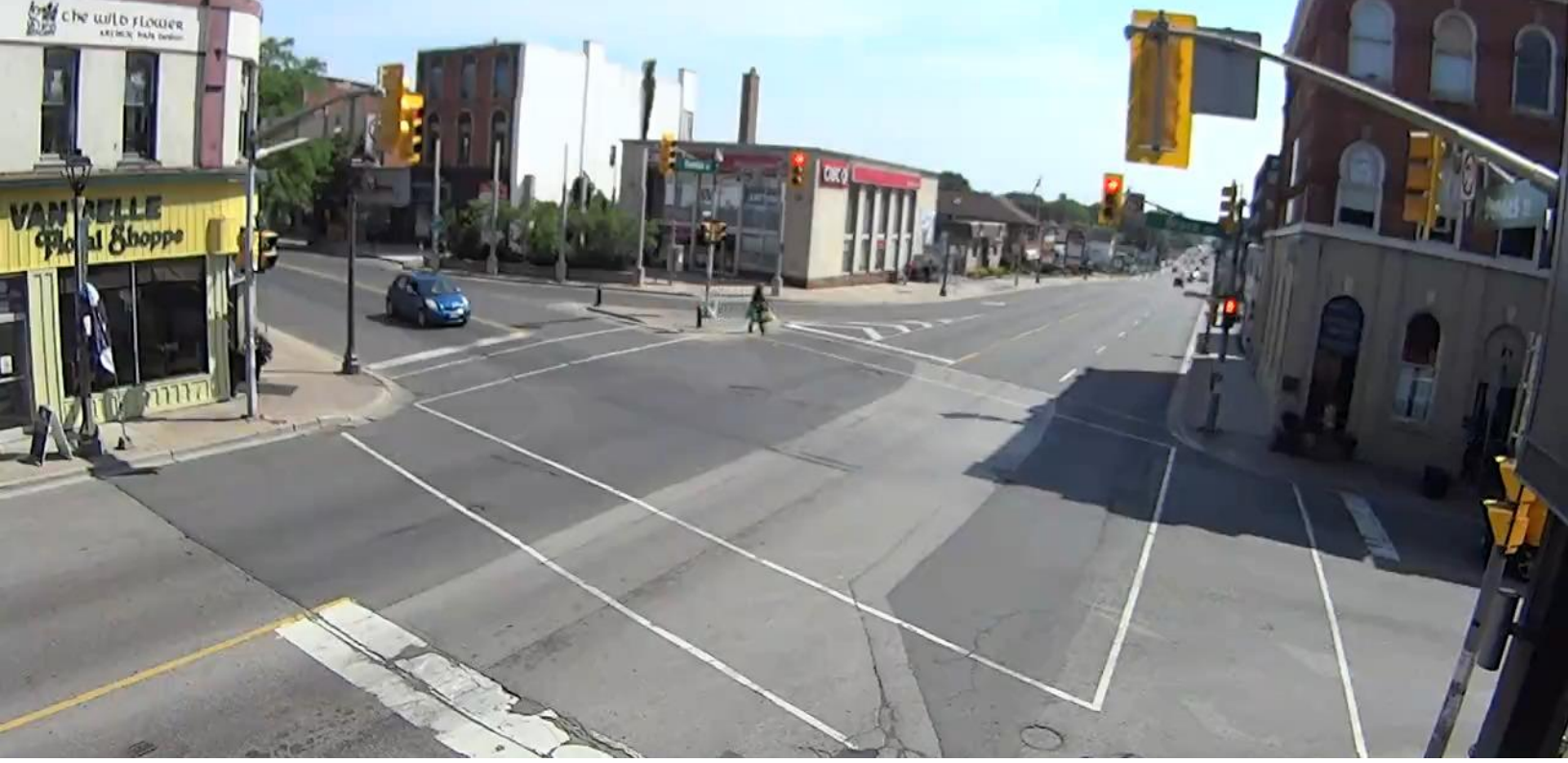

USE OF CONFLICT ANALYSIS TO ASSESS TURNING CONFLICTS WITH VULNERABLE USERS AT SIGNALIZED INTERSECTIONS

ENHANCED ROAD SAFETY TRANSFER PAYMENT PROGRAM – TRANSPORT CANADA

March 2023

USE OF CONFLICT ANALYSIS TO ASSESS TURNING CONFLICTS WITH VULNERABLE USERS AT SIGNALIZED INTERSECTIONS

Enhanced Road Safety Transfer Payment Program

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APPENDIX A: DETAILED SURVEY SUMMARY

1.0 SUMMARY

1.1 Background

The number of collisions involving vulnerable road users (VRU) has been on the rise in most urban areas across Canada. A substantial proportion of VRU collisions involve vehicle turning movement collisions at signalized intersections. To minimize the risk of turning collisions with VRUs at signalized intersections, road authorities have begun implementing and pilot testing several types of geometric and operational road safety countermeasures, including Leading Pedestrian Intervals (LPI). LPIs provide pedestrians with a walk indication starting a few seconds prior to the corresponding vehicular green signal.

This research project was completed through the Transport Canada Enhanced Road Safety Transfer Payment Program. The project used an innovative and emerging video analytics tool to facilitate the evaluation of the safety effectiveness of LPIs without having to wait several years to collect a sufficiently large sample size of collisions involving VRUs. To complete this project, True North Safety Group (TNS) partnered with Transoft Solutions (Transoft) for the conflict data processing, and with the municipalities of Durham, Guelph, and Oakville, for the pilot testing of LPIs at 14 intersections.

The results of this study represent valuable information for road authorities to determine if they should continue implementing LPIs on their road network and determine the preferred designs and locations to maximize safety benefits, and ultimately reduce the number of fatal and injury collisions.

1.2 Summary of Findings

The study team, in collaboration with the partnering municipalities, has identified 14 signalized intersections for the implementation and evaluation of LPIs. LPIs were implemented both at crosswalks where vehicle/pedestrian conflicts were present, as well as crosswalks where there were very few or no conflicts.

For the purposes of the analysis, each crosswalk-day combination was treated independently. A "site" was defined as the crosswalk across approach *a* at intersection *i* during period *p*, where *p* represented eight hours of data within the same day. The sites were assigned to two groups:

- **Before:** All sites where information was collected in the before period, i.e., prior to the implementation of LPIs.
- **After:** All sites where information was collected in the after period and where an LPI was implemented. Crosswalks where the LPI duration was changed, and information was collected again ('after 2') were also included in the after group.

During the analysis, it was noted that several sites showed very few or no conflicts of one or both types, including in the before period. Since no countermeasure can reduce the number of conflicts below zero, including sites where no known conflicts were present in the before period would lead to including sites where the only possible outcomes from the implementation of LPIs were an increase or no change in conflict frequency. Therefore, a minimum value of three conflicts over an eight-hour period was selected for sites in the before period, to allow all three possible outcomes

(decrease, no change, or increase in conflict frequency) while keeping a significant number of sites.

Sites were selected as follows:

- **Before:** Each crosswalk was selected for the days where three or more conflicts of the analyzed type were observed over an eight-hour period.
- **After:** All sites where the crosswalk was included in the before period.

Sites were selected independently for analysis relating to right-turn conflicts and left-turn conflicts.

Analysis was then completed on the results, using conflict rates at 220 sites. The rates were used to control for exposure (using conflicting pedestrian and vehicular volumes across the site). Average conflict rates were calculated for the before and after period, based on conflict type, LPI duration, pedestrian and vehicular volumes, and other geometric and operational characteristics. Statistical testing was completed on each set of results to determine if the before and after average conflict rates were statistically different. Where the before and after results were found to be statistically different, a ratio was calculated by dividing the average conflict rate for the after period by the average conflict rate for the before period. The resulting ratio was equivalent to a conflict rate modification factor (CRMF).

Results show that for sites where three or more conflicts per day were observed in the before period:

- LPIs reduced overall conflicts by 55%.
- LPIs reduced right-turn conflicts by 53%.
- LPIs reduced left-turn conflicts by 69%.
- LPIs reduced conflicts at most intersections studied.
- All LPI durations were shown to reduce conflict rates for both types of conflicts.
- For right-turn conflicts, an LPI duration of 7 s showed the greatest reduction in conflict rate (67%).
- For left-turn conflicts, an LPI duration of 5 s showed the greatest reduction in conflict rates (71%).
- Based on the results, a duration of 5 seconds appeared sufficient to optimize the effectiveness of LPIs.
- LPIs were effective at reducing conflicts for all pedestrian/turning vehicle volume combinations.
- LPIs were effective at reducing the average right-turn conflict rates for sites with a shared through/right-turn lane (reduction of 52%) but may be even more effective at reducing the average right-turn conflict rates for sites with a dedicated right-turn lane (reduction of 81%; however only one site was selected in the before period).
- LPIs were effective at reducing the average left-turn conflict rates for sites with a dedicated left-turn lane (reduction of 59%) but are even more effective at reducing the

average left turn conflict rates for sites with a shared through/left-turn lane (reduction of 85%).

- LPIs were very effective at reducing the average left-turn conflict rates for sites with a permitted-only left turn phase (80%).
- LPIs had no statistically significant effectiveness on left-turn conflicts where the left-turning motorists faced no opposing through vehicular traffic (no statistically significant reduction).
- It should also be noted that none of the selected sites with a protected left-turn phase were treated with an LPI, but the average conflict rate in the before period at these sites was similar to the average conflict rate at sites without protected left-turn phase that were treated with an LPI.

1.3 Recommendations

The results of this study did not lead to a clear justification system to be applied across agencies. Agencies have multiple needs, and the LPI implementation context and priorities may differ from one to the next. In addition, LPIs appear to be effective at reducing conflict rates in most situations, regardless of the LPI duration, pedestrian and vehicular volume combination, geometric conditions, or operational characteristics.

For these reasons, a justification system following a strict methodology is not suggested in this study. However, the CRMF identified through this analysis can be used in site selection and prioritization for LPI implementation. A custom methodology can easily be derived from the information presented below by assigning points to the various factors, considering relative weights based on an agency's needs and priorities.

Sites that do not meet the criteria listed below may also benefit from the implementation of LPIs and should therefore not necessarily be discarded. However, sites meeting one or more of the below criteria should be prioritized as they are expected to benefit most from LPIs.

Overall

The selection of sites for the implementation of LPIs should consider the actual presence of conflicts between pedestrians and right-turning vehicles. This can be confirmed by a video conflict study, observations at the site, a review of collision history, and/or a review of residents' complaints.

Right Turn Conflicts

The selection of sites should consider the presence of a dedicated turning lane. LPIs were found effective at reducing right-turn conflicts at sites with and without a dedicated right-turn lane, although the effectiveness is increased with the presence of a dedicated turning lane.

In addition, where a site is selected with the objective of reducing right-turn conflicts, the agency should consider implementing LPIs with a 7 s duration, as this duration was found to be the most effective at reducing right-turn conflicts.

Finally, although not included in this study, it is expected that right-turn on red restrictions, in addition to LPI implementation, may have a positive impact on the reduction of right-turn conflicts.

Left Turn Conflicts

The selection of sites should consider the following:

- The absence of a dedicated left-turn lane. LPIs were found effective at reducing left-turn conflicts at sites with and without a dedicated turning lane, although the effectiveness is increased where left-turning vehicles share a lane with through vehicles.
- The absence of a protected left-turn phase. LPIs were found effective at reducing conflicts at sites where left-turning vehicles must find a gap in opposing through vehicular traffic. Although none of the selected sites with a protected left-turn phase were treated with an LPI, the average conflict rate in the before period at sites with a protected left-turn phase (156) was similar to the average conflict rate at sites without a protected left-turn phase that were treated with an LPI (155).

