Pedestrian Safety at Crosswalks – Examining Driver Yielding Behavior at Crosswalks with GM1 and OF Systems

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Abstract

Pedestrian crossing control is one of the most critical elements in providing a safe pedestrian network. This paper evaluates and compares the safety of pedestrians at crosswalks with side-mounted passive signs (GM1 systems) and crosswalks with overhead flashing devices (OF systems) by examining driver yielding behavior in Winnipeg.

Past research indicates that driver yielding at uncontrolled marked crosswalks (similar treatments to GM1 systems) tends to be low, as these crosswalks do not have flashing lights or other devices that provide the driver with information about when they need to stop. Previous research on crosswalks with overhead flashing beacons (similar treatments to OF systems) has shown that flashing beacons increase driver awareness, yet exhibit a wide range of driver yielding rates. Furthermore, there is limited research on pedestrian safety at crosswalks in winter, which is a concern for Winnipeg during almost half of the year.

This paper presents results of a collision analysis, environmental scan, and field investigations on driver yielding behaviour to evaluate the safety of pedestrians at crosswalks with GM1 or OF systems in Winnipeg. The collision analysis reflects City of Winnipeg police-reported collision data from 2001 to 2010. The data was analyzed to identify temporal trends and collision frequency by traffic control type and severity. The environmental scan includes a review of literature on driver yielding behavior at crosswalks with similar treatments to GM1 and OF systems, as well as a survey of major Canadian jurisdictions regarding the design and implementation of GM1 and OF systems. The field investigation involved collecting data during off-peak hours on driver yielding behaviour at eight crosswalks with GM1 or OF systems on roadways with two lanes per direction and a raised refuge. The data was analyzed to compare driver yielding at GM1 and OF crosswalks and evaluate the effect of weather and site specific characteristics on driver yielding behavior.

TAC's *Pedestrian Crossing Control Guide* (PCC Guide) recommends that OF systems be implemented on roadways with two lanes per direction and a raised refuge for a range of traffic volumes and speed limits; however, GM1 crosswalks are still widely used across Canada under these circumstances. This paper provides evidence of a significant difference in driver yielding behavior and ultimately pedestrian safety at crosswalks with OF systems compared to crosswalks with GM1 systems, supporting the PCC Guide's recommendation that OF systems be implemented on roadways with two lanes per direction and a raised refuge.

1 Introduction

1.1 Purpose

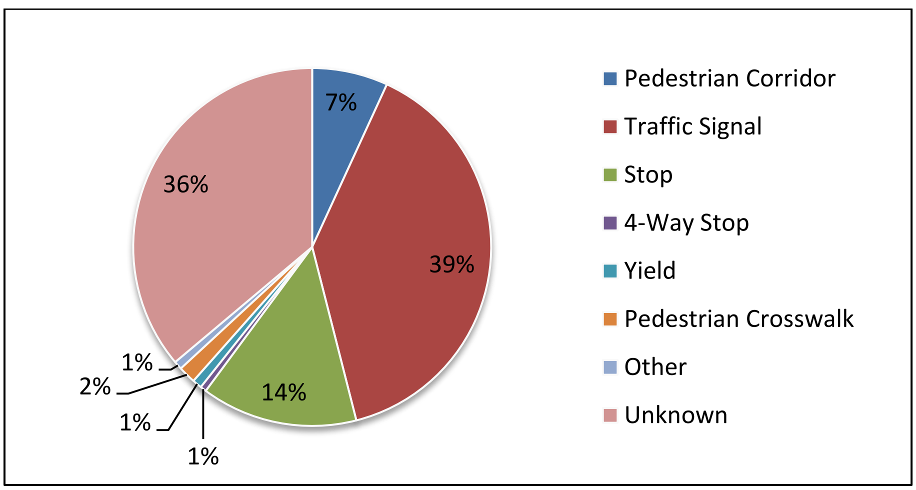
The purpose of this research is to evaluate and compare the safety of pedestrians at crosswalks with side-mounted passive signs (GM1 system) and crosswalks with overhead flashing devices (OF system) by examining driver yielding behavior. In particular, the study fills the gap in knowledge on driver yielding behavior at GM1 and OF systems in winter conditions and provides evidence that crosswalks with overhead flashing devices have a significant pedestrian safety advantage over crosswalks with side mounted passive signs on collector and arterial roadways in Winnipeg.

1.2 Background and Need

Walking is a vital mode of transportation within an urban setting. Regardless of mode choice, a person using the transportation system will be a pedestrian at some point during their trip. Therefore, ensuring that pedestrian networks are safe, equitable, and sustainable will benefit all users of the system.

Pedestrian crossing control is one of the most critical elements in providing a safe pedestrian network. According to TAC's *Pedestrian Crossing Control Guide* (PCC Guide), "it is fundamental that the road system protect pedestrians and other vulnerable road users by achieving a high level of compliance from drivers, bicyclists, and pedestrians, and by minimizing pedestrian exposure to vehicle traffic [1]." In 2013, Transport Canada reported that 15.7 percent of fatalities and 13.5 percent of serious injuries due to motor vehicle collisions in 2011 were pedestrians. This equates to 1725 pedestrians killed or seriously injured in Canada in one year [2]. Even though the number of pedestrian fatalities has been decreasing in Canada since 1991 [2], pedestrians continue to be vulnerable at crosswalks due to their direct interaction with vehicles.

An analysis of police-reported collisions involving pedestrians in Winnipeg from 2001 to 2010 was completed to determine the magnitude of the safety problem for pedestrians. The collision analysis may not be a complete representation of the safety of pedestrians in Winnipeg as near misses and unreported collisions are not included. Of the 3048 pedestrian-vehicle collisions that were recorded between 2001 and 2010, the majority of collisions occurred at an unknown location (1101 collisions) or traffic signal devices (1194 collisions). In addition, 430 of collisions occurred at stop signs (not including 4-way stops), 209 at pedestrian corridors, 48 at pedestrian crosswalks, 26 at yields, 17 at 4-way stops, and 23 at other locations. Figure 1 shows a summary of these results. Furthermore, 61 of the pedestrian-vehicle collisions resulted in fatality, 2908 resulted in injury, 75 resulted in property damage only, and 4 had unknown severity [3].



