Transportation Association of Canada

# Flashing Amber Arrow Signal: Synthesis of Practice

February 2026

## DISCLAIMER

This document is not intended to be used as a basis for establishing civil liability.

The material presented in this text was carefully researched and presented. However, no warranty expressed or implied is made on the accuracy of the contents or their extraction from reference to publications; nor shall the fact of distribution constitute responsibility by TAC or any researchers or contributors for omissions, errors or possible misrepresentations that may result from use or interpretation of the material contained herein.

Information within this report should be considered in the context of local legislation, regulation and policy.


401-1111 Prince of Wales Drive
Ottawa, ON | K2C 3T2
Tel. (613) 736-1350
www.tac-atc.ca

ISBN# 978-1-55187-731-0
TAC Publication Code: PTM-FAAS-E

*Cover photos (L-R) courtesy of: Koch*

# TAC report documentation form

| **Title and Subtitle**<br>Flashing Amber Arrow Signal: Synthesis of Practice | | |
|---|---|---|
| **Report Date**<br>February 2026 | **Coordinating Agency and Address**<br>Transportation Association of Canada<br>401-1111 Prince of Wales Drive<br>Ottawa, Ontario, Canada K2C 3T2 | **ITRD No.** |
| **Author(s)**<br>*MORR Transportation Consulting Ltd.*<br>Jeannette Montufar, Ph.D., P.Eng., PTOE, RSP1<br>Stephen Chapman, P.Eng., RSP1<br>Maryam Moshiri, Ph.D., EIT<br>*CIMA+*<br>Andrew Beal, P.Eng. | **Performing Agency Name and Address**<br>MORR Transportation Consulting Ltd.<br>200 – 1465 Buffalo Place<br>Winnipeg, MB R3T 1L8 | |

**Abstract**

The Flashing Amber Arrow (FAA) or Flashing Yellow Arrow (FYA) signal display has been widely implemented across the United States of America (U.S.) as a permissive turn indication in exclusive turn lanes to mitigate driver confusion caused by the green ball indication for permissive turns, mitigate "yellow trap" incidents, improve intersection operational efficiency, and improve turning safety at intersections amongst conflicting road users. Although traffic signals with FAA indications are now seeing widespread use throughout the U.S., they are not yet present in Canada. This study sought to understand U.S. experience with FAA and its applicability to the Canadian context as well as to gauge Canadian perspectives across the country regarding FAAs.

This report contains a synthesis of findings from a comprehensive literature review on research and practical experience related to flashing amber arrow signals in the U.S., a summary of findings from follow-up interviews with U.S. experts, a survey of Canadian jurisdictions, and two focus group sessions with Canadian jurisdictions that identified key challenges, opportunities, benefits, and risks for the application of FAA signals in Canada. These findings provided the basis for the report's recommended next steps for potential implementation of FAAs in Canada.

**Keywords**

Traffic Control

- Amber light
- Flashing light
- Traffic signal
- Turning

**Recommended Citation:** Montufar, J., Chapman, S., Moshiri, M., and Beal, A. 2026. *Flashing Amber Arrow Signal: Synthesis of Practice*. Ottawa, ON: Transportation Association of Canada.

# Acknowledgements


## Project Funding Partners

- Bunt and Associates
- City of Calgary
- City of Kelowna
- City of Ottawa
- City of Saskatoon
- City of Toronto
- City of Vancouver
- Halifax Regional Municipality
- Ministère des Transports et de la Mobilité durable
- Ville de Montréal

## Project Steering Committee

- Daniel Beaulieu, Ville de Montréal
- Melanie Beaulieu, Ministère des Transports et de la Mobilité durable
- Michelle Buchko, City of Saskatoon
- Winston Chou, City of Vancouver
- Stuart Edison, City of Ottawa
- Alexandre Ferrari, Ministère des Transports et de la Mobilité durable
- Mike Furuya, Bunt and Associates
- Greg Iwaskow, City of Calgary
- Bhanuja Karunamoorthy, City of Toronto
- Roddy McIntyre, Halifax Regional Municipality
- Dominic Methot-Plante, Ministère des Transports et de la Mobilité durable
- Jill Morrison, Halifax Regional Municipality
- Stephen Sargeant, City of Kelowna

## Project Consultants

- Andrew Beal, CIMA+
- Stephen Chapman, MORR Transportation Consulting Ltd.
- Jeannette Montufar, MORR Transportation Consulting Ltd.
- Maryam Moshiri, MORR Transportation Consulting Ltd.

## TAC Project Manager

- Romaine Morrison, Transportation Association of Canada

# Executive summary

The Flashing Amber Arrow (FAA) or Flashing Yellow Arrow (FYA) signal display has been widely implemented across the United States of America (U.S.) as a permissive turn indication in exclusive turn lanes to mitigate driver confusion caused by the green ball indication for permissive turns, mitigate “yellow trap” incidents, improve intersection operational efficiency, and improve turning safety at intersections amongst conflicting road users.

Although traffic signals with FAA indications are now seeing widespread use throughout the U.S., they are not yet present in Canada. This study sought to understand U.S. experience with FAA and its applicability to the Canadian context, as well as gauge Canadian perspectives across the country regarding FAAs.

This report contains a synthesis of findings from a comprehensive literature review on research and practical experience related to FAA signals in the U.S., along with a summary of findings from follow-up interviews with U.S. experts, a survey of Canadian jurisdictions, and two focus group sessions with Canadian jurisdictions that identified key challenges, opportunities, benefits, and risks for the application of FAA signals in Canada. These findings provided the basis for recommended next steps for the potential implementation of FAA signals in Canada.

The literature review and interviews found the U.S. has had an overall positive experience with FAA signals in terms of operational, safety, and user comprehension performance. Published Collision Modification Factors (CMFs) show a reduction in collision rates when converting a permissive or protected-permissive turn phasing to FAA signal heads, with no changes in signal phasing. Published CMFs have also shown that changing from fully protected turn phasing to protected-permissive FAA signal heads can increase collision rates, however this is understood by representatives as being primarily due to the change from protected phasing and not the FAA signal itself. Research has also found improvement in pedestrian safety, with FAA signals improving driver yielding behaviour at intersections with conflicting pedestrian crossings. FAA signals provide operational benefits by allowing changes to phasing by time-of-day, as well as the opportunity to provide lagging left turn phasing at desired intersections, while mitigating the “yellow trap” safety issue.

Canadian jurisdictions showed interest in pursuing the application of FAA signals in Canada through the survey and focus group sessions. FAA is mainly viewed as a tool in the toolbox for targeted application where warranted. However, the study found important differences between the U.S. and Canadian contexts. Two notable examples are:

1. Pre-existing use of flashing green arrows in Canada may affect driver understanding of FAA signals (particularly by colour-blind users). The U.S. does not use flashing green arrows.
2. Canadian interest in applying FAA signals in shared lanes, which has not been recommended or implemented in the U.S.

Consequently, the study recommends an initial step to formalize use of steady green arrows in the *Manual of Uniform Traffic Control Devices for Canada* (MUTCDC) as a precursor to FAA introduction. Subsequent steps prior to a MUTCDC update are to determine, test, and pilot signal head configurations for FAA application in exclusive and shared lane contexts to fill gaps in FAA safety and performance understanding in a Canadian context.

# Table of contents

# List of figures

# List of tables

# 1. Introduction

## 1.1 Background

Traffic signal timing is a challenging task that must balance efficient movement of traffic with collision risk while accommodating traffic variability due to volume fluctuations throughout the day, coordination between intersections, accommodation of different transportation modes (pedestrians, cyclists, motor vehicle traffic), emergency vehicle pre-emption, transit priority, limited resources, data availability, and others. One important aspect of traffic signal timing is permissive motor vehicle turning movements (both left and right turns) that conflict with opposing or impeding traffic and pedestrian and cyclist movements. Approximately 17 percent of all intersection collisions in Canada are associated with left turns across opposing traffic, with more than half of those occurring at signalized intersections (estimated using 2021 data from Transport Canada National Collision Database).

The Flashing Amber Arrow (FAA) or Flashing Yellow Arrow (FYA) signal display has been widely implemented across the United States of America (U.S.) as the permissive left-turn indication to mitigate driver confusion caused by the permissive steady green indication (Zhang, Li, & Wu, 2023). The expressed concern related to driver confusion is that drivers turning left on a permissive circular green signal display might mistakenly assume that the left turn has the right-of-way over opposing traffic, especially under some geometric conditions (Srinivasan, Lan, Carter, Smith, & Signor, 2020). A U.S. nationwide survey indicated, for the majority of responding states, FAA displays are the preferred left-turn signal in terms of operation (Thapa, Asaduzzaman, & Abedi, 2022). The FAA and FYA have the same meaning in this document. The source term is used in this document, which is FYA in all U.S. documents, including in the *Manual on Uniform Traffic Control Devices* (MUTCD).

Following the completion of a study by the National Cooperative Highway Research Program (*NCHRP Report 493,* Brehmer, et al., 2003) that recommended FYA indication be used to indicate permissive left turns on exclusive turning lanes due to increased driver understanding, operational benefits, and significant improvements to left-turn safety, the FYA indication was included in the 2009 edition of the *Manual of Uniform Traffic Control Devices* (FHWA, 2009). Currently, 2009, and now 2023, MUTCD allows the use of a FYA signal display to indicate permissive left turns for all separated left-turn signal heads used over the left-turn lane and operated in a protected/permissive mode or a permissive mode (Qi, et al, 2012). Although the NCHRP Report 493 (Brehmer, et al, 2003) states FYA signals can be used on shared lanes (i.e. shared turning indication with through movements), they ultimately recommended their implementation only on exclusive turning lanes.

Flashing amber arrow signals represent a potential tool to manage conflicts between vulnerable road users and turning vehicles. However, to be effective, this new form of traffic control must be understood by users, applied in the correct context, uniformly presented, be compliant with acts and regulations, and be properly operated to achieve desired outcomes. Although traffic signals with FAA indications are seeing widespread use throughout the United States, they are not yet present in Canada. This study aims to gain knowledge on the U.S. experience on the application and safety and operational performance of FAA signals, and to understand how that might translate into the Canadian context. Without careful consideration, a move towards FAA use could result in a poor first step that limits future use or does not address, or even worsens, conflicts and collisions at intersections. Published Collision

Modification Factors (CMFs) show changing from fully protected turn control to FAA signal heads can increase collision rates (although this is primarily understood to be due to the change from protected phasing), while collision rates for changes from permissive or protected-permissive phasing to flashing amber arrow signal heads result in collision reductions.

This report contains a synthesis of findings from a comprehensive literature review on research and practical experience related to FAA signals in the U.S., as well as a summary of findings from follow-up interviews with U.S. experts, survey of Canadian jurisdictions, and two focus group sessions with Canadian jurisdictions that identified key challenges, opportunities, benefits, and risks for the application of FAA signals in Canada. These findings provided the basis for recommended next steps for the potential implementation of FAAs in Canada.

## 1.2 Methodology

This report involves findings from four tasks involving FAA signals: (1) literature review, (2) interviews with experts on the application of FAA signals, (3) survey of Canadian jurisdictions, and (4) two focus group sessions with Canadian jurisdictions plus a U.S. representative. The methodology of each task is further described below.

### 1.2.1 Literature Review

The literature review component was based on a comprehensive review of U.S. and Canadian literature published in English and French within the last 25 years. However, no Canadian literature, in English or French, were found relevant to this study. The literature review was guided by the topics identified by the Project Steering Committee (PSC), as well as topics brought forward by the research team. The literature review included literature on research and practical experience related to FAA signals in the U.S., including engineering periodicals and journals, readily available papers and texts, conference proceedings, and readily-available government and industry reports and guidelines, listed in Table 1.

The literature review initially identified 107 publications addressing the issues investigated in this project. After further examination of these documents, 68 were deemed to be uniquely applicable to this project. The quality of research was assessed by categorizing each publication as qualitative or quantitative, and rigorous or non-rigorous research, as summarized in Table 2.

Rigorous or non-rigorous research are defined as follows**:**

- Rigorous: analysis based on evidence-based data or for non-analytical is the topic thoroughly explain with sufficient detail
- Non-rigorous: analysis based on qualitative observations, small sample size, biased data etc., or for non-analytical is the content difficult to understand or follow

**Table 1: Resources for literature review**

| *Special library catalogues* | *Government and industry agencies* |
| --- | --- |
| • Transport Research Information Services<br>• American Society for Civil Engineers<br>• Science Direct<br>• NRC Research Press<br>• CMF Clearinghouse<br>• University Theses and Dissertations<br><br>***Scientific journals and conference proceedings***<br>• Transportation Research Record<br>• Institute of Transportation Engineers Journal<br>• Journal of Traffic and Transportation Engineering<br>• Journal of Safety Research<br>• Injury Prevention<br>• Canadian Journal of Civil Engineering<br>• Accident Analysis and Prevention<br>• Journal of Transportation Engineering | • Federal Highway Administration<br>• AASHTO<br>• Transportation Research Board Standing Committee on Traffic Control Devices (ACP 55)<br>• National Committee on Uniform Traffic Control Devices<br>• National Association of City Transportation Officials<br>• State Departments of Transportation<br>• National Highway Traffic Safety Administration<br>• Transportation Association of Canada |

**Table 2: Quality of Literature**

| Research Quality | Rigorous | Non-Rigorous |
| --- | --- | --- |
| Qualitative | 9 | 8 |
| Quantitative | 39 | 14 |
| Total | 48 | 22 |

### 1.2.2 Interviews with Experts

Following the literature review, virtual interviews were conducted with four experts on FAA signals to gain additional understanding of the application of FAAs in the U.S. The interviewed experts were representatives of the Federal Highway Administration (FHWA), the National Committee on Uniform Traffic Control Device (NUTCD), Transportation Association of Canada's Traffic Operations & Management Committee (TOMC), and the City of Richland, Washington State. The City of Richland was selected due their expansive experience and use of FAA signals in their jurisdiction.

### 1.2.3 Canadian Survey

An online survey of Canadian jurisdictions was conducted over four weeks. The survey aimed to gain an understanding on the familiarity and interest of Canadian jurisdictions with the FAA signal, their current traffic signal practices, and the barriers to implementation of FAA signals in their jurisdictions.

The 22-question online survey was distributed to Canadian jurisdictions, and explicitly to the jurisdictional members of TOMC, and jurisdictional members of Road Safety Committee and Active Transportation Integrated Committee who are not part of TOMC, to ensure it is answered by the people who are most knowledgeable about this topic from operations and safety perspectives. The survey aimed to obtain results from a range of municipalities and provincial jurisdictions from different geographic locations with different traffic signal network sizes. The survey received responses from 19 towns/municipalities and four provincial jurisdictions.

### 1.2.4 Focus Group Sessions

Two virtual focus group sessions were organized with 16 jurisdictions of varying sizes and geographic locations (eastern and western Canada), to reinforce/refine and dig deeper into the findings from the survey results. In total, 23 practitioners who oversee their agency's traffic signal operations, maintenance, and or management were engaged. The sessions enabled discussion and learning based on experiences from other agencies on the current difference in signal operations, and the perceived opportunities and challenges of potential use of FAA signals in the Canadian context.

The following topics were discussed in each session:

- Familiarity and interest of FAA implementation
- Current application of flashing arrow turn signals and the potential use of FAAs in Canada
- Purpose and benefits of implementing FAAs in Canada
- Concerns with FAA implementation in the Canadian context
- Discussions on the implementation process of FAAs (e.g. the roll out process, legislative and regulatory requirements, political justification, etc.)

The focus group sessions identified the differences in current signal practices across Canadian jurisdictions, agreements and opposing views on FAA signals, and opportunities and disadvantages with the implementation of FAA signals in the Canadian context. A U.S. representative was present at one of the sessions to allow Canadian participants to learn from the U.S. experience.

# 2. Literature Review

## 2.1 Description of U.S. Flashing Amber Arrow Signals

The flashing yellow arrow (FYA) signal display is used in replacement of the traditional green ball signal display for permissive left turn or right-turn movements, where drivers must yield to conflicting traffic, including pedestrians and cyclists.

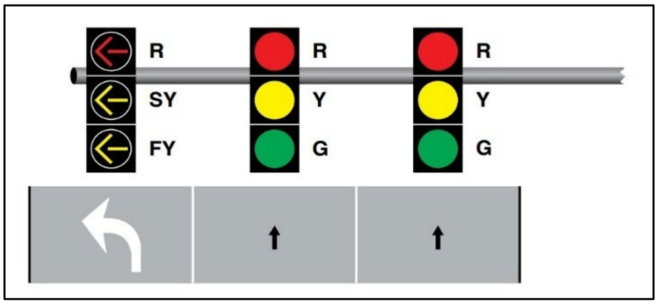
For left-turn movements, the FYA signal display can be used in permissive-only or protected-permissive left-turn phasing, or in a conversion from a protected-only phase to either of the two mentioned left-turn phases. The *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA, 2023) provides signal head arrangements for each left-turn phasing type:

- Permissive-only left-turn FYA: can use a three-section head with a steady red arrow, steady yellow arrow, and flashing yellow arrow, placed exclusively for the left-turn lane, as shown in Figure 1. The permissive-only left-turn FYA display replaces a traditional three-section signal head with solid-coloured displays with no changes to phasing.
- Protected-permissive left-turn FYA (PPLT-FYA): can use a four-section signal head with a steady red arrow, steady yellow arrow, flashing yellow arrow, and steady green arrow, placed exclusively for the left-turn lane, as shown in Figure 2. The flashing yellow arrow is used for the permissive portion of the left-turn movement. The four-section FYA display provides the flexibility of changing between protected-only, permissive only and protected-permissive displays based on time-of-day and traffic characteristics to more efficiently move traffic based on demands. More recently, a three-section signal head with a dual arrow (bimodal) FYA lens has been used in some jurisdictions (e.g., Oregon, Portland, and Richland) with the same functionality as the four section FYA signal head. The 2023 MUTCD also provides a three-section FYA signal head configuration with a bimodal lens sharing a steady yellow and flashing yellow arrow, as shown in Figure 2. An alternative bimodal FYA signal head configuration used by some jurisdictions is a shared lens for the steady green arrow and flashing yellow arrow signals. This is discussed further in Section 3. The PPLT-FYA replaces a traditional five-section signal head (i.e. doghouse signal display or vertical display) with a circular green permissive left-turn display, with unchanged phasing, that is shared between the left turn and adjacent through lane, as shown in Figure 3.
- A fully protected left-turn phase can be converted to a permissive-only or protected-permissive left-turn phase with the implementation of an FYA signal due to operational efficiency objectives, using the two previously mentioned traffic signal devices associated with the left-turn phase (i.e. three section signal head for permissive left turns or a four-section signal head for protected-permissive left turns).

Permissive left-turn maneuvers increase the risk for vehicle-vehicle and vehicle-active transportation conflicts as compared to fully protected left-turn phasing. Younger and older drivers especially have difficulties distinguishing the adequate gap distance needed to make a permissive left-turn safely. The use of permissive phasing also leaves pedestrians without a protected walk phase (FHWA, 2013a). Thus, a FYA signal attempts to bring more awareness to the left-turning driver of the conflicting vehicle and vulnerable road user traffic.

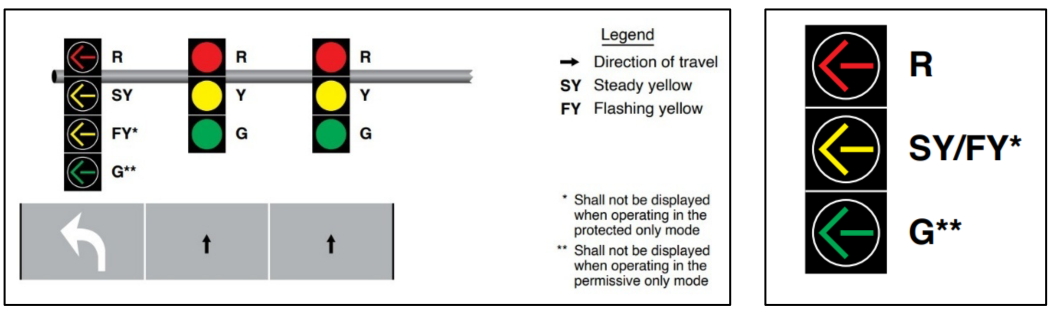
A protected-permissive left-turn phase provides a combination of the two other left-turn phases by providing a balance between the safety of a fully protected left-turn phase and the efficiency of a permissive-only left-turn phase. "*The protected-permissive left-turn phases with flashing yellow arrow (PPLT-FYA) have the potential to improve traffic operations by allowing more vehicles to complete their left turns during permissive phases, especially in off-peak hours; however, their safety is perceived to be less than that of protected-only left-turn phases*" (Hajbabaie, Sattarov, & Mohebifard, 2018). A flashing amber arrow traffic signal device can replace a traditional 5-section signal head or a protected-only signal head if an engineering study determines that the permissive period is safe during certain times of day (Cleveland Utilities, 2024).

**Figure 1: Permissive-Only Left-Turn FYA Phasing using an Exclusive Three-Section Signal Head above the Left-Turn Lane**




*(Source: MUTCD, 2023)*

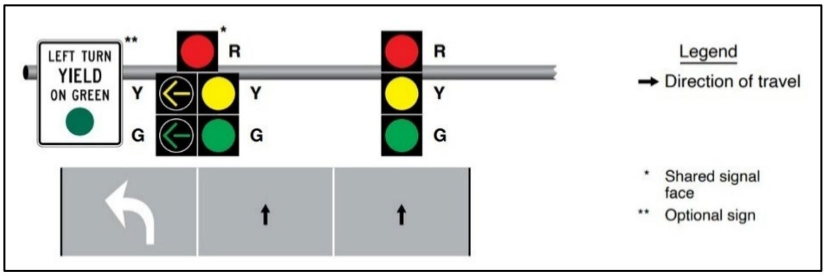
**Figure 2: Protected-Permissive Left-Turn Phasing with a FYA Signal using an Exclusive Four-Section Signal Head (left) or a Bimodal Three Section Signal Head (right) above the Left-Turn Lane**

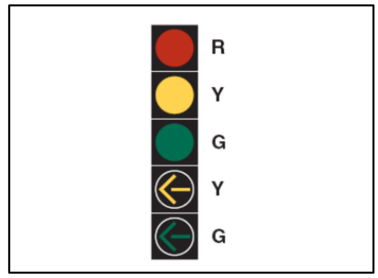



*(Source: MUTCD, 2023)*

Legend: SY- Steady yellow, FY- Flashing yellow

**Figure 3: Traditional Protected-Permissive Left-Turn Phasing using a Five Section Signal Head, in a Doghouse or Vertical configuration**



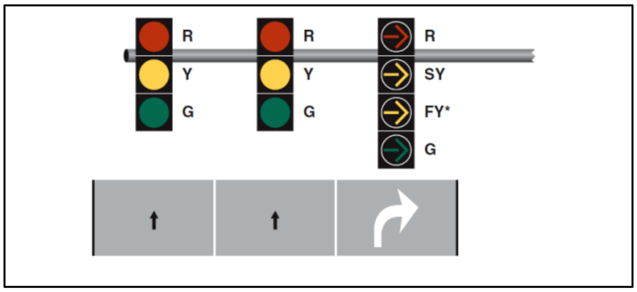




*(Source: MUTCD, 2023)*

The flashing yellow arrow (FYA) right-turn signal phasing is a more recent signal practice in the United States. Similar to the left-turn FYA signal heads, the MUTCD (FHWA, 2023) provides the four-section head FYA signal display for right turns, as shown in Figure 4, that supports multiple phase indications through permissive, protected, and/or permissive/protected phases.

A supplemental sign may be installed adjacent to the left or right-turn flashing yellow arrow signal face, stating LEFT (RIGHT) TURN YIELD ON FLASHING YELLOW ARROW, as presented in the MUTCD (FHWA, 2023) and shown in Figure 5 and Figure 6. The optional supplemental sign has been installed by jurisdictions concerned about the understanding of the new FYA signal by drivers. Studies have found the addition of a supplemental sign has some level of impact on the safety of FYAs and on driver understanding as they are already well understood by drivers. For example, in Illinois, Schattler, et al. (2016) found a nine percent further reduction in left-turn collisions with the installation of supplemental signs with the FYA signal. Minnesota, Davis, et al. (2023) found an increase in understanding of FYA signals from 94 to 96 percent with the installation of a supplemental sign, while finding an increase in driver gap acceptance when the sign is present.

