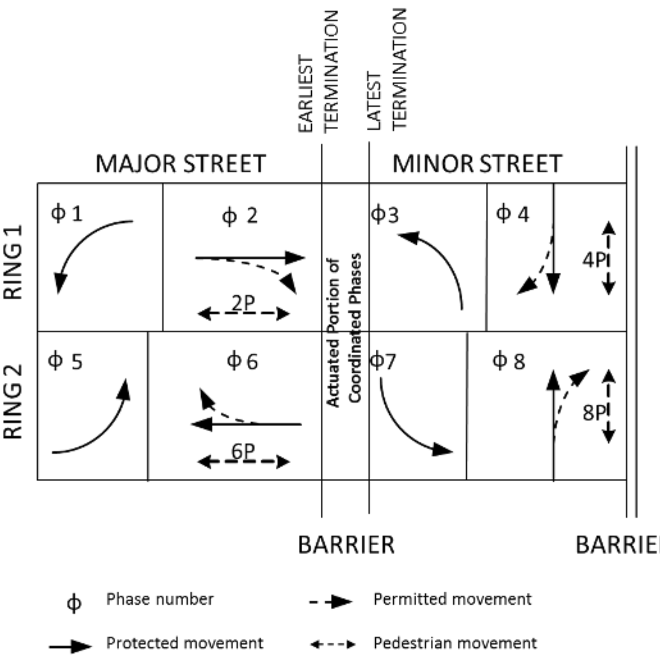

Figure 3. Actuated Coordinated Operation

Pedestrian Priority

Many signal controllers provide users with the ability to incorporate custom logic commands, which allow for greater flexibility in operation. These logic commands can be successfully leveraged to build simple algorithms that provide the user with the flexibility to change modal priorities at the intersection based on real time inputs.

Sobie et al. describe the development and implementation of a pedestrian priority algorithm using the logic processor on an ASC/3 controller. The traffic responsive algorithm is designed to change the operational plan of a traffic signal to a plan that is favorable to pedestrians when vehicular volumes drop below a certain threshold.[13] Their findings revealed that the algorithm was successful in reducing minor-street pedestrian delays.

This algorithm can be implemented at any intersection with a signal controller that has logic command capability. Although this work was constructed on Econolite's ASC/3 platform, it could easily be adapted to other signal controller platforms, or implemented on a PLC or Raspberry Pi type device. The algorithm in its current form is best suited for coordinated intersections, with higher major-street and lower minor-street volumes.

Ranking of Control Strategies

Table 1 shows the ranking of the control strategies based on major-street vehicular delays and minor-street pedestrian delays based on research by Kothuri et al.[4] Higher numbers indicate increased delays. For pedestrians, free operation resulted in lowest delay and Barnes Dance produced the highest delay. For vehicles, coordination produced the lowest delay for the major-street phases and Barnes Dance resulted in the highest delay. Of course, while changes in the settings of the various strategies could adjust the order presented below, these rankings provide a general comparative list of the various strategies. Please note that pedestrian priority is not listed in this table because it can be employed with any of the listed strategies.

Table 1. Ranking of Control Strategies

Control Strategy	Pedestrian Delay Ranking	Vehicle Delay Ranking
Free operation	1	4
Short cycle lengths	2	3
Leading pedestrian intervals	3	5
Actuated coordination	4	2
Coordination	5	1
Barnes dance	6	6

Note: 1 is least amount of delay and 6 is the most, all other things being equal.

Recommendations

While the choice of a control strategy depends on operational objectives and intersection characteristics, a few general recommendations related to the deployment of specific strategies are provided here.

The Barnes Dance is best suited at locations where very high pedestrian or right turning volumes create the need to completely separate modes. An LPI is best suited for locations where geometry and/or vehicle volumes cause issues for pedestrians entering the crosswalk. Short cycle lengths provide the practitioner with the option of operating in coordinated mode while trading green bandwidth for reduced delays for minor-street phases. Free operation is the most aggressive strategy resulting in lower delays for most users at the expense of major-street traffic. Actuated coordinated operation can provide lower pedestrian delays for the minor-street phases, if the major-street phases gap out and is useful for low-moderate pedestrian volumes. The pedestrian priority algorithm bridges the gap between conflicting objectives by allowing the controller to prioritize service to different users based upon vehicle inputs. Figure 4 shows a graphic with recommendation on when and what type of pedestrian strategies to implement based on v/c ratios and pedestrian pushbutton actuation frequency, which is the percent of cycles that have pedestrian calls.