"Other" refers to officer/flagman/school guard, school zone, left turn on red, merge, school crossing, right turn on red, overhead signs, and turn controls.

Figure 1: Collision Frequency from 2001 to 2010 by Traffic Control Type (n=3048) [3]

From 2001 to 2010, 200 to 300 pedestrian-vehicle collisions occurred in each month of the year. Figure 2 shows the monthly pedestrian-vehicle collision trend. It can be seen that higher frequencies of collisions have occurred in late fall and winter months (October, November, December, January, February, and March) [3].

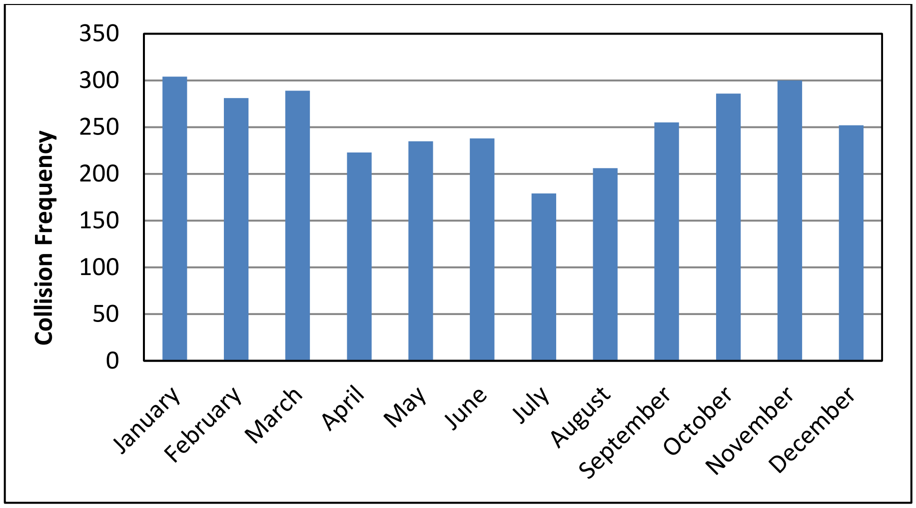


Figure 2: Pedestrian-Vehicle Collision Frequency from 2001 to 2010 by Month [3]

The higher frequencies of collisions in winter months may indicate that weather is a factor which affects the safety of pedestrians. Winnipeg experiences winter weather conditions (i.e., snow, ice, and low temperatures) for at least 5 months of the year, including an average snowfall of 113.7 centimeters per year [4]. These conditions often result in snowbanks along curb edges of roads ranging from one to two meters high. The snowbanks pose a problem at crosswalks as they can hinder a driver's ability to identify a pedestrian wanting to cross the road. In many crosswalk locations in Winnipeg, a driver may not be able to identify a pedestrian until they are at a distance less than the required stopping sight distance away from the crosswalk. This issue is compounded by the fact that icy road conditions may increase vehicle braking distance, which effectively increases the overall stopping sight distance.

Crosswalks with side-mounted passive signs (GM1 systems) and crosswalks with overhead flashing devices (OF systems) are commonly used in Winnipeg for pedestrian crossing control to help pedestrians safely cross a roadway. The GM1 system is defined in TAC's PCC Guide as a treatment system category that includes crosswalks with side-mounted passive signs, twin parallel line pavement markings, and advanced warning signs where visibility is limited. The guide also recommends desirable and optional components that may be implemented if desired. Some of the desirable and optional components include advanced yield to pedestrian signs, crossing guards, and Zebra markings [1]. In Winnipeg, the GM1 system is typically implemented on low volume two-lane local roads near parks or schools, however, GM1 systems can also be found on high volume four-lane collector and arterial roads.

The OF system is defined in TAC's PCC Guide as a treatment system which has overhead alternating amber flashing beacons, overhead- and side-mounted signs, pedestrian pushbuttons, advanced warning signs where visibility is limited, and pavement markings (twin parallel lines at intersections and Zebra markings at mid-block locations). Like the GM1 system, the PCC Guide recommends desirable and optional components for the OF system [1]. In Winnipeg, the OF system is typically implemented on collector or arterial roads with high vehicular volumes.

For clarity and consistency, the GM1 system and OF system will be referred to as GM1 crosswalk and OF crosswalk, respectively, for the remainder of this paper.

As previously mentioned, GM1 crosswalks have been implemented on some high volume four-lane collector and arterial roads in Winnipeg, yet TAC's PCC Guide recommends that OF crosswalks or traffic signals (not GM1 crosswalks) be implemented in these circumstances [1]. One of the reasons for this recommendation is to increase the conspicuity of pedestrians at crosswalks with higher traffic volumes and speeds. By implementing GM1 crosswalks in these circumstances, potential safety threats for pedestrians are more likely to occur due to non-compliance by drivers. This issue is not limited to Winnipeg, as GM1 crosswalks are still widely used across Canada on high volume four-lane collector and arterial roads.

Past research has shown that driver yielding at uncontrolled marked crosswalks (which have similar treatments to GM1 crosswalks) tends to be low, as these crosswalks do not have flashing lights or other devices that provide the driver with information about when they need to stop. Past research on crosswalks with overhead flashing beacons (which have similar treatments to special or OF crosswalks) has shown that flashing beacons increase driver awareness, yet exhibit a wide range of driver yielding rates (25 to 77 percent) [5]. Furthermore, there is limited research on pedestrian safety at crosswalks in winter, which is a concern for Winnipeg for almost half of the year.