**Figure 4: Protected-Permissive Right-Turn FYA Signal using an Exclusive Four-Section Signal Head above the Right-Turn Lane**




*(Source: MUTCD, 2023)*

**Figure 5: Supplemental Sign for FYA Signal Displays**


*(Source: MUTCD, 2023)*

**Figure 6: Supplemental Sign for FYA Signal installed in Minnesota**


*(Koch, 2024)*

## 2.2 Application

This Section provides a synthesis of literature on the application of flashing amber arrow (FAA) signals, identifying implementation contexts and warranting factors where FAAs are suitable for operation such as signal timing, intersection geometry, pedestrian activity, and economic benefits.

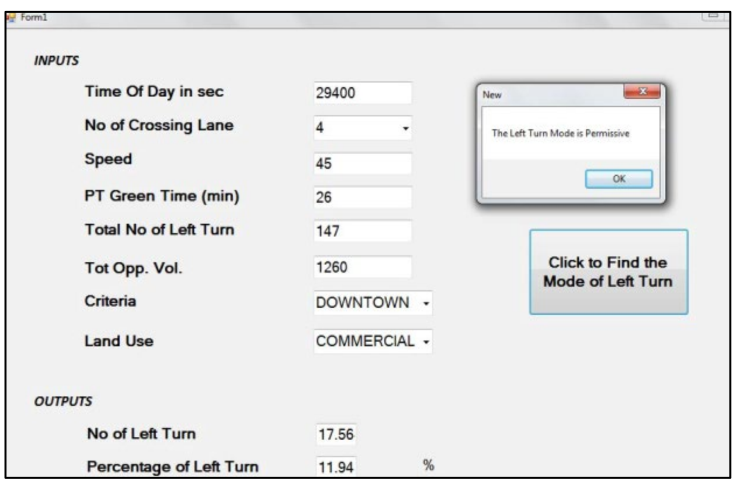
### 2.2.1 Warranting Factors

The selection of an appropriate left-turn control mode at a signalized intersection, with possible variability throughout the day, is a complex decision making-process due to many influencing factors and traffic characteristics (Hajbabaie, Sattarov, & Mohebifard, 2018). Previous research that has identified influencing variables in the decision-making process are summarized:

- Qi, et al (2012) developed guidelines for PPLT-FYA installations in Texas based on a survey of traffic engineers, a field test at five intersections, and a collision analysis at 51 intersections. Based on the study findings, the authors recommended selecting the left-turn control mode considering traffic volume (left turn and opposing traffic volume), speed limit, sight distance, number of lanes, and left-turn crash history. They found that a FYA signal indication can be used at most signals with pre-existing PPLT operations to improve intersection safety and reduce both collisions and conflicts. "However, FYA PPLT operation is not recommended at busy intersections that have high left-turn volumes and opposing volumes, and they should be implemented with great caution at intersections where lead-lead left-turn phasing is used." High traffic volumes can cause confusion with steady-yellow arrows where left-turn drivers in the leading left-turn direction are not aware of the signal change from an FYA to a steady yellow. The field traffic conflict study found an increase in incidents of "running red lights" and "backing into the left-turn lane". The authors recommend a relatively long steady red arrow (of 3-4 seconds) between the steady yellow and FYA to warn left-turning drivers of the end of the protected-phase.

- Radwan et al. (2013) created an interactive decision support system (DSS) framework for the Florida Department of Transportation (FDOT) that provides guidance on whether fully protected left-turn phasing should be modified to protected-permissive phasing (using FYA indications), given inputs including: the time of day, the number of lanes to cross, the speed and volume of opposing traffic, the amount of green time for the protected left-turn phase, the volume of left-turn movements, and the type and density of nearby land uses, as shown in Figure 7. Depending on the parameters, changing fully protected left-turn phasing to protected-permissive phasing may only serve a few vehicles during the permissive part of the phase—creating potential for collisions but only providing a minimal reduction in delay; or it can be more impactful. The DSS used a statistical model developed from more than 200 hours of video data recorded at 13 intersections in Central Florida. There was no assessment of the effect of FYA vs green ball indications—outside of an acknowledgement that four-section FYA left-turn signal heads allow for variable left-turn phasing, where the left-turn phase mode can change from fully permissive, protected-permissive, or fully protected at different times of day. Four-section signal heads with FYA indications were considered the default for variable left-turn phasing, based on a recommendation from the 2009 *Manual on Uniform Traffic Control Devices* (FHWA, 2009).

**Figure 7: Input Window for the Decision Support Tool to Identify Left-Turn Mode**




*(Radwan , Abou-Senna, Navarro, & Chalise, 2013)*

- Radwan et al. (2016) expanded on the work from 2013, to allow for an automated selection of left-turn phasing mode (fully protected or protected-permissive with FYA), potentially changing from cycle to cycle based on real-time gap data from the opposing traffic stream, using the DSS framework from the 2013 study. The model database was expanded to include video data from 38 intersections across the state of Florida—versus 13 intersections in Central Florida in the 2013 study. The expanded data also included additional parameters including left-turn gaps, opposing lane utilization, and left-turn stop delay. The automated system was simulated using VISSIM microscopic traffic simulation software, and then tested at two intersections in Seminole County, Florida, where the DSS framework was integrated with detectors and the signal controller. The testing confirmed the applicability and validity of the DSS framework. Four-section FYA left-turn signal heads allow for the flexibility to adjust left-turn modes on a cycle-by-cycle basis, to operate intersections as efficiently as possible.
- Abou-Senna et al. (2019) developed an exclusive hardware platform for variable left-turn phasing, expanding on the work by Radwan et al. from 2013 and 2016. The expansion included additional software testing with real data, and field testing at six intersections in Florida. The testing verified that the system accurately monitored traffic in real time and switched between fully protected and protected-permissive phasing in a reasonable manner consistent with driver expectations. Testing also found that coordinated signals with very long cycles (three minutes and longer) helped to provide adequate gaps for permissive left turns, even with heavy opposing volumes, as the long cycle lengths would lead to heavily platooned traffic. Conversely, shorter cycle lengths eliminated sufficient gaps, even with coordination. Calculation of minimum gaps used two different methods: one was more accurate, while the other was more conservative. The project resulted in a hardware device that was compatible with the different controller types used in FDOT districts. The device takes input in the form of volume data and signal timing and phasing data returns output in the form of a recommendation on whether to implement fully protected or protected-permissive left-turn phasing on the next cycle. The algorithm developed in the project can allow traffic signal controllers to use variable left-turn phasing where four-section left-turn signal heads are available
- Alfawzan (2019) conducted a literature review and safety performance analysis of right-turn FYA signals in Florida. Right-turn FYA signals can only be installed on exclusive right-turn lanes, as per the MUTCD. Based on previous research, they found that according to the National Cooperative Highway Research Program (NCHRP) Report 279 (Neuman, 1985) right-turn lanes in urban areas are significantly affected by right-turn volumes, right-turning rear end crashes, and/or pedestrian crossing volumes, whereas in the rural area speed, right-turn volumes, and the land use types were the significant factors (Varma, Ale et al. 2008).
- Davis, et al. (2015) created guidelines for variable left-turn phasing, where protected phasing is modified to permissive or protected-permissive at different times of day, using FYA signal heads. A statistical model was developed using traffic volume data and intersection characteristics from 436 left-turn collision events in the Twin Cities area in Minnesota. The model identified the risk of a left-turn collision over the course of a day, based on left turn and opposing movement traffic volumes, the type of left-turn phasing, and classification based on the opposing speed limit and sightline obstruction from opposing left-turning vehicles. A spreadsheet tool was developed to provide users with a prediction of the risk of a left-turn collision on a given approach under permissive or protected-permissive phasing, separately for every hour of the day, based on user-input left turn

and opposing movement traffic volumes (from as little as one hour of the day), and measurements that can be used to calculate whether sightlines might be obstructed.

- Virginia DOT developed *Guidance for Determination and Documentation of Left-Turn Phasing Mode* (2015) to guide the decision-making process of left-turn signal phasing mode selection. They state that the factors that should be considered include sight distance, critical crossing gap, intersection geometry, and correctable left-turn collisions.

### 2.2.2 Signal Timing/Phasing

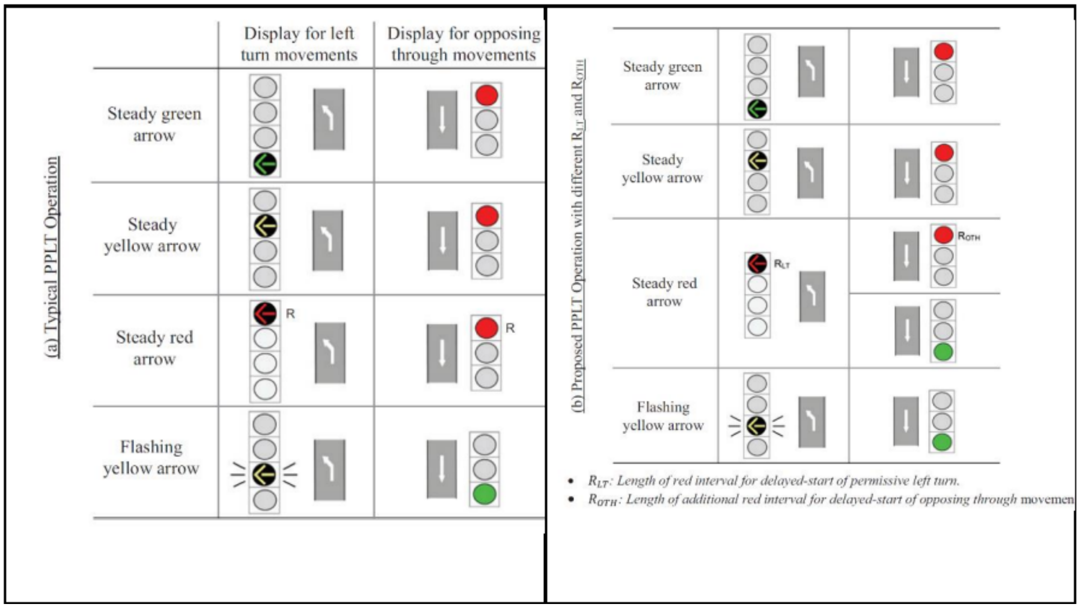
The FYA signal display can be used in a permissive-only left-turn phase or a protected-permissive left-turn (PPLT) phase, by either changing the traditional signal head display while maintaining the same phasing (i.e., replacing a permissive left-turn signal with a permissive left-turn FYA or replacing a PPLT with a PPLT-FYA), or by changing the signal phasing and replacing a protected left turn (PLT) with a PPLT-FYA.

Flashing yellow arrows give traffic engineers the ability to safely use different indications (green or flashing yellow) during different times of day. For example, permissive flashing yellow arrows can be used during low volume timeframes while protected green arrows can be used during high volume timeframes (Beaufort County Government, n.d.). Variable left-turn phasing by time-of day has shown to improve intersection operations and reduce delays, however, has shown to result in some driver confusion (Hajbabaie, Sattarov, & Mohebifard, 2018).

The start of an FYA signal can be delayed when transitioning from a protected left-turn phase to a permissive left-turn phase, with a survey showing that 71 percent of responding state agencies that use FYAs also delay the start of FYAs due to its increased safety benefits (Appiah & Cottrell, 2014). This is typically conducted by implementing a red arrow signal indication prior to starting the FYA signal (i.e., transitioning from a green arrow protected left turn to a steady yellow, to a red arrow, and then finally to a permissive flashing yellow arrow).

Mahbub, Kang, and Lee (2019) conducted micro-traffic simulation and conflict analysis to assess the effects of two red interval transition options on intersection efficiency and safety. They evaluated the appropriate lengths of two red interval phasing options for the transition between an FYA signal to a PPLT phasing using, one is a red interval for delayed start of permissive left-turn movements; the other is an additional red interval for delayed-start of opposing through movements, as shown in Figure 8. A useful reference, which describes the balanced length of the two red intervals under varying traffic levels, is developed as a result. (Mahbub, et. al., 2019; Chen, 2023)

**Figure 8: Typical and Proposed PPLT FYA Signal Timing for the Red Arrow Transition Phase**

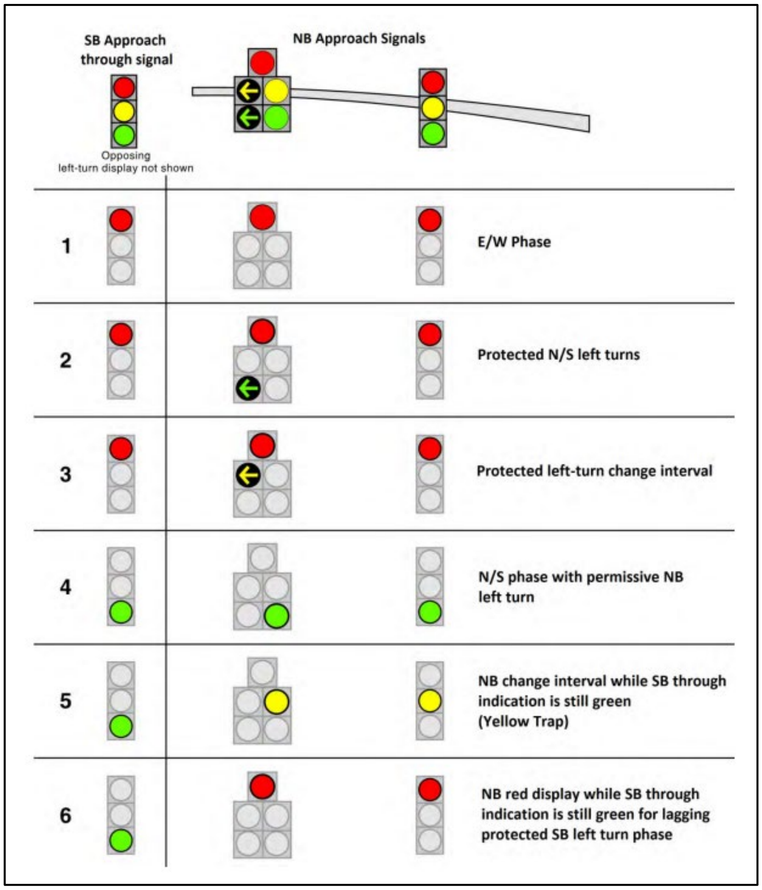



*(Mahbub, Kang, & Lee, 2019; Chen, 2023)*

The FYA signal is also commonly used as a treatment to mitigate the "yellow trap" problem occurring during a lagging permissive left-turn signal phasing also referred to as a lead-lag phasing sequence (FHWA, 2013a). The yellow trap occurs when a permissive left turn is opposed by a lagging green for the opposing through movement, as show in Figure 9. In the yellow trap, the permissive left-turning vehicle either gets stranded in the intersection due to the absence of gaps in the opposing through traffic with a green signal, or the left-turning driver sees a yellow display and incorrectly assumes the opposing traffic is also receiving the similar yellow display, thus maneuvers a left turn into oncoming traffic. The left-turning vehicle assumes the opposing traffic is slowing to a stop when in fact the opposing vehicles are proceeding into the intersection with a circular green signal indication, creating a collision risk.

The flashing yellow arrow is recommended as the most effective option to eliminate the yellow trap, by bringing awareness to the left-turning driver that the maneuver remains a permissive left turn and the driver must yield to opposing through traffic (FHWA, 2013a). However, the FYA does dilute the meaning of the steady yellow display during the change interval, where left-turning vehicles have the right-of-way during a steady yellow arrow change interval in a protected-only left turn, while they must yield to oncoming traffic when the steady yellow arrow signal follows a FYA signal (Hajbabaie, Sattarov, & Mohebifard, 2018).

**Figure 9: Example of the "Yellow Trap" Signal Phasing**




*(Source: FHWA, 2013a)*

- The start of the flashing yellow arrow (FYA) signal indication can be delayed (e.g. with a red arrow signal indication) during the transition from a protected movement to a permissive movement in a leading left protected–permissive left turn. Appiah and Cottrell (2014) conducted a survey of transportation agencies and national experts and found 71 percent implemented a delay to the start of the FYA, and some preference existed for the use of the red arrow signal due to the perceived safety benefit.

## 2.2.3 Intersection Geometry

- AASHTO *Policy on Geometric Design of Highways and Streets* 6$^{th}$ Edition (AASHTO, 2011) states "The driver of a vehicle approaching an intersection should have an unobstructed view of the entire intersection, including any traffic-control devices, and sufficient lengths along the highway to permit the driver to anticipate and avoid protentional collisions," for flashing yellow arrows to be installed.
- In North Carolina, five intersections (at the time of this report) use dual-left flashing yellow arrow (dual-left FYA) displays, with other cities across the states also utilizing them, including Tucson, AZ (NCDOT, 2015). Dual left FYA can be installed on dual left-turn lanes that have sufficient intersection sight distance for left-turning vehicles to scan the opposing traffic. Other factors to consider are corridor operating speeds, opposing through volumes and lanes, left-turn turning crossing distances,

crash history at the intersection, typical corridor left-turn phasing, and other site-specific factors. A case study at one intersection in 2014 found that dual left-turn FYA would lower delay by almost 50 percent and reduce queue lengths by 20 to 30 percent (NCDOT, 2015).

- Zhang, Li and Wu (2023) evaluated the effect of FYA operations on single and dual left-turn lanes, as this is not well investigated. They developed safety performance functions (SPFs) for different combinations of collision types and number of left-turn lanes. The authors found that "intersections with dual left-turn lanes experience a 31.2 percent increase in total crashes when switching from 24-hour to TOD FYA operation type, while intersections with a single left-turn lane see a 60 percent decrease in rear-end crashes."
- Davis, et al. (2015) developed guidelines for the Minnesota Department of Transportation for time-of-day use of permitted left-turn phasing, which can use a FYA. A statistical model was developed to express the risk of left-turn collisions during a given hour as a function of the left-turn demand, the opposing traffic volumes, opposing traffic speed limit, and sight distance obstruction, under permissive or protected-permissive phasing, implemented with FYA signal heads. The model included consideration for obstruction of left-turn sightlines created by the intersection geometry, evaluated using longitudinal distances and lateral offsets between the approach in question and the opposing approach.
- Radwan, et al. (2013) developed a statistical model to provide recommendations for retaining fully protected left-turn phasing or switching to protected-permissive phasing (with FYA indications), based on multiple factors, including the number of through lanes opposing the left turn. The study intentionally combined the effects of all the factors into the left-turn mode recommendation and did not identify any guidelines for use of protected-permissive (FYA) phasing based solely on the number of opposing through lanes.

### 2.2.4 Pedestrian and Cyclist Activity

- Nassereddine, et al. (2023) used video to assess interactions between right-turning vehicles and pedestrians at sites with circular green or flashing yellow arrow permissive right-turn indicators. Timestamps for key vehicle and pedestrian placements were documented and used to calculate how long it took for the driver to complete a right turn, and how long it took the pedestrian to reach the potential conflict point. Non-probabilistic linear regression models were created to describe the relationship between the position of the pedestrian and the time for the vehicle to complete the right turn. Larger right-turn maneuver times were associated with greater respect for pedestrian presence, called a pedestrian respect indicator (PRI). Results indicated that interactions controlled by flashing yellow arrows had higher PRI values than those controlled by circular green.
- Hurwitz, et al. (2018b) studied the implementation of the flashing yellow arrow signal on permissive and protected-permissive right turn (PPRT) operations to investigate the safety and operational effectiveness of implementing FYA at exclusive right-turn lanes. The microsimulation model of several PPRT phasing alternatives under varying volumes (right-turn vehicle volumes, conflicting pedestrian movements, and conflicting left-turn vehicle movements) indicated that the pedestrian volumes had the greatest effects on delays. The authors suggest that the implementation of FYA signal in lieu of a steady circular green display can improve driver-yielding behavior and pedestrian safety at signalized intersections with high volumes of permissive right turns from exclusive right-turn lanes.

- Knodler, et al. (2006) conducted a driver and pedestrian comprehension of the FYA signal in a series of dynamic driving simulator and computer-based evaluations, with a total of 139 drivers and 100 pedestrians in 5,930 experimental scenarios. They found that there was a high level of comprehension to yield requirements to pedestrians and that the driver recognition of yield requirements to pedestrians was not negatively affected by the FYA. The authors recommend the operation of FYA signals at T-intersections where pedestrian crossings are prevalent.

### 2.2.5 Transit Priority

The literature review revealed no references regarding the use of flashing amber arrow signals for transit priority, in terms of prioritizing the movement of buses, reducing delays for transit passengers, and improving the reliability of transit service.

### 2.2.6 Infrastructure and Maintenance

- Virginia Department of Transportation (2016) updated the *2011 Virginia Supplement to the MUTCD, Revision 1* to include recommendations for installing FYA signals at all permissive-only and protected-permissive left turns when there is an exclusive left-turn lane. They also require providing the option for a four-section signal face for permissive only or protected only left turns where there is potential for future conversion to protected-permissive left turns. VDOT (2016) recommends the use of “Left turn yield on flashing amber arrow” sign at all locations with flashing amber arrows.
- Chamber (2016) conducted a clinical study in the field conversion to flashing yellow arrow traffic signals from traditional traffic signals in Glendale, Arizona. The study included six categories: high accident intersections (priority 1), signal head modification only (priority 2), signal head replacement with median modifications (priority 3), signal head and mast arm replacement (priority 4), signal head, signal pole and mast arm replacement (priority 5), and intersections where flashing yellow arrow operation is not recommended (priority 6). To comply with MUTCD standards, data collected included: left-turn signal control, mast arm length, pole type and location, signal head type, signal head lateral location, and the presence of pedestrian heads, pushbuttons, and manhands/countdown timers. Sight distance requirements needed to be met, any equipment in the median was noted, and controller capability had to meet the requirements to qualify for flashing amber arrow signals. The study provided cost estimates for the different FYA implementation categories in 2010 USD dollars.
- Jones, Foster, and Bhagat (2023) evaluated the safety and economic performance of 841 FYA signals installed between 2007 and 2021 in Missouri using a simple before-after analysis. They estimated that the lifecycle benefits of installing FYAs at an intersection approach is expected to be five to 44 times greater than the installation cost, depending on the left-turn phasing used before and after the FYA installation. The lowest B/C ratio was for permissive-only to protected-permissive FYA (PPLT-FYA) phasing conversion (B/C ratio of 5.4), however this phasing scenario had a small sample size, and the highest for FYA installations with unchanged left-turn phasing conversions (i.e. B/C of 39 for permissive-only to permissive-only left turn conversion and B/C of 43.6 for PPLT to PPLT-FYA conversion). The conversion of phasing from protected to protected-permissive FYA resulted in a negative 193 B/C ratio due to the increase in collisions. The analysis assumes a 10-year lifespan of FYA signals and an installation cost of $2,820 USD per approach and does not consider potential benefits of changes in delay.

- Srinivasan, et al. (2020), as part of a FHWA study, evaluated the safety and economic performance of FYAs using collision data from 307 treated sites and 438 untreated sites from four states: Oklahoma, Oregon, Nevada, and North Carolina. The economic performance of FYAs were analyzed for five treatment categories:
    - Category 1: from traditional PPLT to FYA PPLT on one road (on three legs)
    - Category 2: from traditional PPLT to FYA PPLT on one road (on four legs)
    - Category 3: from traditional PPLT to FYA PPLT on both roads
    - Category 4: from permissive or traditional PPLT to FYA permissive on one road
    - Category 5: from permissive to FYA permissive on one road

  Table 3 shows the economic benefits from crash reductions and the associated B/C ratios for treatment categories 1 through 5. They found that the mean benefit-cost ratios ranged from 56:1 to 144:1, based on an assumed installation cost of $6,000 per approach leg and a 10-year expected service life. The B/C ratio for conversions from protected-only to FYA-PPLT phasing was not calculated due to an increase in left-turn collisions.

