OPERATING PERFORMANCE OF AUTOMATED PEDESTRIAN DETECTORS AT SIGNALIZED INTERSECTIONS

BY

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ABSTRACT

The research analyzes the operating performance of three commercially available curbside automated pedestrian detectors (APDs) (infrared and stereovision, passive infrared, and a microwave detector) for the actuation of pedestrian walk phases as a function of winter weather and temperature variations at signalized intersections in terms of detector selectivity and sensitivity. Two sites were selected for field analysis in Winnipeg, Manitoba Canada. Based on a sample of 8,225 detections at the two sites, the research found that overall sensitivity rates of the APDs ranged from 62 to 98 percent while selectivity rates were generally below 50 percent. Regardless of site, the infrared/video APD had the second highest sensitivity and highest selectivity rates of all APDs analyzed. The infrared APD had the highest sensitivity and lowest selectivity rates, and the microwave APD had the lowest sensitivity and second highest selectivity.

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DEDICATION

This thesis is dedicated to the memory of Stephen Dudley Davies, P. Eng., a man whom demonstrated a life of service, dedication, and faith.

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

APD	Automated Pedestrian Detector
APS	Accessible Pedestrian Signals
°C	Degrees Celsius
CBD	Central Business District
FHWA	Federal Highway Administration
FCWM	Frequency Modulated Continuous Wave
IR	Infrared
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LED	Light Emitting Diode
MUTCD	Manual of Uniform Traffic Control Devices
MUTCDC	Manual of Uniform Traffic Control Devices for Canada
PDA	Personal Digital Assistant
PIR	Passive Infrared
PUFFIN	Pedestrian User-Friendly Intelligent Crossing
RPC	Required Pedestrian Call
TRB	Transportation Research Board
UK	United Kingdom
US$	United States Dollar

1.0 INTRODUCTION

1.1 THE RESEARCH

The research analyzes the operating performance of three commercially available curbside automated pedestrian detectors (APDs) as a function of winter weather and temperature variations at signalized intersections. The research defines the operating performance of the curbside APD's in terms of detector selectivity and sensitivity using performance indicators of valid, false and missed calls. Detector sensitivity refers to the ability of a detector to detect objects, usually pedestrians, in its field of view. Any pedestrian at the intersection that is not detected is considered a "missed call", and reduces the detector's sensitivity rating. Selectivity of an automated pedestrian detector refers to the ability to correctly differentiate between pedestrians requiring detection and other objects such as nearby slow-moving vehicles or debris. Any object that is detected other than a pedestrian requiring detection is considered a "false call", and reduces the detector's selectivity rating.

The APDs analyzed in the research are the: (1) AGD 640, manufactured by AGD Systems Ltd. based out the United Kingdom (UK); (2) Xtralis ASIM IR 207, formerly manufactured by ASIM Technologies Inc. in Switzerland, now owned by Xtralis; and (3) Smartwalk XP, manufactured by MS Sedco based out the United States.

1.2 BACKGROUND AND NEED

The equitable accommodation of pedestrians is a critical issue in transportation engineering and planning (Transportation Research Board 2006). “Over the next 4 decades, the number of Canadians living with mobility impairments will grow exponentially” (Canadian Institutes of Health Research 2010). With Canada's population aging steadily and the associated disability rate expected to rise significantly over the coming decade, accessible transportation and travel resources will be in increasing demand (Transport Canada 2007).

In Canada, the United States, and in many other countries, the requirement for accessibility in transportation comes from the statutes that these societies have enacted requiring equitable and reasonable accommodation for all (Mitchell and Suen 2001). In February 1997, November 2001, and April 2002, complaints were made to the Manitoba Human Rights Commission regarding the equitable accessibility provided to pedestrians with visual or physical impairments at signalized intersections in Winnipeg. The complaints addressed issues that pedestrians with visual or physical impairments experience when using signalized intersections. The issues experienced are the inability to see the “Walk/Don’t Walk” pedestrian signal indications, and the inability to find, push, and in some instances hold pushbuttons to provide accommodation for crossing the intersection.

The Manitoba Human Rights Commission found that this complaint represented “a systematic concern which affected many people who had not been able to cross the street safely or get around freely” at signalized intersections (City of Winnipeg 2008). An agreement between the Manitoba Human Rights Commission and the City of Winnipeg resulted, which included the installation of accessible pedestrian signals (APS) at all signalized intersections, the removal of pushbuttons in favour of fixed signal timings in prescribed city areas, and the commitment to study alternative practical technologies to pushbuttons. The first two aspects of the agreement are currently being implemented (APS and fixed signal timings at certain locations). The third aspect, however, requires the analysis and evaluation of technologies that are capable of identifying the presence of a pedestrian and calling the appropriate pedestrian signal.

Automated Pedestrian Detectors (APDs) require careful and verifiable evaluations to determine whether they are a viable option for pedestrian accommodation at signalized intersections. The performance of APDs is not well known or understood due to few evaluated implementations. In a 2008 Report to Congress, the Federal Highway Administration stated that “passive sensors [APDs] to recognize pedestrians and activate pedestrian assistance are in pre-deployment or developmental phasing”(FHWA 2008, pg 9). Furthermore, “in order for the technology to be advanced toward deployment, a major demonstration and validation effort must be undertaken to evaluate the benefits, reliability, costs and performance of passive pedestrian sensors [APDs]"(FHWA 2008, pg 12).

This research analyses the performance of intersection curbside APDs in terms of their sensitivity and selectivity.

This research forms the basis for future decision-making regarding the potential implementation of automated pedestrian detection at signalized intersections. The results from this analysis provide information to transportation engineers on how each studied APD works, and factors that should be considered when deciding whether to install an APD instead of a pedestrian pushbutton at signalized intersections. This research provides an analysis framework upon which subsequent research can compare the future developments of APDs, and it is one of the first of its kind to specifically analyze APDs in winter weather and temperature operation in North America.

1.3 OBJECTIVES AND SCOPE

The objectives and scope of this research are based on the following questions:

1. Does the APD actually work for pedestrian signal activation? This question is independent of further detailed analysis regarding the operating performance of APDs in comparison to classifications of pedestrians by age, physical ability, or impairment.

2. Does the APD accurately detect the presence and intention of a pedestrian to cross from an APD-monitored intersection pedestrian departure zone in the direction governed by the APD?

3. Are there any winter weather conditions or temperatures that negatively or positively affect the performance of the APD?

4. How does daytime APD operation compare to night-time operation?

5. What are the main reasons for false calls by each of the APDs?

The previous questions will be answered by meeting the following specific objectives:

1. Understand the latest developments regarding the types of technologies used in this research for pedestrian detection. This includes documenting research findings about the evaluation of APD technologies in jurisdictions which have implemented them, with particular emphasis on sensitivity and selectivity issues pertaining to winter weather and temperature at signalized intersections.

2. Design, develop, and implement a data collection program to identify the false, missed, and valid call detection rates for each APD technology being analyzed.

3. Identify the main intersection events that lead to false calls by each APD.

4. Identify engineering parameters associated with each of the analyzed APDs. The parameters identified are cost of the APD per observed departure zone, installation cost per observed departure zone, maintenance requirements, ease of installation, and performance of the analyzed APDs in winter conditions and temperatures.

5. Identify future research needs.

This research was conducted in Winnipeg, Manitoba. Winnipeg is a city with an estimated population of 675,000 in 2009 (City of Winnipeg 2010). For a city with a population over 500,000 people, Winnipeg is the coldest midwinter city in the world. (The Canadian Encyclopedia). The temperatures recorded during the research period range from -34°C (-29°F) to 0°C (32°F). The data analyzed in this research was collected over a five-month period starting in November of 2009 and concluding in March of 2010.

1.4 THESIS ORGANIZATION

This thesis is organized into five chapters. Chapter 2 discusses the traditional methods for pedestrian accommodation at signalized intersections, what automated pedestrian detection is, and how an APD works. The chapter summarizes findings from an environmental scan regarding the use and evaluation of APDs. The environmental scan is comprised of a literature review, international jurisdictional survey, and North American web survey completed by (Steindel 2009). An update to the environmental scan summarizes recent literature and jurisdictional use since February 2009.

Chapter 3 discusses the methodology developed and applied in this research to analyze the performance of APDs. The chapter describes the methodology for selecting the signalized intersections that were used to analyze the performance of the APDs. The chapter then presents the methodology for data collection.

Chapter 4 discusses the data analysis involving the performance of APD's in winter weather conditions, winter temperature, and in day or night conditions.

Chapter 5 discusses research findings and conclusions, and opportunities for further research.

1.5 GLOSSARY OF TERMS

The following terms are used throughout the thesis.

Analysis: The objective of analysis is to clarify the issues that should be considered by decision makers, to assist them in reaching a decision on a course of action. (Manheim 1979)

False Call: Sensor detects and sends call to signal controller when anything other than a valid detection occurs. Examples of false detections are:

- Pedestrians who have completed crossing, cross through the intersection and are detected by a sensor for the accommodation of crossing pedestrians in the opposing direction.

- Detected pedestrians who walk adjacent or within the sensor's observed detection zone but do not wait or cross in the direction governed by the tripped sensor.

- Vehicular traffic trigger a sensor's detection due to moving adjacent to the sensor's observed detection zone.

Missed Call: Sensor does not detect, and therefore does not send a call to the signal controller when a pedestrian intends to cross the intersection.

Pedestrian: This research defines pedestrians as any user of pedestrian infrastructure at a signalized intersection.

Selectivity: A measure of the performance of the detectors. It refers to the ability to correctly differentiate between pedestrians and other objects such as nearby slow-moving vehicles or debris. Any object other than a pedestrian that is detected is considered a “false call”, and reduces the detector’s selectivity rating.

Sensitivity: A measure of the performance of the detectors. It refers to the ability of the APD to detect objects, usually pedestrians, in its field of view. Any pedestrian at the intersection that is not detected is considered a “missed call”, and reduces the detector’s sensitivity rating.

Valid Call: Sensor detects and sends a call to the signal controller when a pedestrian who intends to cross the intersection, waits within detectors observed departure zone, and then crosses the intersection in the direction governed by the sensor.

2.0 PEDESTRIAN DETECTION AT SIGNALIZED INTERSECTIONS

This chapter presents a discussion about automated pedestrian detection. It begins with a discussion about pedestrian accommodation at signalized intersections, followed by a description about APD. It continues with a description of current APD technologies and their benefits, followed by a discussion about the current state of deployment worldwide. The chapter ends with a description of previous evaluations regarding APD.

2.1 PEDESTRIAN ACCOMMODATION AT SIGNALIZED INTERSECTIONS

The two common methods of providing accommodation to pedestrians at a signalized intersection are through the use of fixed signal phasing or with pedestrian actuated phases. In fixed signal phasing, the pedestrian phases are activated each cycle according to their assignment order. The activation of the pedestrian phase occurs regardless of whether a pedestrian is present or not. A signalized intersection using actuated pedestrian phases requires the detection of a pedestrian before the associated pedestrian phase is queued for activation.

Pushbuttons are reliable devices to detect pedestrians for pedestrian phase actuation at signalized crossings when the pedestrian is able to, and does, push the pushbutton. According to Zegeer, Opiela and Cynecki (1985), about half of all pedestrians use pushbuttons. In instances where the pedestrian cannot locate the pushbutton due to a visual impairment, or push and hold down the pushbutton due to a physical impairment, or even understand the function of the pushbutton, the applicability of the pushbutton for the accommodation of pedestrians is reduced.

The City of Winnipeg has accessibility design standards which outline the pedestrian infrastructure requirements at signalized intersections (City of Winnipeg 2006). These standards, which are currently in the process of being updated, include requirements for pushbutton orientation, pushbutton height, pole placement, sidewalk curb cuts and sidewalk ramps.

Pushbuttons can be located on poles directly adjacent to a crossing curbside, be located on the opposite side of the pole, in a place that conveys to the pedestrian that the pushbutton is for use in the perpendicular crossing direction, or on poles that are inaccessible to all pedestrians. Bentzen and Tabor (1998) list some questions related to pushbuttons that people who are visually impaired ask when approaching an intersection.