The need for research on driver-yielding behavior at GM1 crosswalks and OF crosswalks in winter conditions became apparent for the following reasons:

1) The existing literature has shown that crosswalks with overhead flashing beacons (OF crosswalks) increase driver awareness and in turn safety of pedestrians crossing a roadway, however, there are major inconsistencies in driver yielding rates.
2) GM1 crosswalks have been implemented in circumstances where OF crosswalks or traffic signals are now recommended by TAC's PCC Guide.
3) There is limited research on the effect of winter conditions on driver yielding behavior for both GM1 and OF systems.

2 Environmental Scan

A literature review and jurisdictional survey were conducted prior to the collection of data. The literature review focused on literature pertaining to systems similar to GM1 crosswalks, OF crosswalks, and crosswalks during winter months. The jurisdictional survey examines current design practices, right-of-way legislation, and implementation of GM1 and OF crosswalks in jurisdictions across Canada.

2.1 Literature Review

The major findings from the literature review on GM1 crosswalks are:

- There is limited research on the safety effects of the entire GM1 system; however, there is research on the safety performance and driver yielding behavior at uncontrolled marked crosswalks (which have similar treatments to GM1 crosswalks).
- One study comparing the safety of uncontrolled unmarked and marked crosswalks has shown that there is no meaningful before/after changes for vehicle volumes, traffic gaps, pedestrian volumes, driver yielding behavior, or aggressive pedestrian crossing behavior [6].
- Another study found that there is no difference in crash rates for uncontrolled unmarked and marked crosswalks on low volume two-lane roadways; however, on roads with higher vehicle volumes and multiple lanes, crash rates for marked crosswalks were found to be higher than those at unmarked crosswalks [7].
- There are conflicting findings on pedestrian behavior at uncontrolled unmarked and marked crosswalks. One study found that pedestrians do not behave less cautiously in marked versus

unmarked crosswalks, while another study found that pedestrians exhibited a greater level of caution at unmarked crosswalks compared to marked crosswalks [6, 8].

- Multiple threat incidents occur more frequently in uncontrolled marked crosswalks compared to unmarked crosswalks. Multiple threat incidents occur on multi-lane roads when two drivers travelling parallel to one another react differently (one yields, one does not yield) when arriving at sidewalk where a pedestrian waits [8].
- Driver and pedestrian behaviors at uncontrolled marked and unmarked crosswalks are similar in both the urban/suburban and rural/recreational context [9].
- At uncontrolled marked crosswalks drivers are more likely to yield to assertive pedestrians and are less likely to yield as speed and deceleration rates increase and/or if travelling in a platoon [10]. This agrees with another study on uncontrolled marked crosswalks on 2-lane roads with 85^{th} percentile speeds of 20 mph (32 km/h), 30 mph (48 km/h) and 40 mph (64 km/h) that found driver yielding rates of 63 to 75 percent, 42 to 52 percent, and 17 to 19 percent, respectively [11].

The major findings from the literature review on OF crosswalks are:

- TAC's *Pedestrian Crossing Control Guide: Technical Knowledge Base* explains that "because special crosswalks [OF crosswalks] feature a combination of treatments, the safety effects of the entire system are not readily available in the literature." While there is limited research on the safety effects of the entire OF system, there is research on safety performance of crosswalks with overhead flashing devices [12].
- The advantages of overhead flashing beacons are that they increase driver awareness and can be pedestrian activated, while the disadvantages are that they do not provide a steady red signal indication requiring traffic to stop, have high installation cost, and some maintenance costs [13].
- One study examined a crosswalk with overhead flashing beacons located on a 4-lane divided road in Philomath, Oregon and found driver compliance to be 77.1 percent [14].
- Another study examined driver compliance at crosswalks with passively-activated or pushbutton-activated overhead flashing beacons in multiple U.S. cities. The study found a wide range of motorist compliance rates (25 to 73 percent) for all flashing beacon installations. In addition, the study found that traffic speeds, volumes, and number of lanes have a statistically significant effect on driver compliance on arterial streets [5]. Table 1 shows driver compliance rates for pushbutton-activated and passively-activated overhead flashing beacons for staged crossings (i.e. deliberate pedestrian crossings made by researchers) and general population pedestrian crossings.

Table 1: Motorist Yielding Compliance for Overhead Flashing Beacons [5]

Crossing Treatment	Staged Pedestrian Crossing			General Population Pedestrian Crossing		
	Number of Sites	Compliance Range (%)	Compliance Average (%)	Number of Sites	Compliance Range (%)	Compliance Average (%)
Pushbutton Activation	3	29 to 73	47%	4	38 to 62	49%
Passive Activation	3	25 to 43	31%	3	61 to 73	67%

The major findings from the literature review on crosswalks in winter are:

- There is limited research on the safety of pedestrians at uncontrolled marked crosswalks and crosswalks with overhead flashing devices in winter conditions.
- One study that surveyed 183 people of all ages in Toronto found that the outdoor locations that were of greatest concern in winter were sidewalks (47 percent of respondents), street crossings (24 percent), and curb ramps (8 percent). In addition, the most common problems experienced at crosswalks include icy surfaces (17 percent), snow banks (20 percent), snowy/slushy surfaces (21 percent), puddles (18 percent), splashes by automobiles (16 percent), and reduced visibility (5 percent) [15].

2.2 Jurisdictional Survey

The survey was primarily online, with a phone-based option. The survey included questions related to the safety, design, and implementation of GM1 and OF crosswalks in each respective jurisdiction. Twenty-one jurisdictions were contacted and five responded to the survey questions. The jurisdictions that responded to the survey are from New Brunswick, Manitoba, Ontario, Saskatchewan and British Columbia. The major findings from the survey were as follows:

- Four of the five jurisdictions give the right-of-way to pedestrians at crosswalks. The fifth jurisdiction follows the Ontario Highway Traffic Act that gives vehicles the right-of-way over pedestrians at crosswalks.
- Every jurisdiction, excluding Ontario, has GM1 crosswalks installed. The Ontario Highway Traffic Act allows similar pedestrian crossing control systems to be implemented.
- Three of the jurisdictions have had previous complaints related to GM1 crosswalks. Complaints in the jurisdictions included vehicles failing to yield to pedestrians and honking.
- The jurisdictions that responded indicated the current practice in Canada is to install GM1 crosswalks at: (1) 3-lane, 1-way streets; (2) multilane, 2-way streets with raised refuge; (3) single-lane roundabouts; (4) school zones; and (5) 4-lane, 2-way streets without raised refuge.
- The jurisdictions that responded indicated that the majority of jurisdictions install OF crosswalks at: (1) 2-lane, 2-way streets, (2) school zones, (3) 4-lane, 2 way street without raised refuge, and (4) multi-lane, 2-way street with raised refuge. In addition, the Manitoba jurisdiction installs OF crosswalks at 3-lane, 1-way streets.
- The majority of jurisdictions that have GM1 and OF crosswalks use pedestrian volumes to determine if a GM1 or OF crosswalk should be implemented.
- The Manitoba jurisdiction considers land-use, vehicular volume, pedestrian volume, collision history and speed limit to determine if a GM1 or OF crosswalk is warranted.
- One jurisdiction stated that they "typically use the GM1 [system] unless the specific location warrants a device such as active pedestrian corridor or pedestrian actuated signal." No additional detail was provided on determining whether additional devices are warranted.
- The four jurisdictions that responded to the survey that use GM1 and OF crosswalks follow TAC's PCC Guide's recommendations. The jurisdiction in Manitoba is currently undergoing changes in pedestrian crossing control and has formally adopted TAC's PCC Guide.

3 Study Methodology

This section describes the methodology used for the field investigation, including site selection, sample size, and data collection.

3.1 Site Selection

Four roadway segments in Winnipeg were identified for the field investigation. The sites (or roadway segments) have similar geometric and operational characteristics, as well as a GM1 crosswalk and OF crosswalk in close proximity to one another (no more than 1.3 kilometers apart). Each site is located in an urban residential area, has two-lanes of traffic in each direction with a raised refuge, and has no stop control on the major road.

TAC's PCC Guide's treatment selection matrix recommends that overhead flashing beacon systems (OF) or traffic signal systems (TS) be implemented on roads with two-lanes per direction for several traffic volume and speed thresholds. The four study sites were selected because they represent cases where the PCC Guide would recommend either an OF or TS treatment, yet have a GM1 crosswalk and OF crosswalk installed at separate locations along the same roadway. Figure 3 shows the typical layout of sites selected for data collection.

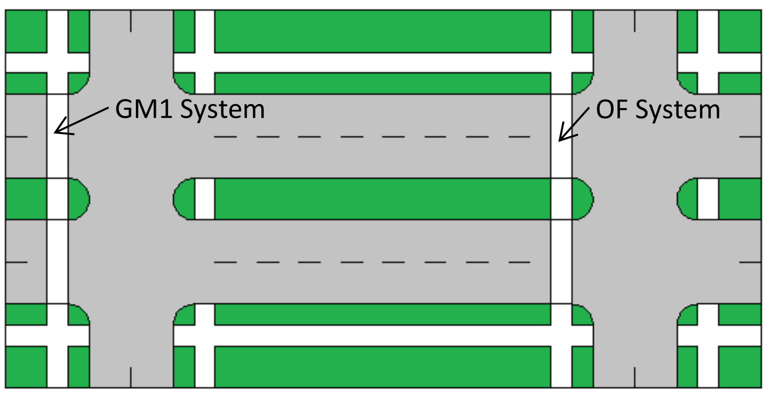


Figure 3: Typical Layout of Sites Selected for Data Collection

The selection of these sites allowed driver yielding rates at GM1 and OF crosswalks to be compared to determine whether the PCC Guide's recommendations are justified. The specific geometric and operational conditions at each site, as well as the crossing control type recommended by the PCC Guide are summarized in Table 2.

Table 2: Site Geometric and Operational Characteristics

Site #	Street Segment	Parking	Number of Lanes per Direction	Intersection Layout at Crosswalk	Speed Limit	Vehicle Volume (ADT)	Crossing Control Type Recommended by PCC Guide	Present Crossing Control Type
1	Dakota Street	Not Permitted	2	N/A (Midblock)	60 km/h	>15,000	TS	OF, GM1
2	Corydon Avenue	Curb Lane	2	GM1: 4-Leg OF: 3-Leg	50 km/h	12,000 - 15,000	OF	OF, GM1
3	Burrows Avenue	Curb Lane	2	GM1: 3-Leg OF: 4-Leg	50 km/h	No data (est. 9,000 - 12,000)	OF	OF, GM1
4	Inkster Boulevard	Curb Lane	2	4-Leg	50 km/h	>15,000	OF	OF, GM1

Site #1: Dakota Street

The GM1 and OF crosswalks on Dakota are located in a suburban residential area. The sites at Dakota differ from the other three crosswalks in several ways. The GM1 and OF crosswalks are at midblock locations, the speed limit on Dakota is 60 km/h, and parking is not allowed on the road. In addition, the site is in a newer suburban neighbourhood which does not follow the grid layout of the other three neighborhoods where crosswalk sites are located. Dakota has an average daily traffic of between 12,000 and 15,000 vehicles.

Figure 4: GM1 Crosswalk on Dakota St.

Figure 5: OF Crosswalk on Dakota St.

Site #2: Corydon Avenue

The GM1 and OF crosswalks on Corydon are located in an area with a mix of urban residential and commercial land use. The neighbourhood is laid out in a grid pattern and has a mature tree canopy along minor streets. The GM1 and OF crosswalks are located across Corydon, on the west side of their respective intersections. Vehicles travelling on Corydon are subject to a 50 km/h speed limit, and vehicles approaching from the minor streets are stop controlled. Corydon has an average daily traffic of between 12,000 and 15,000 vehicles.

Figure 6: GM1 Crosswalk on Corydon Ave. at Lanark St.

Figure 7: OF Crosswalk on Corydon Ave. at Elm St.