**Table 3: Economic Analysis (B/C ratios) of various FYA Treatments**

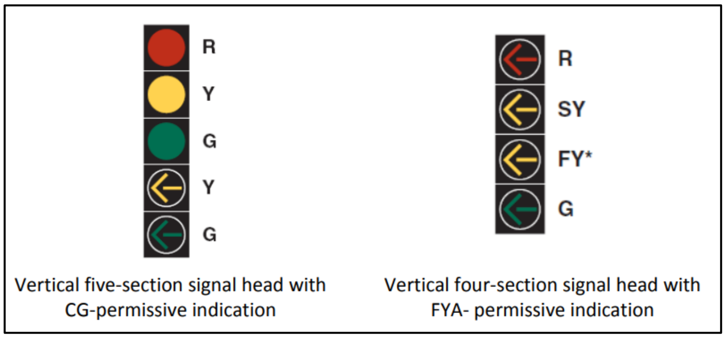
| Treatment Category | KABC Crash Reduction * | PDO Crash Reduction * | Economic Benefits from Crash Reduction * | Annualized Treatment Cost * | B/C Ratio Mean | B/C Ratio Min | B/C Ratio Max |
|---|---|---|---|---|---|---|---|
| 1 | 0.30 | 0.27 | $72, 010 | $854 | 84:1 | 46:1 | 116:1 |
| 2 | 0.5 | 0.18 | $117,626 | $1,709 | 69:1 | 38:1 | 95:1 |
| 3 | 0.78 | 0.85 | $191,990 | $3,417 | 56:1 | 31:1 | 78:1 |
| 4 | 1.16 | -1.12 | $245, 410 | $1,709 | 144:1 | 79:1 | 198:1 |
| 5 | 0.68 | -0.08 | $152,535 | $1,709 | 89:1 | 49.1 | 123:1 |

* Per intersection per year
Min = minimum; Max = maximum.

*(FHWA, 2020; Srinivasan, et al., 2020)*

- Schattler, Anderson, and Hanson (2016) evaluated the effectiveness of changing the circular green-ball for permissive left turns on PPLT control with a five-section signal head to a FYA signal for the same interval but with a four-section signal head, as shown in Figure 10, at 86 intersections in Peoria, Illinois. They found that the implementation of FYAs resulted in a benefit to cost ratio of 19.8:1, using 2010 equivalent costs with a 15-year service life.

**Figure 10: Traffic Signal Heads for a Vertical Five-Section Head with Green Ball and Vertical Four-Section Head wit FYA Indications**




*(Schattler, Rietgraf, Burdett, & Lorton, 2013)*

## 2.3 Operational Performance

This section provides a synthesis of literature on the operational impact of flashing amber arrow signals on traffic flow and intersection efficiency. This involves information that pertains to queue lengths, delay times, intersection capacity, and overall traffic progression with and without the signals.

- Abou-Senna, et al. (2023) developed a hardware platform to provide a generic device compatible with different signal controller types and to automate the selection of flashing yellow arrow left-turn modes based on available gaps in the opposing traffic acquired in real time from existing sensors in the field. The four-section signal display with a FYA signal provides a variable mode that can change left-turn phases on demand, thus utilizing the FYA indication based on traffic conditions. Field testing and evaluation of the decision support system was done by switching between red and flashing yellow arrow modes in a rational manner consistent with driver expectations and left-turning gap acceptable thresholds. The analysis showed that the utilization factor for the decision support system recommendations for intersections ranged from 65 percent to 75 percent during peak periods on weekdays and between 90 percent and 95 percent during off-peak periods and weekends. The decision support system reduced delay from all intersections from 737 vehicle-hours to 440 vehicle-hours.
- Davis, Stern, Duhn and Gao (2023) conducted a field study at nine sites in Minnesota to evaluate the effect of installing a “Left Turn Yield” sign with a FYA and circular green signal display on driver gap acceptance. Generally, the longer the critical gap, the more conservative drivers are when deciding to make a turn. The authors found that at sites with 30 mph opposing speed limit, on average, the supplemental sign significantly increased the critical gap for both FYA and circular green displays, with similar results for FYA signals at 40mph speed limit sites (e.g., for FYA signals the sign increased average gap acceptance from 4.2 sec to 5.2 sec at 30mph and from 4.9 sec to 5.4 sec for 40mph). The absence of a sign generally resulted in shorter gap acceptance for FYA signals compared to circular green displays.
- Thapa, et al. (2022) evaluated the operation of three types of left-turn signals, protected only, protected permissive, and flashing yellow arrow at 28 intersections (72 approaches) in Louisiana through an operational analysis using video data to estimate delay. The analysis showed an average delay of 50.69 seconds/vehicle at protected-only signals, 46.04 seconds/vehicle at protected-

permissive signals, and 31.49 seconds/vehicle at FYA signals. Delay at flashing yellow arrow signals was lower compared to protected-only and protected-permissive overall, however the sample size for flashing yellow arrow signals was smaller.

- Abou-Senna, et al. (2021) developed an algorithm to safely optimize traffic operations through the switching of traffic signals from a red arrow to a flashing amber arrow in real-time dependent on minimum headway of vehicles in the opposing traffic, the number of lanes to cross, the number of cycles to be analyzed before switching. The algorithm calculated headway for each lane independently compared to a pre-determined threshold collected from 30,000 cycles collected in the field through this research. The algorithm was tested at intersections in Florida with video data being collected to capture the algorithm being tested to validate the algorithm decisions.
- Alfawzan (2019) developed a decision support tool through microsimulation analysis to predict the efficient application of a permissive right-turn FYA signal using a set of parametric variables including an impeding flow, impeding green interval, cycle length, and or pedestrian volume. The efficiency of the signal phases was assessed by the average maximum right-turn throughput (MRTT). Three right-turn FYA signal phases were evaluated:
    - Right turn on impeding through (RTOIT) where the right-turning vehicle is impeded by cross-street through traffic and pedestrian crossings,
    - Right turn on impeding left (RTOIL) where the right-turning vehicle is impeded by only impeding opposing left-turn traffic, and
    - Right turn on adjacent through (RTOAT) where the right-turning vehicle maneuvers simultaneously with the adjacent lane green phase and is impeded only by crossing pedestrians.

  Alfawzan (2019) found that RTOIT FYA was efficient and highly recommended at an impending green interval of 40 seconds or longer. A yield to pedestrian sign was strongly recommended to alert right-turning drivers to yield to crossing pedestrians concurrently with impeding through traffic.

  The RTOIL FYA signal phase was overall efficient only at an impeding interval of 45 seconds or longer and was found non-efficient at an impeding green interval of less than 20 seconds.

  It was found that pedestrian volume and pedestrian phasing play a significant role in warranting the efficient use of RTOAT FYA phase. It was found that a permissive FYA phase was efficient at an impeding pedestrian total interval of 25 seconds (i.e. average MRTT of three throughputs or more per cycle) or longer and low-efficient at an impeding pedestrian total interval of less than 20 seconds (i.e. average MRTT ranging from 2.1 to 2.9 throughputs per cycle).
- Panthangi (2019) used VISSIM and the FHWA Surrogate Safety Assessment Model (SSAM) software to analyse the safety of different left-turn phase sequences: FYA and circular green left-turn PPLT signals with and without an all-red clearance interval. It was found that the introduction of an all-red clearance interval between the protected and permissive phases (i.e. delayed start to FYA) increased average vehicle delay, for example, from 27.8 to 29.3 seconds and from 25.1 to 29.9 seconds at two different locations.
- Hajbabaie, Sattarov, and Mohebifard (2018) conducted a simulation to assess the operational performance of time-of-day variable left-turn control mode with a flashing yellow arrow (FYA)

signal, switching between permissive, protected-only, and protected-permissive left-turn phases throughout the day. They found that the variable mode resulted in more efficient traffic operations and lower average delays; however, it also resulted in more confusion for drivers operating under the time-of-day variable signal phasing where a driver comprehension survey showed that about half of drivers encountering variable left-turn phasing believed that they were confused. The statistical analyses of the simulation experiment (with 4,050 total observations) showed that the number of left-turning vehicles and the left-turn control mode had the greatest effect on intersection delay, thus a model was developed to select the best left-turn control mode based on the intersection geometry and the cross-product of the left turn and the opposing through-movements.

- Appiah and Cottrell (2014) conducted a survey and simulation analysis evaluating the safety and operational performance effect of an optional delay in the start of a flashing yellow arrow signal when transitioning from a protected to permissive left-turn movement. They found that 71 percent of responding state agencies that use FYAs also delay the start of FYAs. This is typically done by implementing a red arrow signal indication prior to starting the FYA signal. The authors found "no significant negative impacts on average delay, average queue length, or average stopped delay for either left-turning traffic or the intersection as a whole."
- Medina, et al. (2018) states that PPLT-FYA operations have greater flexibility to improve traffic operations over traditional PPLTs. For example, FYA indications can allow an increasing number of vehicles to turn left under a permissive indication due to only requiring the opposing through vehicles to have a green light. Whereas a traditional PPLT allows a permissive left turn only when both the adjacent and opposing through vehicles have a green light. "Thus, under the same conflicting demands this operational benefit of FYA can improve mobility, but it also creates greater opportunity for permissive conflicts, and therefore also for crashes" (Medina, et al 2018).

## 2.4 Safety Performance

This section provides a synthesis of literature on the safety performance of flashing amber arrow signals in terms of their effect on collisions and conflicts, and impact on vulnerable road users, including collision modification factors.

### 2.4.1 Effect on Collisions

The literature shows that the introduction of a FYA signal has generally been found to have a positive effect on safety, however, in certain situations it has resulted in an increase in collisions (Gong & Yang, 2023). Table 4 provides a summary of collision modification factors (CMFs) found in key publications for the introduction of a flashing amber arrow signal in different left-turning phasing scenarios with statistically significant results (Jones, Foster, & Bhagat, 2023). Jones, Foster, and Bhagat (2023) found that, generally, the introduction of a FYA signal, with no change in phasing resulted in safety improvements with CMFs for fatal and injury collisions (KABC) ranging from 0.75 to 0.86 for protected-permissive phasing and 0.35 to 0.65 for permissive phasing.

The literature also finds that the introduction of a protected left-turn phasing at any degree results in safety improvements (Gong & Yang, 2023), with the conversion of permissive to protected-permissive left-turn FYA phasing resulting in CMFs for KABC collisions ranging from 0.6 to 0.97 (Jones, Foster, &

Bhagat, 2023). Conversely, the literature finds that the removal of a protected-only left-turn signal and the introduction of a permissive phase results in an increase in collisions, with the conversion of protected-only to protected-permissive FYA left-turn phasing resulting in CMFs for KABC collisions ranging from 3.19 to 4.78 (Jones, Foster, & Bhagat, 2023). The studies evaluating the safety performance of flashing amber arrow signals are further described.

**Table 4: Summary of CMFs from the Literature for the Introduction of FYA signals for Different Left-Turn Phasing (Adapted from Jones, Foster, & Bhagat, 2023)**

| Study | CMFS | | | |
|---|---|---|---|---|
| | PP to PP | PT to PP | PM to PP | PM to PM |
| Schattler, et al. (2016) | 0.62 (KABCO) | N/A | | |
| Simpson and Troy (2015)[1] | 0.84 (KABCO)/ 0.75 (KABC) | 3.68 (KABCO)/ 4.78(KABC) | 0.60 (KABCO)/ 0.60 (KABC) | 0.50 (KABCO)/ 0.35 (KABC) |
| Shea and Medina (2018)[1] | 0.98 (KABCO) | N/A | | |
| Srinivasan, et al. (2020) | 0.51 – 0.85 (KABCO)[2] | N/A | | |
| Srinivasan, et al. (2011)[1] | 0.81 (KABCO) | 2.24 (KABCO) | 0.64 (KABCO) | N/A |
| Jones, et al., 2023 | 0.86 (KABC)/ 0.82 (O) | 3.19 (KABC)/ 2.33 (O) | 0.97 (KABC)/ 0.24 (O) | 0.64 (KABC)/ 0.57 (O) |

[1] CMFs are for all left-turn crashes, not just LTOD crashes
[2]CMFs differ based on number of legs at an intersection and number of approaches FYA installed on.
Note: PP – protected-permissive, PT – protected-only, PM – permissive-only

- The FHWA conducted a comprehensive study (Srinivasan, et al., 2020) evaluating the safety performance of FYAs using collision data from 307 treated sites and 438 untreated sites from four states: Oklahoma, Oregon, Nevada, and North Carolina, considering different before-after phasing systems, number of roads with FYA installations, and number of legs at each intersection. They analyzed six different crash types (total, injury and fatal- KABC, rear-end, angle, left turn and left turn with opposite through (LTOT) crashes) for seven different treatment categories:
    - Category 1: from traditional PPLT to FYA PPLT on one road (on three legs)
    - Category 2: from traditional PPLT to FYA PPLT on one road (on four legs)
    - Category 3: from traditional PPLT to FYA PPLT on both roads
    - Category 4: from permissive or traditional PPLT to FYA permissive on one road
    - Category 5: from permissive to FYA permissive on one road
    - Category 6: from at least one protected phase to FYA PPLT without time-of-day operations
    - Category 7: from at least one protected phase to FYA PPLT with changes in time-of-day operations

  They found that overall, the FYA implementation results in a reduction in left-turn collisions if the change is not from a fully protected left-turn phase. Treatment categories that involved permissive or protected-permissive phasing in the before period experienced a reduction in crashes that were under consideration in the study, left-turn collisions, and left turn with opposing through traffic collisions. Table 5 shows the statistically significant CMFs for the six treatment categories, as category seven did not result in statistically significant results. The implementation of an FYA resulted in collision reductions for the primary target collisions under consideration (left turn and left turn opposite through (LTOT) collisions) ranging from 15 to 50 percent depending on the treatment category. For example, the conversion from PPLT to PPLT-FYA resulted in a 19 precent decrease in left-turn collisions. Total collisions were reduced by 11 to 18 percent, depending on the treatment category.

The change from a protected phase to a PPLT-FYA (categories 6 and 7) resulted in increase in LT and LTOT collisions, with category 6 (without time-of-day operations) showing statistically significant increase in LT and LTOT collisions ranging from 55 to 91 percent.

**Table 5: Crash Modification Factors for different Collison Severities and FYA Conversion Categories**

| Recommended CMFs | | | | | | |
|---|---|---|---|---|---|---|
| **Crash Type** | **Category 1** | **Category 2** | **Category 3** | **Category 4** | **Category 5** | **Category 6** |
| Total | 0.849 | 0.889 | 0.818 | _ | _ | _ |
| KABC | 0.791 | 0.801 | 0.782 | 0.808 | 0.787 | _ |
| RE | _ | 0.884 | _ | _ | _ | _ |
| ANG | _ | _ | _ | _ | _ | _ |
| LT | _ | 0.746 | 0.624 | 0.729 | 0.612 | 1.551 |
| LTOT | _ | 0.615 | 0.507 | 0.733 | 0.548 | 1.910 |

_ No Data.

*(Adapted from FHWA, 2020)*

- The City of Chandler, Arizona (2024) are in the process of replacing all of their left-turn arrow signals with four signal display Flashing Yellow Arrows (FYA), and have analyzed three years of collision data before and after each four-signal FYA installation. To date, they have found that on average, left-turn collisions and total intersection collisions decreased by 22 percent post FYA installation.
- Lee, Cunningham, and Simpson (2023) evaluated the safety performance of converting a protected-only left-turn to a protected-permissive left turn with FYA (PPLT FYA) with time-of-day operation through an observational before-after study. They found that for a full day operation, the conversion resulted in a slight increase in total collisions and significant changes in target collisions (i.e., increase in left-turn–same roadway crashes and decrease in rear-end crashes). This finding showed a trade-off between left-turn–same roadway and rear-end crashes after the signal conversion. In addition, the implementation of PPLT FYA at specific times-of-day resulted in significantly higher same-roadway collisions than the full-time operation of the signal phase. The authors suggest that engineers could extend protected-only use more on the fringes of the peak periods to reduce the increase in left-turn-related crashes.
- Jones, Foster, and Bhagat (2023) evaluated the safety performance of FYA signals installed between 2007 and 2021 at 841 approaches in urban and rural locations in Missouri using a simple before-after analysis. They found that FYA operations reduced fatal and injury (KABC) left-turn opposite through (LTOT) collisions by about 14 percent and Property Damage Only (PDO) LTOT collisions by

about 18 percent, at locations with protected-permissive left-turn phasing controls before and after FYA installation. The study found that converting from a permissive-only to a protected-permissive FYA signal resulted in only a three percent reduction in KABC collisions however a 76 percent reduction in PDO collisions, however this was based on a small sample size of seven intersections. They also found that the safety benefits of operating a FYA display are not significant enough to outweigh the negative safety implications of converting an approach from a protected-only left-turn to protected-permissive FYA phasing operation (CMF=2.33).

- Zhang, Li, and Wu (2023) evaluated the safety performance of FYA signals at single and dual left-turn lanes for different operation types: 24-hour, time-of-day, and switching from 24-hour to time-of-day (TOD). They found that intersections with either a single or dual left-turn lanes, 24-hour and TOD FYA operation types reduce crashes by 8.7 to 50 percent. However, intersections with dual left-turn lanes observe an increase of 31.2 percent in total crashes when switching from 24-hour to TOD FYA operations, while intersections with single left-tun lanes observed a 60 percent decrease in rear-end crashes.
- Chen (2023) evaluated the safety effectiveness of flashing yellow arrow indications implemented at protected-permissive left-turn (PPLT) phasing at five selected signalized intersections in City of Rancho Cucamonga, California. The author used the basic proportionality theorem method to compare the actual number of crashes at five intersections to the predicted number of crashes based on measurable factors including AADT, speed limit, and number of lanes. The analysis found that there was improvement in safety at all five intersections, suggesting flashing yellow arrows contribute to a reduction in crash occurrences.
- Thapa, et al. (2022) evaluated the safety of three types of left-turn signals; protected-only, protected-permissive, and flashing yellow arrow, at 166 intersections in Louisiana through a collision analysis. The analysis showed left-turn crashes at protected-permissive left turns were almost double that of protected-only and flashing yellow arrow intersections (2.29, 1.20, and 1.11 crashes per intersection per year, respectively). A before-and-after comparison for FYA intersections showed left-turn crashes reduced by 17.73 percent.
- Tainter, et al. (2021) conducted a before and after study for 350 protected permissive left-turn signals converted to flashing yellow arrows across Massachusetts. This study included a benefit-to-cost analysis, evaluating the economic benefits of installing FYAs across three different FYA intersection types: 3-way with one FYA, 4-way with one FYA, and 4-way with two or more FYAs. Collisions were analyzed per year with the FHWA KACBO injury scale with the economic cost per injury calculated using Massachusetts adjusted FHWA costs. Using the adjusted FHWA costs, the 3-way flashing yellow arrow intersections yielded the highest benefit-to-cost ratio range, from 180:1 to 22:1. The 4-way intersections with multiple flashing yellow arrow approaches yielded the smallest range (22:1 to 3:1). Based on the findings, the authors suggest that flashing yellow arrows should be widely implemented, regardless of the intersection type, as they reduced the average annual number of injury collisions and led to lower economic cost of injuries in all three treatment types.
- Panthangi (2019) used VISSIM and the FHWA Surrogate Safety Assessment Model (SSAM) software to analyse the safety of different left-turn phase sequences: FYA and circular green left-turn PPLT signals with and without an all-red clearance interval. It was found that fewer conflicts occurred when an intersection is changed from a circular green to a FYA indication with an all-red clearance interval between protected and permissive phases (i.e. delayed start to FYA).

- Medina, Shea, and Azra (2018) evaluated the safety performance of various left-turn signal and phasing conversions in Utah, including 74 approaches with FYA signals. They found that overall, the FYA signal and traditional permissive phase had similar annual crash rate performance, while the FYA signal had a higher crash rate compared to a traditional PPLT phase, with a CMF of 1.33. They also found a shift in the distribution of crashes with the installation of an FYA signal, where a higher concentration of crashes occurred in the hours preceding afternoon peaks (2pm-4pm), which provides opportunity for extending operational strategies from peak into off-peak hours.

  Some intersections in Utah had a lagging left turn which created safety problems with the FYA operation. Utah DOT has since removed all lagging left-turn phases from FYA operations and has installed a supplemental sign indicating “Left Turn on Flashing Yellow” for FYA signals.

- Hajbabaie, Sattarov, and Mohebifard (2018) found that the literature shows that converting a protected-only left turn (POLT) to a protected-permissive left turn (PPLT) with a flashing yellow arrow (FYA) is associated with an increase in collision rates while reducing intersection delay. However, compared to doghouse displays (i.e., solid green permissive left-turn signals), four-section vertical display with an FYA are associated with smaller crash modification factors, less confusion among drivers, and reduced delays.

- King, et al. (2018) examined the safety performance of converting left-turn signals from (1) a green ball display to a flashing yellow arrow display for the permissive portion of protected-permissive left turn (PPLT), and (2) a protected-only left turn to a protected-permissive flashing yellow arrow (PPT-FYA) for 28 intersections in Virginia. They found that the conversion in the first scenario (from a PPLT to a PPLT-FYA) was expected to result in a 12 percent reduction in total collisions, 14 percent reduction in fatal and injury collisions, and 30 percent reduction in angle collisions, which is consistent with other studies finding that the FYA display is better understood than the traditional green ball for the permissive portion of PPLT phasing. Based on previous studies, they find that the reduction in collisions can outweigh the cost of signal conversion in most cases.

  King, et al. (2018) also developed prediction models through simulation analyses to predict capacity and conflicts (i.e., safety risk) for permissive-only and PPLT left-turn control modes. The models’ predictor/input variables were found to be different signal timing, traffic volume, and intersection characteristic parameters for each hour of the day. This model is deemed to provide a decision support tool to allow for optimal left-turn control mode choice throughout the course of a day.

- Illinois Department of Transportation implemented the flashing yellow arrow (FYA) at more than 100 intersections operating with protected-permissive left-turn (PPLT) phasing in 2020. Schattler, Anderson, and Hanson (2016) evaluated the effectiveness of changing the circular green-ball for permissive left turns on PPLT control with a five-section signal head to an FYA signal for the same interval but with a four-section signal head on 164 approaches at 86 intersections, using both the naïve before-and-after and the Empirical Bayes methods. Supplemental traffic signs with text “Left Turn Yield on Flashing Yellow Arrow” were also mounted adjacent to over half of the FYA installations.

- Schattler, et al. (2016) found that the FYA replacement resulted in a 23.3 percent reduction in left-turn related crashes and a 24.8 percent reduction in left turn with opposite through (LTOT) crashes, with even greater reductions when supplemental signs were also installed. At the 90 FYA approaches with supplemental signs, a significant reduction of 31.9 percent and 30.9 percent were observed for left turn and LTOT crashes, respectively. They also found a statistically significant reduction in both crash types for younger drivers (age 16 to 21 years), with a 36.1 percent reduction in LTOT crashes for younger drivers versus 24.8 percent reduction for all drivers. This finding suggests that FYAs are especially helpful to younger drivers making left-turn decisions at PPLT controlled intersections.

- Simpson and Troy (2015) developed crash modification factors (CMFs) for the implementation of FYA in different scenarios by analyzing collision data from 222 intersections in North Carolina. The conversion scenarios and findings included:
    - Category 1- Permissive-Only to FYA-PPLT: Exclusive application at intersections resulted in a seven percent reduction in total crashes, 35 percent reduction in total injury crashes, and 26 percent reduction in target crashes. For the 42 treated legs, a 40 percent reduction in target crashes was found.
    - Category 2 - Protected-Only to FYA-PPLT: Exclusive application at intersections resulted in a 12 percent increase in total crashes, 21 percent increase in total injury crashes, and 244 percent increase in target crashes. For the 49 treated legs, a 268 percent increase in target crashes was found.
    - Category 2A - Protected Only to FYA-PPLT with Time-of-Day Operation: Sites with time-of-day signal variations provided FYA during off-peak hours (9pm to 6am) and operated fully protected the remainder of the day. Exclusive application at intersections resulted in a 10 percent reduction in total crashes, seven percent reduction in total injury crashes, and 173 percent increase in target crashes. For the 34 treated legs, a 173 percent increase in target crashes was found. The authors suggest that there may be benefits in the use of time-of-day variation at locations where target crashes occur at specific times, where a fully protected left-turn mode can operate during peak crash frequency
    - Category 3 - 5-Section doghouse PPLT to FYA-PPLT: Exclusive application at intersections resulted in a seven percent reduction in total crashes, 15 percent reduction in total injury crashes, and 22 percent reduction in target crashes. For the 124 treated legs, a 16 percent reduction in target crashes was found.
    - Category 4 - Permissive -Only to FYA-Permissive-Only: Exclusive application at intersections resulted in an 11 percent reduction in total crashes, 31 percent reduction in total injury crashes, and 59 percent reduction in target crashes. For the 64 treated legs, a 50 percent reduction in target crashes was found.