- Is there a need to push a button to actuate the walk interval? If so, where is the button?

- Is the button close enough to the crosswalk so that the pedestrian is ready to cross before the onset of the walk interval?

- Which button controls the walk interval for the street of interest?

- Does the pushbutton stop traffic on one street, or all traffic?

- Is there a second button that must be pushed that is on a median?

These issues result in the need to investigate other alternatives for the accommodation of pedestrians at signalized intersections. Various technologies are used to identify and accommodate the movement of vehicles through an intersection without any special action by the operator of the vehicle, except presence within an area of detection. Conversely, a pedestrian who approaches a signalized intersection must call the signal manually if a pushbutton is present. This may sometimes pose a significant challenge for certain types of pedestrians, particularly those with physical or visual impairments (Hughes, et al. 2001).

2.2 AUTOMATED PEDESTRIAN DETECTION

Automated pedestrian detection is the discovery of a pedestrian within a zone of detection by means of a mode or modes of detection that do not require direct physical interaction by pedestrians. Upon discovery of a pedestrian within the APD's zone of detection an electronic signal is sent to a signal controller. There are three different areas where APDs can be utilized. The APDs are designed for:

1. *Curbside detection at signalized intersections.* The APD monitors one or more departure zones at a signalized intersection. When a waiting pedestrian who desires to cross the intersection is detected within the associated APD's detection zone, a call is sent by the APD to a controller to queue the associated pedestrian signal phase for the pedestrian's eventual accommodation through the intersection.

2. *Curbside detection at flashing midblock pedestrian corridors.* The APD monitors one or more departure zones at a flashing midblock pedestrian corridor. When a waiting pedestrian who desires to cross the intersection is detected within the associated APD's detection zone, a call is sent by the APD to a controller to activate the flashing beacons for the pedestrian's accommodation across the roadway. This area of detection differs from curbside detection at a signalized intersection as pedestrian movements at a pedestrian corridor are typically less complex.

3. *Intersection crossing detection at signalized intersections or flashing midblock pedestrian corridors.* The APD monitors one or more intersection crossing zones at a signalized intersection or flashing midblock pedestrian corridor. When a pedestrian is detected within the APD's detection zone, a call is then sent by the APD. The time allotted to the pedestrian crossing phase can then be shortened or extended based upon the APD's detection

of the pedestrian's presence in the crosswalk, and the hardware and software of the onsite controller.

2.3 AVAILABLE TECHNOLOGIES FOR AUTOMATED PEDESTRIAN DETECTION

The literature identifies six categories of automated pedestrian detection technologies: ultrasonic, microwave-radar, infrared, piezoelectric, laser scanners and video image processing. They can be used individually or in combination with each other to detect pedestrians who want to cross the street at a signalized intersection, or to monitor their presence within a crosswalk (Steindel 2009).

APD technologies have varied installation requirements. Microwave, infrared, ultrasonic, and video detection devices are often installed on poles adjacent to the intersection at heights varying from 2.4 meters (8 ft) to 10.7 meters (35 ft) Piezoelectric mats are installed at ground level within a sidewalk's intersection crossing wait area (curb ramp), and lasers are typically installed in strategically placed bollards and in recessed in-pavement hardware.

The three technologies analyzed in this research are microwave Doppler radar, passive infrared (PIR), and stereo vision video combined with IR detection.

2.3.1 Microwave Doppler Radar Detection

Dharmaraju, Noyce and Lehman (2001) state that microwave radar detectors transmit electromagnetic radiation toward the area of interest from an antenna, mounted overhead or on the side, that illuminates approaching or departing objects. When an object passes through the beam, a portion of the transmitted radiation is reflected back to the antenna. The authors further explain that there are two types of microwave detectors. The first transmits a continuous wave of constant frequency and the change in frequency of the reflected wave is used to calculate the speed of the object. Detectors with such capability alone cannot detect motionless objects. However, detectors that are sensitive to very small motion are being developed. The second type of detectors transmit a saw-tooth waveform, also called frequency modulated continuous wave (FCWM), in which the transmitted frequency constantly changes. The FCWM provides both presence and passage detection. Figure 1 shows an image of the MS Sedco Smartwalk XP microwave detector.

Figure 1: MS Sedco Smartwalk XP

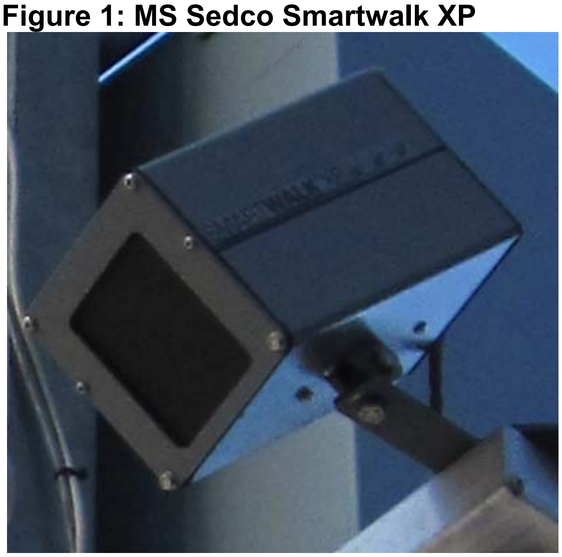


Photo by Jonathan Foord

2.3.2 Passive Infrared Detection

These detectors operate in a way similar to that of passive infrared (PIR) vehicle detectors except in application as both pedestrians and vehicles emit and reflect energy. According to Klein, Mills and Gibson (2006) passive [infrared] sensors transmit no energy of their own. Rather they detect energy from two sources: (1) energy emitted from vehicles, road surfaces, and other objects in their field of view and (2) energy emitted by the atmosphere and reflected by vehicles, road surfaces, or other objects into the sensor aperture. The energy captured by passive infrared sensors is focused by an optical system onto an infrared-sensitive material mounted at the focal plane of the optics. The infrared sensitive element then converts the reflected and emitted energy into electrical signals. Real-time signal processing is used to analyze the signals for the presence of a vehicle. Figure 2 shows an image of the Xtralis Asim 207 IR detector which uses passive infrared detection.

Figure 2: ASIM 207 IR Detector

Photo by Jonathan Foord

2.3.3 Video Image Processing

According to Bu et al. (2007), computer vision utilizes intelligent processing of digital images of pedestrians captured with a video camera to count [detect] pedestrians. The processor subtracts the static background from the image and then tracks the remaining objects to determine whether they are pedestrians.

As de Leon Izeppi et al. (2009) explain, computer stereo vision is achieved by using two cameras, separated by a small baseline distance, to take images of the same scene, very much like a person's eyes. A computer then compares the two images by making relative shifts, effectively placing one image on top of the other and translating them to find the parts that match. The shifted amounts are called the disparity values. The disparities at which objects in the images best match are used by the processing software to calculate their distances from the camera.

The addition of IR detection with video image processing allows an APD to detect pedestrians in low light conditions. Bu and Chan (2005) state that an infrared camera is not that sensitive to the change of lighting condition and that the advantage of an infra-red sensor is the ability to detect pedestrians without illuminating the environment. Figure 3 shows an image of the AGD 640 detector which combines infrared detection with stereovision.

Figure 3: AGD 640 Detector

Photo by Jonathan Foord

2.4 APD TECHNOLOGY DEPLOYMENT WORLDWIDE

A study for the U.S. Department of Transportation about innovative intersection safety practices within the United States found that few jurisdictions are either using or testing technologies for the automated detection of pedestrians (Hughes, Chappell, and Chen 2006). The study concludes that "passive detection technology for pedestrians is still not developed enough for nationwide use. However, the technology offers promise for the future in terms of enhancing pedestrian safety."

Steindel (2009) conducted a comprehensive survey to investigate the extent of use and current experience with automated pedestrian detection in various jurisdictions worldwide. The survey found that a number of APD technologies have been deployed in Europe, Australia, New Zealand, and at select sites throughout the United States. With respect to the use of individual types of technologies for pedestrian detection, the survey found that piezoelectric sensors are currently used in the U.S. mainly for in-pavement light activation.

Video image processing is used in the UK and the U.S. for a wide range of applications (e.g., to activate flashing beacons or to extend pedestrian phases). Infrared technology is being applied or tested for pedestrian detection in Sydney, Australia; Auckland, New Zealand, the UK; and some cities in the United States. Microwave radar technology is the most commonly used for automated pedestrian detection. A number of jurisdictions have used or tested microwave technology for pedestrian detection, including Portland, Oregon; Las Vegas, Nevada; Tucson, Arizona; London, England; Ottawa, Ontario; and Phoenix, Arizona.

One of the most successful applications of automated pedestrian detection technologies has been in the UK, with the implementation of Puffin pedestrian crossings, with over 4,000 existing installations currently in the UK (Maxwell, Kennedy, and Routledge 2010). The "Pedestrian User Friendly Intelligent crossing" (PUFFIN) uses both curbside (kerbside) and crossing detection technologies in conjunction with pedestrian pushbuttons for pedestrian accommodation at the crossings. The APDs used in PUFFIN crossings are for call cancellation rather than phase actuation. If a pedestrian is detected and a pushbutton is pushed the pedestrian corridor will eventually activate. If the pedestrian leaves the APD detection zone and is no longer detected prior to the crossing phase the crossing phase call is cancelled. (Steindel 2009) states that the technologies used at PUFFIN crossings are being studied for their application at signalized intersections.

According to Steindel (2009), in the U.S. and Canada, 22 jurisdictions currently use APD for various purposes such as to activate flashing beacons, in-pavement lights, and pedestrian phases; to extend pedestrian phases, and to count pedestrians. The most common applications of APD are to activate in-pavement lights and to activate flashing beacons.

According to Steindel (2009), none of the responding Canadian jurisdictions currently use APDs, except for Ottawa, Ontario. Ottawa conducted a curbside operational test of an APD at two intersections. The jurisdiction is waiting until further APD improvements are available before further testing due to the false detection rates caused by debris and parallel traffic, and the time to setup and maintain the APDs.

From discussions with AGD Systems in the UK at the end of 2009, countries such as Ireland, Thailand, Singapore, France and the Czech Republic have purchased, or expressed interest in using AGD's APD systems.

2.5 SENSITIVITY AND SELECTIVITY OF APDS

The literature reveals that there have been few field evaluations or analyses on the performance of APDs. The field evaluations that have been conducted tend to focus on curbside detection at flashing mid-block corridors (with or without roadway crossing detection). This lack of field investigations also applies to APD performance based on sensitivity and selectivity.

Beckwith and Hunter-Zaworski (1997) analyzed the operating performance of passive infrared, microwave, and ultrasonic APDs along a sidewalk next to a bus stop in Portland, Oregon. The rates of false, valid, and missed calls are shown for each of the technologies in Table 1.

Table 1: Portland, Oregon Preliminary Test Results

Sensor	False Calls (%)	Detection [Valid] (%)	No Detection [Missed] (%)	Total Pedestrians Detected
Ultrasonic at long range	8	47	45	87
Ultrasonic at close range	8	89	3	97
Doppler Radar	1	92	7	126
Passive Infrared at close range	4	96	-	75
Passive Infrared at long range	5	94	2	134

Source: Beckwith and Hunter-Zaworski (1997)

Further testing by Beckwith and Hunter-Zaworski (1997) of a passive infrared curbside APD and microwave crossing APD were conducted at an intersection in Portland. This testing analyzed the detector reliability while observing pedestrians crossing as a function of weather conditions. Initial results of 60 crossings were presented for the microwave APDs with all pedestrians detected while crossing. The microwave APD remained on during heavy rain.

Hughes, et al. (2001) evaluated the operating performance of microwave and infrared APDs for the accommodation of pedestrians at the curbside and in the crosswalk of signalized intersections in the cities of Rochester, New York; Phoenix, Arizona; and Los Angeles, California. A false detection rate of 48 percent, and missed detection rate of 12 percent were recorded for the SmartWalk 1400 detector testing in Phoenix. Continuous calls by the detector occurred during heavy rain events.