In addition, where a site is selected with the objective of reducing left-turn conflicts, the agency should consider implementing LPIs with a 5 s duration, as this duration was found to be more effective than others.

Future Analyses

Based on the results of this study, the authors recommend a few key aspects that should be taken into consideration for future studies of the impacts of LPI implementation on right-turn and left-turn conflicts:

- The site selection should be designed to include sites where it is known that right-turn and/or left-turn conflicts are present. Sites should also be divided based on their geometric and operational characteristics, and LPIs should be implemented on selected sites with each combination of characteristics. Designing such a study would ensure that the selected sites would allow all three possible outcomes (decrease, no change, or increase in conflict frequency) from the implementation of LPIs.
- At least some of the sites selected should include right-turn on red restrictions for all times of day. The right-turn on red restrictions should be in place prior to data collection for the before period, to ensure roadway users are aware of and have time to adjust to the restrictions.
- As technology evolves and becomes more accurate, it would also be interesting to understand which conflicts coincide with the beginning of green period, which is the period affected by LPI implementation. Conflicts occurring at the end of a green phase or during clearance time would not be directly eliminated through LPI implementation.

2.0 GLOSSARY

Term	Definition for the purpose of this report
Conflict rate modification factor (CRMF)	Similar to a collision modification factor, a conflict rate modification factor is the ratio of expected conflict rate after treatment over the conflict rate before or without the treatment. A CRMF smaller than one shows an expected reduction in the conflict rate after the site is treated.
Dedicated right-turn lane	A dedicated right-turn lane is a lane on the approach to an intersection, that is marked for and used solely by motorists making a right-turn movement at the intersection.
Dedicated left-turn lane	A dedicated left-turn lane is a lane on the approach to an intersection, that is marked for and used solely by motorists making a left-turn movement at the intersection.
Permitted-only left turn phase	A green phase where motorists are allowed to make a left-turn at a signalized intersection but must wait for a gap in oncoming traffic.
Protected-only left turn phase	A phase where left-turning motorists have a dedicated green signal to make a left-turn, during which oncoming through traffic has a red signal. On a protected-only left-turn phase, left-turning motorists are not allowed to enter the intersection during the opposing through green signal.
Protected and permitted left turn phase	A green phase where left-turning motorists have both a protected left-turn phase and are permitted to enter the intersection and make a left-turn when there is a gap in opposing through traffic. The protected phase can occur before or after the through phase for the same approach. At all intersections studied, protected left-turn phases always occurred prior to the permitted phase.
Right-turn on red restrictions	A signalized intersection where motorists are not allowed to turn right when facing a red signal. Right-turn on red can be restricted by time of day (e.g., during peak periods) or at any time.

3.0 INTRODUCTION

3.1 Background

The number of collisions involving vulnerable road users (VRU) has been on the rise in most urban areas across Canada. A substantial proportion of VRU collisions involve vehicle turning movement collisions at signalized intersections. To minimize the risk of turning collisions with VRUs at signalized intersections, road authorities have begun implementing and pilot testing several types of geometric and operational road safety countermeasures, including Leading Pedestrian Intervals (LPI). LPIs provide pedestrians with a walk indication starting a few seconds prior to the corresponding vehicular green signal.

This research project was completed through the Transport Canada Enhanced Road Safety Transfer Payment Program. The project used an innovative and emerging video analytics tool to facilitate the evaluation of the safety effectiveness of LPIs without having to wait several years to collect a sufficiently large sample size of collisions involving VRUs. To complete this project, True North Safety Group (TNS) partnered with Transoft Solutions (Transoft) for the conflict data processing, and with the municipalities of Durham, Guelph, and Oakville, for the pilot testing of LPIs at 14 intersections.

The results of this study represent valuable information for road authorities to determine if they should continue implementing LPIs on their road network and determine the preferred designs and locations to maximize safety benefits, and ultimately reduce the number of fatal and injury collisions.

3.2 Project Objectives

The objectives of this project were the following:

- Use video analytics to evaluate the safety effectiveness of LPIs at signalized intersections.
- Streamline the conflict analysis evaluation process to make it more accessible to road authorities.
- Compare the safety effectiveness of various support measures and/or intersection geometric and operational characteristics.
- Provide recommendations to Canadian road authorities on the designs and operations of LPIs to maximize their safety effectiveness.
- Identify the key safety criteria to consider when road authorities are selecting candidate sites for the installation of LPIs.

3.3 Research Questions

To achieve the project objectives, our team attempted to answer the following research questions:

- Does the presence of an LPI affect conflict rates compared to the absence of an LPI?

- Does the LPI duration impact the safety effectiveness of LPIs? What LPI duration has the greatest safety effectiveness?
- Do intersection geometric and/or operations characteristics affect the effectiveness of LPIs in terms of conflict rates and/or weighted conflict rates? Characteristics could include the presence of a dedicated right-turn lane, the presence of a dedicated left-turn lane, the presence of a protected left-turn phase, and the absence of opposing through vehicular traffic for left-turn motorists.
- Does the volume of pedestrians influence the effectiveness of LPIs, in terms of conflict rates?
- Does the volume of vehicles influence the effectiveness of LPIs, in terms of conflict rates?
- Several operational modifications, such as the implementation of all-way stop control or traffic signals, are guided by warrants or justification systems. Can a similar justification system be developed for LPIs?

3.4 Study Intersections

The study team, in collaboration with the partnering municipalities, has identified 14 signalized intersections for the implementation and evaluation of LPIs. **Table 1** lists the intersections and their characteristics. Most intersections are along a collector or arterial roadway, and most are located near commercial land uses. Two of the intersections lead directly into a private commercial property (D3 and D6).

Table 1: Summary of study intersections and their characteristics.

ID	Intersection Name	Number of Legs	Intersection Characteristics
Durham Region			
D1	Brock Street & Toronto Street	4	Crosswalks on all legs. NBL, SBL, WBL have dedicated left-turn lanes. WBL has a protected and permitted left-turn phase.
D2	Simcoe Street & Reach Street	4	Crosswalks on all legs. SBR has a dedicated right-turn lane. All approaches have dedicated left-turn lanes. NBL has a protected and permitted left-turn phase.
D3	Stevenson Road South & Oshawa Centre	3	No west leg. Crosswalks on all 3 legs. WBR has a dedicated right-turn lane. SBL, WBL have dedicated left-turn lanes. SBL has a protected and permitted left-turn phase.
D4	Brock Street & Dundas Street	4	Crosswalks on all legs. WBR is channelized. Left turns prohibited on all legs.
D5	Harwood Avenue South & Hunt Street	3	No east leg. Crosswalks on all 3 legs. EBR has a dedicated right-turn lane. NBL, EBL have dedicated left-turn lanes.

ID	Intersection Name	Number of Legs	Intersection Characteristics
D6	Harwood Avenue South & Kings Crescent	4	Crosswalks on all legs. NBL prohibited. SBL has a dedicated left-turn lane. SBL has a protected and permitted left-turn phase.
City of Guelph			
G1	Willow Road & Dawson Road	4	Crosswalks on all legs. SBL has a dedicated left-turn lane.
G2	Willow Road & Westwood Road	4	Crosswalks on all legs. NBR, WBR have peak period right-turn on red restrictions.
G3	Edinburgh Road South & Ironwood Road	4	Crosswalks on all legs. NBL, SBL have dedicated left-turn lanes.
Town of Oakville			
O1	Lakeshore Road West & Jones Street	4	Crosswalks on all legs. SBL, EBL, WBL have dedicated left-turn lanes.
O2	Lakeshore Road West & East Street	4	Crosswalks on all legs. EBL, WBL have dedicated left-turn lanes. WBL has a protected and permitted left-turn phase.
O3	Speers Road & Cross Avenue	3	No east leg. Crosswalks on north and west legs. EBR has dual dedicated right-turn lanes. NBL, EBL have dedicated left-turn lanes. NBL has a protected and permitted left-turn phase.
O4	Kerr Street & Stewart Street	4	Crosswalks on all legs. SBL has a protected and permitted left-turn phase.
O5	Sixth Line & Munn's Avenue	4	Crosswalks on all legs. NBL, SBL have dedicated left-turn lanes.

Figures 1 to **3** provide aerial images of the locations of the study intersections.

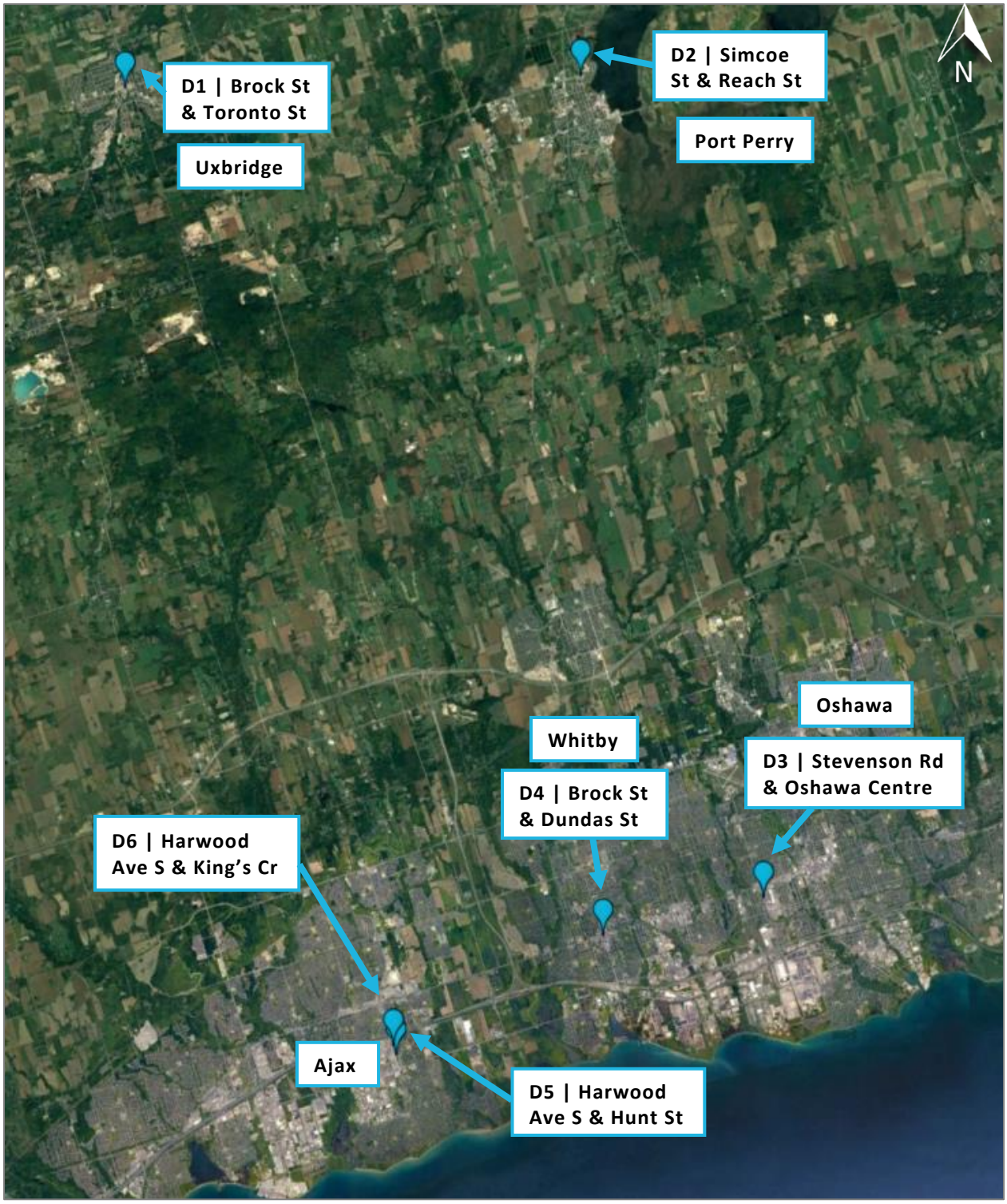

Figure 1: Aerial image showing study intersections in Durham Region (©Google Maps, 2023).