  Categories 3 and 4 provide changes exclusively to the left-turn display, with no changes to the phasing. They found a statistically significant reduction in target left-turn collisions and injury collisions when converting from a green ball to a FYA for permissive left-turns when phasing remains unchanged, regardless of whether the left phasing is protected-permissive or permissive-only (i.e. categories 3 and 4). The findings from Categories 1, 2, and 2A were not as robust, which suggests variability in performance and need for larger sample size.

- Schattler, et al. (2015) compared collisions at 90 FYA approaches with and 74 FYA approaches without a supplemental traffic sign with text “Left Turn Yield on Flashing Yellow Arrow”. They found that the presence of the sign resulted in a greater collision reduction than without. They also found that older drivers (age 65 and older) did not experience the same extent of collision reduction compared to all drivers. The authors suggest that installing supplemental signs and educating the public on new traffic control could improve the safety of the signalized intersection.

- Appiah and Cottrell (2014) conducted a simulation analysis evaluating the safety and performance effect of adding an optional delay in the start of a flashing yellow arrow signal by displaying a red arrow signal when transitioning from a protected green-arrow left turn to a permissive FYA left-turn phase. They found that the delay resulted in significant safety benefits, except when there was low opposing through traffic volumes. Through a survey of state agencies, they also found that using a red arrow signal to delay the start of the FYA was perceived to have safety benefits by majority of the surveyed jurisdictions.
- Pulugurtha et al. (2012) conducted a before and after study at six intersections in the city of Charlotte, North Carolina, using the Empirical Bayes technique to evaluate. Results from the Empirical Bayes method indicated that the number of crashes would have generally increased if flashing amber arrow signals had not been installed in the after scenario.
- Based on data collection and analysis performed at over 50 intersections after the implementation of a flashing yellow arrow (FYA) permissive-only left-turn indication, Noyce, Bergh and Chapman (2007) concluded that a transition from protected/permissive left-turn phasing to the FYA permissive indication resulted in improved safety (significant decreases in crashes). On the other hand, safety was not improved when a protected only left-turn phasing was changed to FYA indication with protected/permissive left-turn phasing.
- Noyce et al. (2007) evaluated the ability for flashing amber arrows to improve safety with respect to crash experience. The crash analysis findings were interpreted with respect to signal phasing, vehicle flow rates, posted speed limits, and intersection geometry. Fifty intersections with flashing amber arrows installed were analyzed through a before and after study. Results showed that safety was improved at intersections with protected permitted phasing prior to implementation of flashing amber arrows with permissive only phasing. Safety was not improved at intersections with protective only phasing prior to flashing amber arrow implementation with protected permissive phasing.

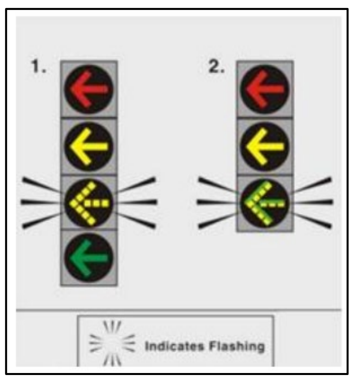
### 2.4.2 Pedestrian and Cyclist Conflicts

- Kothuri, Monsere, Jashami & Hurwitz (2020) conducted an online survey focused on licensed driver’s comprehension of various signal displays for right turns, including the FYA. The primary finding regarding FYA signals was that 20 percent of respondents incorrectly indicated that they would stop before making a right turn on a FYA signal, while 25 percent of respondents incorrectly reported that they had the right-of-way for right turns and did not include the concept of yielding in their understanding of the circular green signal. The authors believe that, although a portion of responses to FYA right turns is incorrect by making a stop before turning, it appears to support increased pedestrian safety.
- Cunningham, et al. (2020) analyzed data from 10 right-turn flashing yellow arrow and 14 leading pedestrian interval treatment locations. These treatment locations were all separate (i.e. no right-turn flashing amber arrows were in the same location as a leading pedestrian interval, and data was collected post construction so before and after data was not available). Because of this, the project was closed early. The study did show that leading pedestrian intervals provided better yielding to pedestrians compared to right-turn flashing yellow arrows at 84 percent compared to 49 percent,

however there may be flaws in comparing the yield rates due to the nature of the data collected. The study also found no difference in yielding rates at single or dual right turning lane configurations, however the sample sizes were relatively small.

- Using Oregon State University's driving simulator, the Tuss (2020) study evaluated the impact of different variables (pedestrian volumes, opposing vehicle volumes, type of signal configuration) on a driver's capacity to perceive pedestrians, based on a drivers' eye fixation duration. The results suggest that for a given situation (three opposing vehicles), drivers focus more of their attention on the crossing pedestrians when presented with a MUTCD standard 4-section vertical FYA signal (average total fixation duration of 1.6 seconds) than when presented with a 3-section FYA signal (average total fixation duration of 0.9 seconds).
- Hurwitz, et al. (2013) conducted a simulator-based study to track participants eye movements when interacting with pedestrians at intersections with flashing yellow arrows, using a three-section dual-arrow FYA signal head and a four section FYA signal head. The simulator had 24 combinations of scenarios, including zero, three and nine oncoming vehicles, pedestrians moving towards, away or from both sides, and three and four section FYA signal heads, as shown in Figure 11. The study used statistical tests and found that four to seven percent of drivers fail to fixate on pedestrians in conflicting crosswalks, there was no statistical difference in glance durations between three or four section signal heads and flashing yellow arrow signals may require additional signage in high pedestrian locations. The data used in this research over sampled young drivers and results may change with a larger sample size.

**Figure 11: Four and Three FYA Signal Head Configurations**




*(Hurwitz & Monsere, Driver Behavior in the Presence of Pedestrians at Signalized Intersections Operating the Flashing Yellow Arrow, 2013)*

- No literature was found on the effect of FAA signals on cyclist safety.

## 2.5 User Comprehension and Compliance

This section provides a synthesis of literature on the driver comprehension and behaviour as well as pedestrian and cyclist behaviour because of a new device, and the need for education of the population about the new device.

- Researchers from the University of Minnesota conducted an online survey to examine drivers' understanding of flashing yellow arrows with and without a "Left Turn Yield on Flashing Yellow Arrow" sign (Koch, 2024; Davis, Stern, Duhn, & Gao, 2023). The survey had 480 respondent and found that almost all the participants appeared to understand the FYA indication (90 percent of respondents who did not identify as transportation professionals interpreted FYA correctly), and that user comprehension increased by two percentage points (94 percent to 96 percent) when the left-turn yield sign was present.

  The researchers also conducted a field study at nine intersections in the Twin Cities to assess gap acceptance. They found that on average drivers waited for larger gaps with solid green circle signals compared to those with flashing yellow arrow signals. They also found that on average, the critical gaps were significantly longer at sites with supplemental yielding signs (for both circular green and FYA signals), where implementing a sign with the FYA signal showed an increase in critical gaps similar to those at circular green sites.
- Tainter, et al. (2020) investigated the connection between traditional signal timing and design and human factors through a computer-based survey and field study to determine comprehension levels between flashing amber arrows and circular green left-turn indications. The survey results suggested similar comprehension levels between the flashing yellow arrow and the circular green indications. The field evaluation had similar results, however drivers appeared to create fewer potential conflicts when there was an all-red clearance interval present between protected and permissive phases.
- Kothuri, Monsere, Jashami & Hurwitz (2020) conducted an online survey focused on licensed driver's comprehension of various signal displays for right turns, including the FYA, in Oregon. The results showed that most respondents (76 percent) understood right-turn FYA displays, and that the yielding response required by the FYA indication for permitted right turns was better understood than for a circular green display, with 25 percent of respondents indicating that they have the right-of-way without indicating yielding with the circular green display.
- Jashami, et al. (2019) evaluated driver comprehension with respect to right-turn signal displays focusing on flashing yellow arrow indicators in a driver simulator in Oregon. The simulator had 46 participants and 16 experimental scenarios. The researchers used a counterbalanced factorial design to investigate three independent variables: signal indication type and active display, length of right-turn bay, and pedestrian presence, assessing driver decision making and visual attention. A Mixed-effects Ordered Probit Model and a Linear mixed model were used to examine the collected data. Results showed when drivers were presented with a flashing yellow arrow, they better understood the permissive right-turn condition. When pedestrians were present with the flashing yellow arrow, nearly all drivers used caution, yielded to pedestrians, and stopped when needed. When the same maneuver was presented with a circular green, drivers were less likely to exhibit the correct behaviour.
- Jashami (2020) continued the Jashami et al. (2019) study with the addition of eight more scenarios and total fixation duration on different areas of interest. The mean total fixation duration on the signal head was significantly higher when drivers were turning right with a flashing yellow arrow display as compared to circular green. The longer duration indicates drivers are doing a more robust visual search and therefore have better yielding behaviour, resulting in improved pedestrian safety.
- Panthangi (2019) used VISSIM and the FHWA Surrogate Safety Assessment Model (SSAM) software to analyse the safety of various left-turn phase sequences. The results made it possible to conclude

that fewer conflicts occur when the left-turn phase sequence at an intersection is changed from circular green to flashing yellow arrow (FYA) and an All-Red Clearance interval is introduced between the protected and permissive phases. Furthermore, they found that changing a left-turn phase sequence from circular green to FYA reduces the total number of crashes with very little negative affect to the performance of that intersection.

- Ryan, et al. (2019) conducted a two-step evaluation of driver behaviour regarding right-turn flashing yellow arrows and yielding to pedestrians. The evaluation included a static survey with over 200 respondents and simulated right-turn scenarios with various pedestrian volumes, half of which had flashing yellow arrows, with 144 participants. Results showed that drivers had a strong comprehension of the flashing yellow arrows as they did not behave unsafely when shown FYAs in the simulation.
- Hurwitz, et al. (2018a) conducted research featuring a survey and a simulator study with drivers in Oregon to assess driver understanding of flashing yellow arrows in the right-turn context. The survey had 399 responses. The survey found that drivers have good comprehension of both circular green and flashing amber arrow signals. Flashing amber arrows did however have more incorrect responses, indicating they thought they should stop, while circular green had more partially correct responses with some respondents failing to mention yielding to pedestrians. The driving simulator had 46 usable participants and found consistent results with the survey for circular green and flashing amber arrow responses.
- Hajbabaie, Sattarov, and Mohebifard (2018) conducted a simulation and comprehension survey of Washington state drivers to assess the driver performance with doghouse display left-turn signals versus four-section vertical display with FYA left-turn signals, as well as time-of-day variable left-turn control mode with flashing yellow arrow (FYA) signal. The survey found that the level of comprehension was similar for both displays, with most drivers not experiencing confusion, while about 40 percent experiencing some confusion in both displays. However, most drivers preferred to see the vertical four-section display with FYA to convey left-turning signals.

  They also found that half of the drivers who encountered variable left-turn control modes felt confused about the phasing strategy, however, the simulation-based analysis showed that changing the left-turn control mode by time-of-day resulted in more efficient traffic operations and lower average delays.
- Casola (2018) conducted a survey to compare flashing amber arrows for right-turning vehicles compared to circular green signals. The survey determined a statistically significant increase in drivers yielding for flashing amber arrows compared to circular green signals. A microsimulation was then conducted and VISSIM was used to determine the right-turning speeds of vehicles with the flashing amber arrow present compared to the circular green signals. It was found that speeds were significantly lower with the flashing amber arrow.
- Knodler, et al. (2017) evaluated driver understanding of flashing yellow arrows in right-turn applications compared to existing conditions in Madison, Wisconsin. This was done through survey-based and field-based evaluations. When 200 survey respondents were asked what circular green and flashing yellow arrows meant in right-turn applications, the researchers were looking for a response of “yield before entering intersection”. The number of responses for this answer increased by 23.7 percent from circular green (24.7 precent) to flashing yellow arrow signals (57.4 precent).

The researchers also documented vehicle-pedestrian interactions at sites with and without FYAs through video analysis and documented the baseline time it would take for a vehicle to make a right turn with no pedestrian present, and the time at which a right-turning vehicle entered the intersection, along with the percentage of crossing completed by the pedestrian. A model was created to show the deviation of a driver from an expected-right-turn behaviour with the presence of a pedestrian. The data was limited thus no robust conclusions were provided, rather this field-based evaluation was completed to show the feasibility of a study of this nature, using a limited dataset of one FYA site and three non-FYA sites.

- Rescot, et al. (2015) investigated installing four-section flashing amber arrow signal heads horizontally while the other signal heads on the traffic signal support system remained vertical to prevent the need to adjust the current infrastructure (support system). Driver behaviour data was collected when a vehicle approached a flashing amber arrow and would have to yield for a permissive left turn compared to five control sites. Through a comparative study, it was found that there was no statistical difference observed in driver acceleration/deceleration between any of the sites. Surveys were also conducted where respondents were asked if they would go, yield, or stop when shown various images for left-turn scenarios. The results of the survey showed most drivers understood what to do in various situations or did not give a fail-critical response. There was one case with an 11% fail-critical response rate when a vertical flashing yellow signal head displayed a solid yellow left-turn arrow while the adjacent through lanes had a circular green signal.
- Noyce et al. (2014) conducted research to analyze driver comprehension of flashing amber arrows when added to three and five section traffic signals. The study was comprised of a computer-based survey and a driver simulator. Findings from the survey showed no significant difference in driver comprehension when the flashing amber arrow was presented bimodally in the bottom or middle section of the three-section vertical signal display. Driver comprehension was significantly lower when the flashing amber arrow was added bimodally to the five-section cluster signal with simultaneous through indicators. The driving simulator showed no significant different in driver performance between the traffic signal display combinations.
- Schattler, et al. (2013) analyzed an online survey completed by 363 drivers that included seven left-turn scenarios with protected and permissive phasing with flashing yellow arrows being used for the permissive phases. The survey found that drivers had a high comprehension of the correct action to take for both FYAs and circular green however, there were significantly higher incorrect “go” responses with the circular green scenarios than with FYAs when a supplemental sign was in place. Drivers had a significantly higher comprehension of the FYAs when opposing traffic had a green signal compared to a red signal, with and without a supplemental sign. The addition of the supplemental sign reading “Left turn Yield on Flashing Arrow” with flashing yellow arrows significantly improved driver understanding regardless of the opposing traffic’s signal colour (i.e., red or green).

  Additionally, 128 hour of field data was collected at 16 study approaches for a before and after comparison of the impacts of converting circular green signals to flashing yellow arrows. The analysis assessed gap size accepted, red light running, yellow light running, and traffic conflicts. Statistical analysis was conducted for the study at a 95% level of confidence with the following results:

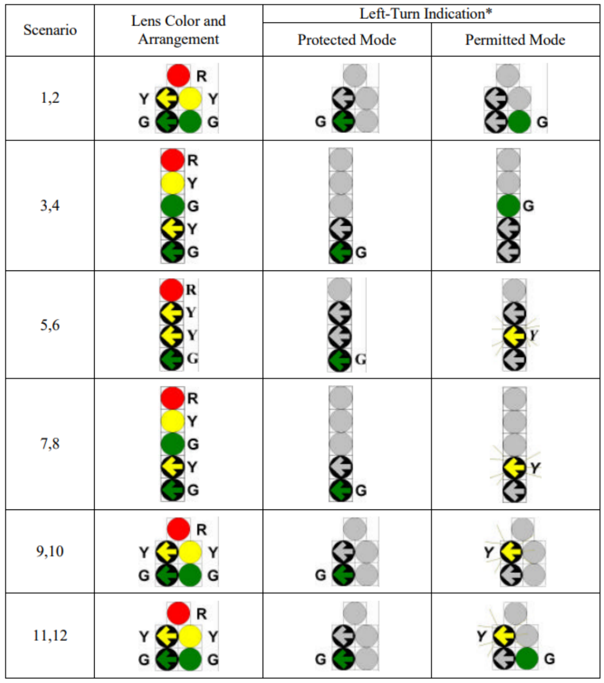
  - Gap size acceptance did not have a significant difference.

  - Red light runs on a per hour basis following the permissive left-turn interval was the only variable to experience a significant increase.
  - There was no significant difference in traffic conflicts experienced.

- Lin, et al. (2012) conducted a before and after study to evaluate flashing amber arrows in terms of short-term safety. The study observed gap acceptance to evaluate safety. Under low to moderate opposing traffic conditions, drivers accepted longer gaps in traffic to make permissive left turns with the flashing amber arrow compared to circular green, while no noticeable difference was seen between the two in high opposing traffic volumes. This indicated that opposing traffic volumes have a significant impact on gap acceptance behaviours.
- Knodler et al. (2005) evaluated driver understanding of flashing yellow arrows in traffic signal displays with simultaneous permissive indications (i.e., shared signal head rather than separate signal heads) in five-section signal heads using a dynamic driving simulator and computer-based survey. A comparison of seven permissive left-turn indications featuring circular green or FYA indicators, or both, was completed by 264 drivers. The results showed simultaneous displays did not affect the drivers' understanding of the permissive indicators. Drivers demonstrated an understanding of needing to yield with simultaneous indications with 65 percent correct response rate for circular green indications and 89 percent for the proposed retrofit, shared signal head, indicating simultaneous indications would be suitable for retrofitted displays with FYAs.
- Brehmer, et al. (2003) conducted an NCHRP study (NCHRP Report 493) evaluating protected-permissive left-turn control displays. Through a photographic driver study, they found that out of the circular green, flashing circular yellow, flashing circular red, and flashing yellow arrow, the circular green permissive indication had the lowest percentage of correct responses for all indications (50 percent), and the flashing circular yellow and flashing circular red had the highest percentage of correct responses. The photographic driver study also resulted in the support of the use of PPLT displays for exclusive turning lanes, as they found that the five-section PPLT signal head arrangement used in shared lanes resulted in the longest average response time than all of the other displays (4-section and 3-section displays) and a lower correct response rate attributed to the simultaneous display of the green left arrow and the solid red circular indication.

  The authors conducted driver confirmation studies in full-scale simulators, finding that the scenarios involving the FYA had a high level of driver understanding, similar to that of a circular green display, and significantly lower fail-critical rates than the scenarios involving the circular green display. In contrast to the photographic study findings, the location of the PPLT display (shared or exclusive) did not result in a statistically significant difference in the percentage of correct responses during the permissive indication.
- Knodler et al. (2001) created a multi-intersection driver simulation completed by 211 participants, to assess driver understanding of 12 different passive-protective signal configurations shown in Figure 12. After the simulator, drivers were given a follow up survey which involved respondents to identify the appropriate left-turn action for the same 12 passive-protective left-turn signals. This study was used to determine if driving simulators were an effective method for evaluating driver comprehension of passive-protective left-turn signals. The percentage of correct results was consistently higher in the driver simulator than the static survey.

**Figure 12: PPLT-FYA Signal Configuration**




*(Knodler M. , Noyce, Kacir, & Brehmer, Driver Understanding of the Green Ball and Flashing Yellow Arrow Permitted Indications: A Driving Simulator Experiment, 2001)*

- Plummer and King (1973) conducted a practice questionnaire and laboratory study to determine which indication (color and arrow indications) is more effective in conveying their intended message to the driver. The practice questionnaire proposed 11 methods of left-turn signal indications and 19 signal configurations, including one configuration with a flashing amber arrow. They found that the three flashing signals proposed were not understood as easily as the fixed indication signals. The effectiveness of the flashing signals was therefore not evaluated in the field study.

# 3. Interview with Experts

Personal interviews were conducted with four United States of America (U.S.) experts on flashing amber arrow (FAA) signal application to understand the U.S. experience with FAA implementation and the benefits and challenges associated with their application that could provide lessons learned for the potential application in Canada. Key findings from the are summarized as follows:

- The flashing yellow arrow (FYA) signal was derived from concerns expressed by jurisdictions and the U.S. national committee in the 1990s regarding driver misunderstanding of the circular green ball for permissive left turns as well as jurisdictional inconsistencies and lack of uniformity with applied treatments for permissive left turns. For example, Seattle (Washington State) operated flashing yellow ball and Michigan operated flashing red ball for permissive left turns. This concern led to the NCHRP 493 study evaluating different left-turn options, which resulted in the recommendation of the FYA signal for permissive left turns, followed by the successful operation of FYA signals in multiple jurisdictions, and finally the inclusion into the 2009 *Manual of Uniform Traffic Control Devices* (MUTCD) (FHWA, 2009).
- NCHRP 493 study (Brehmer, Kacir, Noyce, & Manser, 2003) included video analysis, driver simulations, and field implementations. The study found that the FYA was significantly better understood for permissive turns from turn lanes than the green ball display.
- Originally, most of the FYA applications were for protected-permissive left turns (PPLT), operating with the same phasing 24 hours a day. This evolved to variable phasing by time-of-day to improve operational efficiency (Dallas, Texas was a leader in this approach). From a programming perspective, the FYA signal head is greatly advantageous as it provides many different operational phasing options that can be programmed for 24-hour operation or variable by time-of-day based on traffic demands.
- Currently, states are implementing FYA signal displays with the following main objectives:
    - correcting misunderstanding of a green ball indication from a turn lane,
    - improving traffic coordination and operational efficiency by providing flexibility for time-of-day left-turn phasing (i.e., changing from a protected-only to permissive or PPLT based on time of day),
    - mitigating “yellow trap” incidents resulting from lagging left turns,
    - to a lesser extent to improve permissive left and right-turn safety by emphasizing the yielding requirement to conflicting vehicles, cyclists, and pedestrians and through coordinated use of FYA and LPI phasing.
- FYA signals are currently widely used across the U.S. for left turns, and less commonly for right turns for improved safety of cyclists and pedestrians, with few states lagging in terms of degree of implementation (New York, Illinois, and Maryland mentioned). Jurisdictions are either installing FYA signal heads for new installations or retrofitting existing intersections. There has been hesitation to operate FYAs by some jurisdictions, due to contentment with traditional operations, lack of knowledge leading to concerns about driver comprehension of FYA signals, cost of infrastructure changes, and required changes to the jurisdiction’s rules-of-the-road.