Turner, et al. (2007) evaluated two APD intersection systems at a test location in College Station, Texas. The MS Sedco Smartwalk 1400 and 1800 microwave detectors and the ASIM 201 and 207 passive infrared detectors operating performance were evaluated for the curbside and crosswalk detection of pedestrians at a signalized intersection. The curbside departure zones of the test intersection location are separated and well defined by grass zones. No information is given regarding weather and temperature operating performance. Table 2 illustrates the evaluation results of the APDs by installed area.

Table 2: Texas APD Evaluation Results

Test Location	Sample Size	Overall Error Rate (%)		Missed Detection (%)		False Detection (%)	
		ASIM	SEDCO	ASIM	SEDCO	ASIM	SEDCO
Northwest corner: red zone	2,752	25	30	17	22	8	7
Northwest corner: red & yellow zone	2,752	25	31	22	31	3	0
Southwest corner	2,752	9	11	7	10	2	1
North crosswalk	750	22	23	10	14	13	9
South crosswalk	750	32	39	17	27	16	13

Source: Turner et al. (2007)

Based on a survey conducted by Steindel (2009), Table 3 and Table 4 illustrate findings from 22 responding North American jurisdictions about the noted and perceived APD sensitivity and selectivity by detector type.

Table 3: APD Sensitivity by Detector Type

	% Pedestrians Detected	Detector Type							Total
		Infrared	Video	Microwave	Pressure Mat	Laser Radar	Heat Sensor	No Answer	
Better ↑	91 - 100%	4	3	1		1			9
	81 - 90%				1				1
	71 - 80%	1	1	1					3
	61 - 70%								0
	51 - 60%	1							1
	Unknown		1	2	2		1		6
	No Answer							7	7
	Total	6	5	4	3	1	1	7	27

Note: Does not add up to 22 because some jurisdictions use more than one technology.

Source: Steindel (2009)

Table 4: APD Selectivity by Detector Type

	% False Activations	Detector Type							Total
		Infrared	Video	Microwave	Pressure Mat	Laser Radar	Heat Sensor	No Answer	
Better ↑	Under 10%	4	4		2	1			11
	11 - 20%		1						1
	21 - 30%			1					1
	41 - 50%			1					1
	51 - 60%	1		1					2
	Unknown				1		1		2
	No Answer							9	9
	Total	5	5	3	3	1	1	9	27

Note: Does not add up to 22 because some jurisdictions use more than one technology.

Source: Steindel (2009)

According to Steindel (2009), responses to the APD web survey indicate that main sources of APD operating malfunctions are:

- Vandalism or damage
- Inclement weather
- Installation flaws

2.6 SUMMARY

This section summarizes the material in this chapter:

- There are three different areas where APDs can be utilized for pedestrian accommodation: (1) curbside detection at signalized intersections; (2) curbside detection at flashing midblock pedestrian corridors; and (3) crossing detection at signalized intersections or flashing midblock pedestrian corridors.

- APD technology is still not developed enough for system wide use. However, it offers promise for the future. Intensive field and laboratory research is needed to assess APD in general.

- A number of APD technologies have been deployed in Europe, Australia, New Zealand, and at select sites throughout the United States. The most common applications of APD are to activate in-pavement lights and to activate flashing beacons.

- There have been few field evaluations on the performance of APDs. The field evaluations that have been conducted have focused on curbside detection at flashing mid-block corridors (with or without roadway crossing detection). This lack of field investigations also applies to APD performance based on sensitivity and selectivity.

- APD systems are in a state of evolution, with no technologies that are clearly better than others. For this reason, it is important to conduct a major demonstration and validation effort to evaluate the benefits, reliability, costs, and performance of passive pedestrian sensors before full-scale deployment in the U.S. (and Canada).

3.0 RESEARCH METHODOLOGY

This chapter discusses the methodology developed and applied in this research to analyze the performance of APD technologies. The chapter presents the following: (1) background for the selection of the technologies to be analyzed; (2) methodology for selecting the signalized intersections and curbside pedestrian departure zones that were used to evaluate the performance of APDs; and (3) methodology for collecting, processing, and analyzing data on APD calls and associated weather conditions at designated detection zones at signalized crossings.

3.1 SELECTION OF TECHNOLOGIES FOR ANALYSIS

Steindel (2009) researched current technologies available to detect pedestrians at signalized intersections. Based on Steindel's recommendations, the following three curbside detectors were selected for this research:

- AGD 640 – Infrared and Dual Digital Vision.
- Xtralis Asim IR 207 – Passive Infrared
- MS Sedco Smartwalk – Microwave Radar (K-Band)

A large component of this research involved understanding each of these technologies and identifying a mechanism by which they could be acquired for testing in Winnipeg. Extensive communication was held with each of the technology manufacturers over a period of approximately six months to ensure that the correct products were obtained for testing, and that once they arrived in Winnipeg, they would be properly installed for data collection. While Steindel (2009) provided good theoretical information about each of these devices, it was important to apply this theory with a good understanding of the mechanisms involved with the simultaneous operation of the three devices during testing.

The AGD 640 is the next generation curbside pedestrian detector produced by AGD Systems which supersedes the AGD 625. The company, AGD Systems, which is located in the United Kingdom, released the AGD 640 for full production at the end of 2009. The selection of current technology is important for the relevance of the research, therefore the testing of the AGD 640 by means of final prototypes was favoured over the available, but soon to be dated, AGD 625.

The AGD 640 improves upon the previous design of the AGD 625 by creating a unit that reduces the size and weight of the detector. The new design incorporates improved setup tools which make the installation easier, while adding a motion jpeg camera for stereovision, increased shadow rejection capability, advanced embedded processing, and a combination of both serial and Bluetooth connection capabilities for laptop and personal digital assistant (PDA) connectivity and setup.

The Asim IR 207 detector uses passive infrared detection to measure the temperature changes within its area of detection to detect pedestrians who desire to cross the signalized intersection. ASIM Technologies was acquired by Xtralis Ltd. in April of 2007 (Pacific Equity Partners 2007).

The MS Sedco Smartwalk XP curbside pedestrian detector is a microwave detector manufactured by MS Sedco of the United States. The Smartwalk XP detector uses micro-processed Doppler microwave technology that operates at the same 24.125 GHz frequency as speed radar guns commonly used by law enforcement agencies. The Smartwalk XP is the updated version of the Smartwalk 1400. The Smartwalk XP detector includes hardware and software updates to assist in minimizing false detections from adjacent moving vehicles.

Table 5 provides a specification comparison for each of the analyzed detectors. These specifications are based on information provided by each manufacturer as a result of the test requirements. Although two of the detectors have stated operating temperatures higher than the lowest temperatures commonly experienced in Winnipeg, Manitoba, these detectors were still selected for analysis as they were determined to have the greatest potential of currently available APDs.

Table 5: Specifications by Curbside APD

Manufacturer	AGD	MS Sedco	Xtralis
Device	AGD 640	Smartwalk XP	Asim 207 IR
Technology	Infrared and Stereoscopic Video	K-Band Microwave	Passive Infrared
Mounting Height	3 to 5 meters	3.05 to 3.7 meters	3 to 5 meters
Exterior LED Indication	Detect, Bluetooth Connection	Internal LED	Internal LED
Weight	600 g	1800 g	700 g
Housing Material	Polycarbonate	Powder Coated Aluminum	Anodised Aluminum
Seal	IP66	Not Stated	IP53
Operating Temperature	-20°C (-4 °F) to 60°C (140 °F)	-30°C(-22 °F) to 70°C (158 °F)	-40°C (-40 °F) to 70°C (158 °F)
Power Supply	24 VAC/DC	12 to 24 VAC/DC	10.5 to 26 VDC
Detection Output	Single Pole Double Throw (SPDT) Relay	SPDT Relay	SPDT Relay
Device Configuration	Bluetooth or Serial Cable Connection w/ Software	Internal Dials and Switches	n/a
Onset Delay	User Defined (increments of 200 ms)	User Defined (0.1 to 10 seconds)	n/a

n/a refers to not available

3.2 SELECTION OF SITES FOR DATA COLLECTION

This research was conducted in Winnipeg, Canada, a city with an estimated population of 675,000. Winnipeg has an average daily temperature for the month of January of -18°C (- 0.4°F), based on Environment Canada data from 1971 to 2000. Table 6 provides other average winter climate statistics for Winnipeg based on the same years.

Table 6: Winnipeg Winter Climate Statistics

Coldest Temperature (Recorded)	- 45°C (-49°F)
Daily Temperature Average (Nov. - Mar.)	-5°C (23°F)
Average Temperature (Coldest Month: Jan.):	-17.8°C (0°F)
Days Below Freezing (0°C (32°F)) (Year)	194
Annual Average Snowfall:	110.6 cm
Wind Speed Average (Year)	16.9 km/hr (10.5 mph)
Maximum Wind Speed (Recorded: Nov. - Mar)	129 km/hr (80.1 mph)

Adapted from Environment Canada: Canadian Climate Normals for 1971-2000, Winnipeg Richardson International Airport, Manitoba. (Environment Canada)

Two sites were selected for this research in consultation with City of Winnipeg Traffic Signals Branch engineers and manufacturers of the different technologies being tested. The two sites, which are located in the central business district of Winnipeg, were chosen based on their intersection characteristics, availability of suitable traffic signal poles, and specific environmental conditions. Each location has predominately captive pedestrian flows, and nearby transit stops and establishments that are open after sunset. Each location has the availability for shadows due to large structures and buildings in the vicinity, and has limited wind shelter. The research developed and applied the criteria shown in Table 7 to select the two sites for the APD field analysis. Land use characteristics around each intersection were used to account for the availability of pedestrian crossing flows given that available pedestrian traffic counts were limited, or dated.

Table 7: Selection Criteria of Field Analysis Locations

Intersection Characteristics	***Captive Pedestrian Flows***	Locations are favoured where walking is done predominately by necessity rather than for leisure due to the availability of pedestrian calls during extreme winter temperature and weather conditions.
	Nearby Bus Stops	Bus stops near an intersection may contribute to increased pedestrian crossing flows as pedestrians travel to and from a bus stop.
	Nearby Establish - ments that are Open at Night	Establishments near an intersection may contribute to increased pedestrian crossing flows as pedestrians travel to and from an establishment. Establishments open at night provide the availability of pedestrian calls during low light conditions. Examples of establishments that attract pedestrians at night are universities, restaurants, shopping centres, movie theatres, concert halls, and sport stadiums.
	Parking for Data Collection	A direct Ethernet connection from the APD mounting pole to a vehicle is required to collect data from the intersection.
Departure Zone Characteristics	***Dual Pedestrian Crossing Directions***	Pedestrians are able to cross the intersection in two governed directions. Cross pedestrian flows may induce detection and false calls. The availability of cross pedestrian flows within an APD detected zone differentiates the APD's use from curbside pedestrian corridor detection.
	Curb Ramp Styles	There is an array of intersection curbside geometries within Winnipeg. Two common intersection corner designs are selected. (1) Dual pedestrian crossing directions governed by a single diagonal curb ramp. (2) Dual pedestrian crossing directions governed by separated individual curb ramps.
Pole Characteristics	***Straight Pole***	Existing 3 meter (10 ft) straight poles are exchanged for 5.5 meter (18 ft) straight poles to provide sufficient mounting height for the video camera and space for the mounting onsite data collection enclosure. The use of poles with davit arms are not selected due to the mounting heights required for the video camera and increased loading induced by the camera and data collection enclosure on the pole.
	Adjacent to Curbside Departure Zone	The APDs are mounted to the pole directly adjacent to the departure zone. The performance of the APDs is reduced if the line of sight between the placement of the APD on the pole and the observed departure zone is obstructed by other street infrastructure or by pedestrian flows in the cross direction.
	Minimal pre-existing hardware	Space is required to mount the APDs with an unobstructed departure zone view and to mount the data collection equipment.
	Available Power	Power is required to operate the APDs and the data collection equipment.
	Traffic Signal Use	Un-decorative poles used solely by traffic signals are only considered to minimize coordination with other utilities.
Environ - mental Conditions	***Availability of Shadows***	Shadows may result in false calls due to changes in the observed heat and visual imagery within an APD's zone of detection.
	Availability of Wind Gusting	Wind may induce movement of the mounted APDs which may affect the performance of the APDs.