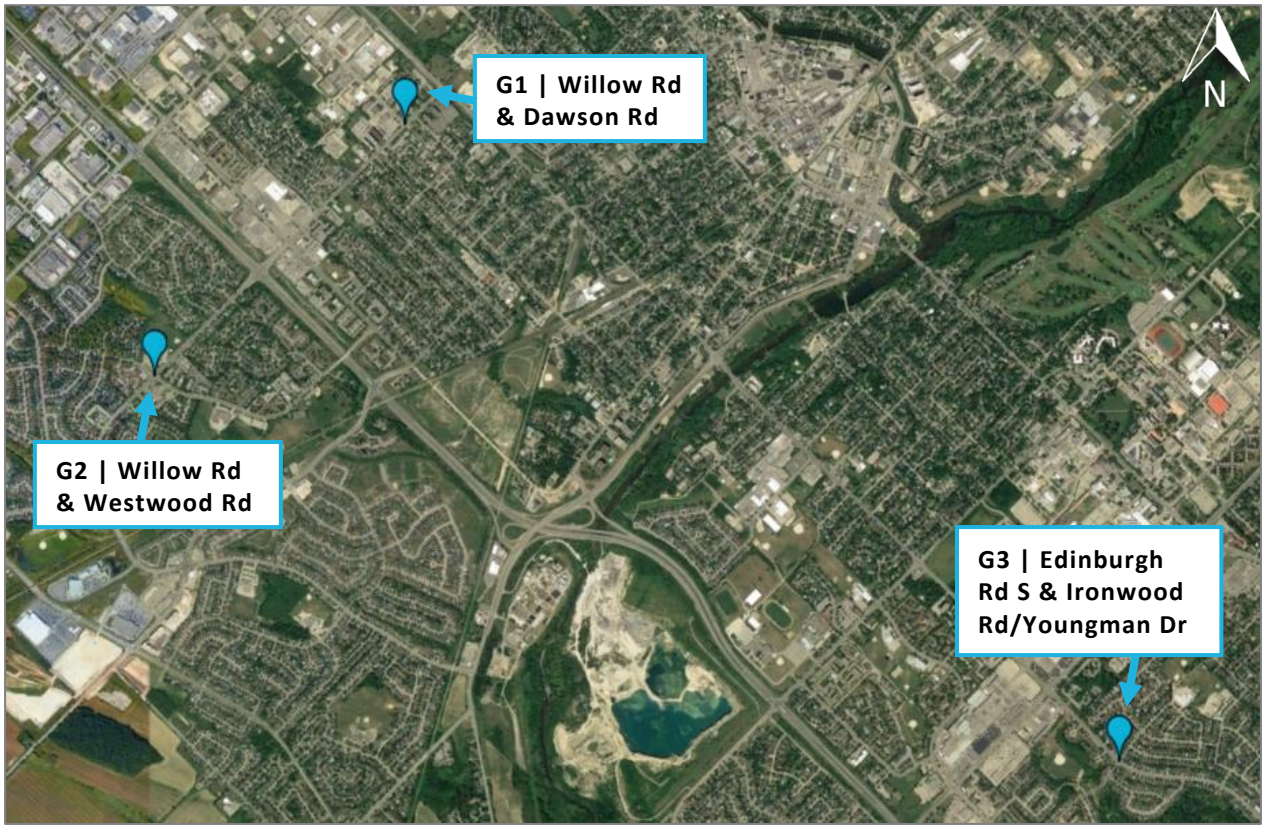

Figure 2: Aerial image showing study intersections in the City of Guelph (©Google Maps, 2023).

Figure 3: Aerial image showing study intersections in the Town of Oakville (©Google Maps, 2023).

4.0 LITERATURE REVIEW

4.1 Review of Published Literature

A review of literature was completed. Relevant information from previous studies includes:

- Conflicts have long been known to be linked to collision frequency. Although no estimation methodology has been widely accepted to correlate collision and conflict frequencies, research is ongoing to develop a methodology of estimating collision frequency based on observed conflicts. Tarko (2018) found that "*traffic conflicts claimed based on sufficiently small threshold separation (such as Time to Collision) allow unbiased estimation of the expected number of crashes during the conflicts observation period*."[1] Arun et al. (2021) have estimated the frequency and severity of collisions using a bivariate extreme value model based on conflict information, such as Time to Collision and predicted post-collision change in velocity.[2]
- An LPI implementation and evaluation study was recently completed in the City of Toronto. The team developed a systematic implementation approach, based on a network screening method using the Empirical Bayes approach. They also developed assessment criteria for isolated priority locations, which included a points system based on intersection geometry (e.g., T-intersection), identified safety issues, pedestrian volumes, collision rate, proximity to pedestrian generators (e.g., schools, seniors' centres, etc.), number of transit stops, operational impacts (increases in vehicular delays, volume/capacity ratio of the through vehicles), and the presence of left-turning transit vehicles.[3]
- An LPI evaluation study was completed in 1999 in New York City, using collision information at 26 intersections for periods of 5 years prior to and following the implementation of LPIs. Results showed a decrease in vehicle/pedestrian collisions at treated sites (28%), compared to control sites. It also showed a decrease in severity of collisions following the implementation of LPIs.[4]
- An LPI evaluation study was completed in 2010, using collision information at 10 intersections in Pennsylvania. A before and after study with a comparison group was used to evaluate the safety effectiveness of LPI implementation. The intersections included average daily traffic volumes between 12,000 and 13,500 vehicles, and hourly pedestrian volumes between 100 and 1,000 pedestrians, due to the proximity to the downtown area

[1] Tarko AP. Estimating the expected number of crashes with traffic conflicts and the Lomax Distribution - A theoretical and numerical exploration. Accid Anal Prev. 2018 Apr;113:63-73. doi: 10.1016/j.aap.2018.01.008. Epub 2018 Mar 7. PMID: 29407670.

[2] Arun, Ashutosh & Haque, Shimul Md. Mazharul & Bhaskar, Ashish & Washington, Simon & Sayed, Tarek. (2021). A Bivariate Extreme Value Model for Estimating Crash Frequency by Severity using Traffic Conflicts. Analytic Methods in Accident Research. 32. 100180. 10.1016/j.amar.2021.100180..

[3] Omrani, Reza & Mahboubi, Mateen & Saneinejad, Sheyda & Hadayeghi, Ali (2021). Implementation and Evaluation of Leading Pedestrian Intervals: A Novel Prioritization Methodology. Presented at the Transportation Association of Canada 2021 Conference and& Exhibition.

[4] King, M.R. (2000). "Calming New York City Intersections," Transportation Research E-Circular: Urban Street Symposium, Number E-C019, Transportation Research Board, Washington, DC. Available online: http://onlinepubs.trb.org/onlinepubs/circulars/ec019/Ec019_i3.pdf.

and a university. This analysis showed a reduction of vehicle/pedestrian collisions (59%).[5] The British Columbia Community Road Safety Toolkit[6] and the National Cooperative Highway Research Program (NCHRP) Research Report 926: Guidance to Improve Pedestrian and Bicyclist Safety at Intersections[7] both refer to this study as the source of their Collision Modification Factor (CMF) of 0.41.

- An LPI evaluation study was completed for the Federal Highway Administration (FHWA) in 2018, using collision information for periods of five years prior to and three years following the implementation of LPIs. A before and after study using the Empirical Bayes approach was completed using 150 intersections where LPIs were implemented, in three cities in the United States (Chicago, New York City, and Charlotte). This analysis showed a reduction of vehicle/pedestrian collisions (13%).[8]
- An LPI evaluation study was completed in 2022 using conflict information at 10 pedestrian crossings located at three signalized intersections in the City of Bellevue, Washington. A before and after study was completed, using "*a bivariate peak-over threshold modelling approach to model the tail distributions of pedestrian-vehicle Time-to-collision (TTC) conflicts, with the objective of studying whether the LPI treatment leads to a reduction in such conflicts.*" Conflicts with a TTC of 3.0 s or less were used for the analysis. This analysis showed a reduction of vehicle/pedestrian conflicts at treated crosswalks (42%).

Past studies have shown a relationship between conflict frequency and collision frequency, and research is ongoing to determine correlations allowing the estimation of collision frequencies based on conflict frequencies. Multiple studies have evaluated LPI effectiveness on vehicle/pedestrian collisions, and a recent study has evaluated their effectiveness on vehicle/pedestrian conflicts.

None of the above studies were completed at Canadian intersections. Although the Canadian transportation network context is usually similar to the United States, where the intersections studied were located, it is relevant to understand the effectiveness of LPIs in a Canadian context.

Further, the use of conflicts as a safety evaluation tool allows practitioners to complete safety studies in a more pro-active manner. Since the frequency of conflicts is typically much higher than the frequency of collisions, data collection periods are much shorter for conflicts than collisions. This allows for modifications to be done quickly, should the results show negative impacts of a countermeasure on transportation safety. Recent studies have shown the possibility to estimate collision frequency and severity based on conflict information.

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[5] Fayish, A.C. and F. Gross, "Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before–After Study with Comparison Groups." Transportation Research Record: Journal of the Transportation Research Board, No. 2198, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 15–22. DOI: 10.3141/2198-03.

[6] British Columbia Community Road Safety Toolkit, Module 1: Protecting people walking and cycling. February 2018.

[7] Associates, Inc., William W. Hunter, and Peter Koonce; National Cooperative Highway Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine National Academies of Sciences, Engineering, and Medicine 2020. Guidance to Improve Pedestrian and Bicyclist Safety at Intersections. Washington, DC: The National Academies Press. https://doi.org/10.17226/25808.

[8] Goughnour, E., D. Carter, C. Lyon, B. Persaud, B. Lan, P. Chun, I. Hamilton, and K. Signor. "Safety Evaluation of Protected Left-Turn Phasing and Leading Pedestrian Intervals on Pedestrian Safety." Report No. FHWA-HRT-18-044. Federal Highway Administration. (October 2018).

4.2 Summary of Jurisdiction Survey Results

A survey on the use of LPIs was developed and shared with several municipalities. Responses were received from 21 municipalities: 19 in Canada and 2 in the United States. The municipalities who responded to the survey were:

- City of Brantford
- City of Burlington
- City of Calgary
- City of Guelph
- City of Nanaimo
- City of Peterborough
- City of Red Deer
- City of Richmond Hill
- City of St. Petersburg, FL
- City of Tampa, FL
- City of Vancouver
- City of Victoria
- City of Winnipeg
- Region of Durham
- Region of Halton
- Region of Peel
- Region of York
- Town of Milton
- Town of Oakville
- Township of Langley
- Ville de Montréal

Their answers provided the following information:

- Most municipalities surveyed implement LPIs occasionally (62%), some municipalities implement LPIs never (19%), some municipalities implement LPIs frequently (9.5%), and some implement LPIs as part of pilot projects (9.5%).