Site #3: Burrows Avenue

The GM1 and OF crosswalks on Burrows are located in an urban residential area. The neighbourhood is laid out in a grid pattern and has a mature tree canopy along the road edge and median. The GM1 and OF crosswalks are located across Burrows. Vehicles travelling on Burrows are subject to a 50 km/h speed limit and vehicles approaching from the minor streets are stop controlled. The GM1 crosswalk is located at a 3-leg intersection, while the OF crosswalk is located at a 4-leg intersection. The traffic volume is estimated to be between 9,000 and 12,000 vehicles per day.

Figure 8: GM1 Crosswalk on Burrows Ave. at Fife St.

Figure 9: OF Crosswalk on Burrows Ave. at Shaughnessy St.

Site #4: Inkster Boulevard

The GM1 and OF crosswalks on Inkster are located in an urban residential area. They are located at the south corners of the Inkster School property and are therefore used by students traveling to and from school. Inkster School is an elementary school in the Winnipeg School Division. The neighbourhood is laid out in a grid pattern and has a mature tree canopy along the road edge and median. The GM1 and OF crosswalks are located across Inkster, on the west sides of their respective intersections. Vehicles travelling on Inkster are subject to a 50 km/h speed limit and vehicles approaching from the minor streets are stop controlled. Inkster has an average daily traffic of between 12,000 and 15,000 vehicles.

Figure 10: GM1 Crosswalk at Inkster Blvd. & Parr St.

Figure 11: OF Crosswalk on Inkster Blvd. at McKenzie St.

3.2 Sample Size

The following equation was used to determine the required sample size for each location given a certain probability of success for immediate yields:

$$n=[p(1\text{-}p)]*\left[\frac{Z}{m}\right]^2$$

where n is the required sample size, p is the probability of success (i.e., proportion of immediate yields), Z is the critical value for a certain confidence level, and m is the chosen margin of error. The researchers chose a 95% confidence level resulting in a critical Z-value of 1.96, a margin of error of 10%, and a conservative probability of success of 0.5 for immediate yields [16]. Substituting these values into the above equation resulted in a required sample size of 96.04. This means at least 97 observations were required at each location to ensure a 95% chance that the observed proportion of immediate yields is within 10% of the actual value. The researchers collected at least 100 observations at each crosswalk site. Table 3 shows the sample size for each crosswalk site.

Table 3: Crosswalk Sample Sizes

Site #	Roadway Segment	GM1 Crosswalk Sample Size	OF Crosswalk Sample Size
1	Dakota Street	106	107
2	Corydon Avenue	102	107
3	Burrows Avenue	110	106
4	Inkster Boulevard	110	106
Total		**428**	**426**

3.3 Data Collection

This study used “staged” pedestrian crossings so that each driver approaching a crossing site would be faced with the same pedestrian. The staged crossing was conducted by one of the researchers, while the two other researchers observed and recorded driver yielding data for each crossing. Pedestrian characteristics or behaviour were not considered in the research and were held constant using the same pedestrian and pedestrian approach behaviour at each site. The pedestrian wore consistent clothing with the same dark coloured jacket, as well as a hat, mitts and a scarf on each data collection day.

Data collection occurred during off-peak hours. Off-peak was defined for the research as the time between the end of the morning peak and the start of the afternoon peak, roughly between the hours of 9:00 a.m. and 4:30 p.m., respectively. Data was not collected in school zone locations between approximately 3:30 p.m. and 4:00 p.m., corresponding to the end of the school day and the presence of crossing guards at or near the crosswalks. The data collection was completed in blocks of 1 to 2 hours at a time, corresponding to approximately 75 to 100 crossings recorded per hour. In total, data collection took place on six different days: two days on Dakota Street (March 5 and March 10), three days on Corydon Avenue (February 25, March 10 and March 11), two days on Burrows Avenue (March 6 and March 13), and two days on Inkster Boulevard (March 10 and March 13). For consistency and safety, weather conditions for data collection at all four sites had the following characteristics: (1) a clear day with no snowfall, (2) roads clear of snow, and (3) outside temperatures above -15°C.

On the day of data collection the sites were driven through to understand visibility issues specific to the day of data collection, such as the presence of snowbanks. Furthermore, to determine the stopping distance required for drivers to yield to pedestrians, the stopping sight distance formula from the TAC’s *Geometric Design Guide for Canadian Roads* was used [17]. The stopping sight distance calculations for each site are presented in Table 4.

Table 4: Stopping Sight Distance for Crosswalk Sites [17]

Site #	Roadway Segment	Posted Speed (km/hr)	Initial Speed (km/hr)	Coefficient of Friction	Stopping Sight Distance (m)
1	Dakota Street	60	50	0.35	63
2	Corydon Avenue	50	40	0.38	44
3	Burrows Avenue	50	40	0.38	44
4	Inkster Boulevard	50	40	0.38	44

The following procedure was followed for each staged road crossing event:

1. Prior to the crossing, the pedestrian was out of sight of the approaching vehicles.
2. The pedestrian then approached the crosswalk when a single vehicle or the first vehicle in a platoon of vehicles passed a specific location in advance of the crosswalk corresponding to the calculated stopping sight distance.
3. For the GM1 crosswalks, the pedestrian waited for the approaching vehicle(s) to stop or slow down enough for the pedestrian to feel safe crossing the road. For the OF crosswalk, the pedestrian activated the push button and waited for approaching vehicle(s) to stop or slow down enough for the pedestrian to feel safe before crossing the road.
4. The pedestrian stood and waited at the edge of the road until they were able to cross safely in cases where an immediate yield did not occur.