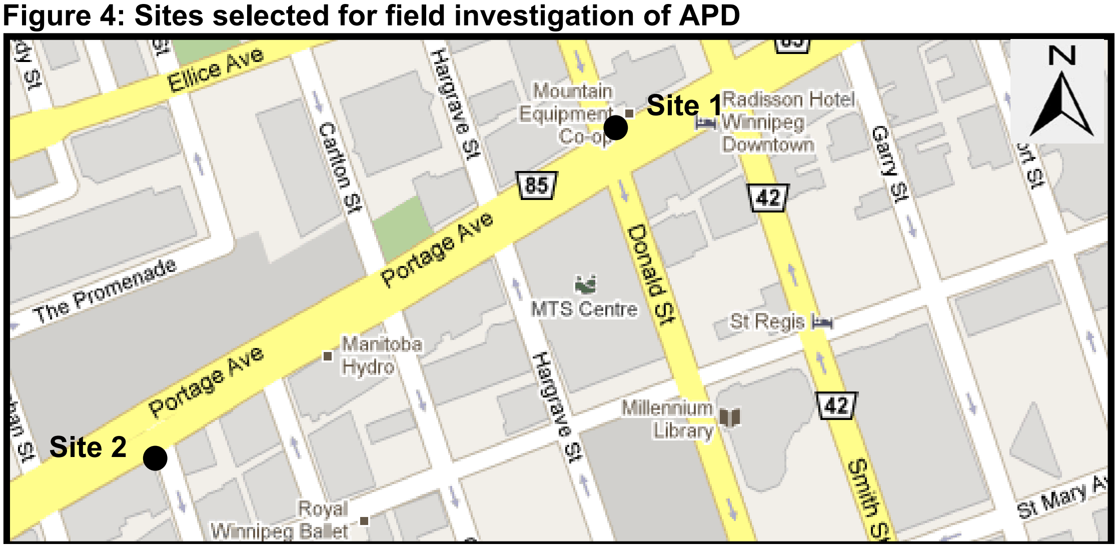
In the selection of the two sites, multiple intersections throughout Winnipeg were identified and visited during the summer of 2009. Using the criteria listed in Table 7 two intersection curbside wait areas were selected for the field analysis of the APDs. The two intersection curbside wait areas selected are:

- Donald Street and Portage Avenue – Northeast corner curbside accommodating westbound pedestrian crossings. This intersection has dual separated curb ramps.

- Kennedy Street and Portage Avenue – Southwest corner curbside accommodating eastbound pedestrian crossings. This intersection has a single diagonal curb ramp.

The two sites are identified in Figure 4.

Figure 4: Sites selected for field investigation of APD



3.2.1 Donald Street and Portage Avenue

The selected curbside wait area for APD field analysis is located on the northeast corner of the intersection of Portage Avenue and Donald Street for the northeast to northwest pedestrian intersection crossing movement. The curbside geometry on the northeast corner of Donald Street and Portage Avenue has dual separated curb ramps for two directions of governed pedestrian crossing.

This selected curbside wait area is located in the central business district (CBD), diagonally across from the city's main concert and sporting event facility, the MTS Centre. The MTS Centre with over 15,000 seats is an entertainment, sports, performing arts, and community events facility which attracts day and night-time pedestrian flows during events year round. Portage Place Mall, a major shopping centre in Winnipeg, is located three blocks west. The availability of commercial and business activity in the CBD contributes to pedestrian crossings at the intersection.

This intersection corner wait area was selected for the following reasons.

- Dual pedestrian crossing directions each with separated curb ramps.

- The potential for pedestrian crossings during the day and night.

- Pedestrian crossings that are mainly necessity-based.

- Availability of shadows to be present within the APD observed wait area from adjacent buildings.

- Open space providing the potential of wind-induced movement of the selected intersection pole and mounted APDs.

- Unshared and non-decorative 3 meter (10 ft) straight traffic signal pole with limited hardware.

- Hardware currently on pole includes one pedestrian head for the northbound pedestrian crossing, two street name signs, and signs indicating hours where left turns are not permitted.

- Traffic signal pole for APD mounting is adjacent to the intended zone of detection.

- Close proximity to a bus stop.

- Availability of nearby parking for data collection.

Figure 5 illustrates the curbside geometry of the intersection with clear sidewalk widths, and intersection crossing distances in meters. Figure 5 also presents pictures of the detected curbside wait area and the APDs with installed data collection equipment.

Figure 5: Intersection of Donald St & Portage Ave

Note: Intersection drawing created from City of Winnipeg CAD and Ortho data (left), photo facing east from the northwest corner (middle), photo facing south from the northeast corner (right).

3.2.2 Kennedy Street and Portage Avenue

The selected curbside wait area for APD field analysis is located on the southwest corner of the intersection of Kennedy Street and Portage Avenue for the southwest to southeast pedestrian intersection crossing movement. The curbside geometry at the southwest corner of Kennedy Street and Portage Avenue has a single diagonal curb ramps for two directions of governed pedestrian crossing.

The intersection of Kennedy Street and Portage Avenue is located directly across from the main entrance of the Portage Place Mall. The Portage Place Mall is a major shopping centre in Winnipeg. Located three blocks east is the city's main concert and sporting event stadium, the MTS Centre. Pedestrian flows are also influenced by the commercial and business activity in the CBD.

This intersection corner wait area was selected for the following reasons:

- Dual pedestrian departure directions from a single diagonal curb cut.

- The potential for pedestrian crossings during the day and night.

- Demand-based pedestrian crossings.

- Availability of shadows to be present within the APD observed wait area from adjacent buildings.

- Open space providing the potential of wind induced movement of the selected intersection pole and mounted APDs.

- Unshared and non-decorative 3 meter (10 ft) straight traffic signal pole with limited hardware.
- Hardware currently on pole includes one pushbutton, one accessible pedestrian signal, one pedestrian signal head for one direction of travel and one street name sign.

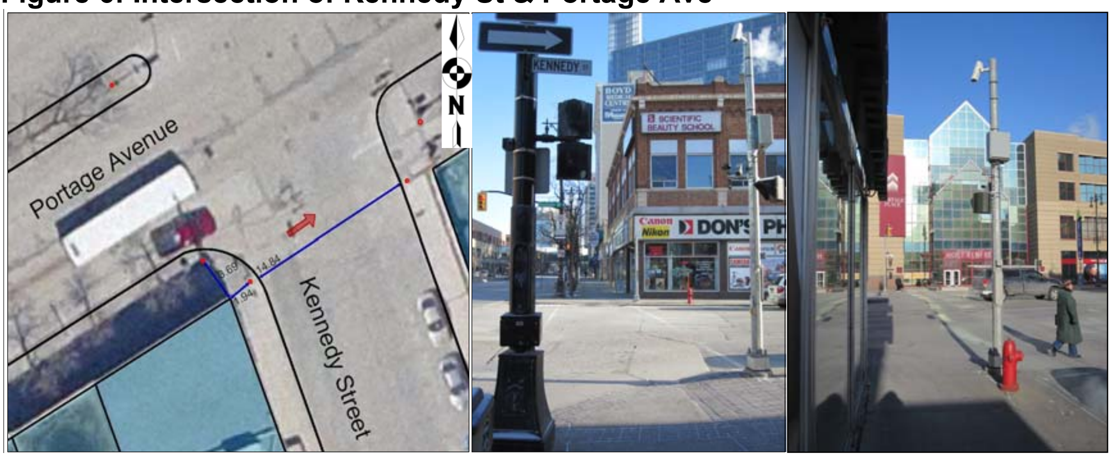
- Traffic signal pole for APD mounting is adjacent to the intended zone of detection.

- Close proximity to a bus stop.

- Availability of nearby parking for data collection.

Figure 6 illustrates the curbside geometry of the intersection with clear sidewalk widths, and intersection crossing distances in meters. Figure 6 also presents pictures of the detected curbside wait area and the APDs with installed data collection equipment.

Figure 6: Intersection of Kennedy St & Portage Ave



Note: Intersection drawing created from City of Winnipeg CAD and Ortho data (left), photo facing east from the southwest corner (middle), photo facing north from the southwest corner (right).

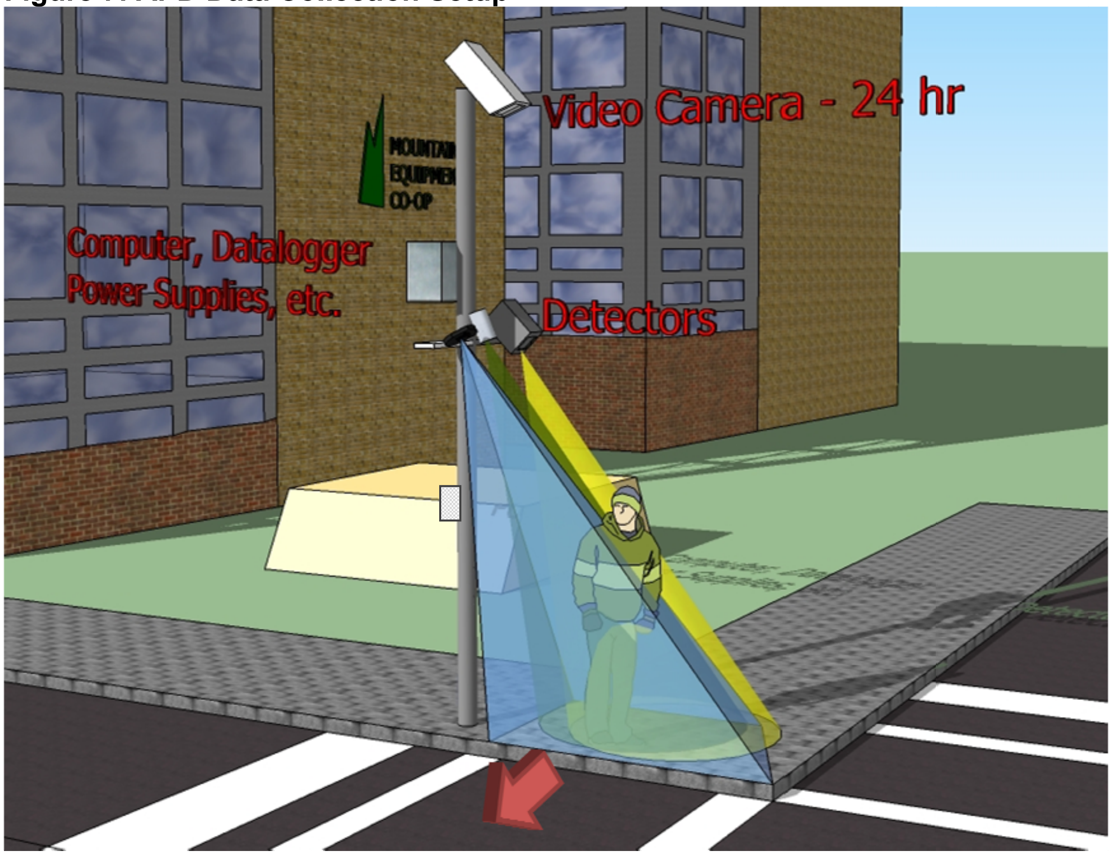
3.3 DESIGN OF A DATA COLLECTION SYSTEM

The evaluation of the operating performance of APDs requires a reproducible procedure and a data collection equipment setup that ensures that future evaluations of any APD changes can be compared to prior results.

3.3.1 Field Equipment Setup

All three detectors at each of the two locations were installed in September 2009, and functioned independent of signal operation to avoid potential problems created by interference with the signal controller. The design of the evaluation setup required that each APD have equal opportunity to monitor the same intersection crossing wait area. Each APD was installed with the manufacturer's instructions and installed as to avoid interference from other detectors or data collection equipment. Interference between detectors can occur when one detector is mounted in a way that diminishes or hampers another detector's field of view. Figure 7 illustrates the typical setup for the detectors including the pedestrian crossing direction as indicated by a red arrow. APDs are not manufactured to a uniform standard for detection zone dimensions, shape or area, and have varying installation requirements, detection modes, and configurability. Figure 7 illustrates the approximate detection zones for each APD by color (infared/video– blue, infrared – green, and microwave – yellow).