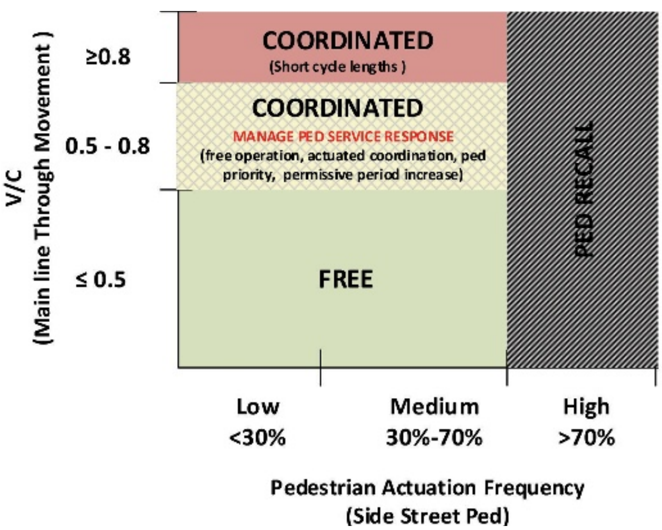

Figure 4. Recommendation on Implementation of Pedestrian-focused Strategies

Conclusions

Traditional signal timing practices often prioritize vehicular movements at signalized intersections over other system users. However, an increase in non-motorized modes especially in urban areas had led to greater consideration of the actual operating environment and incorporates the needs of all users. In this article, a number of pedestrian focused signal control strategies were presented along with expected impacts and recommendations on what might meet the needs based on activity and context. Generally, there is no one solution for all situations. Implementation of a control strategy depends upon operational objectives and intersection characteristics. Ultimately, tradeoffs in delays between user groups should be addressed to prioritize different modes based upon time of day. **itej**

References

1. Vallyon, C., S. Turner, and S. Hodgson. Reducing pedestrian delay at traffic signals. New Zealand Transport Agency: 2011.
2. Urbanik, T., et al. NCHRP Report 812: *Signal Timing Manual*, 2nd Edition. National Cooperative Highway Research Program, 2014.
3. Fayish, A. and F. Gross."Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before-After Study with Comparison Groups." *Transportation Research Record,* Vol. 2198, 2010: 15-22.
4. Kothuri, S., A. Kading, E. Smaglik, and C. Sobie. "Improving Walkability through Control Strategies at Signalized Intersections." Final Report, NITC-RR-782. Portland, OR, USA: Transportation Research and Education Center, 2017.
5. Saneinejad, S. and J. Lo. "Leading Pedestrian Interval Assessment and Implementation Guidelines." *Transportation Research Record*, Vol. 2519, 2015: 85-94.
6. Bechtel, A., K. MacLeod, and D. Ragland. "Pedestrian Scramble Signal in Chinatown Neighborhood of Oakland, California: An Evaluation." *Transportation Research Record*, Vol. 1878, 2004: 19-26.
7. Koonce, P., L. Rodegerdts, L. Lee, S. Quayle, S. Beaird, C. Braud, J. Bonneson, P. Tarnoff, and T. Urbanik. FHWA-HOP-08-204: *Traffic Signal Timing Manual*. Washington, DC, USA: 2008.
8. Transportation Research Board. *Highway Capacity Manual*. Washington, DC, USA: 2010.
9. Kothuri, S., T. Reynolds, C. Monsere, and P. Koonce. "Testing Strategies to Reduce Pedestrian Delay at Signalized Intersections: A Pilot Study in Portland, Oregon." *Transportation Research Board 92nd Annual Meeting,* Washington, DC, USA: 2013.
10. de Castro-Neto, M., T. Urbanik, and L. Han. "Noncoordinated Phases in Coordinated Traffic Signal System. Evaluation of Alternative Permissive Periods on Performance." *Transportation Research Record*. Vol. 1978, 2006: 8-15.
11. Kothuri, S., P. Koonce, C. Monsere, and T. Reynolds. "Exploring Thresholds for Timing Strategies on a Pedestrian Active Corridor." *Transportation Research Board 91st Annual Meeting*, Washington, DC, USA: 2015.
12. Day, Christopher, E. Smaglik, D. Bullock, and J. Sturdevant. "Quantitative Evaluation of Fully Actuated Versus Nonactuated Coordinated Phases." *Transportation Research Record,* Vol. 2080, 2008: 8-21.
13. Sobie, C., E. Smaglik, A. Sharma, A. Kading, S. Kothuri, and P. Koonce. "Managing User Delay with a Focus on Pedestrian Operations." *Transportation Research Record.* Vol. 2558, 2016.

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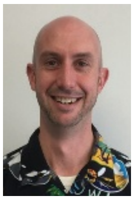

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