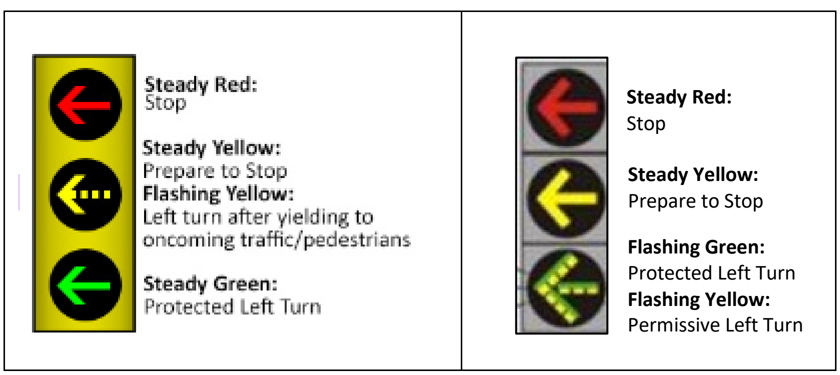
- Technology is trending towards easier implementation of right-turn FYA phasing as this phasing often needs a more advanced cabinet (Advance Traffic Controller Cabinets were mentioned). However, currently there is no uniformity capability amongst controllers for FYA, LPI, etc. so phasing capabilities are controller dependent.
- The four-section FYA signal head is the commonly used display for protected-permissive FYA left turn (PPLT FYA) phasing, as presented in the MUTCD. The four-section head enables application of different left-turn phasing (i.e., protected-only, permissive-only, and PPLT) but would typically be converted to a three-section head if full time protected-only phasing was implemented.
- Retrofitting a traditional signalized intersection to a standard FYA signal is reported to be simple with basic programming. However, there is a learning curve when more advanced phasing sequences are implemented. The FYA signal vendors provide training and support on their application and programming. Thus, there could be issues when there is change in traffic signal personnel, with some not feeling comfortable with setting up the controllers to run FYA signal phasing, especially if the FYA signal phasing logic is more complicated.
- The four-section FYA signal display is seen to be superior to the traditional five-section doghouse or vertical left-turn display due to the flexibility of providing different phasing options by time-of-day, as well as resulting in less driver confusion with the permissive left turn. The doghouse display is shared between the left-turn lane and adjacent lane and has shown to be confusing to drivers thinking that they have the right-of-way with the permissive green ball for left turn and through movements, especially if the doghouse display is placed over the left-turn lane. The four-section FYA display is exclusive to the left-turn lane (or right-turn lane).
- Relative to a green ball permissive phasing, the FYA signal display also has the advantage of the ability to hold different Leading Pedestrian Interval (LPI) lengths separately for different pedestrian crossings which would result in improved operational efficiency and improved yielding to pedestrians and cyclists in the crossings. This hybrid operation also allows providing a red turning interval (variable for right and left turns) during a LPI phase instead of providing a protected turn and increasing the cycle length, if increasing the cycle length is undesirable. For example, in the city of Richland, Washington State, a FYA signal was implemented at an intersection to resolve issues with vehicular collisions with cyclist (specifically children) at the left turn as well as an issue with delays due to connected LPI signals at parallel pedestrian crossings resulting in both LPIs to be active when only one crossing was active with a pedestrian. In this scenario, with the FYA signal and logic programming, variable LPI intervals were provided for the pedestrian crossings conflicting with right-turn and left-turning vehicles (with longer LPI provided for the left turn due to the higher collision risk) which resulted in improved yielding to pedestrian and cyclist crossings and allowed less delay for turning vehicles.
- U.S. research is currently focused on use of three-section signal heads that use (1) dual arrow (bimodal) signals where flashing green and flashing yellow arrows can be shown on the same display on the bottom lens or (2) dual functions for the yellow arrow display (i.e., bimodal yellow) – steady and flashing, in the middle lens, as provided in the MUTCD (2023). The two configurations of the dual lens (bimodal lens) FAA signal heads are shown in Figure 13. The three-section FYA signal heads have greater advantage to the four-section FYA signal heads due to (1) easier retrofit of existing three-section signal heads by only replacing one lens along with minor rewiring/reprogramming, (2) having the flexibility to convert the signal phasing to a 24-hour protected-only phase with minor

rewiring and setting changes, without changing the signal head, (3) having a lower clearance thus beneficial in locations with limited headway clearance, and (4) having a lower installation cost, due to the four-section signal head requiring additional hardware including extra lens, larger back plates, longer brackets and pole design to withstand larger wind loading.

The dual arrow lens (green and yellow arrow shared lens) itself has a slightly higher cost relative to a traditional lens, however, conversion to a three-section dual arrow FYA signal head may be less costly overall as it requires only lens changes on an existing three-section signal head along with some minor changes in wiring. The dual arrow lens has been researched by David Noyce, at the University of Wisconsin, and found to be effective for improved driver understanding. The dual arrow lens is the dominant FYA signal installed in Richland, WS. A disadvantage is that the dual arrow lens can be an issue for those who are colour blind as the green and yellow arrow are displayed in the same lens, however, a U.S. driver can differentiate the signal phase/colour by the flashing and not flashing mode because flashing green arrows are not used in the U.S. The colour-blind issue would likely be a greater concern in Canada where flashing green arrow is used as it would make it difficult for colour blind drivers to distinguish the meaning of a flashing arrow if green and yellow are displayed on the same lens, as the flashing arrow could be indicating a protected turn (flashing green) or permissive turn (flashing yellow).

The dual function for the yellow arrow display (steady and flashing with one lens) is another option for a three-section FYA signal head. Similar to the dual arrow lens, it provides adequate driver understanding due to mode change (i.e. steady and flashing), while maintaining predictable color sequencing (red, yellow, green from top to bottom), however, it does not provide signal positional change, which could result in the driver not noticing if the yellow arrow has changed from steady to flashing (or vice versa). The dual arrow lens with the shared green and yellow arrow, has the additional benefit of signal position change (i.e. the signal head for flashing yellow is different than for steady yellow) which would help the driver to distinguish the change in yellow arrow mode.

**Figure 13: Three Section Dual Lens (or bimodal lens) FYA signal**

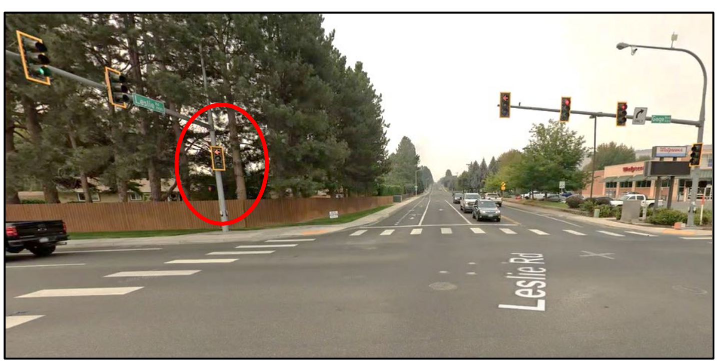



*(Source: Cleveland Utilities, 2024, Hurwitz and Mosere, 2013)*

- The conversion of a protected-only phase to a PPLT can cause negative safety implications (see Collision Modification Factors) due to the introduction of a permissive left turn, regardless of the FYA signal. If a protected left turn is changed to a PPLT for operational and capacity reasons, providing a three or four-section FYA signal is preferred to enable time of day phasing variation, providing the safety benefits of protected left turns during peak hours and the operational benefits of permissive left turns during off-peak hours.

- A jurisdiction's approach to signal phasing in terms of whether it is variable by time of day or same phasing 24-hours a day significantly influences the extent of operational efficiency and safety benefits they will achieve from FYA.
- There are locations with FYA signals used where transit or light rail is running down the middle of the road or median, however this is not recommended. Denver Regional Transportation District and Aurora, Colorado had light-rail operating down the centre of the road with permissive FYAs, however there were issues with increased frequency of left turns in front of the rail. The FYA was used when the train was not operating, and a red arrow would be displayed and held when the train was present. The presence of a light rail would provide adequate reason to provide protected-only left turns.
- It is important to consider that in the U.S., the rules of the road for drivers facing a yellow light can vary with implications to traffic operations. For example, in Washington, a driver can enter the intersection and yield within the intersection to make a left turn during a yellow light, whereas in Oregon the driver must stop before the stop line until a gap is noticed to conduct the turn. Requiring drivers to stop behind the stop line increases the time it takes to complete a turn and may limit visibility to oncoming traffic.
- A supplemental left-turn FYA signal can be installed at the intersection corner in the line of sight of left-turning vehicles, as shown in Figure 14, to allow drivers yielding in the intersection (past the stop line), to be able to see their turning FYA signal display while also watching the opposing traffic. This allows drivers not to be forced to make quick glances back at the main traffic signals where they could have difficulty identifying whether the yellow arrow is steady or flashing. This supplemental signal would be especially beneficial for three-section FYA signal heads with the middle dual function display for the yellow arrow showing both steady and flashing arrow displays in the same bulb.

**Figure 14: Intersection in Oregon with a supplementa.**
**l left-turn FYA signal**




*(Source: Google Maps)*

- The geometric features needed for providing a FYA permissive left turn are the same as for a green ball permissive left turn, for single and dual left-turn lanes. Primarily adequate sight distance of opposing traffic is required, followed by left-turning volumes and opposing through traffic considerations.

- A supplemental sign with FYA signal displays (such as Left(Right) Turn Yield on Flashing Yellow Arrow) has always been optional and not "recommended", however some jurisdictions with new FYA installations use them for reinforced driver understanding. It is noted that the supplemental sign would be very challenging to develop as a bilingual sign, due to the amount of text, or as a symbolic sign in Canada. Public education and awareness are important for jurisdictions with new FYA operations; however, the extent and method of public education has varied significantly from state to state. Some methods include providing information on state websites, providing informational mailouts with license renewals, and including the FYA signal in the driver's manual. Virginia created educational videos of real-life driver interaction with FYA signals. The comprehension of FYA signals by drivers is generally intuitive and well understood, however, education of local public officials is important to provide an understanding of their benefits and encourage the movement towards FYA signals.
- Introduction of the FYA signal required each state to make amendments to their rules-of-the-road to create rules for flashing yellow arrows as they were not covered by the rules-of-the-road prior to the amendments.

# 4. Canadian Survey

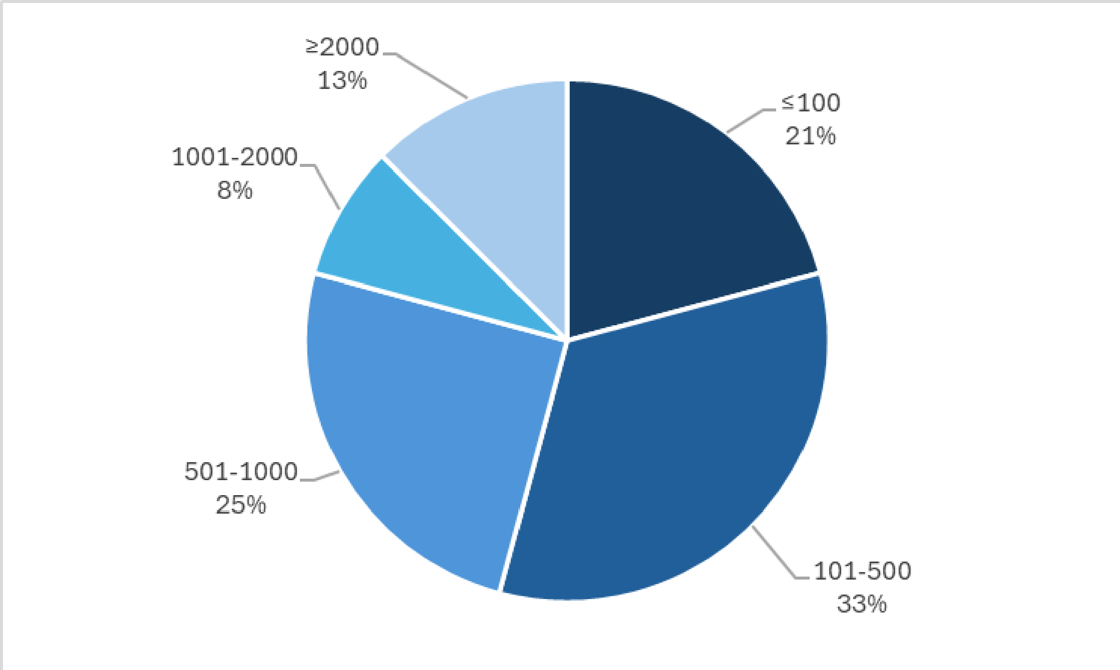
The Canadian survey resulted in 24 complete responses, representing 23 jurisdictions (Ville de Québec provided two responses). Table 6 provides the list of the 23 jurisdictions that provided complete responses, along with the number of traffic signals in their network. A summary of survey responses is provided in Appendix A.

**Table 6: Canadian Survey Responding Jurisdictions**

| Municipalities/Regions | No. of Signals | Provinces | No. of Signals |
|---|---|---|---|
| Halifax Regional Municipality, NS | 286 | Nova Scotia | 100 |
| Fredericton, NB | 50 | Québec | 2000 |
| Ville de Laval, QC | 300 | Alberta | 300 |
| City of Gatineau, QC | 246 | British Columbia | 800 |
| Ville de Québec, QC *(Two responses)* | 900 | | |
| Ville de Montréal, QC | 2200 | | |
| Corporation of the Town of Milton, ON | 58 | | |
| Region of Durham, ON | 650 | | |
| Toronto, ON | 2500 | | |
| Mississauga, ON | 562 | | |
| Halton Hills, ON | 38 | | |
| Winnipeg, MB | 700 | | |
| Saskatoon, SK | 265 | | |
| Calgary, AB | 1250 | | |
| Edmonton, AB | 1200 | | |
| Lethbridge, AB | 150 | | |
| Red Deer, AB | 150 | | |
| Strathcona County, AB | 100 | | |
| Kelowna, BC | 135 | | |

The 23 participating jurisdictions represented a range of geographic locations across eastern (13 jurisdictions) and western (10 jurisdictions) Canada and different scales in terms of their traffic signals network. Figure 15 shows the distribution of the responding jurisdictions' traffic signal network, ranging from less than 100 signals to over 2,000 signals.

**Figure 15: The responding jurisdictions' size of traffic signal network**




Key findings from the jurisdictional survey are summarized by category below.

**Meaning of Signal Indications:**

- The interpretation of meanings of arrow signal indications are mostly consistent across jurisdictions, except for the steady green turn arrow. The steady green turn arrow was indicated as used solely for protected turning movements by one-third of respondents (8 out of 24), and not solely for protected turning movements by 42 percent of respondents (10 out of 24). Based on focus group discussions, this mixed result regarding the meaning of the steady green turn arrow may reflect lack of use in western Canada where flashing green turn arrows are more common, prevalent use of the steady green turn arrow as a protected arrow in Ontario, and use of steady green turn arrows for permissive right turns running concurrently with pedestrian indications in Québec. ***In addition, the steady left green arrow is not in the Manual of Uniform Traffic Control Devices for Canada (MUTCDC) (TAC, 2021) and as a result there is no common national reference for its meaning and application.***
- The steady green turn arrow had a mixed response in terms of application with 25 percent of respondents (6 out of 24) predominantly in eastern Canada indicating that it can overlap with a conflicting pedestrian clearance phase.
- The flashing green turn arrow was understood by respondents across the country to be used solely for protected turning movements and not overlapping with a conflicting pedestrian clearance phase.
- The steady amber turn arrow was interpreted to have a consistent meaning across jurisdictions, which was that approaching drivers or cyclists facing the indication must stop before entering the intersection unless the stop cannot be made safely. If the driver or cyclist is proceeding on a steady amber turn arrow, they must proceed with caution and yield the right-of-way to

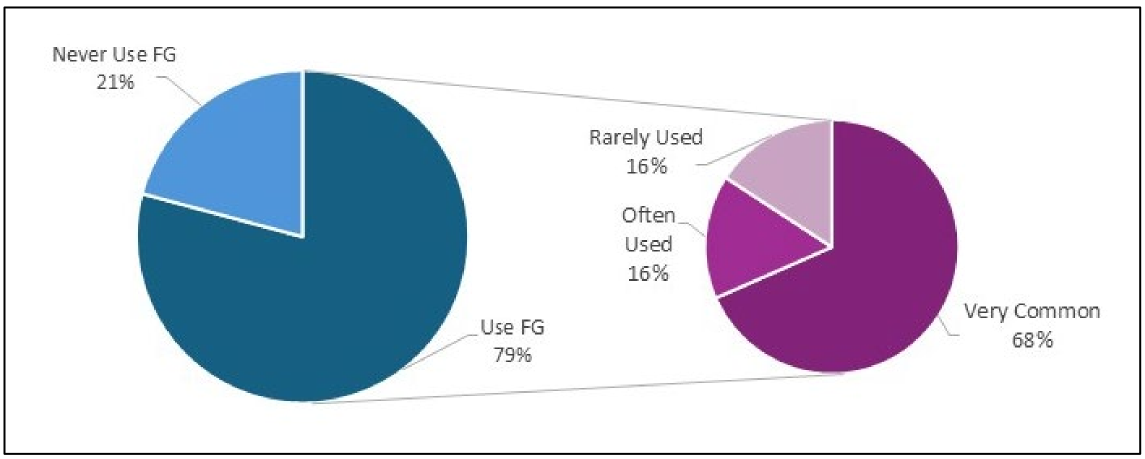
pedestrians lawfully in the intersection or in an adjacent crosswalk, and to other vehicles lawfully in the intersection.

- The steady red turn arrow was interpreted to have a consistent meaning across jurisdictions, where it is used to regulate the stopping of vehicles for a particular movement. Flashing the red turn arrow is prohibited by 37 percent of respondents' jurisdictions (9 out of 24).
- Although the flashing amber arrow has not yet been implemented in Canada, the survey found that most of the responding practitioners understood the FAA signal meaning. Eighty-seven percent of respondents (20 out of 23) correctly indicated that the FAA means that turning drivers must yield to opposing traffic and pedestrians in adjacent crosswalks and 78 percent (18 out of 23) correctly indicated that it had the same meaning as a green ball. Seventeen percent of respondents (4 out of 23) inaccurately indicated that a FAA signal is used as a short transition from green turn arrow to red turn arrow or red ball or that turning drivers have priority over opposing traffic and pedestrians in adjacent crosswalks.

**Current Traffic Signal Operations:**

- The flashing green turn arrow is used for protected left turns by almost 80 percent of respondents (19 out of 24), with 68 percent of those indicating that they commonly use them, 16 percent indicating that they often use them, and 16 percent indicating they rarely use them, as shown in Figure 16. The five respondents indicating that they never use flashing green turn arrows were from Ontario and Québec.

**Figure 16: Percent of survey respondents that use flashing green (FG) turn arrows for protected left turns**




- The flashing green turn arrow is less commonly used for protected right turns, with 42 percent of respondents (10 out of 24) indicating that they use them, with the majority indicating that they rarely use them. Over half (14 out of 24) indicated that they are never used for right turns. Flashing right green arrows are not in the MUTCDC.
- Almost all the responding jurisdictions (23 out of 24) indicated that they do not have any signals operating with a "yellow trap" (entrapment) phasing, which occurs when a permissive left-turn is opposed by a lagging green for the opposing movement. The MUTCDC states if left turns are permitted in both opposing directions only simultaneous lagging left-turn operation, either permissive/protected or fully projected should be used to avoid entrapment. Other jurisdictions

prohibit entrapment by law or by practice. Participants in the focus groups expanded on this response by indicating that in avoiding creating “yellow-trap” situations, practitioners are not able to employ more efficient lagging phases at some intersections.

- Almost all responding jurisdictions indicated that they do not have issues with drivers misinterpreting the meaning of a green ball when turning right or left from a turn lane under a fully permissive phasing (23 out of 24) or under a protected-permissive phasing (22 out of 24). In the focus groups, participants made clear a distinction between understanding the meaning (which was not an issue as indicated in the survey) and drivers safely judging gaps in opposing traffic (which was an issue for many jurisdictions).
- The majority of responding jurisdictions indicated that they do have issues with collisions with opposing vehicle traffic, pedestrians, and/or cyclists involving permissive turns at intersections to varying degrees, as shown in Table 7.

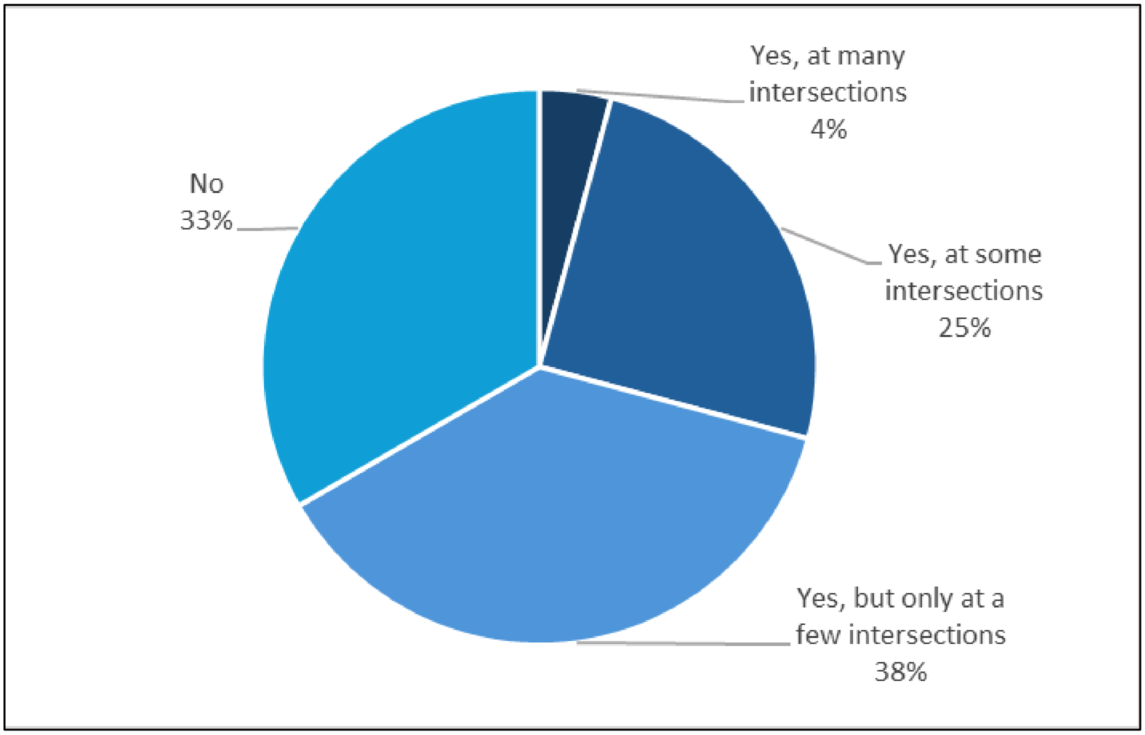
**Table 7: Number of responding jurisdictions indicating issues with collisions involving permissive turns and different road users at intersections to varying degrees**

| | Yes, at many intersections | Yes, at some intersections | Yes, but only at a few intersections | No | Total |
|---|---|---|---|---|---|
| **Opposing vehicle traffic** | 5 | 12 | 4 | 3 | 24 |
| **Pedestrians** | 3 | 10 | 7 | 4 | 24 |
| **Cyclists** | 3 | 10 | 7 | 4 | 24 |

- The responding jurisdictions indicated that turning movements from turning lanes are typically controlled by the following signal phasing when movements conflict with a pedestrian crosswalk, in the order of highest ranking (indicated as the most commonly used by the greatest number of jurisdictions) to lowest (indicated as the least commonly used by the greatest number of jurisdictions):
    1. Separate phasing is used to separate conflicts
    2. Protected permissive turn phasing
    3. Fully permissive phasing
    4. A Leading Pedestrian Interval (LPI) phase is used but turns are permissive
- The responding jurisdictions indicated that turning movements from turning lanes are typically controlled by the following signal phasing when movements conflict with a cycling facility in the order of highest ranking to lowest:
    1. Separate phasing is used to separate conflicts
    2. Fully permissive phasing
    3. A Leading Cycling Interval is used, but turns are permissive
    4. Protected permissive turn phasing

- The majority of responding jurisdictions (80 percent) indicated that their jurisdiction allows changes to phase sequencing at intersections by time of day, while 67 percent indicated that they currently do make time of day changes. Figure 17 shows the percentage of responding jurisdictions that alter phase sequencing at intersections by time of day and the extent of this practice.