Of those municipalities who implement LPIs:

- Most use a standard duration (76%). The standard durations used are 3 seconds (23%), 5 seconds (54%), 6 seconds (15%), and 7 seconds (8%).
- Most implement LPIs on both actuated and fixed-time signals (53%), some on actuated signals only (41%) and one on fixed-time signals only (8%).
- A majority do not use support treatments alongside LPIs (71%).
- Approximately half of the municipalities do not implement LPIs where an advanced protected left-turn phase is provided (53%).
- Approximately one-third of the municipalities have adopted a policy or general practice for the selection of suitable sites for LPI implementation (35%). Elements commonly used in policies/practices include:
  - Pedestrians and vehicular volumes
  - Presence of crossing guards
  - Proximity to pedestrian generators (e.g., schools, seniors' centres, etc.)
  - Pedestrian collision history
  - T-intersections
  - Intersections with one-way roadways
  - Visibility issues
  - Wide intersections and/or intersections without median refuge

- Most never conducted an assessment (e.g., a before and after study) to determine the safety benefits of LPIs implemented (82%).

A detailed survey summary is provided in **Appendix A**.

5.0 METHODOLOGY

5.1 Data Collection

Overhead cameras were installed at the 14 study intersections. At each intersection, video footage was recorded for five days, from Tuesday to Saturday, prior to the implementation of any LPI ('before' period). Following this, municipalities would install LPIs on the Monday, and record video footage for another five days, again from Tuesday to Saturday ('after 1' period). At seven, or half, of the study intersections an additional period was recorded in the same manner, after municipalities extended the LPI duration by two to three seconds ('after 2' period).

Video recordings of the before periods were captured between April 26, 2022, and June 18, 2022. Recordings of the after periods were captured between May 3, 2022, and July 2, 2022. **Table 2** presents the dates of data collection and LPI implementation at each intersection.

Table 2: Data collection periods in 2022.

Int	# of Cameras	Before Period	Date LPI Implemented	After 1 Period	Date LPI Duration Extended	After 2 Period
D1	2	April 26 – April 28	May 2	May 3 – May 7	-	-
D2	1	May 31 – June 4	June 6	June 7 – June 11	-	-
D3	1	May 31 – June 4	June 6	June 7 – June 11	-	-
D4	1	May 31 – June 4	June 6	June 7 – June 11	June 13	June 21 – June 25
D5	1	May 31 – June 4	June 6	June 7 – June 11	-	-
D6	2	May 31 – June 4	June 6	June 7 – June 11	-	-
G1	1	May 10 – May 14	May 16	May 17 – May 21	May 23	May 24 – May 28
G2	1	May 10 – May 14	May 16	May 17 – May 21	May 23	May 24 – May 28
G3	1	May 10 – May 14	May 16	May 17 – May 21	May 23	May 24 – May 28
O1	1	May 24 – May 28	May 30	May 31 – June 4	June 6	June 7 – June 11
O2	1	May 24 – May 28	May 30	May 31 – June 4	June 6	June 7 – June 11

Int	# of Cameras	Before Period	Date LPI Implemented	After 1 Period	Date LPI Duration Extended	After 2 Period
O3	2	June 14 – June 18	June 20	June 21 – June 25	-	-
O4	1	June 7 – June 11	June 6	May 31 - June 4	-	-
O5	1	June 14 – June 18	June 20	June 21 – June 25	June 27	June 28 – July 2

The videos were processed by Transoft to identify conflicts. Two types of datasets were then provided to TNS. The first dataset consisted of the attributes of each road user who passed through the intersection. The second consisted of each near miss event, or conflict, that occurred between any two road users at the intersection.

Figure 4 shows an example of a camera view at the intersection of Willow Road and Westwood Road, in Guelph.

Figure 4: Camera view at the intersection of Willow Road and Westwood Road.

5.2 Conflict Analysis

5.2.1 Identification of Hazardous Conflicts

Traffic conflicts can be grouped in two main types: evasive action conflicts and time-proximity conflicts. Traffic conflicts based on an evasive action consist of an event involving two or more

road users, in which the action of one user causes the other user to brake or swerve. Time-proximity conflicts consist of determining how close in time or space the involved road users are to colliding. The time-proximity conflict measures include Post Encroachment Time (PET) and Time to Collision (TTC).

PET is defined as the time between the first road user leaving the common spatial zone (i.e., where two road users could potentially collide) and the second road user arriving to the common spatial zone. TTC describes the time until a collision that would have happened if two conflicting road users were to continue their paths and speeds. The lower the PET and/or TTC, the smaller the temporal and/or spatial proximity between the road users and the lower the available reaction time.

Transoft's video conflict algorithm captures all safety-related events in a recording with a PET/TTC of less than ten seconds. The information about each safety-related event (e.g., speed of the road users, PET or TTC values, first user who arrived at the conflict location, date, and time) is recorded in a disaggregated database. Video footage for each safety-related event with a PET/TTC of less than two seconds is provided.

The safety-related events identified by Transoft's algorithm are not differentiated as to whether they are the result of normal operations or hazardous road user behaviours. Determining which safety-related events involved a hazardous behaviour by the motorist and/or pedestrian can only be accomplished by reviewing individual video footage. Video footage for each safety-related events with a PET/TTC of less than two seconds was therefore reviewed and the safety-related events that required evasive actions were flagged.

5.2.2 Classification of Conflicts

Given that LPIs are expected to impact conflicts between vehicles and pedestrians within the crosswalks, only the conflicts between these users were reviewed and identified. They were also separated into the following conflict types:

- **Right-turn conflict:** Conflict between a right-turning vehicle and a pedestrian located within the crosswalk.
- **Left-turn conflict:** Conflict between a left-turning vehicle and a pedestrian located within the crosswalk.

Conflicts can occur on the departing crosswalk (across the lanes where the vehicle enters the intersection) and on the receiving crosswalk (across the lanes where the vehicle leaves the intersection). LPIs separate motorists and pedestrians in time by providing a head start to pedestrians immediately prior to the vehicle signal turning green, therefore targeting conflicts occurring on the receiving crosswalk. Conflicts occurring on the departing crosswalk would occur in one of the following scenarios, none of which are targeted by LPIs:

- A pedestrian enters the crosswalk on a WALK signal, and a motorist enters the intersection on a red signal.
- A pedestrian enters the crosswalk on a steady DON'T WALK signal, and a motorist enters the intersection on a green signal.

- A pedestrian enters the crosswalk on a steady DON'T WALK signal, and a motorist enters the intersection on a red signal.

Figure 5 illustrates left-turn and right-turn conflicts occurring on the receiving crosswalk.

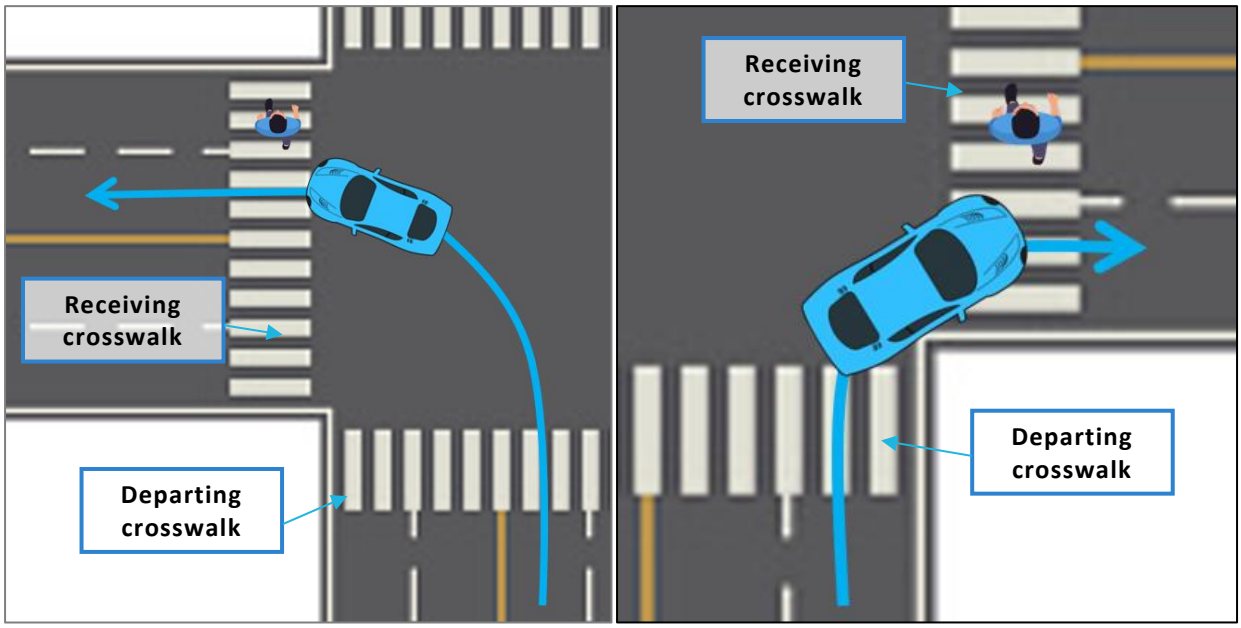

Figure 5: Depiction of left-turn conflict (left) and right-turn conflict (right).

5.3 Assessment Measures

The analysis was completed using conflicts, pedestrian volumes, and vehicular volumes that occurred during an 8-hour period, including the following times: 7:00 a.m. to 9:00 a.m., 11:00 a.m. to 2:00 p.m., and 3:00 p.m. to 6:00 p.m. These were chosen as they are the typical periods used during 8-hour turning movement counts.

The assessment measures and the calculation methodologies used are described below.

5.3.1 Conflict Frequency

The conflict frequency represents the number of conflicts observed within a crosswalk during a selected period of time. For the purposes of this study, TNS counted the frequency as the number of conflicts of each type occurring on a specific crosswalk during an eight-hour period. Conflict frequency was used to determine the conflict rates.

5.3.2 Conflict Rates

In order to consider exposure, TNS calculated conflict rates for each intersection and each period (before, after 1, and after 2). The equation for calculating the conflict rate is as follows:

$$CR_{itp} = \left(\frac{\sum C_{itp}}{V_{itp}}\right) \times 10^7$$

Where:

$\sum C_{itp}$ is the total number of conflicts at intersection *i* for conflict type t during period *p*

V_{itp} is the exposure measure at intersection *i* for conflict type t during period *p*
i is the intersection
t is the conflict type
p is the period

The exposure was calculated as the sum of the product of vehicular and pedestrian volumes for each approach, as follows:

$$V_{itp} = \sum_a \left(N_{veh,a} \times N_{ped,a}\right)_{itp}$$

Where:

$N_{veh,a}$ is the total number of vehicles crossing approach *a* at intersection *i* for conflict type *t* during period *p*
$N_{ped,a}$ is the total number of pedestrians using the crosswalk on approach *a* at intersection *i* for conflict type *t* during period *p*
a is the approach
i is the intersection
t is the conflict type
p is the period

5.4 Evaluation Methodology

5.4.1 Selection of Sites

A "site" was defined as the following: the crosswalk across approach *a* at intersection *i* during period *p*, where *p* represents eight hours of data within the same day. The sites were assigned to two groups:

- **Before:** All sites where information was collected in the before period, i.e., prior to the implementation of LPIs.
- **After:** All sites where information was collected in the after period and where an LPI was implemented. Crosswalks where the LPI duration was changed, and information was collected again ('after 2') were also included in the after group.

