Using Microsimulation to Investigate the Optimal Deployment of Leading Pedestrian Intervals at Signalized Intersections

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Extended Summary

The provision of leading pedestrian intervals (LPI) has emerged in recent years to achieve safety equitability for pedestrians at signalized intersections. LPI is a way to provide the pedestrian walk interval a few seconds before starting the circular green indication to adjacent parallel traffic. Although the safety benefit of LPI is indisputable, fundamental questions need to be addressed for the optimal deployment of this strategy. First, can significant safety benefits for pedestrians be achieved while maintaining a satisfactory operational level of service for vehicles? Second, what are the application circumstances most conducive to achieving the greatest safety benefits for pedestrians? Third, how can a jurisdiction effectively assess contemplated treatments to achieve optimal deployment?

This exploratory study addresses these three fundamental questions by providing more information on the influence of site features and LPI implementation circumstances on both the safety and operational effects of LPIs. A literature review confirmed the need for such a study in that it indicated there is precious little consistent information on the influence of site features and LPI implementation circumstances on both the safety and operational effects of LPIs. In addressing these questions, the paper provides a blueprint for jurisdictions to undertake such assessments in optimizing the deployment of contemplated LPI installations.

Microsimulation, which involved using a recently released module for accommodating LPI phasing in the PTV Vistro software, was used to estimate delay, and vehicle-to-pedestrian conflicts with and without LPI implementation. For one of these intersections, a similar evaluation was done for eight more hypothetical scenarios that were defined based on indications from previous studies to examine the potential influence of factors such as turning volumes, crossing width, length of the LPI interval, pedestrian volumes, and whether or not right turn on red (RTOR) is allowed.

The vehicular delay incurred due to LPI implementation at the 15 intersections was measured by creating a layout in PTV Vistro containing all relevant parameters, including vehicles, pedestrians, and signal timing. Using this software, one can calculate the level of service (LOS), vehicle delay, and maximum queue length for each scenario. In order to measure the number of conflicts, PTV VISSIM *(1)* was first used to develop a simulation of pedestrians and vehicles for each scenario using the intersection file developed on PTV Vistro. Second, the Surrogate Safety Assessment Model (SSAM) *(2)* was applied to automatically identify, classify, and evaluate pedestrian-vehicle conflicts from the VISSIM trajectory output. Each simulation run lasted for one hour in PTV VISSIM, and ten simulation runs were done for each scenario. SSAM identified simulated conflicts based on the threshold values of two surrogate safety measures: the maximum time to collision (TTC), and the maximum post encroachment time (PET).

The results of from the microsilulation of the 15 intersections indicated that vehicle delay increased after LPI was implemented, while the number of vehicle-to-pedestrian conflicts decreased. Of special note is the fact that, despite

the tangible increase in delay, the level of service post-LPI is still at an acceptable level (i.e., "C" or "D"). However, there was substantial variation in the effects for the number of vehicle-to-pedestrian conflicts, suggesting that influencing factors may be at play.

In the next step, the eight additional scenarios were investigated for one intersection with high pedestrian volume during morning peak hours to gain insights into the effects of influencing factors on safety and operational impacts. The following observations can be made by comparing the % change of each scenario to the original scenario.

- Providing LPI for both approaches (E.W. and N.S.) can increase the reduction in both initial vehicle-to-pedestrian conflicts and extreme ones, but simultaneously can produce a high increase in delay that, nevertheless, still results in a tolerable LOS.
- Increased crossing distance results in an 8% increase in the conflicts and a 60% increase in extreme ones, but it has a negligible effect on delays.
- Prohibiting RTOR has a great impact, with a 27% decrease in the conflicts and a 28% increase in delay that, nevertheless, still results in a tolerable LOS.
- Reducing the LPI from 5-sec to 3-sec results in a substantial increase in vehicle-to-pedestrian conflicts and a considerable increase in extreme vehicle-to-pedestrian conflicts, and, logically, a notable decrease in vehicle delay.

After identifying the initial number of vehicle-to-pedestrian conflicts, a deep learning method called AutoEncoder neural network was used to label extreme vehicle-to-pedestrian conflicts (anomalies) based on the values of TTC and PET reported from SSAM. This method has been selected over the other neural network techniques since, in most relevant studies, unsupervised anomaly detection methods have relied mainly on AutoEncoders *(3-7)*. Key advantages of this algorithm include the capability of learning the inherent data characteristics that distinguish safe events from anomalous or unsafe events without requiring labeled data, and the ability to work with multidimensional data *(7)*. Thus, it seems natural that AutoEncoders provide an ideal technique for detecting extreme vehicle-to-pedestrian conflicts. In the application of this study, a threshold was set based on the trained samples for classifying those trajectories with extreme values.