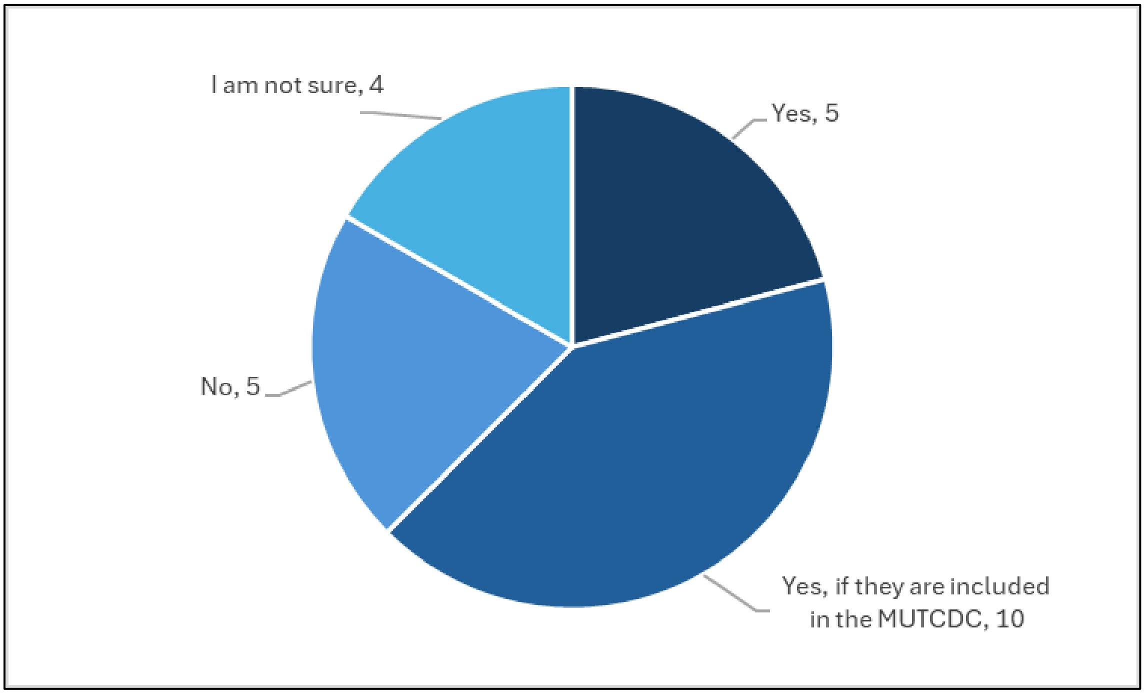
**Figure 17: Percentage of responding jurisdictions that alter phase sequencing at intersections by time of day**




**Flashing Amber Arrow Implementation:**

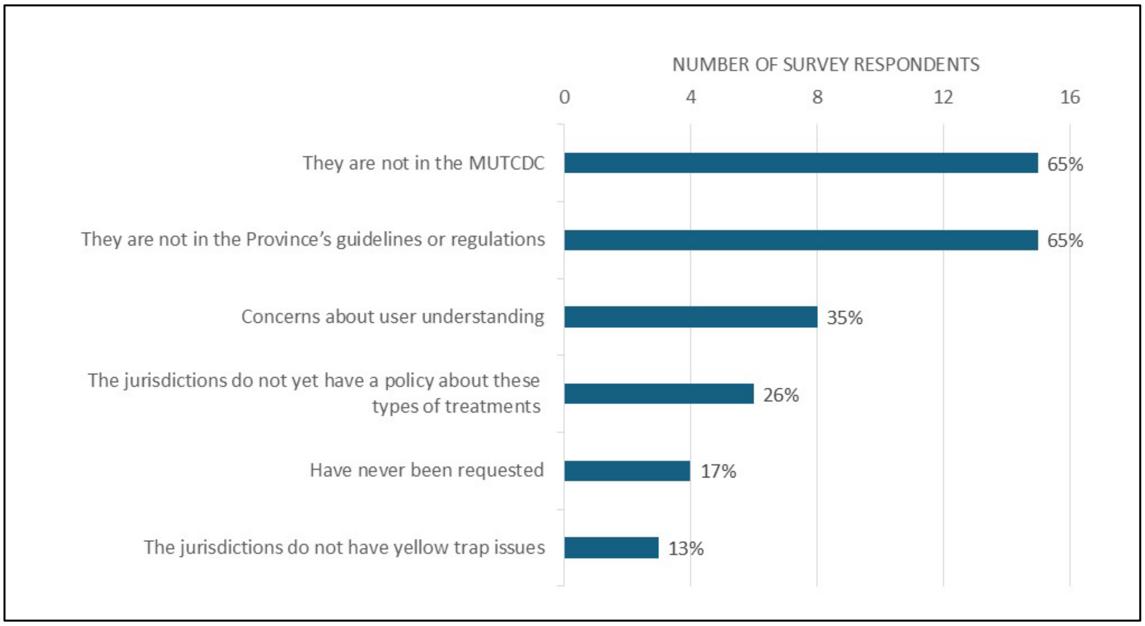
- All the respondents indicated that they currently do not use FAA signals in their jurisdictions.
- Fifteen out of 24 responding jurisdictions indicated that they are interested in, or considering, implementing FAA signals, however 10 of those respondents indicated that they are interested only if they are included in the MUTCDC (or provincial standards interpreting other survey question responses), as shown in Figure 18. Five respondents indicated that they are not interested, and four were unsure.

**Figure 18: Number of responding jurisdictions that are interested in implementing FAA signals**




- Sixty four percent of jurisdictions indicated the absence of FAA signals in the MUTCDC is a barrier to implementation in their jurisdiction, while 36 percent (8 out of 22) indicated that it is not an issue.
- Flashing the amber arrow is currently prohibited by 30 percent (7 out of 23) of responding jurisdictions and not recommended by 37 percent (9 out of 24) of responding jurisdictions. Québec indicated that they have regulations prohibiting the use of FAA.
- The top reasons identified by the responding jurisdictions as to why their agency does not currently have flashing amber arrows, are listed in Figure 19. Other reasons indicated by less than three respondents included:
    - Do not have issues with permissive turns
    - Safety reasons
    - Act or regulation prohibits their use
    - The jurisdiction has a policy against these installations
    - Signal hardware limitations

**Figure 19: Top reasons by survey respondents as to why not currently implementing FAA signals in their jurisdiction**



# 5. Focus Group Sessions

The engagement with Canadian road authorities was done through two focus group sessions lasting two hours each in the following groupings:

- Western jurisdictions (November 25, 2024)
- Eastern jurisdictions (November 27, 2024)

The purpose of the focus group sessions was to have a facilitated discussion to better understand jurisdictions' current thoughts about FAA signals across the country. The focus groups provided a deeper discussion of survey topics and identified aspects of FAA signals where there was general agreement, where there were opposing views, where jurisdictions saw opportunities, and where jurisdictions saw disadvantages to moving forward with FAAs. Invited municipalities represented jurisdictions across the country including medium and large municipalities and one provincial agency (Nova Scotia).

Focus group sessions began with an overview of the project and summary information from the literature review, interview with experts, and Canadian jurisdiction survey. It was understood that some participants were not familiar with FAAs prior to the sessions. Discussions proceeded regarding the current signal practices in the jurisdictions, the perceived benefits, concerns, and challenges, and the implementation process for FAA signals if they were to be introduced in Canada.

A total of 11 (east) and 12 (west) people participated over two sessions, representing 16 agencies as shown in Table 8.

**Table 8: Agencies Participating in the Focus Group Discussions**

| Eastern Jurisdictions | Western Jurisdictions |
|---|---|
| Nova Scotia | Winnipeg, MB |
| Halifax Regional Municipality, NS | Saskatoon, SK |
| Fredericton, NB | Calgary, AB |
| Ville de Laval, QC | Lethbridge, AB |
| Ville de Montréal, QC | Strathcona County, AB |
| Ottawa, ON | Kelowna, BC |
| Toronto, ON | Vancouver, BC |
| Mississauga, ON | Richland, Washington, U.S. |

Input from the focus group sessions is summarized in Table 9.

**Table 9: Focus Group Input**

| Agreement On | Opposing Views |
|---|---|
| • The MUTCDC needs to add the steady green left turn arrow indication to enable jurisdictions to move away from flashing green left turn arrows if FAA is introduced.<br>• Need to work towards consistency across Canada on the use of flashing and steady green left turn arrows.<br>• A four section signal head is likely required to address colour blind concerns/confusion with FAA indications in the same position as former flashing green turn arrows.<br>• FAA signals should not be used with dual turn lanes.<br>• Full implementation of FAA at all locations across a jurisdiction with permissive left turn phasing may be daunting from a cost and cost-benefit perspective for some jurisdictions.<br>• The U.S. context was more straightforward as they did not have flashing green balls or arrows, and messaging was consistent across all signal displays in terms of flashing meaning caution.<br>• Whether accomplished through FAA or otherwise, a signal configuration accommodating part-time protected operation is a gap that existing signal options cannot fully satisfy.<br>• In Québec, an FAA for permissive right turns would be clearer than existing use of steady green arrows and pedestrian indications for permissive right turns. Currently in Québec, a steady green turn arrow represents permissive right turns and protected left turns. | • The need for FAA comprehension testing in Canada was generally but not fully supported. Those in support thought it was important to understand how the FAA would be interpreted by people in the different signal display contexts that exist across the country.<br>• There are varied opinions on the use of FAA signals in shared lanes. FAA signal heads in the U.S. are installed for exclusive turning lanes. However, there is interest by some jurisdictions (e.g. Montréal) in more information on the use of FAA signal heads on shared lanes due to the large number of shared signal heads in large municipalities.<br>• Differing opinions as to whether FAA is a device that should have a full rollout versus a partial rollout and can be considered a universal tool versus a targeted tool. Eastern jurisdictions generally anticipated a focused and limited rollout for specific contexts and expressed that it could be considered a tool in the toolbox for targeted implementation, while some western jurisdictions felt that an across-the-board implementation would be necessary for consistency.<br>• Expectations of capital cost requirements for implementation varied. Some jurisdictions anticipated a targeted rollout with less capital-intensive requirements while others anticipated a broader rollout with higher costs to position signal heads appropriately at PPLT locations.<br>• Some jurisdictions felt there was a need for a big-ticket safety benefit to politically justify implementation, while others thought that FAA installation can be justified relatively easily based on current proven safety and operational benefits.<br>• The difficulty level pitching to decision makers varied. Some jurisdictions anticipated an easy sales pitch based on alignment with Vision Zero and protection of vulnerable road user policies, as the literature shows the implementation of FAAs result in improved driver comprehension, improved yielding to pedestrians, and reduced turning movement collisions compared to the green ball display. Others saw difficulties selling a FAA display |

| Agreement On | Opposing Views |
|---|---|
| | that has the same meaning as the green ball display that is already in use.<br>• The interest in conducting pilot projects varied. Eastern jurisdictions were generally more open to piloting FAAs than western jurisdictions.<br>• Some saw FAAs as within their controller capabilities while others were unsure.<br>• There were opposing views and practices regarding the use of steady green arrows versus flashing green arrows for left turns. |
| **Opportunities** | **Disadvantages** |
| • Opportunities generally fell into capacity and safety categories.<br>• Signal phasing and timing flexibility provides an opportunity to work around self-imposed 'yellow-trap' limitations to signal phasing.<br>• Lead-lag timing options are possible if there is not heavy traffic on the left turn and opposing through.<br>• Ability to do time-of-day specific protected left turns instead of full time protected left turns that may not be necessary or efficient during off-peak hours.<br>• Ability to add a layer of caution for permissive left turns crossing pedestrian or cyclist facilities.<br>• Interest in the warning aspect of FAAs versus green balls, which imply caution.<br>• Useful to enhance timing and phasing options with Leading Pedestrian Intervals (LPI). Separate and varying LPIs can be implemented for different crosswalks at an intersection based on traffic demands at each leg, thus improving pedestrian safety and operational efficiency at intersections.<br>• A tool to consider at intersections with collision history related to permissive left or right turns.<br>• An additional tool in the signal display, timing, and phasing toolbox. | • Confusion with the meaning of flashing green turn arrows and in some jurisdictions (BC and Ontario) potential confusion of meaning with flashing green balls. May require moving away from flashing green turn arrows and losing the quicker reaction time benefits advertised with flashing arrows.<br>• FAA could add to the decreased uniformity of traffic signals across the country with inconsistent adoption by jurisdictions.<br>• Rules of the road would need updating in most jurisdictions. Some jurisdictions would see automatic updates due to MUTCDC referencing in regulations.<br>• Issues with signal head positioning relative to turn lane wherever turns are permissive. FAA signal heads require placement directly over the turning lane, where many jurisdictions place a shared signal head above two lanes (through and turning lanes). Resource implications of signal layout changes could be significant for some jurisdictions.<br>• Need to communicate to drivers about the meaning of FAA and potentially green turn arrows as well.<br>• There are likely real-world limitations to signal timing and phasing flexibility due to detection limitations and driver understanding limitations. |

# 6. Summary of Findings

This chapter provides a summary of key findings on the benefits and challenges associated with the implementation of flashing amber arrow (FAA) signals in Canada, separated into two components: (1) findings from the U.S. experience (obtained from the literature review and interviews with U.S. experts) and (2) applicability of FAA signals to the Canadian context (obtained from the Canadian survey and focus groups with Canadian jurisdictions).

## 6.1 Findings from the U.S. Experience

Key findings from the U.S. experience on the effectiveness and risks of FAA signal implementation are listed below. When evaluating the effectiveness of FAA signals, it is important to consider the previous traffic signal display and phasing prior to conversion to an FAA to identify the context of conversion.

- The flashing amber arrow (FAA) display provides clearer guidance on permitted left turns, with exclusive guidance over the left-turn lane (i.e., no shared signals with the adjacent through lane) and increased awareness for the left-turning vehicles to yield to the oncoming opposing traffic. In addition, the exclusive left-turn signal head improves traffic operations by only requiring a green light for the opposing traffic, while a shared signal head would require both opposing and adjacent traffic to have a green light (Medina, et al. 2018).
- There is consensus in the research that FAA signals generally result in a reduction in total and left-turn collision rates when the left-turn phase is converted from a traditional circular green permissive-only or a protected-permissive turning (PPLT) phase, with a wide range in collision reduction rates depending on the traffic conditions, intersection geometry, and FAA implementation type and phasing. A FHWA study with data from across four states (Srinivisan, et al., 2020) found a reduction in left-turn collisions when converting from a permissive left turn to a permissive FAA left turn ranging from 39 to 45 percent, and when converting from a PPLT to a PPLT FAA ranging from 11 to 18 percent. Safety benefits are also observed when converting the left-turn phasing from a permissive-only circular green left-turn signal to a protected-permissive FAA left-turn signal (PPLT FAA), with one study finding a 40 percent reduction in left-turn collisions (Simpson & Troy, 2015).
- Driver simulation, survey, and field observation studies have found that flashing amber arrow signals are well-understood and have a significantly higher yielding performance than circular green permissive left and right turns. In general, the FAA results in a better understanding of permissive left and right-turn conditions, with greater compliance and yielding to pedestrians crossing.
- Due to the improvement in driver yielding behaviour, FAAs can increase pedestrian safety at signalized intersections with high volumes of turning traffic (Hurwitz, et al., 2018). Research has found longer vehicle wait times for right-turn maneuvers with FYA signals, indicating greater respect for pedestrian presence (Nassereddine, et al., 2023). The literature also suggests that although some users show incorrect understanding of FAAs by making a stop before turning, the yielding behaviour would support increased pedestrian safety (Kothuri, et al., 2020). No research was found for cyclist safety.
- The FAA signal can provide operational flexibility to improve intersection efficiency and reduce average delays by allowing variability in the left-turn mode by time-of-day and traffic demand. A

traditional protected-only left turn cannot be changed throughout the day, while a three or four-section FAA signal head can transition from protected-only to permissive-only or protected-permissive left turns during low volume timeframes. A study (Abou-Senna, et al., 2023) found a 25 percent reduction in delay throughout the day with the implementation of a variable FAA left-turn signal based on real-time measured gaps in the opposing traffic.

- Relative to a green ball permissive phasing, the FAA signal display also has the advantage of the ability to hold different Leading Pedestrian Interval (LPI) lengths separately for different pedestrian crossings which would result in improved operational efficiency and improved yielding to pedestrians and cyclists in the crossings. This hybrid operation also allows providing a red-turning interval (variable for right and left turns) during a LPI phase instead of providing a protected turn and increasing the cycle length, if increasing the cycle length is undesirable.
- The flashing amber arrow signal head can have a three or four section signal head. The four-section FAA signal head is the commonly used display for protected-permissive FAA left-turn (PPLT FAA) phasing, as presented in the MUTCD, however would typically be converted to a three-section head if full time protected-only phasing was implemented. Three section FAA signal heads have dual lens (bimodal) FAA displays, with either a shared flashing green and yellow bulb at the bottom or a shared steady and flashing amber arrow in the middle. The three section FAA signal heads have the advantage of easier retrofit of existing traditional signal heads, flexibility to convert the signal phasing to a 24-hour protected-only phase, lower vertical clearance, and overall lower cost of installation relative to a four-section FAA signal head.
- The MUTCD allows, but does not “recommend”, the installation of a supplemental sign stating, “Left Turn Yield on Flashing Yellow Arrow” (or “Right Turn”) adjacent to the FYA signal. Research has shown that the installation of a supplemental sign may improve safety, where in Illinois, Schattler, et al. (2016) found an additional nine percent reduction in left-turn collisions with the installation of supplemental signs with the FAA signal, and in Minnesota, Davis, et al. (2023) found an increase in understanding of FAA signals from 94 to 96 percent with the installation of a supplemental sign, while finding an increase in driver gap acceptance when the sign is present (i.e., more conservative driving). It is noted that the supplemental sign would be very challenging to develop as a bilingual sign, due to the amount of text, or as a symbolic sign in Canada.
- The start of a FAA signal can be delayed when transitioning from a protected to a protected-permissive left turn, by operating a red clearance interval (i.e., red arrow) before starting the FAA. Many U.S. jurisdictions that operate FAA signals also implement a delay (Appiah & Cottrell, 2014). One study found that the introduction of an all-red clearance interval between the protected and permissive phases (i.e., delayed start to FAA) had no significant impact on average delay for the left-turning traffic or intersection as a whole (Appiah & Cottrell, 2014), while another study found a slight increase in average vehicle delay by a few seconds (Panthangi, 2019), however, the red clearance interval resulted in greater safety performance (Panthangi, 2019; Tainter, Christofa, & Knodler, 2020).
- Studies have shown the positive economic benefits of operating FAA signals when converting from permissive-only or protected-permissive left-turn phases due to the collision reductions. The FHWA study (Srinivasan, et al, 2020) found a range in mean benefit-cost (B/C) ratios from 56:1 to 144:1, with the highest B/C ratio when converting from permissive-only to protected-permissive left-turn

FAA phasing. Conversions from protected-only left-turn phases do not show positive benefit-cost ratios.

- Protected-only left-turn phases can be converted to protected-permissive left turn with FAA (PPLT FAA) phasing due to the operational benefits of reduced delay by implementing a permissive turning phase and flexible signal phasing conversions of using a four section FAA signal head, that allow the operation of all left-turn phases (protected, permissive, and PPLT). However, generally, converting a protected-only signal phase to a PPLT FAA results in an increase in left-turn collisions by a factor of 2.7 to 3.4 (Medina, et al., 2018) as well as an increase in collision severity, with a smaller impact on total collisions. However, it is important to understand that the increase in collisions is due to the introduction of a permissive phase and not due to the FAA signal. The FAA signal head can reduce the negative safety implications of converting from a protected-only to PPLT phasing by allowing the flexibility of only operating permissive movements when needed by time-of-day and traffic demands. Although beneficial, the benefits of operating a FAA signal in this phasing conversion scenario (protected to PPLT) is not significant enough to outweigh the negative safety implications of the change in phasing.
- In the Canadian context, the use of a three section FAA signal head with a dual arrow lens with a shared flashing green and amber lens at the bottom can be an issue for those who are colour blind. In the U.S., drivers can differentiate the signal phase/colour by the flashing and not flashing mode because flashing green arrows are not used in the U.S. The colour-blind issue would likely be a greater concern in Canada where flashing green arrow is used as it would make it difficult for colour blind drivers to distinguish the meaning of a flashing arrow if green and amber are displayed on the same lens, as the flashing arrow could be indicating a protected turn (flashing green) or permissive turn (flashing amber). Although the green/amber bimodal lens has many advantages relative to other FAA signals, in the Canadian context a four section FAA signal head or a three section signal head with a shared middle lens for steady and flashing amber may provide better understanding for colour-blind drivers due to maintaining the predictable colour sequence of red, amber, green from top to bottom.
- The interviews reported that although the FAA is widely used across the U.S., there has been hesitation to operate FAAs by some jurisdictions, due to contentment with traditional operations, lack of knowledge leading to concerns about driver comprehension of FAA signals, cost of infrastructure changes, and required changes to the jurisdiction's rules-of-the-road. There is a cost associate with converting traditional signal heads to three or four section FAA signal heads. Some studies have presented the costs associated with these upgrades which can vary depending on the left-turn signal control, mast arm length, pole type and location, signal head type, signal head lateral location, and the presence of pedestrian heads, pushbuttons, and manhands/countdown timers (Chambers, 2016; Jones, Foster, & Bhagat, 2023). In addition, similar to the Canadian context, the introduction of the FAA signal in the U.S. requires each state to make amendments to their rules-of-the-road to create rules for flashing amber arrows as they are not covered by the rules-of-the-road prior to the amendments.

## 6.2 Applicability of FAA Signals to the Canadian Context

Key findings from the Canadian jurisdictional survey and focus group sessions with practitioners representing jurisdictions of various sizes and geographic locations across Canada are listed below.

- There are concerns regarding existing inconsistent use of steady and flashing green signal indications across Canada and that the introduction of the FAA in this current context could exacerbate the lack of uniformity in traffic signal displays across Canada and create driver confusion. This is a key point of difference relative to U.S. findings. Current key Canadian inconsistencies include:
    - Predominant use of flashing green arrows for protected left turns in most western Canadian jurisdictions versus steady green arrows for protected left turns in most eastern Canadian jurisdictions.
    - Use of the flashing green circular ball to indicate pedestrian half signals in BC and for protected left turns in some jurisdictions in Québec and Ontario (although Ontario has almost eliminated this display based on an original sunset date for use in 2010)
    - Use of the steady green turn arrow for protected left turns and a permissive right turns in Québec.
- The steady left green arrow should be included in the MUTCDC to reflect its existing widespread use in eastern Canada regardless of the FAA outcome. If FAA proceeds to adoption, inclusion of the steady left green arrow in the MUTCDC would provide jurisdictions whose signal indication legislations and regulations are closely tied to the MUTCDC with the option to move away from the flashing left green arrow as part of the introduction of FAA.
- Most jurisdictions agreed additional driver comprehension tests and pilot studies for FAA would be beneficial specific to understanding driver comprehension of FAA in the different signal contexts across Canadian jurisdictions.
- Jurisdictions' intensions regarding FAA signals vary between safety and operational benefits. However, most jurisdictions agreed that the safety benefits would be the primary selling factor for decision makers, specifically those with Vision Zero and protection of vulnerable road user policies. Some jurisdictions stated concerns with difficulty in justifying the costs and costs-benefits associated with replacing the circular green balls that have the same meaning as FAA signals.
- The survey found that although the responding jurisdictions do not experience issues with misinterpretation of the green ball for permissive turns, they indicate that they do have behavioural/compliance issues due to collisions with the permissive movement. Although it is not fully understood whether compliance issues are rooted in comprehension or drivers misjudging gaps in conflicting movements, current issues with permissive turns present an opportunity to potentially improve the safety of permissive turns with FAA.
- The existence of yellow trap phasing is not a concern in Canada; however, its absence is due to intentional avoidance, either due to prohibition by regulatory standards (for example, yellow trap phasing is prohibited in Québec) or lack of signal phasing ability to accommodate them safely (i.e., not able to use a FAA signal indication), whereas some intersections could benefit

from this type of phasing for operational efficiencies. The introduction of a flashing amber arrow could enable this type of phasing (permissive turns with an opposing lagging green) to be implemented while improving the safety of permissive turns during these phasing sequences due to reinforcing caution to the permitted turning vehicles.

- There were mixed reviews on the implementation process. The eastern jurisdictions mostly considered partial targeted implementation and considered the FAA to be a tool in the toolbox to be used at intersections that would benefit from it, whereas the western jurisdictions mostly considered a jurisdiction-wide rollout to avoid confusion between two signal displays with the same meaning (FAA and circular green ball). A full rollout would require a larger capital cost and is seen as a challenging undertaking to approve, fund, and implement.
- The absence of FAAs in the MUTCDC and government regulations were found to be the primary reason of not implementing FAAs in Canada. The regulatory requirements for FAA implementation vary across jurisdictions, where some only require inclusion in the MUTCDC as their regulations reference the MUTCDC, while others require changes to their government agency regulations and rules of the road.
- Overall, there were mixed views on the implementation of FAA signals across Canadian jurisdictions. Concerns included introducing a new indication in a Canada-wide context that currently lack of uniformity in traffic signal displays, confusion with the flashing green turn arrow (and flashing green ball in some jurisdictions), capital cost associated with signal head and signal layout changes (FAA signal head must be placed separately overly turning lanes), and justification of cost-benefit to decision makers for the replacement of the circular green ball with FAAs that conduct the same function. Conversely, there was interest in FAA signals by some jurisdictions that found that having this signal indication in the toolbox would provide intersection safety and operational benefits, and that applying a targeted implementation approach would allow a more justifiable implementation process.