During the analysis, it was noted that several sites showed very few or no conflicts of one or both types, including in the before period. Since no countermeasure can reduce the number of conflicts below zero, including sites where no conflicts were present in the before period would lead to including sites where the only possible outcomes from the implementation of LPIs were an increase or no change in conflict frequency. Therefore, a minimum value of three conflicts over an eight-hour period was selected for sites in the before period, to allow all three possible outcomes (decrease, no change, or increase in conflict frequency) while keeping a significant number of sites.

Sites were selected as follows:

- **Before:** Each crosswalk was selected for the days where three or more conflicts of the analyzed type were observed over an eight-hour period.
- **After:** All sites where the crosswalk was included in the before period.

Sites were selected independently for analysis relating to right-turn conflicts and left-turn conflicts.

No comparison group was used during our analysis. Although LPIs were not implemented at all crosswalks for every intersection, they were implemented at most crosswalks, leaving a small number of potential comparison crosswalks within the study intersections. In addition, conditions at the untreated crosswalks would have changed between the before and after periods since implementation of LPIs at any crosswalk of an intersection would affect the overall signal timings at the intersection. Comparison sites are usually selected to control for changes in traffic volumes, weather, or long-term changes in vehicle types or road users' behaviours. Since the use of conflicts allows for short before and after periods and data collection was completed at each site within a maximum of four weeks, the need to account for change in traffic conditions with comparison sites was significantly reduced.

5.4.2 Evaluation

Average Conflict Rates

Conflict frequency was used for the selection of sites, as discussed in the previous section. However, conflict rates were used to analyze the impacts of LPIs on conflicts in order to account for exposure. Average conflict rates were calculated for the before and after period, for the following:

- Overall impacts of LPIs.
- Impacts of LPIs on right-turn conflicts.
- Impacts of LPIs on left-turn conflicts.
- Effects of LPI duration.
- Effects of LPIs based on pedestrian and vehicle volumes. Sites were categorized based on the following volume combinations:
  - Pedestrian volume between 0 and 250 pedestrians and vehicular volume between 0 and 500 vehicles.
  - Pedestrian volume between 0 and 250 pedestrians and vehicular volume above 500 vehicles.
  - Pedestrian volume above 250 pedestrians and vehicular volume between 0 and 500 vehicles.
  - Pedestrian volume above 250 pedestrians and vehicular volume above 500 vehicles.
- Effects of LPIs based on various geometric and operational characteristics, including:
  - Presence of dedicated right-turn lane.
  - Presence of dedicated left-turn lane.
  - Presence of protected left-turn phase.
  - Presence of permitted-only left-turn phase.
  - Absence of opposing through vehicular traffic (for left-turn conflicts).

Statistical Testing

Statistical testing was completed on each set of results to determine if the before and after average conflict rates were statistically different. First, an F-test was completed on the sample variances to determine if they could be assumed to be equal or unequal. Based on the F-test results, a t-test was completed on each paired group of data, assuming either an equal variance or an unequal variance. The t-tests were completed using the Microsoft Excel Data Analysis package, with a level of confidence of 0.05.

Ratios

Where the before and after results were found to be statistically different, a ratio was calculated by dividing the average conflict rate for the after period by the average conflict rate for the before period. The resulting ratio was equivalent to a conflict rate modification factor ('CRMF'). A ratio below one indicated a safety improvement following the implementation of LPIs. For example, a ratio of 0.75 would indicate there was a 25% reduction in conflicts after the implementation of LPIs.

5.4.3 Site Selection and Prioritization Criteria

The analysis results were reviewed to identify factors with a positive influence on LPI effectiveness. These results were used to suggest criteria which should be included in the selection and prioritization of sites for LPI implementation, in order to produce the greatest positive impacts on safety.

6.0 ANALYSIS

6.1 Data Collected

Data was collected at a total of 684 sites (i.e., crosswalk-days, where each day is represented by an eight-hour period). However, as noted in **Section 5.4.1**, several sites showed very few or no conflicts, including in the before period. To allow all three possible outcomes (decrease, no change, or increase in conflict frequency) while keeping a significant number of sites, a minimum value of three conflicts over an eight-hour period was selected for sites in the before period. In the after period, all sites where the crosswalk was included in the before period were selected for analysis.

Table 3 shows the LPI duration assessed for each site and the total number of sites selected for each period at each intersection. A total of 204 sites were used for the analysis. Of those, 20 sites were used for both the right-turn and left-turn conflict analyses.

Table 3: Intersection characteristics at each study location.

Int.	Crosswalks with LPI	LPI Duration (s)		Number of sites selected		
		After 1	After 2	Before	After 1	After 2
D1	E, W	5		4	10	0
D2	N, S	5		0	0	0
D3	N, S	5		1	5	0
D4	All	3	6	10	10	10
D5	N, S	5		10	5	0
D6	N, S	5		0	0	0
G1	All	5	N, S: 5 E, W: 7	11	15	14
G2	All	5	N, S: 5 E, W: 7	2	10	8
G3	All	5	N, S: 7 E, W: 5	0	0	0
O1	All	5	8	3	10	10
O2	All	5	8	9	15	15
O3	N, W	5		4	0	0
O4	All	5		3	10	0
O5	All	5	8	0	0	0
Total				57	90	57

6.2 Impacts of LPIs and Associated Factors

6.2.1 Effects of LPI

Table 4 shows the difference in conflict rates before and after the implementation of LPIs. It shows statistically significant different average conflict rates in the before and after periods, with an overall conflict rate modification factor ('CRMF') of 0.46, representing a reduction of 55% of the overall average conflict rate. Right-turn conflicts were reduced by 53% and left-turn conflicts were reduced by 69%.

Table 4:Differences in conflict rates before and after the implementation of LPIs.

Conflict Type	Average Conflict Frequency		Average Conflict Rate		Statistical Analysis Results	Conflict Rate Modification Factor: A/B Ratio
	Before	After	Before	After		
Overall	7.0	2.9	701	312	A<B A (M=312, SD=329) B (M=701, SD=695) t(72)=4.22, p<.01	0.45
Right Turn	9.2	3.6	840	392	A<B A (M=392, SD=342) B (M=840, SD=655) t(37)=3.70, p<.01	0.47
Left Turn	4.8	1.6	553	172	A<B A (M=172, SD=251) B (M=553, SD=716) t(33)=2.83, p<.01	0.31

Table 5 shows the average conflict rates before and after the implementation of LPIs at each intersection, based on the selected sites. Four intersections (D2, D6, G3, and O5) had no selected site, meaning no crosswalk that experienced a minimum of three conflicts of the same type (right-turn or left-turn) in any of the eight-hour days in the before period. **Table 5** shows that most intersections with selected crosswalks experienced a reduction in conflict rates after LPI implementation.

Table 5: Average conflict rates before and after the implementation of LPIs at each intersection.

Int.	Right-Turn Conflicts				Left-Turn Conflicts			
	Average Conflict Frequency		Average Conflict Rate		Average Conflict Frequency		Average Conflict Rate	
	Before	After	Before	After	Before	After	Before	After
D1	3.0	1.4	301	90	4.7	0.4	351	58
D2	-	-	-	-	-	-	-	-
D3	5.0	0.6	1297	249	-	-	-	-
D4	14.9	7.4	877	458	-	-	-	-
D5	-	-	-	-	3.6	3.2	500	472
D6	-	-	-	-	-	-	-	-
G1	3.6	6.7	75	85	7.8	2.4	195	57
G2	3.0	1.1	744	328	-	-	-	-
G3	-	-	-	-	-	-	-	-
O1	3.0	5.3	827	822	3.5	0.7	227	103
O2	5.0	1.7	2096	494	5.6	0.9	997	239
O3	-	-	-	-	-	-	-	-
O4	5.0	2.5	398	240	5.0	1.6	3870	446
O5	-	-	-	-	-	-	-	-

6.2.2 Effects of LPI Duration

Table 6 shows the average conflict rates for each type of conflict and each LPI duration. Overall, an LPI duration of 7 s showed the greatest reduction in conflict rates (65%). For right-turn conflicts, an LPI duration of 7 s showed the greatest reduction in conflict rate (67%). For left-turn conflicts, an LPI duration of 5 s showed the greatest reduction in conflict rates (71%). Based on the results, a duration of 5 seconds appeared sufficient to optimize the effectiveness of LPIs. All LPI durations were shown to reduce conflict rates for both types of conflicts. These results suggest that an LPI duration of 7 seconds may be optimal for reducing right-turn conflicts, whereas a duration of 5 seconds may be optimal for reducing left-turn conflicts.

Table 6: Differences in conflict rates based on duration of LPIs.

Conflict Type	LPI Duration (s)	Average Conflict Rate	Statistical Analysis Results	Conflict Rate Modification Factor: A/B Ratio
Overall	No LPI	701	-	-
	3	466	A<B A (M=466, SD=161) B (M=701, SD=695) t(62)=2.31, p=0.01	0.66
	5	256	A<B A (M=256, SD=314) B (M=701, SD=695) t(78)=4.73, p<.01	0.37
	6	450	A<B A (M=450, SD=241) B (M=701, SD=695) t(39)=2.15, p=0.02	0.64
	7	248	A<B A (M=248, SD=269) B (M=701, SD=695) t(50)=3.93, p<.01	0.35
	8	439	A<B A (M=439, SD=428) B (M=701, SD=695) t(71)=2.13, p=0.02	0.63
Right Turn	No LPI	840	-	-
	3	466	A<B A (M=466, SD=161) B (M=840, SD=655) t(39)=2.96, p<.01	0.55
	5	325	A<B A (M=325, SD=346) B (M=840, SD=655) t(41)=4.11, p<.01	0.39
	6	450	A<B A (M=450, SD=241) B (M=840, SD=655) t(39)=2.81, p<.01	0.54
	7	280	A<B A (M=280, SD=346) B (M=840, SD=655) t(21)=3.32, p<.01	0.33

Conflict Type	LPI Duration (s)	Average Conflict Rate	Statistical Analysis Results	Conflict Rate Modification Factor: A/B Ratio
	8	603	A<B A (M=603, SD=394) B (M=840, SD=655) t(42)=1.53, p=0.06	0.72
Left Turn	No LPI	553	-	-
	3	-	-	-
	5	163	A<B A (M=163, SD=236) B (M=553, SD=716) t(34)=2.87, p<.01	0.29
	6	-	-	-
	7	196	A<B A (M=196, SD=31) B (M=553, SD=716) t(30)=2.72, p<.01	0.35
	8	193	A<B A (M=193, SD=367) B (M=553, SD=716) t(31)=2.06, p=0.02	0.35

6.2.3 Effects of LPI Based on Pedestrian and Vehicular Volumes

Table 7 shows the average conflict rates in the before and after periods for each type of conflict based on pedestrian and vehicular eight-hour volumes. It shows that LPIs are effective at reducing conflicts for all pedestrian/turning vehicle volume combinations. The overall conflict rate reduction factors are similar for all volume combinations. For right-turn conflicts, LPIs appear most effective with lower volume of pedestrians (0-250 pedestrians in an eight-hour period) and for a combination of higher pedestrian and turning vehicular volumes (250+ pedestrians and 500+ turning vehicles in an eight-hour period). For left-turn conflicts, LPIs appear most effective with lower volumes of turning vehicles (0-500 turning vehicles in an eight-hour period).