Figure 7: APD Data Collection Setup

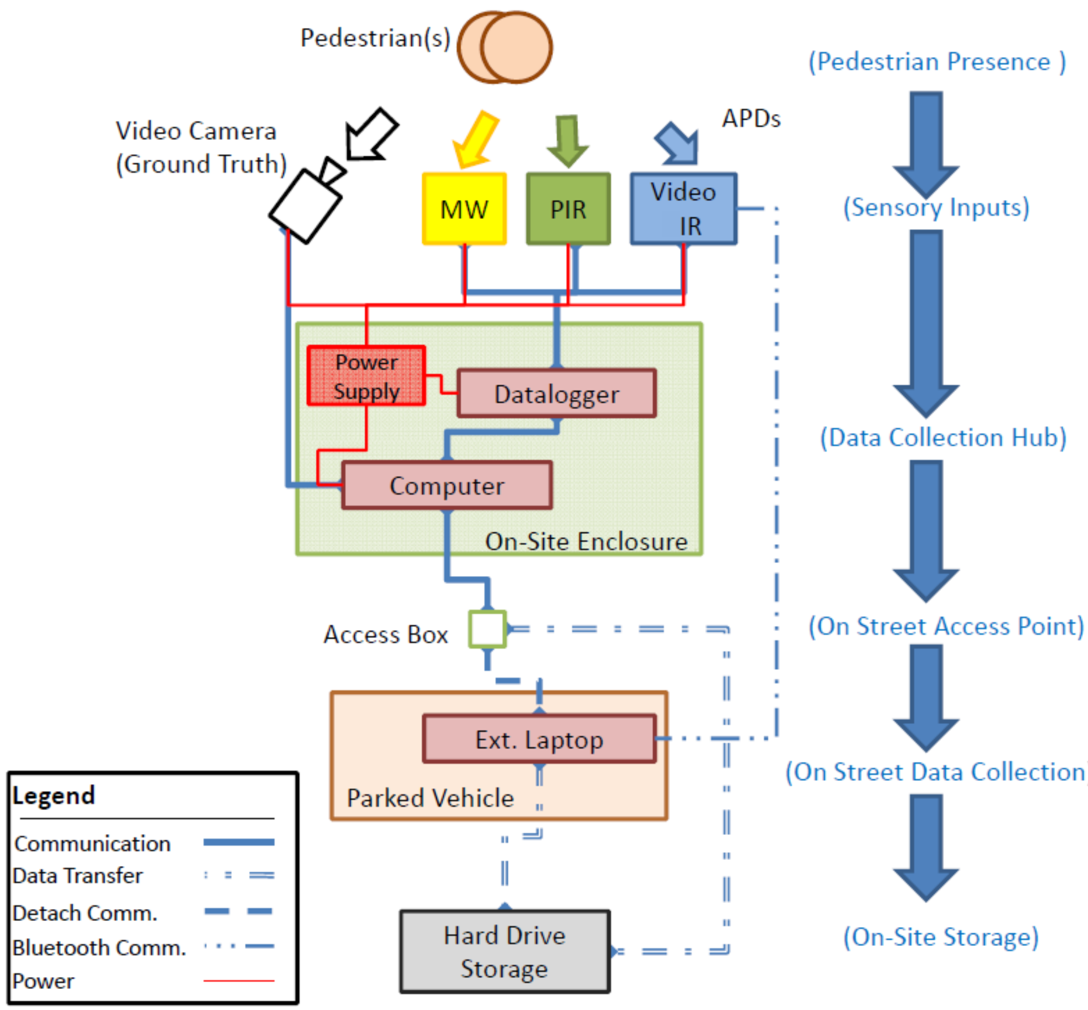


3.3.2 Field Data Collection

The installed APDs monitor the curbside crossing wait area 24 hours a day, seven days a week. Ground truth (i.e., call verification) is provided by continuous digital video recording of the intersection curbside.

As Figure 8 illustrates, once a pedestrian arrives at the APD observed curbside of the signalized intersection the pedestrian's activity is recorded by a continually running digital video camera. The datalogger located inside the onsite data collection enclosure scans the electrical outputs of the APDs for pedestrian calls. The call status of each APD is recorded with a corresponding time-stamp by the datalogger on the datalogger's internal memory. Video data from the digital video camera is stored on the hard drive of the onsite computer for weekly retrieval. The datalogger is connected to the onsite computer using a serial (RS-232) connection to enable the collection of the APD call data from the datalogger's internal memory and to view the real-time call status.

Figure 8: APD Data Collection Schematic



The onsite computer has an Ethernet and USB cable wired to an access box accessible at street level to facilitate the networking of an external laptop and transference of data to a high capacity USB flash drive. The video and APD call data is collected weekly through the use of remote computer control software accommodated by the direct Ethernet network connection from the onsite computer to the external laptop. Once the video and APD call data have been exported to the USB flash drive the data is transferred to an off-site location for processing, analysis, and secure storage.

Table 8 provides a sample of APD call data collected by a datalogger in December of 2009. The datalogger scans the APDs' call output every second. When the datalogger receives an electrical signal representing an APD call, a value of '1' is recorded in the column associated with the APD that is active. When a call event is recorded, the call state of each of the other detectors is also recorded. When an APD is not sending a call a '0' is recorded. The 'IR_ON' column represents the infrared detector's call activity, the 'MW_ON' column represents the microwave detector's activity, and the 'AGD_ON' column represents the activity of the infrared/video detector. The datalogger does not store a record in instances when all APDs are not sending a call in order to maximize storage time period available according to the datalogger's fixed internal memory.

Table 8: APD Datalogger Detection Log

TIMESTAMP	IR_ON	MW_ON	AGD_ON
12/12/2009 10:34:24 AM	1	1	0
12/12/2009 10:34:25 AM	1	1	0
12/12/2009 10:34:26 AM	1	1	0
12/12/2009 10:34:27 AM	1	1	1
12/12/2009 10:34:28 AM	1	1	1
12/12/2009 10:34:29 AM	1	1	1
12/12/2009 10:34:30 AM	1	0	0

Notes:
IR_ON indicates that the IR 207 detector is sending a call when the value = "1" and not sending a call when the time stamped value = "0"
MW_ON indicates the call status for the MS Sedco Smartwalk XP detector
AGD_ON indicates the call status for the AGD 640 detector.

Figure 9 illustrates the field of view recorded by the video camera at the intersection of Donald Street and Portage Avenue. The video data image quality is intentionally reduced by compression to avoid the identification of pedestrian users at an intersection. This compression enables a week duration of video data storage, and ensures adherence to the ethics approval for the field analysis. Ethics approval was attained from the Nursing and Education Research Ethics Board at the University of Manitoba prior to commencement of the field analysis.

The video camera and datalogger are both connected to the onsite computer. The onsite computer's date and time are referenced by both the video camera and datalogger to maintain clock synchronization of video and APD call data. The clock synchronization enables the analysis of APD performance by comparing video data to corresponding APD call data.

Figure 9: Sample Video Data Screenshot (Donald St & Portage Ave)

3.3.3 Weather and Temperature Data collection

The weather data was collected from the Environment Canada website (www.ec.gc.ca) for Winnipeg as referenced by Winnipeg's airport, James A. Richardson International Airport. Special programming was implemented to scan the Environment Canada website for Winnipeg temperature and weather and to record the changes to the current weather and temperature as the website was updated. The following information fields were recorded. Date and time of the updated weather information, sunrise and sunset times, weather condition, pressure, wind direction, wind speed, wind gusting speed, wind chill, temperature, and humidity.

3.4 DATA SAMPLING AND REVIEW

A sample size of 100 calls per weather, temperature, or temporal condition of interest (i.e., cloudy, sunny, fog, rain, temperature, day, night, and other combinations) provided the resolution for the ground truth comparison review. The sample size is found by using the following equation:

$$Sample\ Size = \frac{Z^2 * (p) * (1 - p)}{C^2}$$

Where “Z” = 1.96 (for 95 percent confidence), “p” = 50 percent (0.5) for the worst case scenario, and “C” = the desired confidence interval percentage in decimal format (in this research C = 0.1).

A smaller confidence interval is expected when all weather, temperature, and temporal conditions are computed for overall sensitivity and selectivity performance due to the increased sample size.

After the video and datalogger data was collected from the field, the data was processed before a ground truth comparison review occurred. The processing of the data involved:

- Copying the APD datalogger data from its original file format to formatted cells in a spreadsheet.

- Merging the weekly data spreadsheets into a single spreadsheet, sorted into ascending records by date and time.

- Running a macro program that copied the associated weather record to each recorded APD record according to the date and time of the APD record.

- Saving the combined APD datalogger data and weather data to individual monthly spreadsheets.

The ground truth comparison review was accomplished by comparing individual hours of APD datalogger data to the corresponding video data. Automated review of the APD datalogger data to the corresponding video data would require the capability to extract pedestrian movement from the video data. Manual review was employed to ensure the accuracy of valid, false, and missed call identifications as any automated extraction of pedestrian movement data from the video data would be prone to the same errors and limitations of the APDs employed.

To ensure that representative data was sampled from the entire winter period the following sampling controls were used.

- Each month of data was divided into thirds and assigned to a data reviewer (i.e., a person doing the manual data processing).

- The data reviewer was then required to independently select individual hours that included the following:
    - o The coldest temperature within the third of a month segment followed by increasing increments of 5 °C
    - o Hours when weather conditions were stated as snowing, foggy, sunny, partly cloudy, cloudy, clear, or freezing ice.

- Additionally, the hours selected were to be balanced between daytime hours and night-time hours as defined by Environment Canada's stated sunrise and sunset time for a given day, and selected in nonconsecutive hours throughout the assigned third of a month.

Each hour of data required two to four and one-half hours to review, depending on the number of calls made, which is a function of intersection curbside activity (pedestrian and vehicular). A budget of 500 hours was available for data review. To best answer the objectives of the research, the hours of data compared for the Donald St & Portage Ave site were then used for the selection of hours for the Kennedy St & Portage Ave site. As such, the Donald St & Portage Ave site review resulted in 84 hours of reviewed data corresponding to 6,310 calls. The Kennedy St & Portage Ave site review resulted in 71 hours of reviewed data corresponding to 1,915 calls. The number of calls was greater at the Donald St & Portage Ave site as pedestrian and vehicular flows are greater than at Kennedy St & Portage Ave; as such, the time required to process the Donald St & Portage Ave site data was near twice that of the Kennedy St & Portage Ave site.

The number of calls reviewed from the Donald St & Portage Ave site provides overall performance data with 95 percent confidence intervals less than ± 4 percent, representative data for false call causation, and weather, temperature, and temporal data performance near the ± 10 percent confidence interval originally set when determining sample size.

The number of calls reviewed from the Kennedy St & Portage Ave site provides overall performance data with 95 percent confidence intervals less than ± 8 percent, and representative data for false call causation. Weather, temperature, and temporal data performance are presented with confidence intervals according to the sample available.

4.0 ANALYSIS

4.1 ANALYSIS BACKGROUND

The research defines the operating performance of the curbside APDs in terms of detector sensitivity and selectivity using performance indicators of valid, missed and false calls. In order for a call to be defined as a required pedestrian call (RPC), the following criteria had to be met:

- A pedestrian had to be present at the intersection
- The pedestrian(s) had to enter the APD wait area
- The same pedestrian(s) had to wait in the APD monitored area
- The same pedestrian(s) after waiting had to cross the intersection in the direction intended (in this case, the direction governed by the APD).

For this research, a valid call is defined as a call made by an APD when all four criteria for a RPC are met. A missed call is defined as a situation where an APD fails to make a call even though all four criteria for a RPC are satisfied. A false call results from a situation where an APD makes a call but one or more criteria for a RPC are not met.