# 7. Recommendations for Next Steps

Based on findings from this report, there is an interest by Canadian jurisdictions to further pursue the potential application of Flashing Amber Arrow (FAA) signals in Canada. The recommended next steps by Transportation Association of Canada for the potential implementation of FAA signals are as follows:

*Step 1:* Initiate the addition of the steady left green arrow in the MUTCDC. This recommendation is independent of, but beneficial to, FAA implementation. Steady left green is in use in Canada and its adoption in the MUTCDC would create an opportunity for greater uniformity across Canada and would benefit future FAA implementation.

*Step 2:* Develop signal head display layouts and signal indication sequencing for FAA signals in exclusive lane contexts, in shared lane contexts, with permissive turn phasing, and with phasing with protected and permissive turns. Use of bimodal lenses should also be considered in this step. Comprehension testing of these elements is recommended.

*Step 3 (done by organizations):* Conduct pilot studies to evaluate the effectiveness of FAAs for left and right turns in different contexts. These contexts could include:

- exclusive turning lanes
- shared lanes
- permissive turn phasing
- protected and permissive turn phasing
- in jurisdictions that have extensively used flashing green turn arrows
- in jurisdictions that have extensively used steady green turn arrows

*Step 4:* Develop the text for FAA signals in the MUTCDC. Concurrently review whether modifications are required to MUTCDC section B4.5.4 – Entrapment, in consideration of FAA availability.

# 8. References


AASHTO. (2010). *Highway Safety Manual (1st Edition).* American Association of State Highway and Transportation Officials.

AASHTO. (2012). *Guide for the Development of Bicycle Facilities (fourth edition).* Washington DC: American Association of State Highway and Transportation Officials.

Abou-Senna, H., Hibbert, J., & Hashim, A. (2023). Evaluation of Dynamic Flashing Yellow Arrow Decision Support System in the Field Using Before and After Real-Time Data. *Transportation Research Record: Journal of the Transportation Research Board*, 2677(8).

Abou-Senna, H., Radwan, E., & Eldeeb, H. (2019). *Dynamic Flashing Yellow Arrow (FYA): A Study on Variable Left Turn Mode Operational and Safety Impacts, Phase III .* Florida Department of Transportation Research Center.

Abou-Senna, H., Radwan, E., & Eldeeb, H. (2021). A peer-to-peer logic environment to validate flashing yellow arrow decision support system. *Journal of Traffic and Transportation Engineering*, 8(5):735-750.

Alfawzan, M. (2019). *Warrants for Right-Turn Flashing Yellow Arrow Signal Phases.* University of Central Florida.

Appiah, J., & Cottrell, B. (2014). Safety and Operational Impacts of Optional Flashing Yellow Arrow Delay. *Transportation Research Record: Journal of the Transportation Research Board*, 2463(1).

Brehmer, C., Kacir, K., Noyce, D., & Manser, M. (2003). *NCHRP Report 493- Evaluation of Traffic Signal Displays for Protected/Permissive Left-Turn Control.* Washington, D.C.: Transportation Research Board.

Buehler, R., & Dill, J. (2016). Bikeway Networks: A Review of Effects on Cycling. *Transport Reviews*, 9-27.

Casola, E. (2018). *Driver Understanding of the Flashing Yellow Arrow and Dynamic No Turn on Red Sign for Right Turn Applications.* Amherst: University of Massachusetts.

Chambers, E. (2016). *Flashing Yellow Arrow Traffic Signal Operation: A Clinical Methodology for Field Conversion.* Arizona State University.

Chandler, AZ. (2024). *Yellow Flashing Left Turn Arrow*. Retrieved from Chandler, Arizona: https://www.chandleraz.gov/residents/transportation/traffic-management/yellow-flashing-left-turn-arrow

Chen, C. (2023). *Evaluation of the Flashing Yellow Arrow Safety and Effectiveness.* Pomono: California State Polytechnic University.

City of Santa Rosa. (2024). *Flashing Yellow Arrow Left Turn Signals*. Retrieved from City of Santa Rosa: https://www.srcity.org/909/Flashing-Yellow-Arrow-Left-Turn-Signals

CROW. (2016). *Dutch Design Manual for Bicycle Traffic.* Utrecht: Technology Platform for Transport, Infrastructure and Public Space.

Cunningham, C., Pyo, K., Baek, J., Byrom, E., & Warchol, S. (2020). *Guidelines for Implementation of Right Turn Flashing Yellow Arrows and Leading Pedestrian Intervals.* Institute for Transportation Research & Education, North Carolina State University.

Davis, G., Hourdos, J., & Moshtagh, V. (2015). *Development of Guidelines for Permitted Left-Turn Phasing* . St. Paul, MN: Minnesota Department of Transportation.

Davis, G., Stern, R., Duhn, M., & Gao, J. (2023). *Driver Comprehension of Flashing Yellow Arrows.* St. Paul, Minnesota: Minnesota Department of Transportation.

DiGioia, J., Watkins, K. E., Xu, Y., Rodgers, M., & Guensler, R. (2017). Safety Impacts of Bicycle Infrastructure: A Critical Review. *Journal of Safety Research*, 105-119.

Dill, J., & McNeil, N. (2013). Four Types of Cyclists?: Examination of Typology for Better Understanding of Bicycling Behavior and Potential. *Transportation Research Record No. 2387*, 129-138.

Dill, J., & McNeil, N. (2016). Revisiting the Four Types of Cyclists: Findings from a national survey. *95th Annual Meeting of the Transportation Research Board*.

Fehr and Peers. (2015). *Active Transportation Performance Measures.* Walnut Creek, California.

Ferenchak, N., & Marshall, W. (2019). Advancing healthy cities through safer cycling: An examination of shared lane markings. *International Journal of Transportation*, 136-145.

FHWA. (2010). *A Guide to Developing Quality Crash Modification Factors.* Washington DC: Federal Highway Administration.

FHWA. (2013). *Traffic Monitoring Guide (No. FHWA-PL-13-015).* Washington D.C.: Federal Highway Administration.

FHWA. (2013a). *Signalized Intersections Informational Guide, Second Edition.* Washington, D.C.: Federal Highway Administration .

FHWA. (2013b). *Traffic Monitoring Guide (No. FHWA-PL-13-015).* Washington D.C.: Federal Highway Administration.

FHWA. (2015). *Separated Bike Lane Planning and Design Guide.* Washington DC: Federal Highway Administration.

FHWA. (2019). *Bikeway Selection Guide.* Washington DC: U.S. Department of Transportation Federal Highway Administration.

FHWA. (2020). *TechBrief- Safety Evaluation of Flashing Yellow Arrows at Signalized Intersections.* Washington, D.C.: Federal Highway Administration.

FHWA. (2023). *Manual on Uniform Traffic Control Devices for Streets and Highways, 11th Edition.* Washignton, D.C.: FHWA.

Gong, Y., & Yang, X. (2023). *Development of Crash Modification Factors (CMFs) for Utah* . Salt Lake City, UT: Utah Department of Transportation.

Hajbabaie, A., Sattarov, S., & Mohebifard, R. (2018). *Safety and Operations Assessment of Various Left-Turn Phasing Strategies.* Olympia, Washington: Washington State Department of Transportation.

Harris, A., Reynolds, C., Winters, M., Cripton, P., Shen, H., Chipman, M., . . . Teschke, K. (2013). Comparing the effects of infrastructure on bicycling injury at intersections and non-intersections using a case–crossover design. *Injury Prevention*, 303-310. doi:10.1136

Hurwitz, D., & Monsere, C. (2013). *Driver Behavior in the Presence of Pedestrians at Signalized Intersections Operating the Flashing Yellow Arrow.* Portland State University.

Hurwitz, D., Monsere, C., Kothuri, S., & Jashami, H. (2018a). *Driver Comprehension of Permissive Right-Turns with a Flashing Yellow Arrow (FYA).* Oregon State University and Portland State University.

Hurwitz, Monsere, Kothuri, Jashami, Buker, & Kading. (2018b). *Improved Safety and Efficiency of Protected/Permitted Right-Turns in Oregon.* Salem, OR: Oregon Department of Transportation.

Jashami, H. (2020). *Evaluation of Driver Behavior during Right Turn Maneuvers at Signalized Intersections: Mitigation of Driver-Pedestrian Conflicts with a Right Turn Flashing Yellow Arrow.* Oregon State University .

Jashami, H., Hurwitz, D., Monsere, C., & Kothuri, S. (2019). Evaluation of Driver Comprehension and Visual Attention of the Flashing Yellow Arrow Display for Permissive Right Turns. *Transportation Research Record*, 2673(8): 397-407.

Jones, J., Foster, N., & Bhagat, K. (2023). *Safety Evaluation of Permissive Flashing Yellow Arrows for Left-Turning Movements in Missouri.* Jefferson City, MO: Missouri Department of Transportation.

Kassim, A., Ismail, K., & McGuire, S. (2019). Operational Evaluation of Centeral Sharrows and Dooring Zone Treatment on Road User Behaviour. *Transportation Research Board 98th Annual Meeting.* Washington DC: TRB.

Knodler , M., Noyce, D., Kacir, K., & Brehmer, C. (2001). Driver Understanding of the Green Ball and Flashing Yellow Arrow Permitted Indications: A Driving Simulator Experiment. *ITE 2001 Annual Meeting and Exhibit.* Chicago, Illinois, USA: Institute of Transportation Engineers.

Knodler, et al. (2017). *A Driving Simulator Evaluation of Red Arrows and Flashing Yellow Arrows in Right-Turn Applications: Establishing the Foundation for Future Research* . SAFER SIM, University Transportation Center.

Knodler, M., Noyce, D., & Brehmer, C. (2005). Evaluation of Flashing Yellow Arrow in Traffic Signal Displays with Simultaneous Permissive Indications. *Transportation Research Record: Journal of the Transportation Research Board*, 1918(1).

Knodler, M., Noyce, D., Kacir, K., & Brehmer, C. (2006). Analysis of Driver and Pedestrian Comprehension of Requirements for Permissive Left-Turn Applications. *Transportation Research Record: Journal of the Transportation Research Board*, 1982(1):65-75.

Koch, S. (2024). *Do drivers understand flashing yellow arrows? U research offers guidance for local agencies*. Retrieved from University of Minnesota, Center for Transportation Studies: https://www.cts.umn.edu/news-pubs/news/2024/may/arrows

Lee, T., Cunningham, C., & Simpson, C. (2023). Safety Evaluation for Conversion From Protected-Only Left-Turn Phasing to Time-of-Day Protected-Permissive Left-Turn Phasing Using Flashing Yellow Arrows. *Transportation Research Record, Journal of the Transportation Research Board*, 2677(6): 609-619.

Lin, P., Fabregas, A., & Gonzalez-Velez, E. (2012). Assessment of a Flashing Yellow Arrow Signal Implementation Using Gap Acceptance Measures. *Nineth Asia Pacific Transportation Development Conference.* Sustainable Transportation Systems: Plan, Design, Build, Manage, and Maintain.

Llorca, C., Angel-Domenech, A., Agustin-Gomez, F., & Garcia, A. (2017). Motor vehicles overtaking cyclists on two-lane rural roads: analysis on speed and lateral clearance. *Safety Science*, Vol 92: 302-310.

Lubitz, W., & Rubie, B. (2018). Wing Loads on Cyclists Due to Passing Vehicles. *Proceedings of The Canadian Society for Mechanical Engineering (CSME) International Congress 2018.* Toronto: CSME.

Mahbub, M., Kang, M., & Lee, J. (2019). Protected–Permissive Left Turn Phasing with Flashing Yellow Arrow Signal: Study of Red Intervals for an Effective Phase Transition. *Canadian Journal of Civil Engineering*, 46(8).

MASSDOT. (2015). *Separated Bike Lane Planning & Design Guide.* Boston: Massachusetts Department of Transportation.

Medina, J., Shea, M., & Azra, N. (2018). *Safety Effects of Protected and Protected/Permissive Left-Turn Phases.* Salt Lake City, UT: Utah Department of Transportation.

MTO. (2014). *Ontario Traffic Manual - Book 18 - Cycling Facilities.* St. Catherines: Ministry of Transportation of Ontario.

NACTO. (2014). *Urban Bikeway Design Guide (second edition).* New York: National Association of City Transportation Officials.

Nassereddine, H., Santiago-Chaparro, K., & Noyce, D. (2023). Evaluating Right-Turn Flashing Yellow Arrow for Vehicle–Pedestrian Interactions Using a Non-Probabilistic Regression Approach. *Transportation Research Record: Journal of the Transportation Research Board*, 2678(2).

NCDOT. (2015). *Dual Left Flashing Yellow Arrow.* North Carolina Department of Transportation.

NCHRP. (2018, 10). *NCHRP 17-84: Pedestrian and Bicycle Safety Performance Functions for the Highway Safety Manual*. Retrieved from National Cooperative Highway Research Program: http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4203

NHTSA. (2017). *Traffic Safety Facts 2015.* Washington DC: National Highway Traffic Safety Administration.

Noyce, D., Bergh, C., & Chapman, J. (2007). *Evaluation of the Flashing Yellow Arrow Permissive Left-Turn Indication Field Implementation.* Madison, WI: University of Wisconsin-Madison.

Noyce, D., Bill , A., & Knodler, M. (2014). *Evaluation of the Flashing Yellow Arrow (FYA) Permissive Left-Turn and Yellow Arrow Change Indications in Protected/Permissive Left-Turn Control: The Impact of Separate and Shared Yellow Signal Sections and Head Arrangements.* National Cooperative Highway Research Program Transportation Research Board of the National Academies.

Panthangi, R. (2019). *Modelling the Surrogate Safety of Various Left-Turn Phase Sequences.* University of Massachusetts.

Pulugurtha, S., Agurla, M., & Khader, K. (2012). *How Effective are "Flashing Yellow Arrow" Signals in Enhancing Safety?* Transportation and Development Institute Congress 2011: Integrated Transportation and Development for a Better Tomorrow.

Radwan , E., Abou-Senna, H., Navarro, A., & Chalise, S. (2013). *Dynamic Flashing Yellow Arrow (FYA): A Study on Variable Left Turn Mode Operational and Safety Impacts .* FLORIDA DEPARTMENT OF TRANSPORTATION.

Radwan, E., Abou-Senna , H., Eldeeb, H., & Navarro, A. (2016). *Dynamic Flashing Yellow Arrow (FYA): A Study on Variable Left-Turn Mode Operational and Safety Impacts, Phase II – Model Expansion and Testing .* Florida Department of Transportation.

Ramage-Morin, P. (2017). Cycling in Canada. *Health Reports*, 3-8.

Rescot, et al. (2015). *Evaluation of Flashing Yellow Arrow Traffic Signals in Indiana.* Indianapolis, IN: Indiana Department of Transportation.

Ryan, A., Casola, E., Fitzpatrick, C., & Knodler, M. (2019). Flashing yellow arrows for right turn applications: A driving simulator study and static evaluation analysis. *Transportation Research Part F: Traffic Psychology and Behaviour*, 66:324-338.

Ryus, P., Ferguson, E., Lausten, K. M., Schneider, R. J., Proulx, F. R., Hull, T., & Miranda-Moreno, L. (2014). *NCHRP Report 797: Guidebook on Pedestrian and Bicycle Volume Data Collection.* Transportation Research Board, National Cooperative Highway Research Program. Washington D.C.: National Academies.

Santacreu, A. (2018). *"Safer City Streets Global Benchmarking for Urban Road Safety" International Transport Forum Working Document.* Paris: OECD Publishing.

Sattarov. (2018). *A Framework for Analyzing the Effects of Left-Turn Control Modes on Intersection Operations.* Washington State University.

Schattler, K., Anderson, E., & Hanson, T. (2016). *Safety Evaluation of Flashing Yellow Arrows for Protected/Permissive Left-Turn Control.* Springfield, IL: Illinois Department of Transportation.

Schattler, K., Gulla, C., Wallenfang, T., Burdett, B., & Lund, J. (2015). Safety Effects of Traffic Signing for Left Turn Flashing Yellow Signals. *Accident Analysis and Prevention*, 75, pp 252-263.

Schattler, K., Rietgraf, A., Burdett, B., & Lorton, W. (2013). *Driver Comprehension and Operations Evaluations of Flashing Yellow Arrows.* Illinois Center for Transportation.

Semler, C., Vest, A., Kingsley, K., Mah, S., Kittelson, W., Sundstrom, C., & Brookshire, K. (2016). *Guidebook for Developing Pedestrian and Bicycle Performance Measures (HEP-16-037).* Washington DC: FHWA.

Simpson, C., & Troy, S. (2015). Safety Effectiveness of Flashing Yellow Arrow: Evaluation of 222 Signalized Intersections in North Carolina. *Transportation Research Record*, 2492(1).

Srinivasan, R., Lan, B., & Signor, K. (2018). Crash Modification Factors for the Flashing Yellow Arrow Treatment at Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, 2672(30).

Srinivasan, R., Lan, B., Carter, D., Smith, S., & Signor, K. (2020). *Safety Evaluation of Flashing Yellow Arrow at Signalized Intersections, FHWA-HRT-19-036.* U.S. Department of Transportation, FHWA.

TAC. (2012). *Bikeway Traffic Control Guidelines for Canada (Second Edition).* Ottawa: Transportation Association of Canada.

TAC. (2017). *Geometric Design Guide for Canadian Roads* . Ottawa: Transportation Association of Canada.

TAC. (2017). *Traffic Monitoring Practices Guide for Canadian Provinces and Municipalities.* Ottawa: Transportation Association of Canada.

Tainter, F., Christofa, E., & Knodler, M. (2020). All-Red Clearance Intervals for Use in the Left-Turn Application of Flashing Yellow Arrows. *Journal of Transportation Engineering, Part A: Systems*, 146(4).

Tainter, F., Fitzpatrick, C., & Knodler, M. (2021). *Evaluating the Safety Impacts of Flashing Yellow Permissive Left-Turn Indications in Massachusetts.* Amherst: University of Massachusettes.

Thapa, R., Asaduzzaman, M., & Abedi, K. (2022). *Evaluating Permitted/Protected Versus Protected Left-Turn Signals in Louisiana.* Louisiana Department of Transportation and Developmen.

Translink. (2013). *Wayfinding Guidelines for Utility Cycling in Metro Vancouver.* Vancouver.

Transport Canada. (2017). *Canadian Motor Vehicle Traffic Collision Statistics 2015.* Ottawa.

U.S. HHS. (2018). *U.S. Department of Health & Human Services, Centre for Disease Control and Prevention*. Retrieved from WISQRAS, Web-based Injury Statistics Query and Reporting System: https://webappa.cdc.gov/sasweb/ncipc/nfirates.html

Velo Quebec. (n.d.). *Planning and Design for Pedestrians and Cyclists.* Montreal.

Virginia DOT. (2016). *Instructional and Informational Memorandum: Flashing Yellow Arrow Signal Indication for Permissive Left-Turn Movements.* Richmond, VA: Virginia Department of Transportation.

Walton, D., Dravitzki, V. K., Cleland, B. S., Thomas, J. A., & Jackett, R. (2005). *Balancing the needs of cyclists and motorists (Report 273).* Auckland: Land Transport New Zealand.

Zhang, X., Li, X., & Wu, Y. (2023). Safety Performance Evaluation of Flashing Yellow Arrow: Time-of-Day Versus 24-Hour Operation. *Transportation Research Record: Journal of the Transportation Research Board*, 2677(7).

# 9. APPENDIX A - Canadian Jurisdiction's Survey Responses

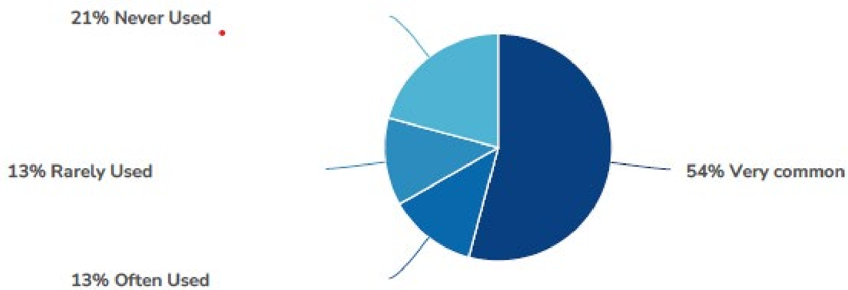
1. Do the following statements apply with respect to the meaning of steady green arrows in your jurisdiction?

| | Yes | No | Not Sure | Not Applicable | Responses |
|---|---|---|---|---|---|
| May proceed in the direction of the arrow only<br>Count<br>Row % | 18<br>75.0% | 1<br>4.2% | 0<br>0.0% | 5<br>20.8% | 24 |
| Must **yield** to traffic/vehicles/cyclists/pedestrians lawfully within/in/using/already in intersection or adjacent crosswalk.<br>Count<br>Row % | 10<br>43.5% | 6<br>26.1% | 1<br>4.3% | 6<br>26.1% | 23 |
| Pedestrians in the crosswalk that conflicts with the arrow movement shall not enter intersection unless or until pedestrian control signal says then can.<br>Count<br>Row % | 17<br>70.8% | 1<br>4.2% | 0<br>0.0% | 6<br>25.0% | 24 |
| Solely used for protected turning movements.<br>Count<br>Row % | 8<br>33.3% | 10<br>41.7% | 1<br>4.2% | 5<br>20.8% | 24 |
| Green arrow phases may overlap conflicting pedestrian clearance phase.<br>Count<br>Row % | 6<br>25.0% | 12<br>50.0% | 1<br>4.2% | 5<br>20.8% | 24 |
| Totals<br>Total Responses | | | | | 24 |

## 2. Do the following statements apply with respect to the meaning of flashing green arrows in your jurisdiction?

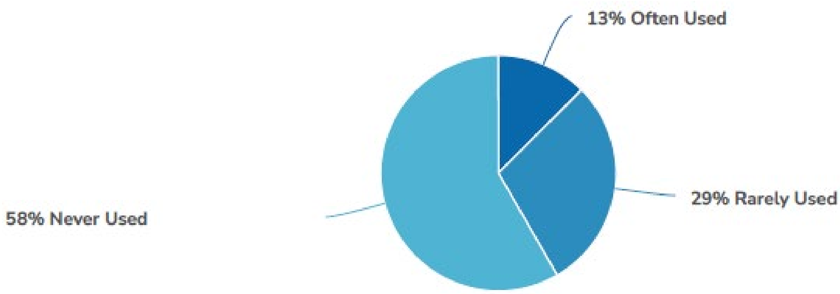
| | Yes | No | Not Sure | Not Applicable | Responses |
|---|---|---|---|---|---|
| May proceed in the direction of the arrow only<br>Count<br>Row % | 16<br>66.7% | 1<br>4.2% | 0<br>0.0% | 7<br>29.2% | 24 |
| Must **yield** to traffic/vehicles/cyclists/pedestrians lawfully within/in/using/already in intersection or adjacent crosswalk.<br>Count<br>Row % | 5<br>21.7% | 7<br>30.4% | 0<br>0.0% | 11<br>47.8% | 23 |
| Pedestrians in the crosswalk that conflicts with the arrow movement shall not enter intersection unless or until pedestrian control signal says then can.<br>Count<br>Row % | 15<br>62.5% | 0<br>0.0% | 0<br>0.0% | 9<br>37.5% | 24 |
| Solely used for protected turning movements.<br>Count<br>Row % | 17<br>70.8% | 1<br>4.2% | 0<br>0.0% | 6<br>25.0% | 24 |
| Green arrow phases may overlap conflicting pedestrian clearance phase.<br>Count<br>Row % | 0<br>0.0% | 15<br>62.5% | 0<br>0.0% | 9<br>37.5% | 24 |
| Totals<br>Total Responses | | | | | 24 |

3. How prevalent is the use of flashing green arrows for protected left turns in your jurisdiction?




| Value | Percent | Responses |
|---|---|---|
| Very common | 54.2% | 13 |
| Often Used | 12.5% | 3 |
| Rarely Used | 12.5% | 3 |
| Never Used | 20.8% | 5 |
| | | Totals: 24 |