Table 7: Differences in conflict rates before and after the implementation of LPIs based on pedestrian and vehicular eight-hour volumes.

Eight-Hour Pedestrian Volume	Eight-Hour Turning Vehicular Volume	Average Conflict Rate		Statistical Analysis Results	Conflict Rate Modification Factor: A/B Ratio
		Before	After		
Overall					
0-250	0-500	1203	449	A<B A (M=449, SD=416) B (M=1203, SD=791) t(14)=3.32, p<.01	0.37
	500+	485	182	A<B A (M=182, SD=220) B (M=485, SD=354) t(37)=3.79, p<.01	0.38
250+	0-500	940	361	A<B A (M=361, SD=270) B (M=940, SD=954) t(13)=2.17, p=0.02	0.38
	500+	309	92	A<B A (M=92, SD=93) B (M=309, SD=332) t(12)=2.22, p=0.02	0.30
Right Turn					
0-250	0-500	1592	513	A<B A (M=513, SD=406) B (M=1592, SD=1023) t(5)=2.56, p=0.03	0.32
	500+	648	201	A<B A (M=201, SD=182) B (M=648, SD=3803) t(13)=3.65, p<.01	0.31
250+	0-500	853	439	A<B A (M=439, SD=264) B (M=853, SD=303) t(12)=3.67, p<.01	0.51
	500+	394	109	A<B A (M=109, SD=87) B (M=394, SD=425) t(6)=1.75, p=0.07	0.28

Eight-Hour Pedestrian Volume	Eight-Hour Turning Vehicular Volume	Average Conflict Rate		Statistical Analysis Results	Conflict Rate Modification Factor: A/B Ratio
		Before	After		
Left Turn					
0-250	0-500	870	191	A<B A (M=191, SD=367) B (M=870, SD=313) t(15)=3.97, p<.01	0.22
	500+	358	162	A<B A (M=162, SD=259) B (M=358, SD=283) t(29)=2.01, p=0.03	0.45
250+	0-500	1137	232	A and B are not different A (M=232, SD=231) B (M=1137, SD=1822) t(3)=0.99, p=0.20	0.20*
	500+	190	76	A<B A (M=76, SD=99) B (M=190, SD=44) t(14)=2.42, p=0.01	0.40

*Not statistically significant.

6.2.4 Effects of LPIs based on Various Geometric and Operational Characteristics

Table 8 shows the average conflict rates in the before and after periods for each type of conflict, based on various geometric and operational characteristics. It shows that LPIs are effective at reducing conflict rates for most geometric and operational characteristics assessed. It also shows that:

- LPIs were effective at reducing the average right-turn conflict rates for sites with a shared through/right-turn lane (reduction of 52%) but may be even more effective at reducing the average right-turn conflict rates for sites with a dedicated right-turn lane (reduction of 81%; however only one site was selected in the before period).
- LPIs were effective at reducing the average left-turn conflict rates for sites with a dedicated left-turn lane (reduction of 59%) but are even more effective at reducing the average left-turn conflict rates for sites with a shared through/left-turn lane (reduction of 85%).
- LPIs were very effective at reducing the average left-turn conflict rates for sites with a permitted-only left turn phase (80%).

- LPIs had no statistically significant effectiveness on left-turn conflicts where the left-turning motorists faced no opposing through vehicular traffic (no statistically significant reduction).

It should also be noted that none of the selected sites with a protected left-turn phase were treated with an LPI, but the average conflict rate in the before period at these sites (156) is similar to the average conflict rate at sites without protected left-turn phase that were treated with an LPI (155).

Table 8: Differences in conflict rates before and after the implementation of LPIs based on various geometric and operational characteristics.

Conflict Type	Characteristic	Average Conflict Rate		Statistical Analysis Results	Conflict Rate Modification Factor: A/B Ratio
		Before	After		
Right Turn	Dedicated right-turn lane	1297	249	Cannot be completed, only one site in before period	0.19*
	Shared through/right-turn lane	825	400	A<B A (M=400, SD=345) B (M=825, SD=661) t(36)=3.43, p<.01	0.48
Left Turn	Dedicated left-turn lane	435	178	A<B A (M=178, SD=259) B (M=435, SD=382) t(36)=2.92, p<.01	0.41
	Shared through/left-turn lane	1026	155	A<B A (M=155, SD=235) B (M=1026, SD=1402) t(5)=1.51, p=0.10	0.15
	Protected and permitted left-turn phase**	156	-	-	-
	Permitted left-turn phase	696	142	A<B A (M=142, SD=228) B (M=696, SD=847) t(19)=2.81, p<.01	0.20
	No opposing through vehicular traffic	487	472	A and B are not different A (M=472, SD=298) B (M=487, SD=378) t(8)=0.07, p=0.47	0.97*

*Not statistically significant.
**None of the receiving crosswalks with a protected left-turn lane phase treated with an LPI were selected for analysis.

6.3 Site Selection and Prioritization Criteria

The results of this study did not lead to a clear justification system to be applied across agencies. Agencies have multiple needs, and the LPI implementation context and priorities may differ from one to the next. In addition, LPIs appear to be effective at reducing conflict rates in most situations, regardless of the LPI duration, pedestrian and vehicular volume combination, geometric conditions, or operational characteristics.

For these reasons, a justification system following a strict methodology is not suggested in this study. However, the CRMF identified through this analysis can be used in site selection and prioritization for LPI implementation. A custom methodology can easily be derived from the information presented below by assigning points to the various factors, considering relative weights based on an agency's needs and priorities.

Sites that do not meet the criteria listed below may also benefit from the implementation of LPIs and should therefore not necessarily be discarded. However, sites meeting one or more of the below criteria should be prioritized as they are expected to benefit most from LPIs.

Overall

The selection of sites for the implementation of LPIs should consider the actual presence of conflicts between pedestrians and turning vehicles. This can be confirmed by a video conflict study, observations at the site, a review of collision history, and/or a review of residents' complaints.

Right Turn Conflicts

The selection of sites should consider the presence of a dedicated turning lane. LPIs were found effective at reducing right-turn conflicts at sites with and without a dedicated right-turn lane, although the effectiveness is increased with the presence of a dedicated turning lane.

In addition, where a site is selected with the objective of reducing right-turn conflicts, the agency should consider implementing LPIs with a 7 s duration, as this duration was found to be the most effective at reducing right-turn conflicts.

Finally, although not included in this study, it is expected that right-turn on red restrictions, in addition to LPI implementation, may have a positive impact on the reduction of right-turn conflicts.

Left Turn Conflicts

The selection of sites should consider the following:

- The absence of a dedicated left-turn lane. LPIs were found effective at reducing left-turn conflicts at sites with and without a dedicated turning lane, although the effectiveness is increased where left-turning vehicles share a lane with through vehicles.
- The absence of a protected left-turn phase. LPIs were found effective at reducing conflicts at sites where left-turning vehicles must find a gap in opposing through vehicular traffic. Although none of the selected sites with a protected left-turn phase were treated with an LPI, the average conflict rate in the before period at sites with a protected left-turn phase

(156) was similar to the average conflict rate at sites without a protected left-turn phase that were treated with an LPI (155).

In addition, where a site is selected with the objective of reducing left-turn conflicts, the agency should consider implementing LPIs with a 5 s duration, as this duration was found to be more effective than others.

7.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

7.1 Summary of Findings

The study team, in collaboration with the partnering municipalities, has identified 14 signalized intersections for the implementation and evaluation of LPIs. LPIs were implemented both at crosswalks where vehicle/pedestrian conflicts were present, as well as crosswalks where there were very few or no conflicts.

For the purposes of the analysis, each crosswalk-day combination was treated independently. A "site" was defined as the crosswalk across approach *a* at intersection *i* during period *p*, where *p* represented eight hours of data within the same day. The sites were assigned to two groups:

- **Before:** All sites where information was collected in the before period, i.e., prior to the implementation of LPIs.
- **After:** All sites where information was collected in the after period and where an LPI was implemented. Crosswalks where the LPI duration was changed, and information was collected again ('after 2') were also included in the after group.

During the analysis, it was noted that several sites showed very few or no conflicts of one or both types, including in the before period. Since no countermeasure can reduce the number of conflicts below zero, including sites where no known conflicts were present in the before period would lead to including sites where the only possible outcomes from the implementation of LPIs were an increase or no change in conflict frequency. Therefore, a minimum value of three conflicts over an eight-hour period was selected for sites in the before period, to allow all three possible outcomes (decrease, no change, or increase in conflict frequency) while keeping a significant number of sites.

Sites were selected as follows:

- **Before:** Each crosswalk was selected for the days where three or more conflicts of the analyzed type were observed over an eight-hour period.
- **After:** All sites where the crosswalk was included in the before period.

Sites were selected independently for analysis relating to right-turn conflicts and left-turn conflicts.

Analysis was then completed on the results, using conflict rates at 220 sites. The rates were used to control for exposure (using conflicting pedestrian and vehicular volumes across the site). Average conflict rates were calculated for the before and after period, based on conflict type, LPI duration, pedestrian and vehicular volumes, and other geometric and operational characteristics. Statistical testing was completed on each set of results to determine if the before and after average conflict rates were statistically different. Where the before and after results were found to be statistically different, a ratio was calculated by dividing the average conflict rate for the after period by the average conflict rate for the before period. The resulting ratio was equivalent to a conflict rate modification factor.

Results show that for sites where three or more conflicts per day were observed in the before period:

- LPIs reduced overall conflicts by 55%.
- LPIs reduced right-turn conflicts by 53%.
- LPIs reduced left-turn conflicts by 69%.
- LPIs reduced conflicts at most intersections studied.
- All LPI durations were shown to reduce conflict rates for both types of conflicts.
- For right-turn conflicts, an LPI duration of 7 s showed the greatest reduction in conflict rate (67%).
- For left-turn conflicts, an LPI duration of 5 s showed the greatest reduction in conflict rates (71%).
- Based on the results, a duration of 5 seconds appeared sufficient to optimize the effectiveness of LPIs.
- LPIs were effective at reducing conflicts for all pedestrian/turning vehicle volume combinations.
- LPIs were effective at reducing the average right-turn conflict rates for sites with a shared through/right-turn lane (reduction of 52%) but may be even more effective at reducing the average right-turn conflict rates for sites with a dedicated right-turn lane (reduction of 81%; however only one site was selected in the before period).
- LPIs were effective at reducing the average left-turn conflict rates for sites with a dedicated left-turn lane (reduction of 59%) but are even more effective at reducing the average left turn conflict rates for sites with a shared through/left-turn lane (reduction of 85%).
- LPIs were very effective at reducing the average left-turn conflict rates for sites with a permitted-only left turn phase (80%).
- LPIs had no statistically significant effectiveness on left-turn conflicts where the left-turning motorists faced no opposing through vehicular traffic (no statistically significant reduction).
- It should also be noted that none of the selected sites with a protected left-turn phase were treated with an LPI, but the average conflict rate in the before period at these sites was similar to the average conflict rate at sites without protected left-turn phase that were treated with an LPI.

7.2 Recommendations

The results of this study did not lead to a clear justification system to be applied across agencies. Agencies have multiple needs, and the LPI implementation context and priorities may differ from one to the next. In addition, LPIs appear to be effective at reducing conflict rates in most situations, regardless of the LPI duration, pedestrian and vehicular volume combination, geometric conditions, or operational characteristics.