Using these definitions, APD sensitivity refers to the ability of an APD to identify a required pedestrian call and make a valid call:

$$APD\ Sensitivity = \left({}^{Valid}/_{(RPCs)} \right)$$

$$RPC = (Valid + Missed)$$

The selectivity of an APD refers to the ability of an APD to differentiate between valid and false calls:

$$APD\ Selectivity = 1 - (False\ /\ Total\ Detections)$$

$$Total\ Detections = (Valid + False)$$

The use of sensitivity and selectivity rates helps address questions regarding whether the APD is capable of making calls for pedestrians that require accommodation (sensitivity); or how often the APD call is valid when the APD detects and sends a call (selectivity). The analysis presented in the following sections deals with winter months at the two sites where the equipment was installed.

There were a total of 8,225 detections at both sites combined (6,310 at Donald St & Portage Ave, and 1,915 at Kennedy St & Portage Ave).

4.2 OVERALL APD SENSITIVITY AND SELECTIVITY PERFORMANCE

4.2.1 Donald St & Portage Ave

A sample total of 84 processed video and data collection hours from November 2009 to March 2010 resulted in 6,310 calls. Of these calls, 811 or 13 percent are RPCs. Calls occur, on average, every 48 seconds, and a RPC occurs every 6 minutes and 13 seconds on average. There are no instances where all three of the APDs did not send a call for a pedestrian who met all four criteria for a RPC. Table 9 shows the total number of valid, false, missed, and held calls by APD at the Donald Street location.

Table 9: APD Overall Performance Indicators (Donald St & Portage Ave)

	Valid	Missed	False	Held
Infrared	794	17	4710	130
Microwave	506	305	1820	3094
Infrared/Video	719	92	756	209

Total Calls	Held Calls	RPCs
6310	3265	811

Note: The sum of an APD's valid, missed, and false calls will not equal the 6310 observed calls because during a detection event not all detectors make a call.

As Table 9 shows, the infrared and infrared/video APDs have the highest number of valid calls and the infrared APD has the lowest number of missed calls. However, the infrared APD has over double the number of false calls as the microwave and near six fold the number of false calls as the infrared/video APD. The number of total calls shows the number of individual detection events where one or more of the APDs made a call at the site. A held call occurs when an APD sends a call for an event occurring within its detection zone and then continues to hold the call for greater than 4 consecutive seconds after all perceived detection causes have exited the vicinity around the APD's detection zone. If the APD holds the call consecutively into the next detection event, the performance of the APD call event cannot be determined as no information is available to ascertain whether the APD has actually sent or not sent a call for the new event. The microwave APD has the largest number of held calls. The number of held calls at this location failed to be reduced after replacing the microwave APD prior to this research's sample winter time period.

4.2.2 Kennedy St & Portage Ave

A sample total of 71 processed video and data collection hours from November 2009 to March 2010 resulted in 1915 detections. Of these detections, 172 or nine percent are RPCs. Calls occur, on average, every 2 minutes and 12 seconds, and a RPC occurs every 26 minutes and 52 seconds on average. This intersection has fewer calls due to lower pedestrian activity at the location. There are no instances where all three APDs did not send a call for a pedestrian who met all four criterions for a RPC. Table 10 shows the total number of valid, false, missed, and held calls by APD at the Kennedy Street location.

Table 10: APD Overall Performance Indicators (Kennedy St & Portage Ave)

	Valid	Missed	False	Held
Infrared	162	10	1438	213
Microwave	100	72	333	308
Infrared/Video	128	44	277	31

Total Calls	Held Calls	RPCs
1915	494	172

Note: The sum of an APD's valid, missed, and false calls will not equal the 1915 observed calls because during a detection event not all detectors make a call.

As Table 10 shows, the infrared APD has the highest number of valid calls and the lowest number of missed calls. However, the infrared APD has over four times the number of false calls as the infrared/video and microwave APDs. The number of total calls shows the number of individual detection events at the Kennedy St & Portage Ave site where one or more of the APDs made a call. As was noted with the Donald St & Portage Ave site, the microwave APD has the highest number of held calls although the number of held calls is closer to the infrared APD at this site, then at the Donald St & Portage Ave site.

Overall sensitivity and selectivity results for each APD are calculated from the total valid, false, and missed calls. The sensitivity and selectivity rates by APD with 95 percent confidence limits are illustrated for the research sites in Table 11. Where the sensitivity and selectivity 95 percent confidence limits are calculated by the following formulas:

- APD Sensitivity 95 percent Confidence Limits

$$= APD\ Sens. \pm 1.96\sqrt{\frac{APD\ Sens. - (1 - APD\ Sens.)}{\#\ of\ APD\ Valid\ Calls + \#\ of\ APD\ Missed\ Calls}}$$

- APD Selectivity 95 percent Confidence Limits

$$= APD\ Select. \pm 1.96\sqrt{\frac{APD\ Select. - (1 - APD\ Select.)}{\#\ of\ APD\ Valid\ Calls + \#\ of\ APD\ False\ Calls}}$$

Table 11: APD Overall Sensitivity and Selectivity (Donald St & Portage Ave and Kennedy St & Portage Ave)

	Sensitivity (%)	Selectivity (%)
Donald St & Portage Ave		
Infrared	97.9 ± 1.0	14.4 ± 2.4
Microwave	62.4 ± 3.3	21.8 ± 1.7
Video/Infrared	88.7 ± 2.2	48.7 ± 2.6
Kennedy St & Portage Ave		
Infrared	94.2 ± 3.5	10.1 ± 2.6
Microwave	58.1 ± 7.4	23.1 ± 3.7
Video/Infrared	74.4 ± 6.5	31.6 ± 4.3

From Table 11, it can be seen that the infrared detector has the highest overall sensitivity of all the examined detectors at 97.9 ± 1.0 percent and the lowest selectivity at 14.4 ± 2.4 percent at the Donald St & Portage Ave site, and 94.2 ± 3.5 percent and 10.1 ± 2.6 percent at the Kennedy St & Portage Ave site, respectively. As described in Table 5, the infrared detector has limited configurability and the inability to define an onset delay. This detector detects and indiscriminately sends a call for every detected change in thermal energy. It is sensitive because it detects and sends a call for almost all RPCs. However, with 4,710 false detections at the Donald St & Portage Ave site and 1,438 false detections at the Kennedy St & Portage Ave site, it is not selective because it cannot differentiate between RPCs and other thermal energy changes.

The video and infrared detector, equipped with onset delay, has the second highest sensitivity of 88.7 ± 2.2 percent and the highest selectivity at 48.7 ± 2.6 percent at the Donald St & Portage Ave site and the second highest sensitivity rating of 74.4 ± 6.5 percent and highest selectivity of 31.6 ± 4.3 percent at the Kennedy St & Portage Ave site.

All sensitivity and selectivity rates for each APD are greater at the Donald St & Portage Ave site than the Kennedy St & Portage Ave site except for the microwave detector selectivity which remains fairly consistent between sites.

Table 12

Table 12 illustrates comparisons of the APDs' overall operating performance using McNemar's test (paired Chi squared test) at the Donald and Kennedy locations. As the table shows, there are significant statistical differences between the sensitivity and selectivity rates of all the APDs, at both locations, as all paired tests exceed the 0.001 or 0.005 critical value for Chi squared with one degree of freedom.

Table 12: APD Overall Sensitivity and Selectivity Comparison (Donald St & Portage Ave and Kennedy St & Portage Ave)

	Sensitivity		Selectivity	
	χ2 Value	p >	χ2 Value	p >
Donald St & Portage Ave				
Microwave vs. Infrared	45.2	0.001	344.6	0.001
Microwave vs. Infrared/video	28.5	0.001	51.3	0.001
Infrared vs. Infrared/video	9.1	0.005	570	0.001
Kennedy St & Portage Ave				
Microwave vs. Infrared	49	0.001	1057.1	0.001
Microwave vs. Infrared/video	12.6	0.001	9.1	0.005
Infrared vs. Infrared/video	24.8	0.001	1380	0.001

4.3 SENSITIVITY AND SELECTIVITY AS A FUNCTION OF WEATHER CONDITIONS

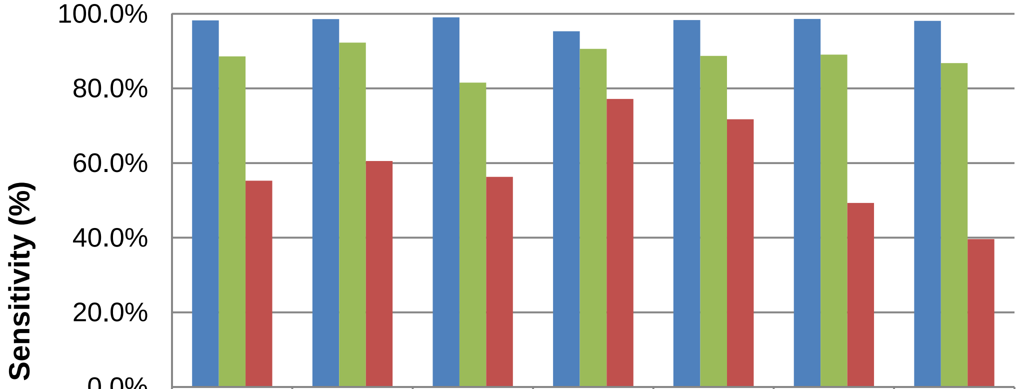
The sensitivity and selectivity of each detector was analyzed as a function of weather condition based on Environment Canada data for Winnipeg. The recorded conditions as per Environment Canada definitions are: sunny, mainly clear or clear, partly cloudy or mainly sunny, cloudy or mostly cloudy, fog or rain, freezing ice, and snow. Figure 10 and 11 illustrate the sensitivity and selectivity of these detectors at the Donald St & Portage Ave site. Figure 12 and Figure 13 illustrate the sensitivity and selectivity of these detectors at the Kennedy St & Portage Ave site.

The research found that the infrared detector has the highest sensitivity in all recorded weather conditions, ranging from 95 to 99 percent at the Donald St. site, and from 88 to 100 percent at the Kennedy St. site. The microwave detector has the lowest sensitivity for all weather conditions, ranging from 40 to 77 percent at the Donald St. site, and from 44 to 68 percent at the Kennedy St. site. The lowest sensitivity for this detector is during periods of snow fall or freezing ice, or when it is partly cloudy. The infrared and video detector performs best when it is sunny, with sensitivity over 90 percent. The overall APD performance is better at the Donald St. site than at the Kennedy St. site.

Regarding APD selectivity, in general, it is low under all weather conditions for all detectors, except for the infrared/video detector at the Donald site. The selectivity rates for the infrared and microwave detectors range between 6 and 42 percent at the two sites. This means that under these weather conditions, there is a false detection rate of anywhere between 58 and 94 percent, depending on the detector and the site.

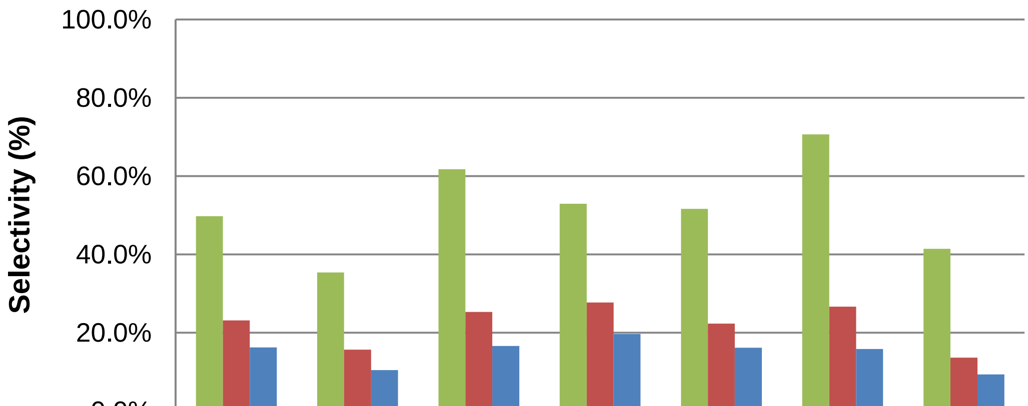
The infrared/video detector shows the highest selectivity of all APDs for all analyzed weather conditions. However, its best performance is under freezing ice conditions, resulting in a selectivity rate of 70 percent.