For three scenarios, initial conflicts and extreme ones show different trends. For example, prohibiting RTOR decreased vehicle-to-pedestrian conflicts but increased the extreme vehicle-to-pedestrian conflicts. Moreover, for the other scenarios, extreme conflicts trends did not follow the logical trend, which may be because the extreme conflicts are intuitively rare; in addition, each simulation iteration ran for only one hour, so that more simulation time may resolve the apparent anomaly.

In summary, the results (of comparing % change of each scenario to the original scenario) illustrate the order and direction of the effects of the influencing factors for pedestrian safety and delay with LPI implementations, namely, left-turn volume, RTOR prohibition, crossing width, duration of LPI, number of approaches with LPI implemented, and pedestrian volume. Moreover, the results of this exploratory investigation were encouraging. In addition, vehicle-to-pedestrian conflicts and vehicle delay were estimated for ten scenarios that allowed for the provision of, and variability in the LPI interval, right turn volumes, right turn on red provision, pedestrian and vehicle volumes, and crossing width. The results suggest that significant safety benefits can be achieved for pedestrians while maintaining a satisfactory level of service for vehicles. They further suggest that potential LPI deployments need to be assessed on a case-by-case basis since the effects of LPI can be significantly impacted by the influencing factors investigated.

The final part of the analysis was the development of statistical models to quantify the effects of LPI implementation on pedestrian-vehicle conflicts after controlling for pedestrian and turning vehicle volumes. Two sets of conflicts were modeled – the initial ones identified from the SSAM software outputs, and the extreme ones identified using the AutoEncoder technique. Several observations can be made from the results in these models.

- In general, the estimated effects for all variables in terms of direction are consistent with logic and previous research findings. For example, more pedestrian and vehicle turning volumes are associated with more vehicle-pedestrian conflicts. And LPI implementation is associated with reduced conflicts.
- The p-values for all variables were estimated to be highly significant, indicating a reasonable statistical fit for each model.

- The estimated coefficient in the conflict-based optimum model (Eq. 1) for LPI implementation suggests a reduction in initial conflicts of [100(1-exp(-0.76)] = 53%, approximately. Considering the recent crash-based CMF estimate of 0.87, this would imply that a 10% reduction in pedestrian conflicts would be associated with a 2% reduction in crashes. Although there are no available crash prediction models for vehicle-pedestrian conflicts, there can be some assurance that these effects are reasonably consistent with indications from crash prediction models currently available for vehicle-vehicle conflicts *(8, 9)*. For the extreme conflict-based optimum model (Eq. 2), the estimated coefficient for LPI implementation suggests a reduction in extreme conflicts of [100(1-exp(-0.65)] = 48%, approximately.

$$Conflict_i = e^{-5.93} \times (\text{Pedestrian Crossing Volume} + \text{Turning Volume})^{1.31} \times e^{-0.76\{\text{with } LPI\}} \quad (1)$$

$$\text{Extreme conflict}_i = e^{-16.34} \times (\text{Pedestrian Crossing Volume} + \text{Turning Volume})^{1.19} \times e^{-0.65\{\text{with } LPI\}} \quad (2)$$

- It should be stressed that the estimated models are simply exploratory, given that the data are very limited, especially for the extreme conflict-based model, which is arguably the most beneficial model, but has the largest overdispersion parameter by far. The results nevertheless indicate that quantifying the effects of influencing factors is feasible for a full investigation with larger sample sizes. Such an investigation would consider using separate terms for vehicle and pedestrian volumes, alternative model forms and the inclusion of other influencing factors found in this research to be pertinent.

This study provided a blueprint for investigating the design, traffic, and operational factors that can influence the impact of LPI on pedestrian safety without detrimentally impacting vehicle level of service. The research was an exploratory demonstration, with only fifteen intersections analyzed. As such, the results, though interesting and consistent with the literature and logical considerations, are not generalizable. The results do suggest, however, that significant safety benefits can be achieved for pedestrians while maintaining a satisfactory level of service for vehicles. They further indicate that potential LPI deployments need to be assessed on a case-by-case basis, as the effects of LPI can be significantly impacted by influencing factors such as left-turn and right-turn volumes, RTOR prohibition, crossing width, duration of LPI, number of approaches with LPI implemented, and pedestrian volume. The paper illustrates that such case-by-case assessments, using state-of-the-art software, are doable and can be valuable for optimizing the deployment of such strategies.

Further work could evaluate a larger sample and perhaps a wider variety of intersections and scenarios to make the results more generalizable and facilitate the further development of the statistical models. Such research can be complemented by a case-control methodological approach applied to pedestrian crash data to identify factors influencing pedestrian crashes at intersections with and without LPI. Considering the paucity of such data, it may be informative to further explore the extreme conflicts.

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