For these reasons, a justification system following a strict methodology is not suggested in this study. However, the CRMF identified through this analysis can be used in site selection and prioritization for LPI implementation. A custom methodology can easily be derived from the

information presented below by assigning points to the various factors, considering relative weights based on an agency's needs and priorities.

Sites that do not meet the criteria listed below may also benefit from the implementation of LPIs and should therefore not necessarily be discarded. However, sites meeting one or more of the below criteria should be prioritized as they are expected to benefit most from LPIs.

Overall

The selection of sites for the implementation of LPIs should consider the actual presence of conflicts between pedestrians and right-turning vehicles. This can be confirmed by a video conflict study, observations at the site, a review of collision history, and/or a review of residents' complaints.

Right Turn Conflicts

The selection of sites should consider the presence of a dedicated turning lane. LPIs were found effective at reducing right-turn conflicts at sites with and without a dedicated right-turn lane, although the effectiveness is increased with the presence of a dedicated turning lane.

In addition, where a site is selected with the objective of reducing right-turn conflicts, the agency should consider implementing LPIs with a 7 s duration, as this duration was found to be the most effective at reducing right-turn conflicts.

Finally, although not included in this study, it is expected that right-turn on red restrictions, in addition to LPI implementation, may have a positive impact on the reduction of right-turn conflicts.

Left Turn Conflicts

The selection of sites should consider the following:

- The absence of a dedicated left-turn lane. LPIs were found effective at reducing left-turn conflicts at sites with and without a dedicated turning lane, although the effectiveness is increased where left-turning vehicles share a lane with through vehicles.
- The absence of a protected left-turn phase. LPIs were found effective at reducing conflicts at sites where left-turning vehicles must find a gap in opposing through vehicular traffic. Although none of the selected sites with a protected left-turn phase were treated with an LPI, the average conflict rate in the before period at sites with a protected left-turn phase (156) was similar to the average conflict rate at sites without a protected left-turn phase that were treated with an LPI (155).

In addition, where a site is selected with the objective of reducing left-turn conflicts, the agency should consider implementing LPIs with a 5 s duration, as this duration was found to be more effective than others.

Future Analyses

Based on the results of this study, the authors recommend a few key aspects that should be taken into consideration for future studies of the impacts of LPI implementation on right-turn and left-turn conflicts.

- The site selection should be designed to include sites where it is known that right-turn and/or left-turn conflicts are present. Sites should also be divided based on their geometric and operational characteristics, and LPIs should be implemented on selected sites with each combination of characteristics. Designing such a study would ensure that the selected sites would allow all three possible outcomes (decrease, no change, or increase in conflict frequency) from the implementation of LPIs.
- At least some of the sites selected should include right-turn on red restrictions for all times of day. The right-turn on red restrictions should be in place prior to data collection for the before period, to ensure roadway users are aware of and have time to adjust to the restrictions.
- As technology evolves and becomes more accurate, it would also be interesting to understand which conflicts coincide with the beginning of green period, which is the period affected by LPI implementation. Conflicts occurring at the end of a green phase or during clearance time would not be directly eliminated through LPI implementation.

1.0 JURISDICTIONAL SURVEY

1.1 Overview

For this study, an online survey was developed and distributed across Canada to road safety practitioners involved in the design, construction, operations, and/or maintenance of leading pedestrian intervals (LPIs) at signalized intersections. The intention was to gain a better understanding of the following:

- The ease of which road authorities have been able to implement LPIs across their jurisdiction area.
- The guidelines and standards currently used by road safety practitioners that address the provision of leading pedestrian intervals in the public right-of-way.
- The advance pedestrian interval timings (duration of the pedestrian head start) and details of support treatments (e.g., no right-turn on red signs and protected left turn phases) used by road authorities.

1.2 Survey Process

1.2.1 Development of Survey

The survey was intended to be completed by road safety practitioners involved in the design, construction, maintenance, and/or operations of LPIs at signalized intersections in the public right-of-way. The respondents were asked about the type of guidelines and standards they use (if any) and their opinion on the challenges they have experienced in the design, construction, maintenance, and/or operation of LPIs. The survey contained a total of nine technical questions.

The survey was developed in both French and English. An initial email was circulated by the Road Safety Committee of Ontario (ROSCO) on February 2, 2022, to all its members. This email included the link to the English survey. To ensure respondents from both official languages were received, a distribution list of municipalities in Quebec was developed, and individual emails were sent to municipalities. The survey was also circulated across North America through an ITE community post. Responses were received over a six-week period spanning from February 2, 2022, to March 16, 2022. The survey was created and hosted online. It was recorded who completed the survey and the survey results were concisely summarized question by question.

1.2.2 Survey Response Summary

In total, 21 responses were received from North American road authorities. **Figure 1** provides the distribution by province of the people who responded to the survey. From this figure, the following was identified:

- The responses received provided a relatively good representation of the country, where responses from five of the ten provinces were received. Note that no responses from any

of the territories were received. Two responses from municipalities in the United States of America were received.

- The responses to the survey of transportation practitioners were distributed among provinces, with the top two provinces being Ontario (52%) and British Columbia (19%), followed by Alberta (10%), Manitoba (5%), and Quebec (5%). Both responses from the United States were from Florida (10%).

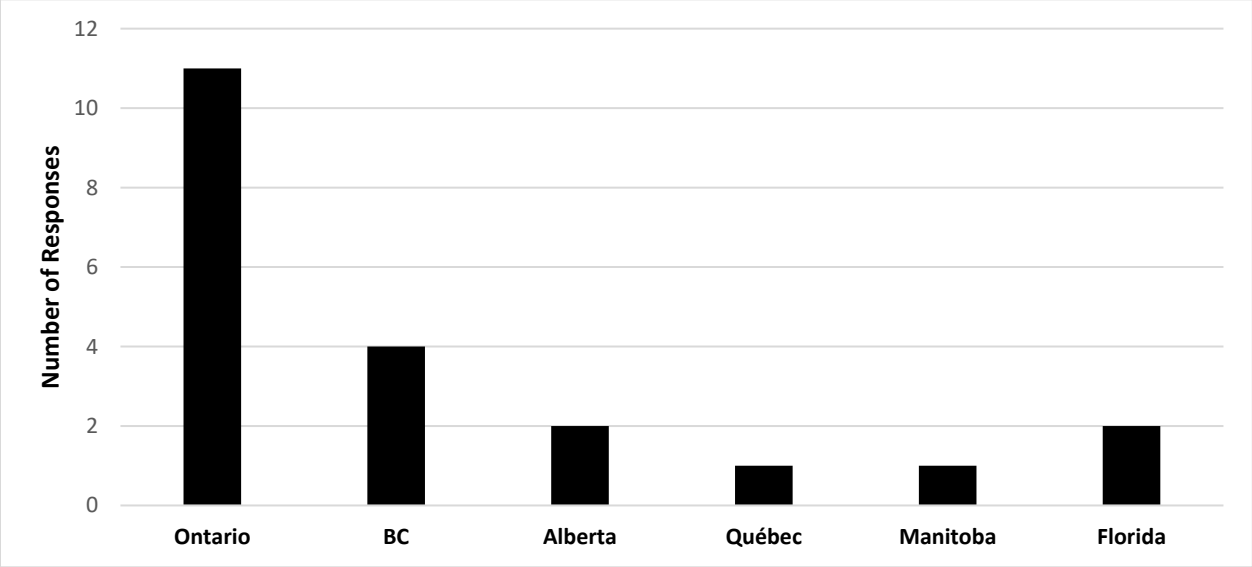

Figure 1: Distribution of responses by province.

1.2.3 Survey Summary

Each question of the survey is listed below, along with a summary of the responses received.

Question 1 – To what extent has your road authority installed LPIs? If none, please explain the reason or any challenges you've experienced with implementing LPIs.

Thirteen respondents stated that they have occasionally implemented LPIs in their area of jurisdiction, while 4 stated that they have not. Respondents who selected "none implemented" were then questioned about the challenges they have experienced and directed to the end of the survey.

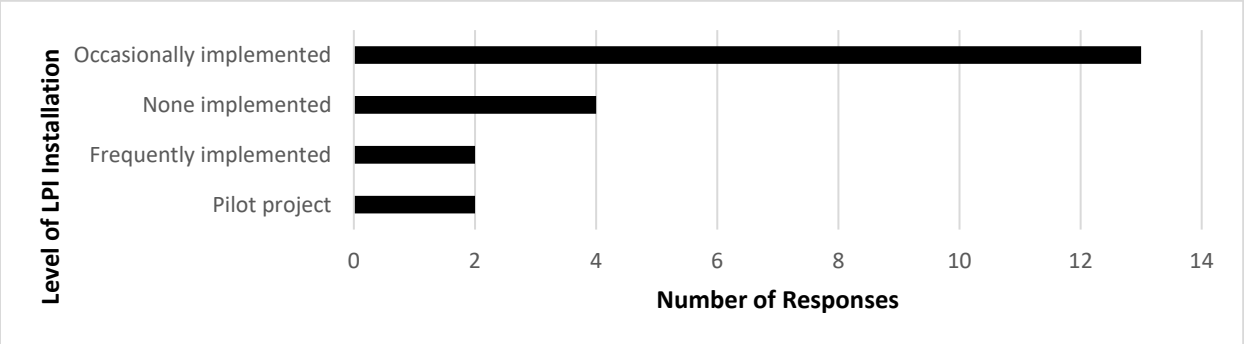

Figure 2: Level of LPI installation frequency.

Respondents who selected “none implemented” indicated the following challenges:

- Conflicts with protected left-turn phasing.
- Unsure of criteria for potential site selection.
- Lack of locations with high pedestrian volumes.
- Lack of public education.

Question 2 – Do you use a standard advance pedestrian interval (duration of the pedestrian head start) for LPIs?

Fourteen of the respondents who had implemented LPIs indicated that they use a standard duration of advance pedestrian interval for LPIs. Seven (54%) of these respondents use a standard interval of five seconds. These durations are shown in **Figure 4**.

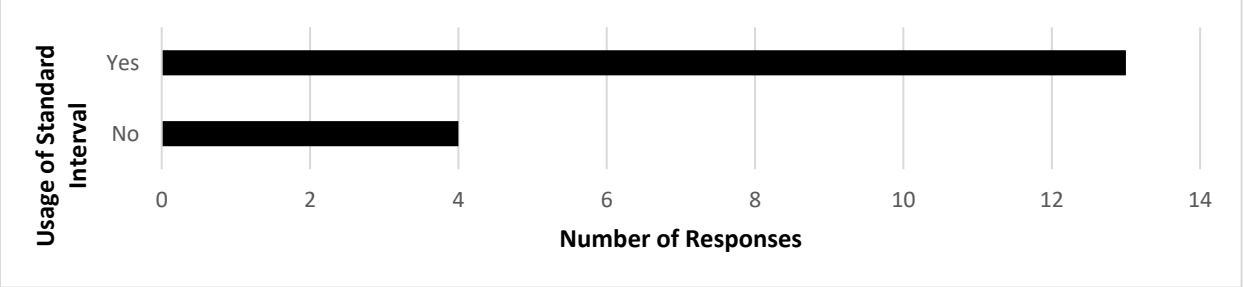

Figure 3: Usage of standard advance pedestrian interval.