Figure 10: APD Sensitivity as a Function of Weather Conditions (Donald & Portage)



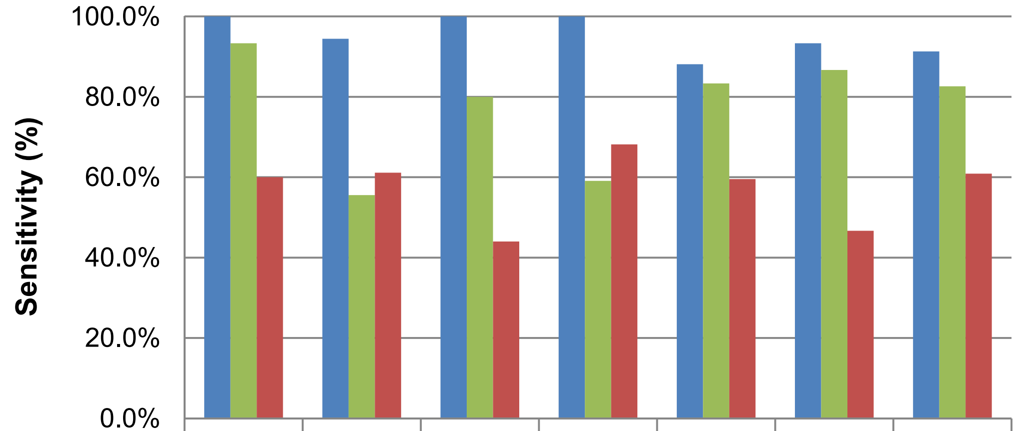
	Sunny	Mainly Clear / Clear	Partly Cloudy / Mainly Sunny	Cloudy / Mostly Cloudy	Fog, Rain	Freezing Ice	Snow
Infrared	98.2%	98.6%	99.0%	95.3%	98.3%	98.6%	98.1%
Infrared/Video	88.6%	92.3%	81.6%	90.6%	88.7%	89.0%	86.8%
Microwave	55.3%	60.6%	56.3%	77.2%	71.8%	49.3%	39.6%

Figure 11: APD Selectivity as a Function of Weather Conditions (Donald & Portage)



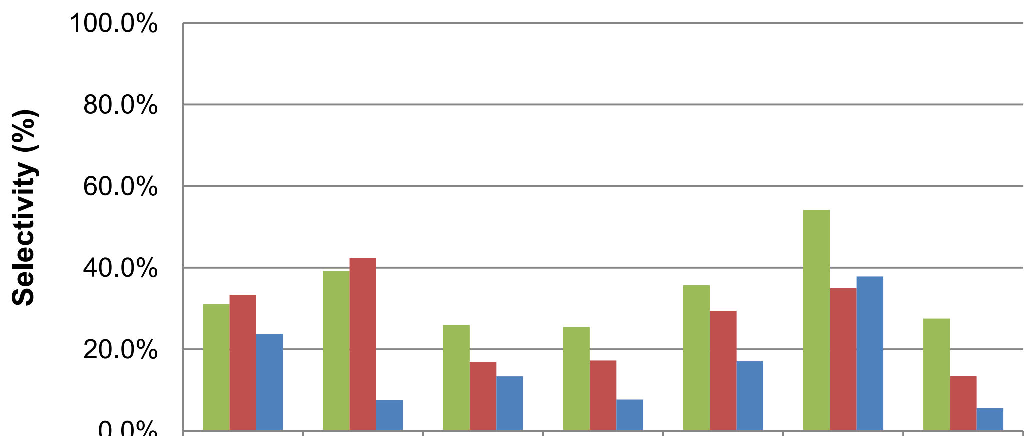
	Sunny	Mainly Clear / Clear	Partly Cloudy / Mainly Sunny	Cloudy / Mostly Cloudy	Fog, Rain	Freezing Ice	Snow
Infrared/Video	49.8%	35.4%	61.8%	52.9%	51.6%	70.7%	41.4%
Microwave	23.2%	15.7%	25.3%	27.7%	22.3%	26.7%	13.6%
Infrared	16.2%	10.5%	16.6%	19.7%	16.2%	15.9%	9.3%

Figure 12: APD Sensitivity as a Function of Weather Conditions (Kennedy & Portage)



	Sunny	Mainly Clear / Clear	Partly Cloudy / Mainly Sunny	Cloudy / Mostly Cloudy	Fog, Rain	Freezing Ice	Snow
Infrared	100.0%	94.4%	100.0%	100.0%	88.1%	93.3%	91.3%
Infrared/Video	93.3%	55.6%	80.0%	59.1%	83.3%	86.7%	82.6%
Microwave	60.0%	61.1%	44.0%	68.2%	59.5%	46.7%	60.9%

Figure 13: APD Selectivity as a Function of Weather Conditions (Kennedy & Portage)

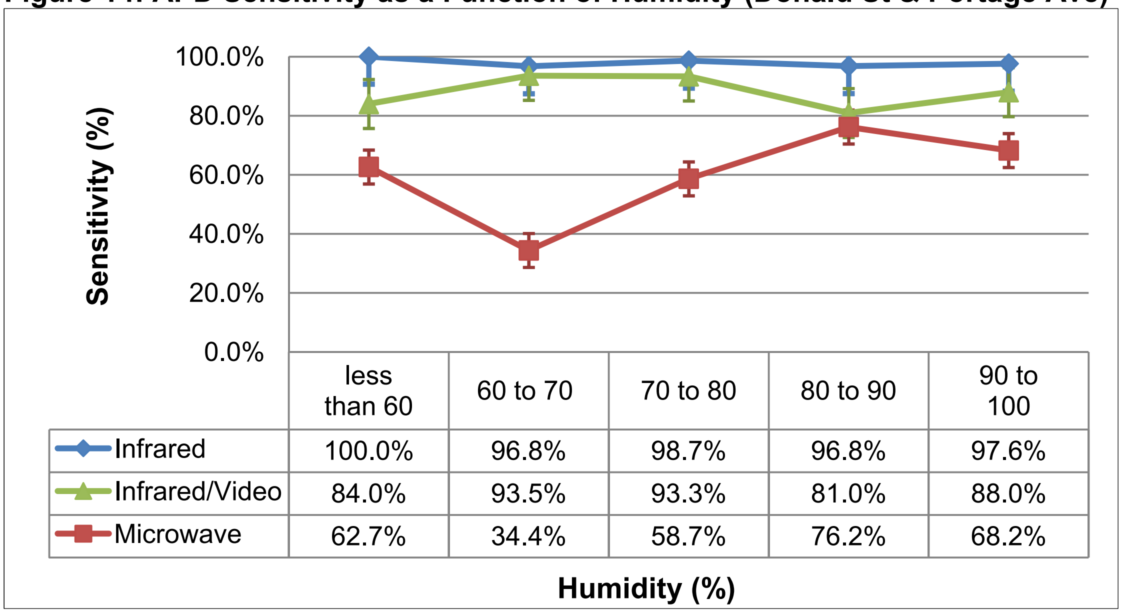


	Sunny	Mainly Clear / Clear	Partly Cloudy / Mainly Sunny	Cloudy / Mostly Cloudy	Fog, Rain	Freezing Ice	Snow
Infrared/Video	31.1%	39.2%	26.0%	25.5%	35.7%	54.2%	27.5%
Microwave	33.3%	42.3%	16.9%	17.2%	29.4%	35.0%	13.5%
Infrared	23.8%	7.6%	13.4%	7.7%	17.1%	37.8%	5.6%

4.4 SENSITIVITY AND SELECTIVITY AS A FUNCTION OF HUMIDITY

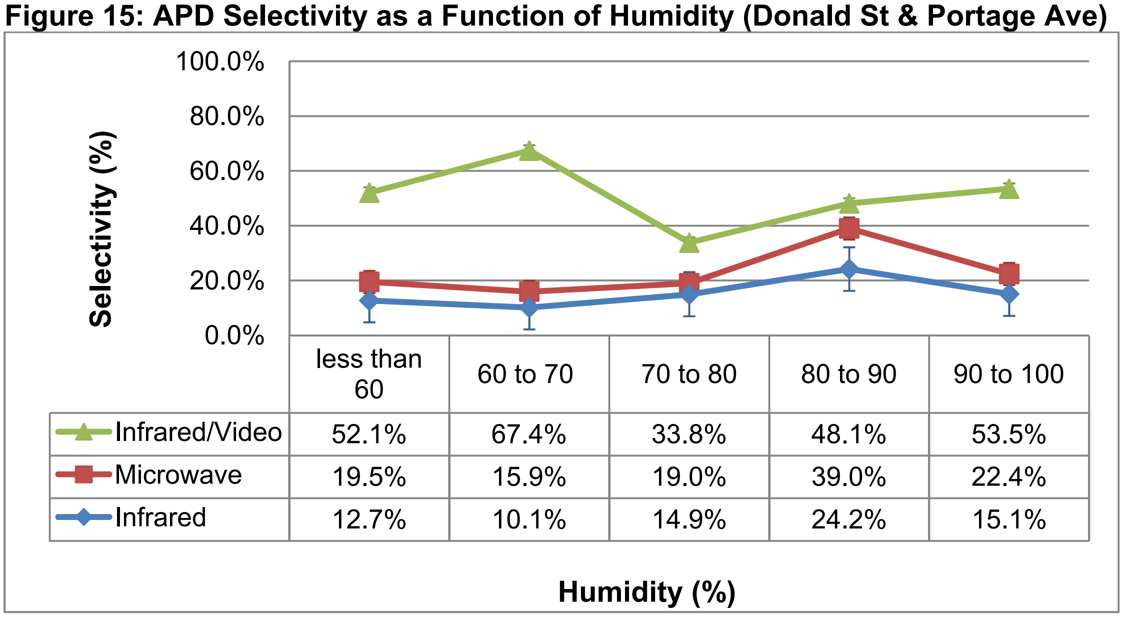
Figure 14 and Figure 15 illustrate the sensitivity and selectivity of the three detectors at Donald St & Portage Ave site as a function of the humidity level. Figure 16 and Figure 17 illustrate the same variables for the Kennedy St & Portage Ave site.

Figure 14: APD Sensitivity as a Function of Humidity (Donald St & Portage Ave)



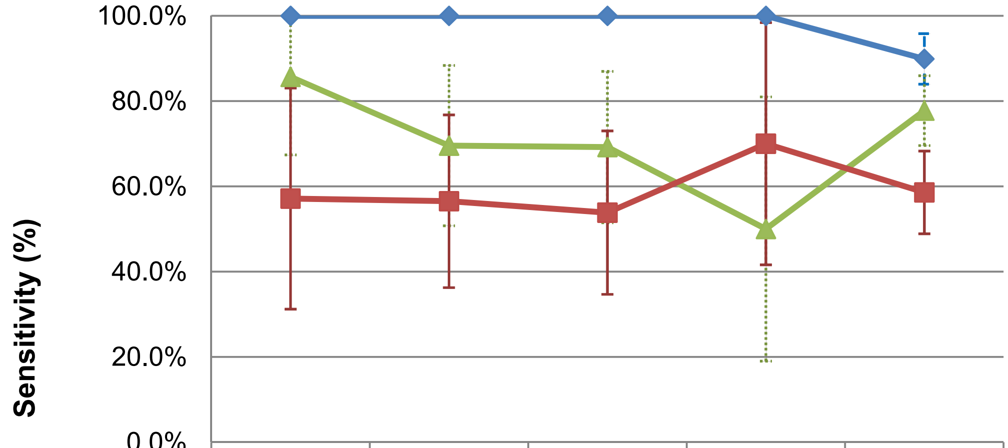
	less than 60	60 to 70	70 to 80	80 to 90	90 to 100
Infrared	100.0%	96.8%	98.7%	96.8%	97.6%
Infrared/Video	84.0%	93.5%	93.3%	81.0%	88.0%
Microwave	62.7%	34.4%	58.7%	76.2%	68.2%