The two observers positioned themselves in order to minimize their visibility to passing motorists but close enough to the crosswalk to have an unimpeded view of driver yielding behaviour on both sides of the GM1 or OF crosswalk. Data collectors sat in a nearby parked car at every location except Dakota Street due to parking restrictions. In the case of Dakota Street, the researchers observed the staged pedestrian crossings from a nearby bus shelter. The researchers recorded the following information about each interaction:

- The pedestrian walking direction and the direction of approaching traffic.
- The pedestrian location prior to crossing: edge of the crosswalk or the median.
- Whether the interaction was with a single vehicle or a platoon.
- Whether or not the first vehicle in the platoon (or the single vehicle) stopped or slowed down sufficiently enough for the approaching pedestrian. This was identified as an *immediate yield*.
- The number vehicles that failed to yield in a platoon, if an immediate yield did not occur.
- If no vehicles yielded before a gap in traffic, which provided sufficient time to cross safely, this was identified as *no yield before gap*.

A special case of driver yielding behaviour called a *multiple threat* was also recorded. Multiple threats occur in two situations: (1) roads with no raised refuge having a minimum of one lane each direction, and (2) multi-lane, two-way streets with a raised refuge. A multiple threat occurs when one vehicle yields but one or more subsequent vehicles fail to yield after the first vehicle has already stopped or slowed down. Multiple threats may occur when the stopping vehicle blocks other vehicles' view of the approaching pedestrian. Each multiple threat incident was recorded along with the number of vehicles continuing through the crosswalk after the initial yield and the lane in which the multiple threat incidents occurred.

4 Results and Discussion

The results of this research are focused on comparing driver yielding at GM1 crosswalks and OF crosswalks as well as examining driver yielding behaviour in winter weather conditions. The results of the field investigation are discussed in the following sections.

4.1 Driver Yielding at GM1 Crosswalks and OF Crosswalks

Table 5 summarizes the driver yielding rates for each site, defined as the percent of pedestrian crossings resulting in an immediate yield. The results are also categorized by the location of the pedestrian in the vicinity of the crosswalk, either approaching from the edge of the road or crossing from the median. At each site, approximately 65 percent of crossings correspond to the pedestrian approaching from the road edge and 35 percent of crossings correspond to pedestrians approaching from the median. The overall driver yielding rates for GM1 crosswalks ranged from 42 to 65 percent, while the overall driver yielding rates for OF crosswalks ranged from 83 to 96 percent.

Table 5: Immediate Yielding by Site and Location of Pedestrian Approach

Site #	Street Segment	PCC System		Pedestrian Approach Location: Road Edge	Median	Total
1	Dakota Street	GM1	Sample Size	71	35	106
			Yielding Rate	41%	69%	**50%**
		OF	Sample Size	66	41	107
			Yielding Rate	95%	98%	**96%**
2	Corydon Avenue	GM1	Sample Size	66	36	102
			Yielding Rate	33%	58%	**42%**
		OF	Sample Size	67	40	107
			Yielding Rate	90%	90%	**90%**
3	Burrows Avenue	GM1	Sample Size	70	40	110
			Yielding Rate	59%	60%	**59%**
		OF	Sample Size	73	33	106
			Yielding Rate	86%	91%	**88%**
4	Inkster Boulevard	GM1	Sample Size	68	42	110
			Yielding Rate	60%	71%	**65%**
		OF	Sample Size	70	36	106
			Yielding Rate	84%	81%	**83%**

Figure 12 illustrates the differences in driver yielding behavior between OF crosswalks and GM1 crosswalks at each site.

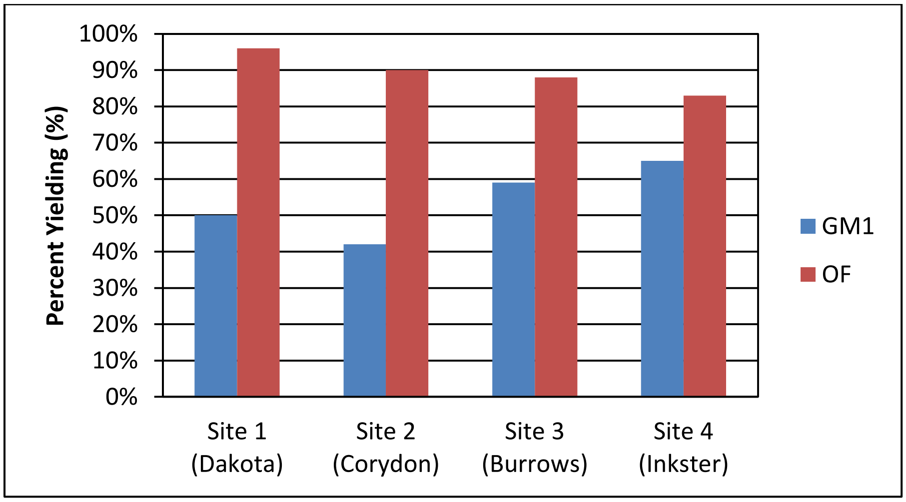


Figure 12: Yielding Rates at GM1 and OF Crosswalks

For all sites, OF crosswalks had higher average yielding rates (83 to 96 percent) than GM1 crosswalks (42 to 65 percent). Furthermore, at site 1 and 2 the OF crosswalks had the highest average yielding rates among all of the OF crosswalks, while the GM1 crosswalks had lowest average yielding rates among all of the GM1 crosswalks. The larger difference in average yielding rates between the GM1 and OF crosswalk at site 1 and 2 compared to other street segments may be due to (but not limited to) the following five factors: (1) vehicles were observed to be operating at higher speeds at site 1 and 2 compared to site 3 and 4; (2) site 1 and 2 do not have houses fronting the street, whereas site 3 and 4 do; (3) the driver's visibility of the OF crosswalks at site 1 and 2 was good as there was little to no on-street parking when the data was being collected; (4) the driver's visibility of the GM1 crosswalks at site 1 and 2 was reduced as there was on-street parking or large snowbanks that obstructed drivers view when the data was being collected; and (5) both GM1 and OF crosswalks at site 3 and 4 had reduced driver visibility as there was on-street parking and/or large snowbanks when data was being collected.