4. How prevalent is the use of flashing green arrows for protected right turns in your jurisdiction?




| Value | Percent | Responses |
|---|---|---|
| Often Used | 12.5% | 3 |
| Rarely Used | 29.2% | 7 |
| Never Used | 58.3% | 14 |
| | | Totals: 24 |

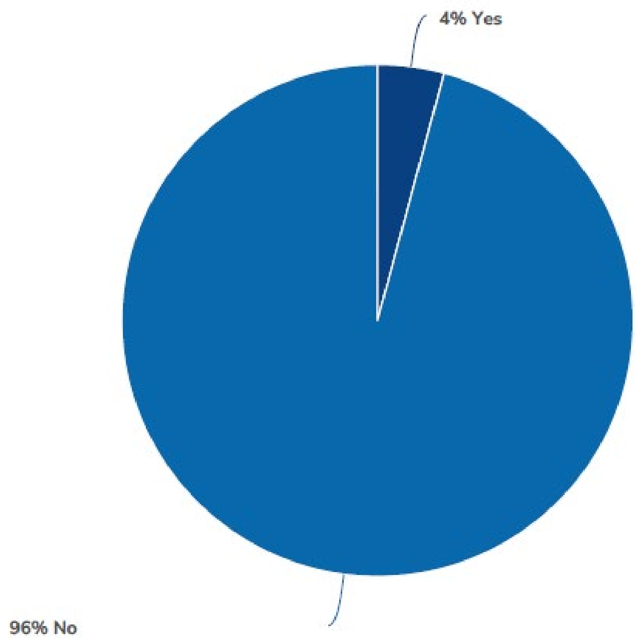
## 5. Do the following statements apply with respect to the meaning of steady amber arrows in your jurisdiction?

| | Yes | No | Not Sure | Not Applicable | Responses |
|---|---|---|---|---|---|
| May proceed in the direction of the arrow only<br>Count<br>Row % | 15<br>65.2% | 3<br>13.0% | 1<br>4.3% | 4<br>17.4% | 23 |
| Approaching driver, or cyclist, must **stop** before entering the intersection/nearside crosswalk unless the stop cannot be made in safety.<br>Count<br>Row % | 17<br>70.8% | 2<br>8.3% | 1<br>4.2% | 4<br>16.7% | 24 |
| If proceeding, must proceed with caution to make the only movement indicated by the arrow but must **yield** the right of way to pedestrians lawfully in the intersection or in an adjacent crosswalk, and to other vehicles lawfully in the intersection.<br>Count<br>Row % | 14<br>58.3% | 3<br>12.5% | 1<br>4.2% | 6<br>25.0% | 24 |
| Pedestrians facing the amber arrow must not enter the roadway.<br>Count<br>Row % | 15<br>62.5% | 1<br>4.2% | 2<br>8.3% | 6<br>25.0% | 24 |
| Flashing the amber arrow is prohibited by regulation<br>Count<br>Row % | 7<br>30.4% | 6<br>26.1% | 7<br>30.4% | 3<br>13.0% | 23 |
| Flashing the amber arrow is not recommended by jurisdiction<br>Count<br>Row % | 9<br>37.5% | 4<br>16.7% | 2<br>8.3% | 9<br>37.5% | 24 |
| Totals<br>Total Responses | | | | | 24 |

6. Do the following statements apply with respect to the meaning of red arrows in regular operation (not out of service or flashing operation) in your jurisdiction?

| | Yes | No | Not Sure | Not Applicable | Responses |
|---|---|---|---|---|---|
| **Steady red arrow**: Unless otherwise indicated, drivers and cyclists must **immobilize** their vehicle before the crosswalk or the stop line. A red arrow is used to regulate the **stopping** of vehicles for a particular movement.<br>Count<br>Row % | 10<br>41.7% | 0<br>0.0% | 0<br>0.0% | 14<br>58.3% | 24 |
| **Flashing red arrow**: Unless otherwise indicated, drivers and cyclists must immobilize their vehicle and **yield** to vehicles on any other roadway approach that has engaged into the intersection or is close enough that there is a risk of a collision<br>Count<br>Row % | 3<br>12.5% | 2<br>8.3% | 0<br>0.0% | 19<br>79.2% | 24 |
| Flashing the red arrow is prohibited<br>Count<br>Row % | 9<br>37.5% | 1<br>4.2% | 4<br>16.7% | 10<br>41.7% | 24 |
| Pedestrian clearance phase may overlap the red arrow<br>Count<br>Row % | 6<br>25.0% | 1<br>4.2% | 3<br>12.5% | 14<br>58.3% | 24 |
| Totals<br>Total Responses | | | | | 24 |

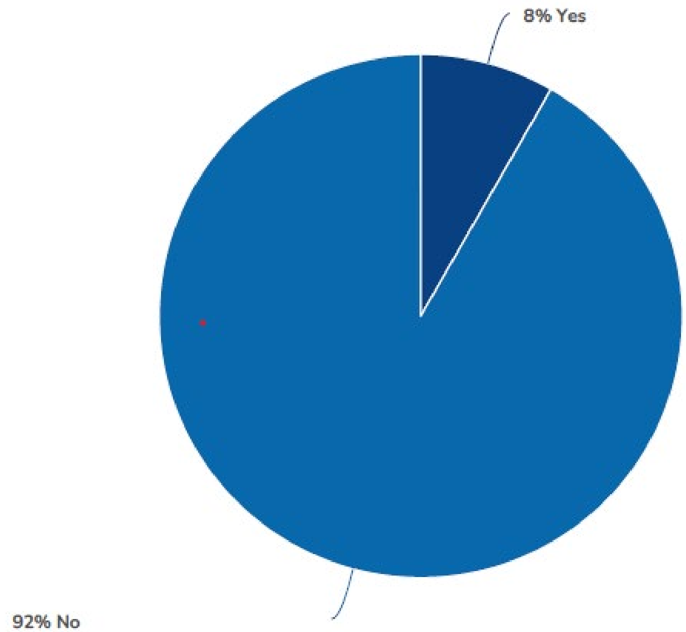
7. Does your jurisdiction have issues with drivers misinterpreting the meaning of a green ball when turning right or left from a turn lane under fully permissive phasing?




| Value | Percent | Responses |
|---|---|---|
| Yes | 4.2% | 1 |
| No | 95.8% | 23 |

Totals: 24

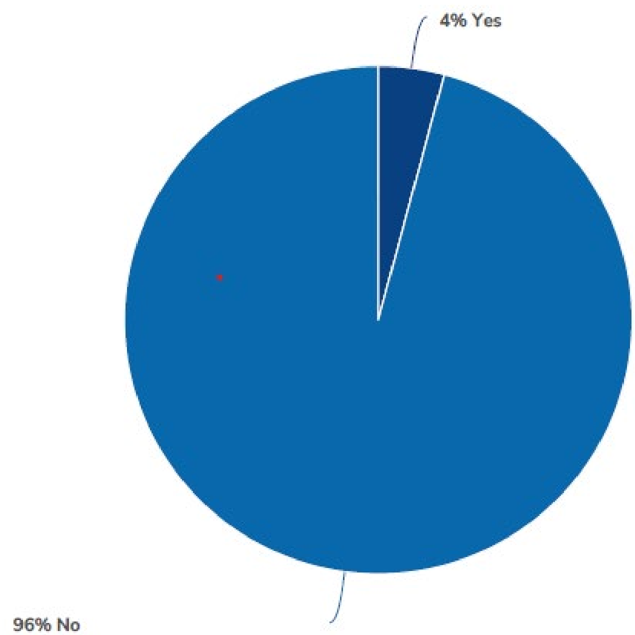
8. Does your jurisdiction have issues with drivers misinterpreting the meaning of a green ball when turning right or left from a turn lane under protected-permissive phasing?




| Value | Percent | Responses |
|---|---|---|
| Yes | 8.3% | 2 |
| No | 91.7% | 22 |

Totals: 24

9. Does your jurisdiction have any signals operating with 'yellow trap' phasing? (The yellow trap occurs when a permissive left-turn is opposed by a lagging green for the opposing through movement.)




| Value | Percent | Responses |
|---|---|---|
| Yes | 4.2% | 1 |
| No | 95.8% | 23 |
| | | Totals: 24 |

10. Does your jurisdiction have issues with collisions involving permissive turns from turn lanes and the following:

| | Yes, at many intersections | Yes, at some intersections | Yes, but only at a few intersections | No | Responses |
|---|---|---|---|---|---|
| Opposing vehicle traffic<br>Count<br>Row % | 5<br>20.8% | 12<br>50.0% | 4<br>16.7% | 3<br>12.5% | 24 |
| Pedestrians<br>Count<br>Row % | 3<br>12.5% | 10<br>41.7% | 7<br>29.2% | 4<br>16.7% | 24 |
| Cyclists<br>Count<br>Row % | 3<br>12.5% | 10<br>41.7% | 7<br>29.2% | 4<br>16.7% | 24 |
| Totals<br>Total Responses | | | | | 24 |

11. How are turning movements from turning lanes typically controlled in your jurisdiction when movements conflict with a pedestrian crosswalk at a traffic signal-controlled intersection. Select all that apply.

| Item | Overall Rank | Rank Distribution | Score | No. of Rankings |
|---|---|---|---|---|
| Protected permissive turn phasing | 1 | | 56 | 20 |
| Separate phasing is used to separate conflicts | 2 | | 52 | 18 |
| Fully permissive phasing | 3 | | 48 | 18 |
| A Leading Pedestrian Interval (LPI) phase is used but turns are permissive | 4 | | 44 | 17 |

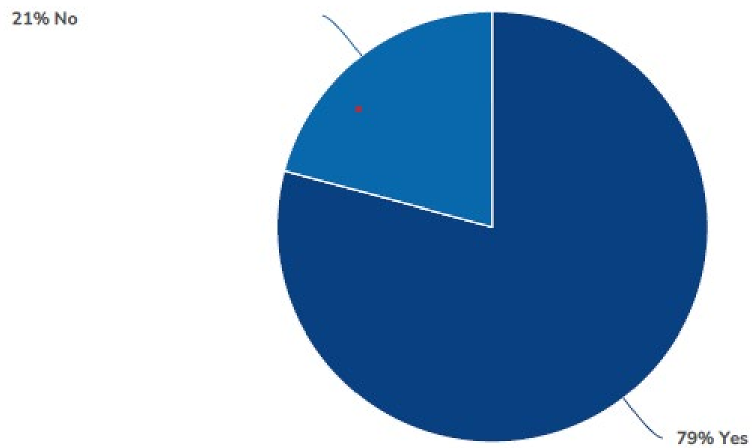
Lowest Rank    Highes t Rank

12. How are turning movements from turning lanes typically controlled in your jurisdiction when movements conflict with a cycling facility at a traffic signal-controlled intersection. Select all that apply.

| Item | Overall Rank | Rank Distribution | Score | No. of Rankings |
|---|---|---|---|---|
| Separate phasing is used to separate conflicts | 1 | | 51 | 15 |
| Fully permissive phasing | 2 | | 40 | 16 |
| Leading cycling phasing is used but turns are permissive | 3 | | 35 | 12 |
| Protected permissive turn phasing | 4 | | 33 | 15 |

Lowest Rank Highest Rank

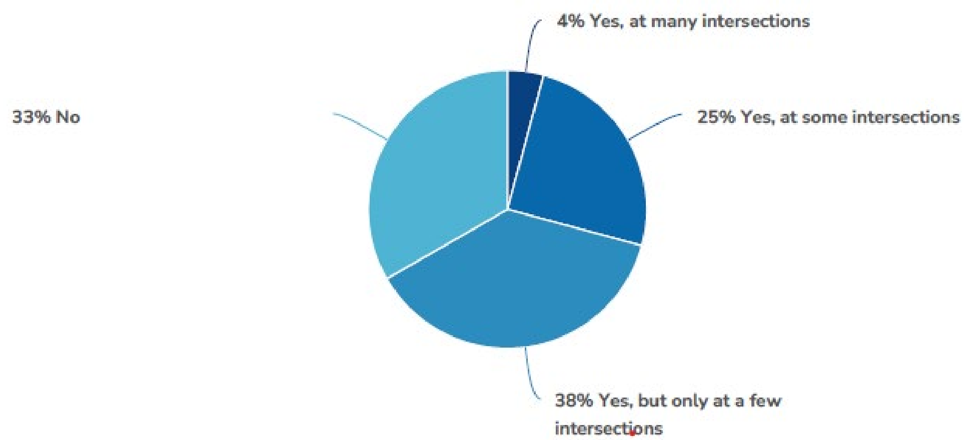
13. Does your jurisdiction allow changes to phase sequencing at an intersection by time of day?




| Value | Percent | Responses |
|---|---|---|
| Yes | 79.2% | 19 |
| No | 20.8% | 5 |

Totals: 24

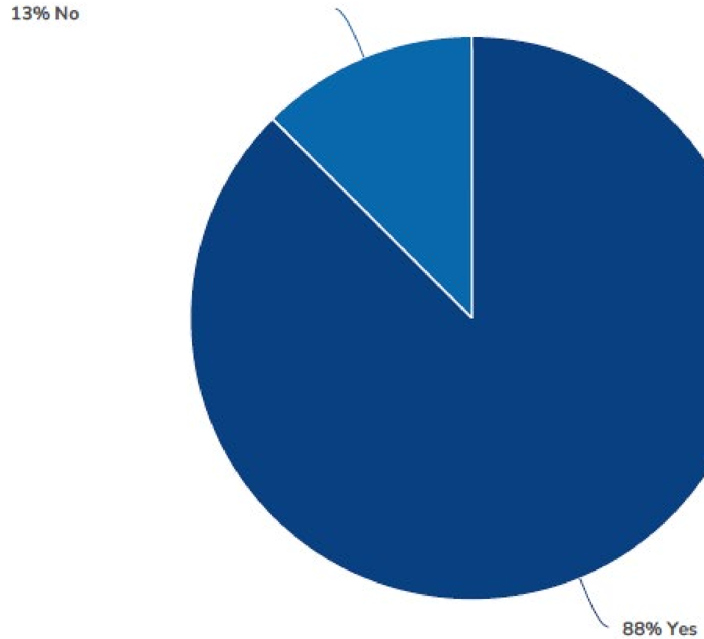
## 14. Does your jurisdiction alter phase sequencing at intersections by time of day?




| Value | Percent | Responses |
|---|---|---|
| Yes, at many intersections | 4.2% | 1 |
| Yes, at some intersections | 25.0% | 6 |
| Yes, but only at a few intersections | 37.5% | 9 |
| No | 33.3% | 8 |

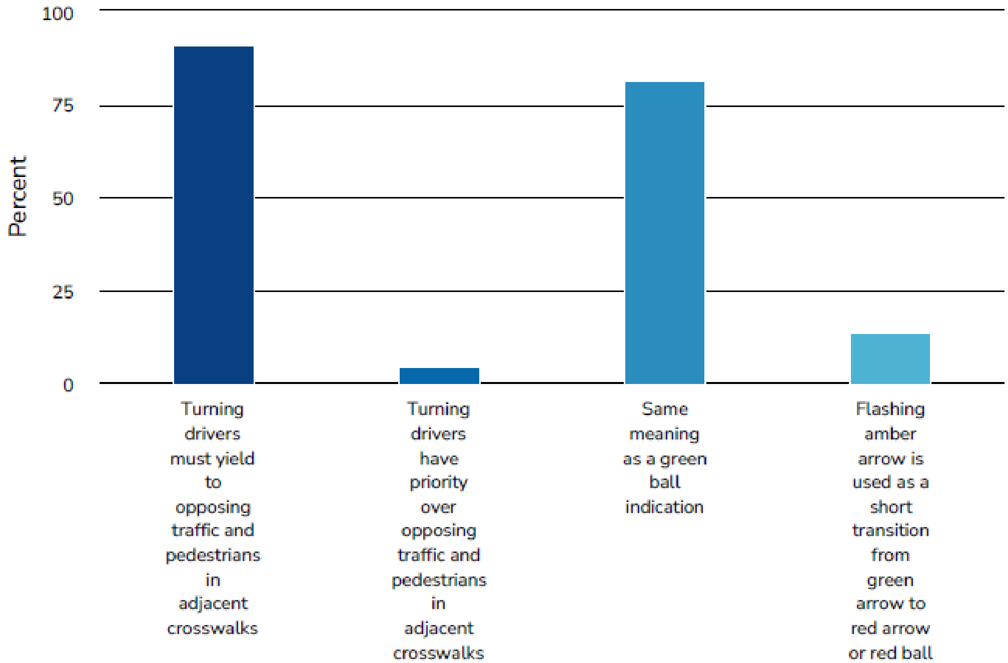
**Totals: 24**

15. Would your jurisdiction be interested in traffic signal display options that enable different turn signal phasing at different times of day?



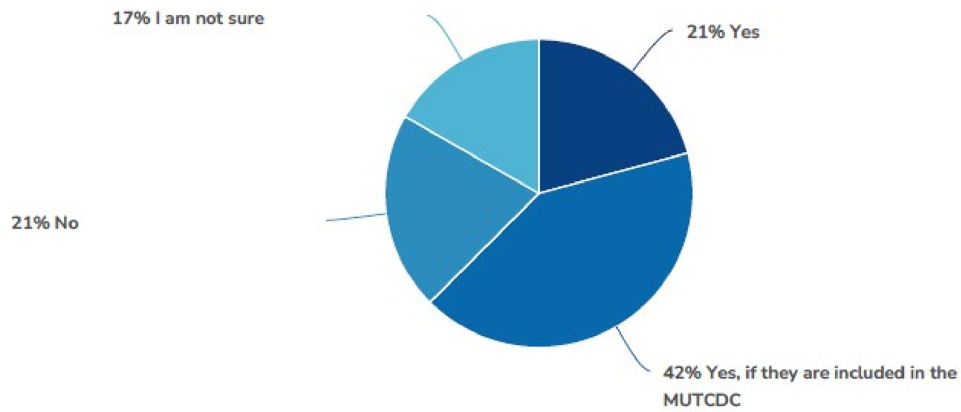

| Value | Percent | Responses |
|---|---|---|
| Yes | 87.5% | 21 |
| No | 12.5% | 3 |
| | | Totals: 24 |

## 16. What is your understanding of the meaning of a flashing amber arrow (select all that apply)?



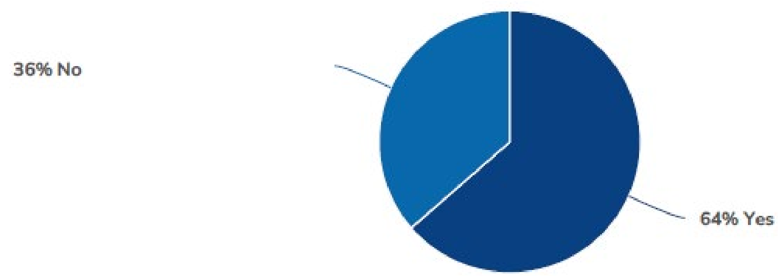

| Value | Percent | Responses |
|---|---|---|
| Turning drivers must yield to opposing traffic and pedestrians in adjacent crosswalks | 90.9% | 20 |
| Turning drivers have priority over opposing traffic and pedestrians in adjacent crosswalks | 4.5% | 1 |
| Same meaning as a green ball indication | 81.8% | 18 |
| Flashing amber arrow is used as a short transition from green arrow to red arrow or red ball | 13.6% | 3 |

17. Is your agency currently interested in, or considering, implementing flashing amber arrows?




| Value | Percent | Responses |
|---|---|---|
| Yes | 20.8% | 5 |
| Yes, if they are included in the MUTCDC | 41.7% | 10 |
| No | 20.8% | 5 |
| I am not sure | 16.7% | 4 |
| | | Totals: 24 |

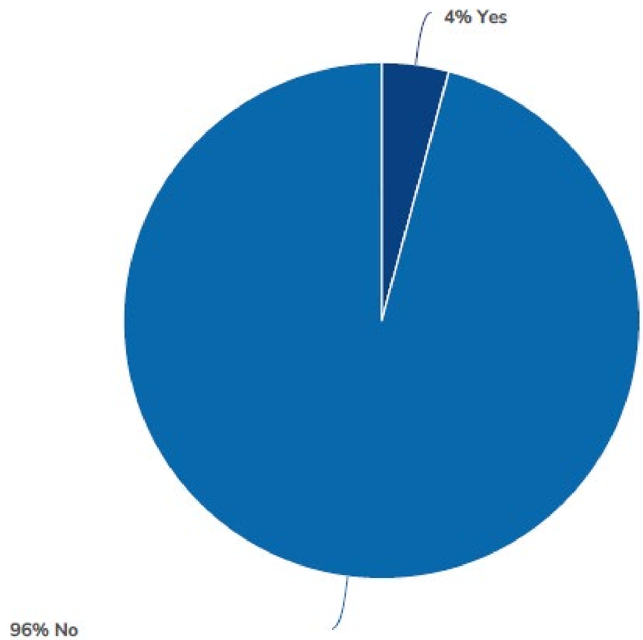
18. If considering, is the absence of flashing amber arrow in the MUTCDC a barrier to implementation?




| Value | Percent | Responses |
|---|---|---|
| Yes | 63.6% | 14 |
| No | 36.4% | 8 |

Totals: 22

## 19. Has your agency installed any flashing amber arrows?




| Value | Percent | Responses |
| --- | --- | --- |
| Yes | 4.2% | 1 |
| No | 95.8% | 23 |

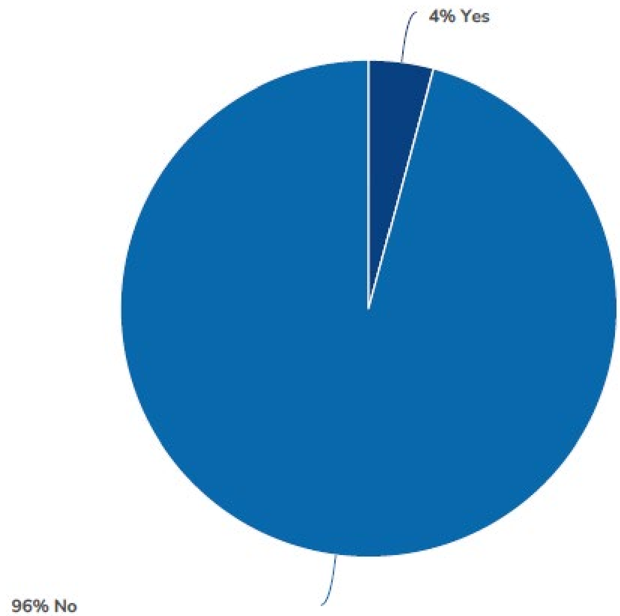
**Totals: 24**

## 20. How many flashing amber arrows has your agency installed?

| Value | Percent | Responses |
| --- | --- | --- |
| Between 1 and 5 | 100.0% | 1 |

**Totals: 1**

## 21. Does your agency have guidelines for use of flashing amber arrows?




| Value | Percent | Responses |
|---|---|---|
| Yes | 4.2% | 1 |
| No | 95.8% | 23 |

**Totals: 24**

## 22. Select the top three reasons that your agency does not currently have flashing amber arrows?

| Value | Percent | Responses |
|---|---|---|
| Have never been requested | 17.4% | 4 |
| They are not in the Manual of Uniform Traffic Control Devices for Canada | 65.2% | 15 |
| They are not in the Province's guidelines or regulations | 65.2% | 15 |
| We have a policy against these installations | 4.3% | 1 |
| We do not yet have a policy about these types of treatments | 26.1% | 6 |
| Safety reasons | 8.7% | 2 |
| Don't have issues with permissive turns | 8.7% | 2 |
| Don't have yellow trap issues | 13.0% | 3 |
| Act or Regulation prohibits their use | 8.7% | 2 |
| Signal hardware limitations | 4.3% | 1 |
| Concerns about user understanding | 34.8% | 8 |
| Other (explain) | 4.3% | 1 |
| I do not know | 4.3% | 1 |

Transportation Association of Canada

401–1111 Prince of Wales Drive, Ottawa, ON K2C 3T2
(613) 736-1350 secretariat@tac-atc.ca

For more information about the Transportation Association of Canada and its activities, products and services, visit www.tac-atc.ca.