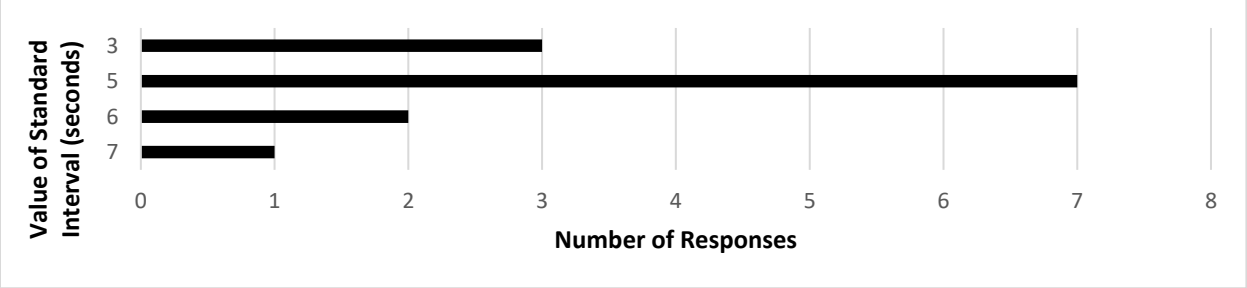

Figure 4: Value of standard advance pedestrian interval.

The other respondents indicated that LPI durations vary from 4 to 7 seconds depending on a variety of factors such as crossing distance, cycle length, and walking speed.

Question 3 – Do you use actuated signal timings or fixed signal timings with LPIs?

A majority of respondents (53%) indicated that they use both fixed-time and actuated signal timings with LPIs, while 41% indicated that they use actuated-signals only. Only one respondent indicated that they use fixed-time signals only.

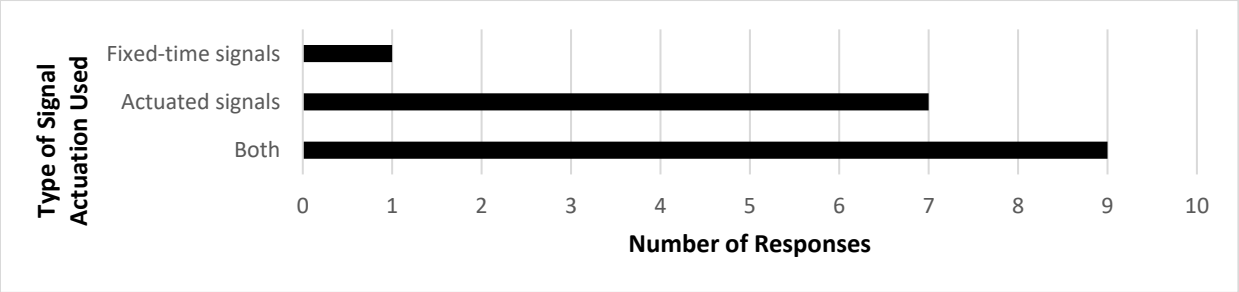

Figure 5: Type of signal actuation used with LPIs.

Question 4 – Do you generally use support treatments alongside LPIs (e.g., no right-turn on red signs and protected left turn phases)?

Some respondents (29%) indicated that they use support treatments alongside LPIs. Three respondents stated that they use No Right Turn on Red (RTOR) restrictions, two stated that they use fully protected left-turn phasing, and one stated that they use countdown signals and accessible pedestrian signals (APS).

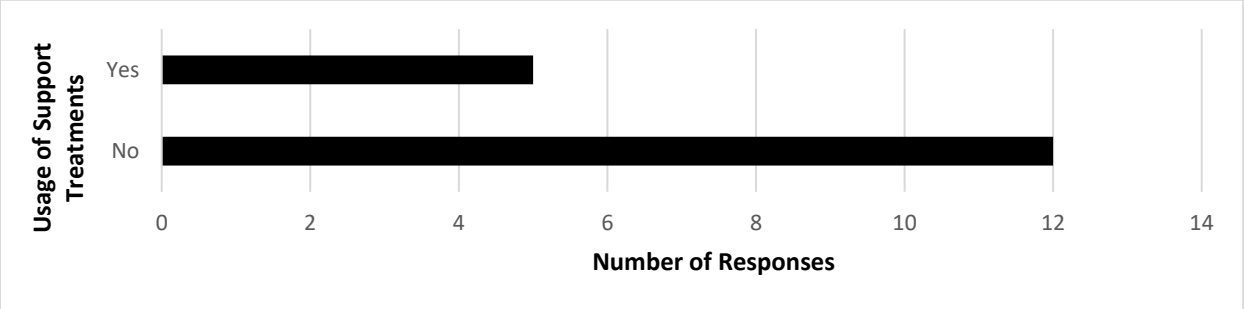

Figure 6: Usage of support treatments alongside LPIs.

Question 5 – Do you implement LPIs at locations where advanced left turn phases are provided?

A majority of respondents (53%) indicated that they do not use advanced left-turn phasing alongside LPIs. Some respondents (24%) indicated that they use protected-permissive phasing only, and others (24%) indicated that they use both protected-permissive and protected-only phasing with LPIs.

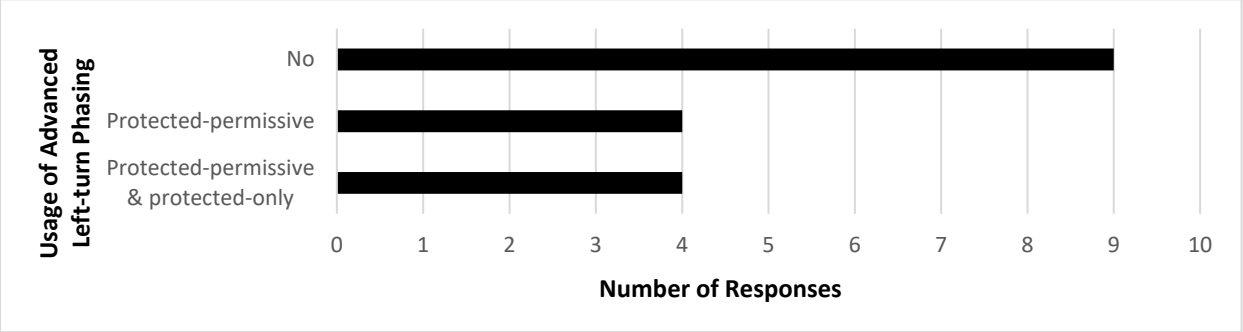

Figure 7: Usage of advanced left-turn phasing alongside LPIs.

Question 6 – Has your road authority adopted a policy/practice for the selection of suitable sites for the implementation of LPIs?

Approximately one-third of respondents (35%) indicated that they have adopted a policy or practice for selecting suitable LPI implementation sites. Two respondents stated that they prioritize sites with high pedestrian crossing volumes, a high proportion of pedestrian collisions, and close proximity to high pedestrian generators (i.e., schools, shopping malls, and senior centres). Other warrant criteria included: the effect of deactivating protected permissive left-turn phasing on intersection operations, the presence of school crossing guards, and intersections with a T-configuration or one-way streets. Additionally, one respondent indicated that network screening results are reviewed to determine whether the implementation of an LPI will adversely affect intersection operations.

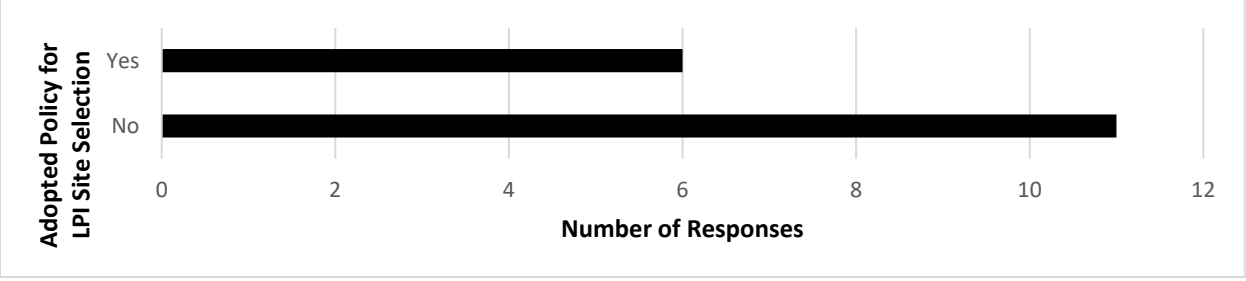

Figure 8: Adoption of LPI site selection policy among road authorities.

Question 7 – Has your road authority ever conducted an assessment (e.g., before and after study) to determine the safety benefits of installed LPIs?

Three respondents indicated that they have conducted an assessment to determine the safety benefits of installed LPIs. One respondent indicated that they conducted before/after LPI studies at five signalized intersections utilizing video conflict analysis, and another indicated that they only collected observations.

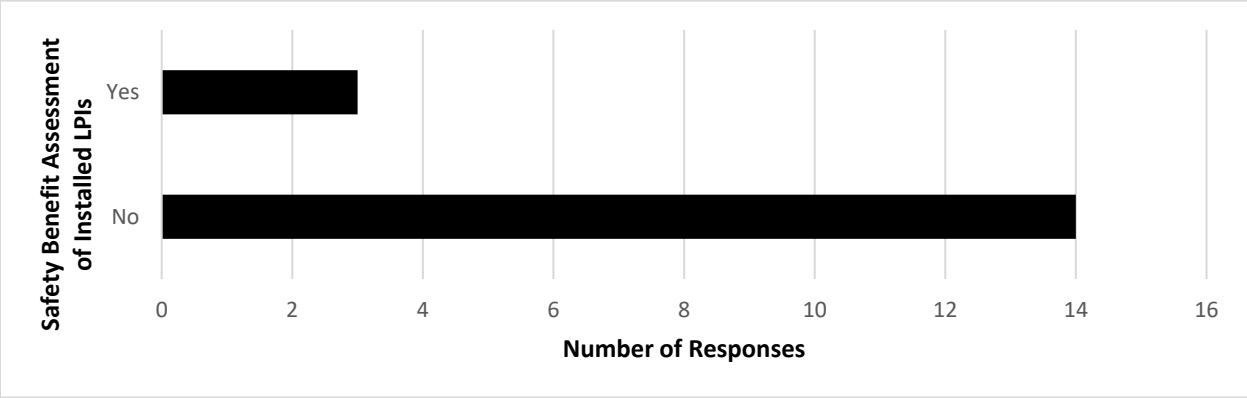

Figure 9: Whether a safety benefit assessment of installed LPIs was conducted.

Question 8 – What has been your road authority's overall experience (successes and challenges) with LPIs?

Several responses to this open-ended question were received and are summarized below:

- Successes:
  - LPIs are effective in helping pedestrians cross intersections.
  - Feedback from the public has been positive, and requests for additional locations have been received by municipalities.
- Challenges:
  - Certain controllers require upgrades to implement LPIs.
  - Struggles with implementing LPIs at intersections with protected/permissive left turns.
  - Issues with right turning traffic congestion.
  - Public education is a challenge. Pedestrians were observed to hesitate before crossing due to the red signal phase for motorists.
  - Little guidance available regarding the implementation of supplemental treatments such as APS and RTOR restrictions.
  - Pushback received regarding implementation of RTOR restrictions as a standard supplemental treatment when installing LPIs.

- Once installed, it is difficult to remove LPIs. Decreasing lead time is perceived as an action against active transportation.
- Lack of feedback from the public.

Question 9 – If you would like to provide any other comments that have not been addressed above, please enter them below.

Several responses to this open-ended question were received. Respondents suggested that a variety of factors should be considered, including community concerns, pedestrian volume, collision history, vehicular capacity impacts, intersection geometry, and traffic signal operation. Additionally, respondents indicated that there should be a guideline or standard that informs practitioners on recommended LPI duration.