Since both GM1 crosswalks and OF crosswalks can be considered as two-stage crossings, Figure 13 illustrates the differences in driver yielding rates at GM1 crosswalks and OF crosswalks depending on whether the pedestrian crosses from the road edge or median. For GM1 crosswalks, crossing from the median resulted in higher yielding rates (about 65 percent) than crossing from the road edge (about 48 percent). In contrast, for OF crosswalks, crossing from the median resulted very similar yielding rates (about 89 percent) to crossing from the road edge (about 90 percent).

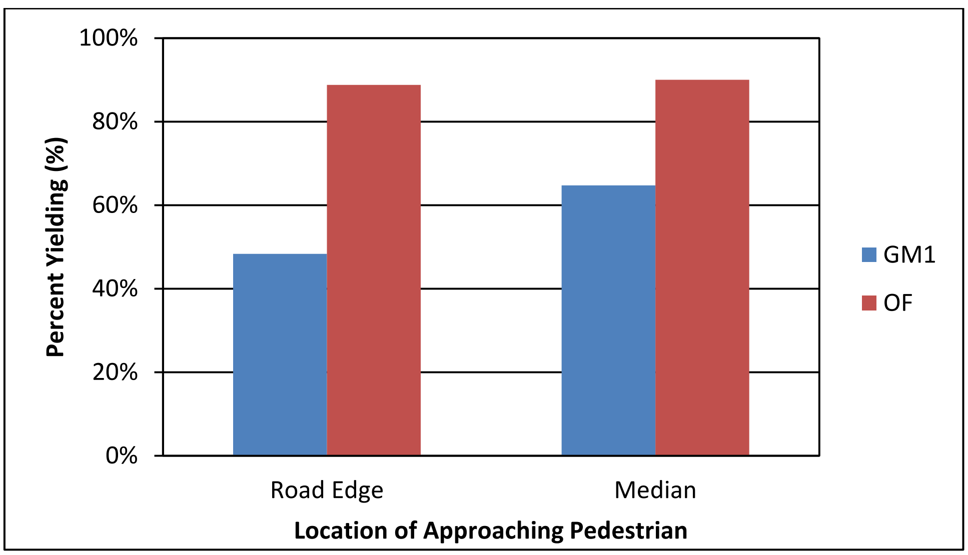


Figure 13: Percent of Immediate Yields from the Road Edge and Median

Figure 14 illustrates the difference in driver yielding rates when pedestrians approach the roadway from the median or road edge at each crosswalk. For each GM1 crosswalk, driver yielding rates for pedestrians approaching from the road edge is lower than when the pedestrian approaches from the median, which corresponds to the overall result shown in Figure 13. The difference may be because drivers are better able to detect pedestrians and/or are less confused about a pedestrian's intention to cross when the pedestrian is located on the median as opposed to along the edge of the roadway. For each OF crosswalk, driver yielding rates for pedestrians approaching from the road edge and median were similar, which again corresponds to the overall result shown in Figure 13. The similarity may be because drivers are more aware of a pedestrian's intention to cross regardless of whether the pedestrian is crossing from the median or road edge, as OF crosswalks require pedestrians to use a pushbutton to activate each stage of the crossing.

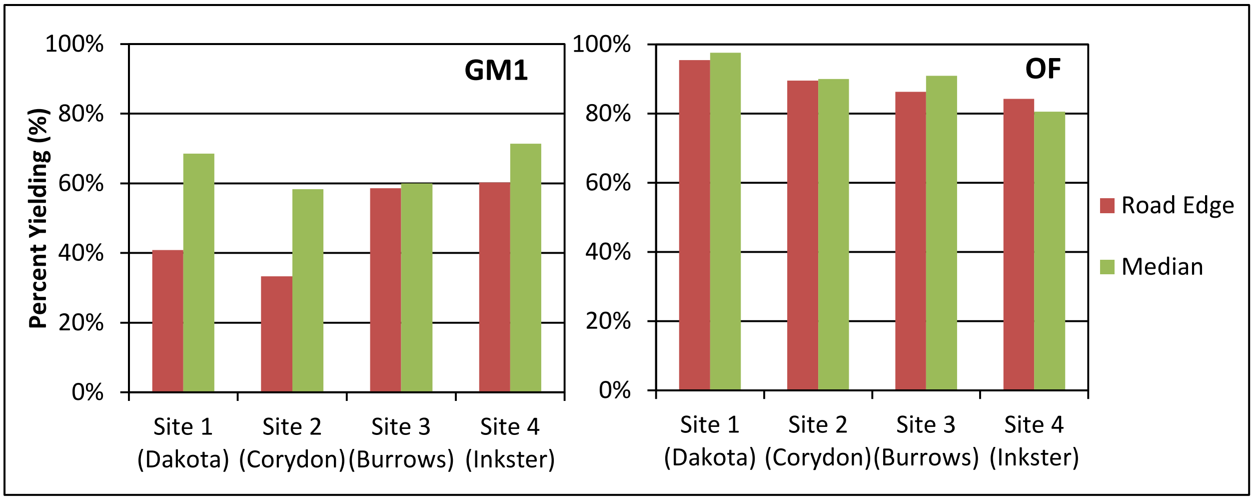


Figure 14: Percent of Immediate Yields from Road Edge and Median by Site Location

Another consideration is that data collection took place during winter, which poses some additional safety issues for pedestrians attempting to cross a roadway. At the sites considered in this study, snowbanks obstructed visibility while the data was collected. In addition, slippery conditions could create a potentially unsafe situation for pedestrians. With the exception of the crosswalks on Corydon Avenue, snowbanks in the vicinity of the crosswalks were approximately 2 to 2.5 meters high in some places and may have led to lower yielding rates than might be seen otherwise because approaching drivers could not see the crossing pedestrian early enough to anticipate the need to stop.

In order to examine the effect of weather conditions on driver yielding behavior in winter, data was collected at the GM1 crosswalk on Dakota street (site 1) on three different days (Jan. 3, Jan. 24, and Mar. 5, 2014). Each data collection day presented a different weather condition and provides some interesting context related particularly to the effects of extreme winter conditions on driver yielding behaviour.

Table 6 provides a summary of driver yielding rates on each day of data collection for the GM1 crosswalk at site 1. The data collection on January 3, 2014 took place during a heavy snowfall, with poor visibility and reduced vehicle speeds; the data collected on January 24, 2014 took place during a light snowfall; and the data collected on March 5, 2014 took place on a clear day with no snowfall. The data from March 5 was also used and presented in the above analysis, because the weather conditions were consistent with the rest of the sites.

Table 6: Immediate Yields at Site 1 GM1 Crosswalk in Winter Weather Conditions

Location	Weather Condition	Sample Size	Total: Immediate Yields	Pedestrian Location	
				Road Edge	Median
03-Jan-14	Heavy Snow	102	62%	51%	81%
24-Jan-14	Light Snow	100	56%	46%	76%
05-Mar-14	No Snow	106	50%	41%	69%

Figure 15 illustrates the changes in driver yielding rates on the different days of data collection. Interestingly, yielding rates were highest on the day with the most snowfall and poorest road conditions, and worst on the day with no snowfall and dry road conditions. The researchers noticed while conducting the data collection, and generally observing driver behaviours, that days with a new snowfall, slippery roads, and/or colder weather conditions had slower drivers and an increased driver yielding. This could be attributed to drivers being more cautious in extreme weather conditions. Another potential lurking variable in these results is the presence of snowbanks, which increased in height throughout the winter, creating drifts 2 to 2.5 meters tall along the edge of the road, as observed on March 5, 2014.

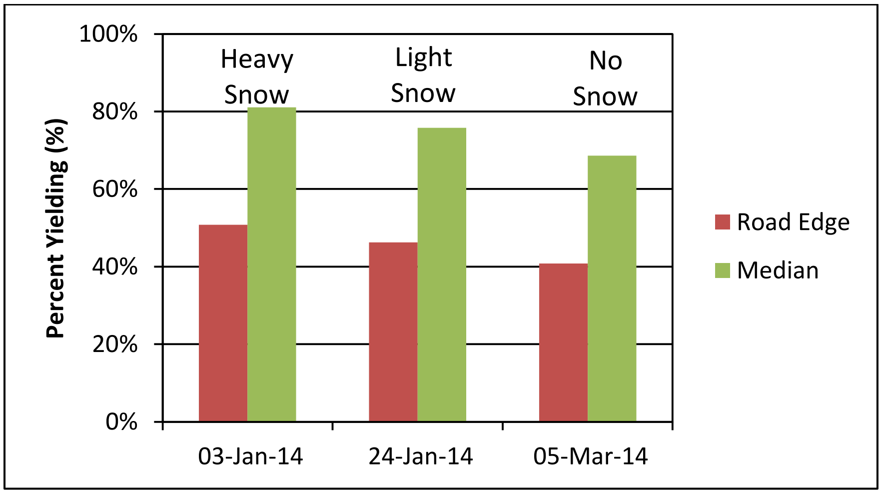


Figure 15: Percent of Immediate Yields by Date at GM1 Crosswalk at Site 1 (Dakota Street)

Overall, the analysis shows that for all sites, driver yielding rates were higher at OF crosswalks compared to GM1 crosswalks. In the case of GM1 crosswalks, driver yielding rates were generally higher for pedestrians completing the second stage of the crossing (from the median) compared to the first stage (from the road edge).

5 Conclusion

This paper provides evidence that crosswalks with overhead flashing devices (OF crosswalks) have higher driver yielding rates and in turn a pedestrian safety advantage over crosswalks with side mounted passive signs (GM1 crosswalks) on roadways with two lanes per direction and a raised refuge in Winnipeg.

The major findings in this research are as follows:

- OF crosswalks had higher average yielding rates (83 to 96 percent) than GM1 crosswalks (42 to 65 percent). The result agrees with previous research that driver yielding is low (17 to 52 percent) at crosswalks with side-mounted passive signs (GM1 crosswalks) [11]. The result also provides a narrower range of driver yielding rates for crosswalks with overhead flashing devices (OF crosswalks) than what has been reported in previous research (25 to 73 percent) [5].
- For GM1 crosswalks, crossing from the median resulted in higher yielding rates (about 65 percent) than crossing from the road edge (about 48 percent). For OF crosswalks, crossing from the median resulted in very similar yielding rates (about 89 percent) to crossing from the road edge (about 90 percent).

- Driver yielding rates increase as road conditions worsen (i.e., as the roads become more snow covered). This is likely due to lower vehicular speeds, and drivers being more cautious and focused on the driving task. However, this finding requires further investigation due to the limited data available.

This paper also demonstrates that driver yielding behaviour is complex and is influenced by many factors. Some of the factors that were identified as having a potential impact on driver yielding behaviour are:

- Presence and height of snowbanks
- The location of the pedestrian in the crosswalk, specifically, whether the pedestrian was at the edge of the road or on the median
- Site specific features such as the presence of a school, neighbourhood form, the geometry of the roadway, speed limit, the proximity to an intersection, the presence of parked vehicles, and the presence of trees
- Weather conditions

In summary, this paper provides evidence of a significant difference in driver yielding behavior and ultimately pedestrian safety OF crosswalks compared to GM1 crosswalks. This paper supports TAC's PCC Guide's recommendation that OF crosswalks be implemented on roadways with two lanes per direction, a raised refuge, 50 km/h speed limit, and annual daily traffic volumes greater than 9,000 (site 2, site 3, and site 4). In addition, this paper recognizes that the PCC Guide recommends that traffic signals be implemented on roadways with two lanes per direction, a raised refuge, 60 km/h speed limit, and annual daily traffic volume greater than 12,000; however, has found that the highest driving yielding rate (96 percent) among all the sites occurred at an OF crosswalk with those particular geometric and operational characteristics (site 1) [1].

Preliminary observations from this study show that driver yielding rates within a platoon are lower than immediate yield rates when the first vehicle does not yield. Further research could be completed to evaluate the effects of platooning on driver yielding behaviour, as well as driver yielding behaviour during summer months.

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