Figure 15: APD Selectivity as a Function of Humidity (Donald St & Portage Ave)



	less than 60	60 to 70	70 to 80	80 to 90	90 to 100
Infrared/Video	52.1%	67.4%	33.8%	48.1%	53.5%
Microwave	19.5%	15.9%	19.0%	39.0%	22.4%
Infrared	12.7%	10.1%	14.9%	24.2%	15.1%

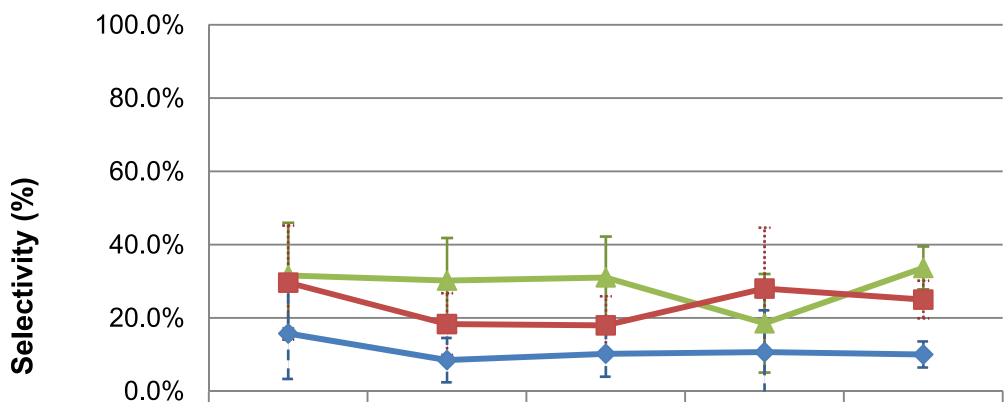
Figure 16: APD Sensitivity as a Function of Humidity (Kennedy St & Portage Ave)



	less than 60	60 to 70	70 to 80	80 to 90	90 to 100
Infrared	100.0%	100.0%	100.0%	100.0%	89.9%
Infrared/Video	85.7%	69.6%	69.2%	50.0%	77.8%
Microwave	57.1%	56.5%	53.8%	70.0%	58.6%

Humidity (%)

Figure 17: APD Selectivity as a Function of Humidity (Kennedy St & Portage Ave)



	less than 60	60 to 70	70 to 80	80 to 90	90 to 100
Infrared/Video	31.6%	30.2%	31.0%	18.5%	33.6%
Microwave	29.6%	18.3%	17.9%	28.0%	25.0%
Infrared	15.7%	8.5%	10.2%	10.6%	10.0%

Humidity (%)

As the figures illustrate, the infrared detector has the highest sensitivity in all humidity ranges with relatively little change throughout the humidity spectrum at both sites. The infrared/video detector operates with a sensitivity rating over 80 percent at all humidity levels at the Donald St site. The microwave detector operates at the lowest sensitivity of the three at both sites, except for humidity levels between 80 and 90 percent. This detector experiences a sensitivity drop of about 40 percent from the 80 to 90 percent humidity range as compared to the 60 to 70 percent humidity range. The microwave detector's performance in the 60 to 70 percent humidity range represents a drop of 28 percent from the detector's overall sensitivity performance at the Donald St site.

4.5 SENSITIVITY AND SELECTIVITY AS A FUNCTION OF WIND

Table 13 illustrates the sensitivity and selectivity for each analyzed APD in wind speeds above and below 20 kilometers per hour at the two sites. All APDs have similar sensitivity and selectivity rates at wind speeds above and below 20 km/h, except for the microwave APD, which has a lower sensitivity when wind speeds are greater than 20 km/h. Either the wind speed does not impact the sensitivity or selectivity of the APDs, or greater wind speeds are required to impact the operating performance of the APDs. Prior to installing the infrared detector at the test site, it was turned on and held by hand. Slight movements of the detector would cause the detector's detection indication LED to flash rapidly on and off. If the wind speed is inducing motion of the actual APD on the pole, the device detection and calls would be increased leading to a higher sensitivity, and conversely a lower selectivity rate. It is expected that the APDs' performance due to wind speed would be a function of rigidity of the APD mounted pole and installed hardware.

Table 13: APD Sensitivity and Selectivity as a Function of Wind (Donald St & Portage Ave and Kennedy St & Portage Ave)

	Sensitivity (%)		**Selectivity (%)**	
Wind Speed	**≥ 20 km/h**	**< 20 km/h**	**≥ 20 km/h**	**< 20 km/h**
Donald St & Portage Ave				
Infrared	96.8 ± 2.5	98.1 ± 1.1	12.6 ± 2.9	14.9 ± 1.6
Infrared/video	92.5 ± 3.8	86.9 ± 2.7	51.6 ± 5.2	47.6 ± 2.9
Microwave	52.4 ± 7.2	65.1 ± 3.9	24.3 ± 3.8	21.1 ± 1.8
Kennedy St & Portage Ave				
Infrared	100.0 ± 0.0	92.7 ± 4.7	11.9 ± 5.0	9.7 ± 3.2
Infrared/video	83.1 ± 10.8	69.9 ± 8.1	27.8 ± 7.4	33.0 ± 5.3
Microwave	56.8 ± 14.6	56.9 ± 8.8	18.0 ± 6.0	24.6 ± 4.6

4.6 SENSITIVITY AND SELECTIVITY AS A FUNCTION OF TEMPERATURE

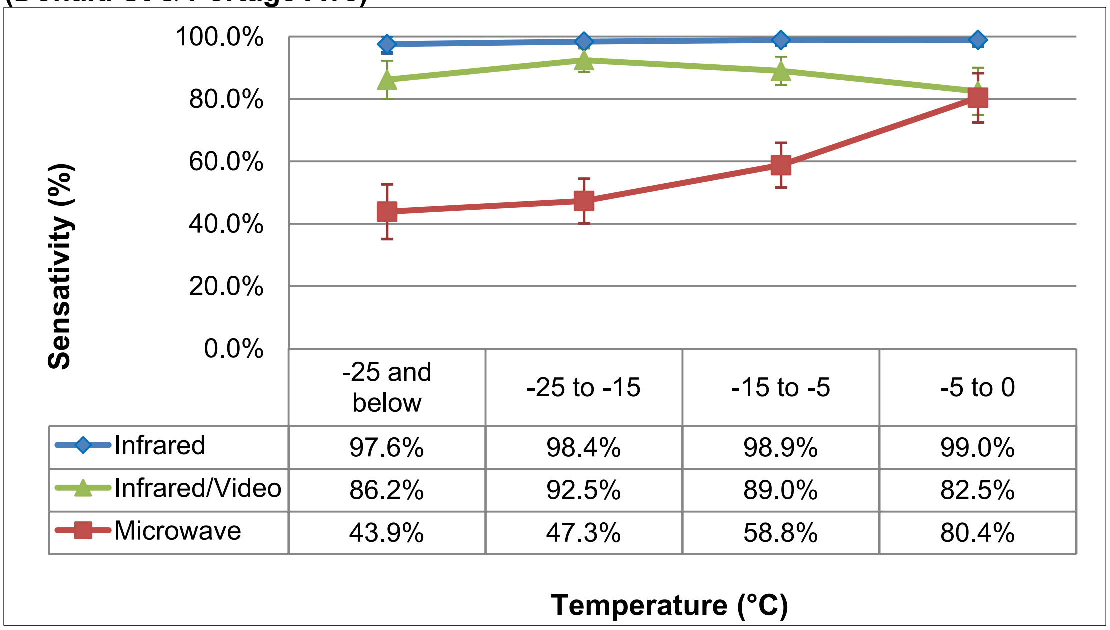
Figure 18 and Figure 19 illustrate the APD sensitivity and selectivity rates and trends as a function of recorded winter temperatures at the Donald St & Portage Ave site. The sensitivity and selectivity rates for the Kennedy St & Portage Ave site are shown in Figure 20 and Figure 21 for the Kennedy St. site. The coldest temperature sampled during the five-month period was -34^{o}C (-29^{o}F).

Figure 18 reveals that the same overall sensitivity and selectivity ratings exist throughout the temperature range. The infrared has the highest sensitivity and the lowest selectivity, the infrared/video has the second highest sensitivity and the highest selectivity and the microwave has the lowest sensitivity and second highest selectivity. The infrared and infrared/video APD sensitivity rates remain constant at values above 97 percent and 82 percent respectively. The microwave detector shows a tendency for the sensitivity of the detector to increase with increasing temperature, up to 0°C (32°F).

With respect to APD selectivity (i.e., the number of calls triggered by valid pedestrian movements), Figure 19 shows that selectivity increases for the infrared and microwave detector as the temperature increases. The opposite is true of the infrared/video which shows a steady trend in decreasing selectivity with increasing temperature across all temperature ranges. This detector also shows the highest selectivity rate.

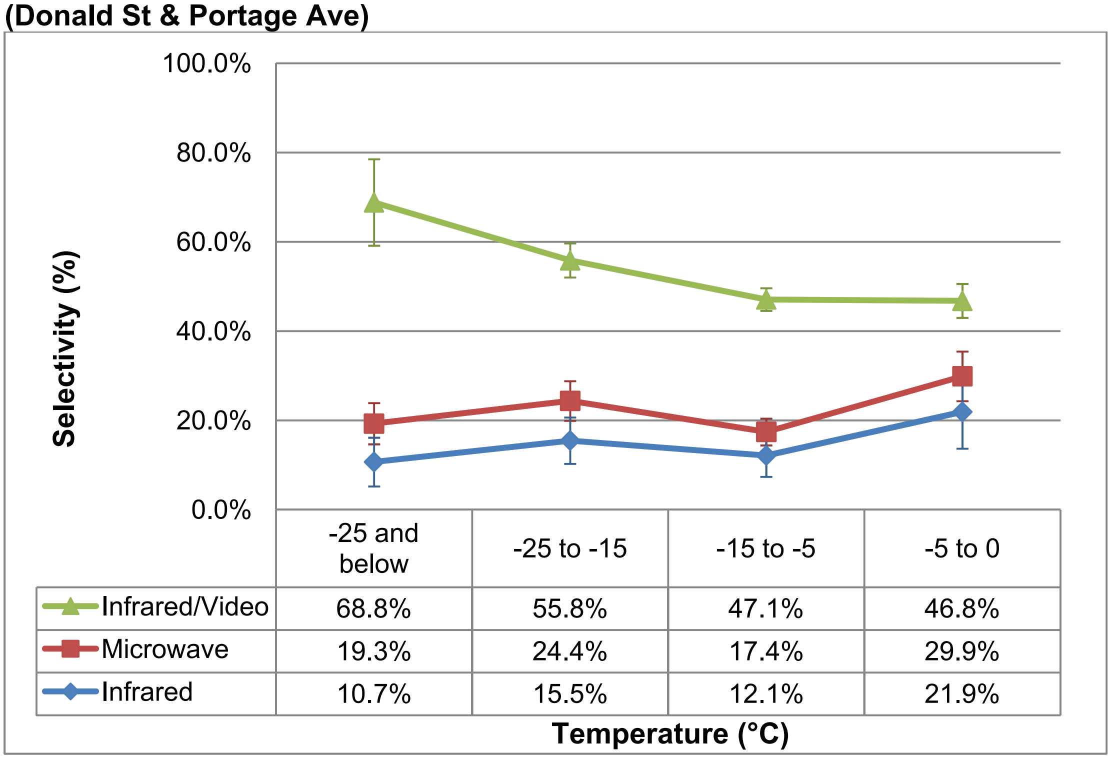
Wind chill factor is a function of air temperature and wind speed. For example, if wind speed is 20 km/h (12 mph) and air temperature is -25°C (-13°F), the resulting wind chill index is -37°C (-34°F). Wind chill does not affect objects and does not lower the actual temperature. It only describes how a person would feel in the wind at the ambient temperature (Occupational Health Clinics for Ontario Workers Inc.). Because of this, the sensitivity and selectivity among the detectors as a function of wind chill are similar to the rates for temperature. Detector performance with respect to wind is discussed in the previous section.

Figure 18: APD Sensitivity as a Function of Temperature (Donald St & Portage Ave)



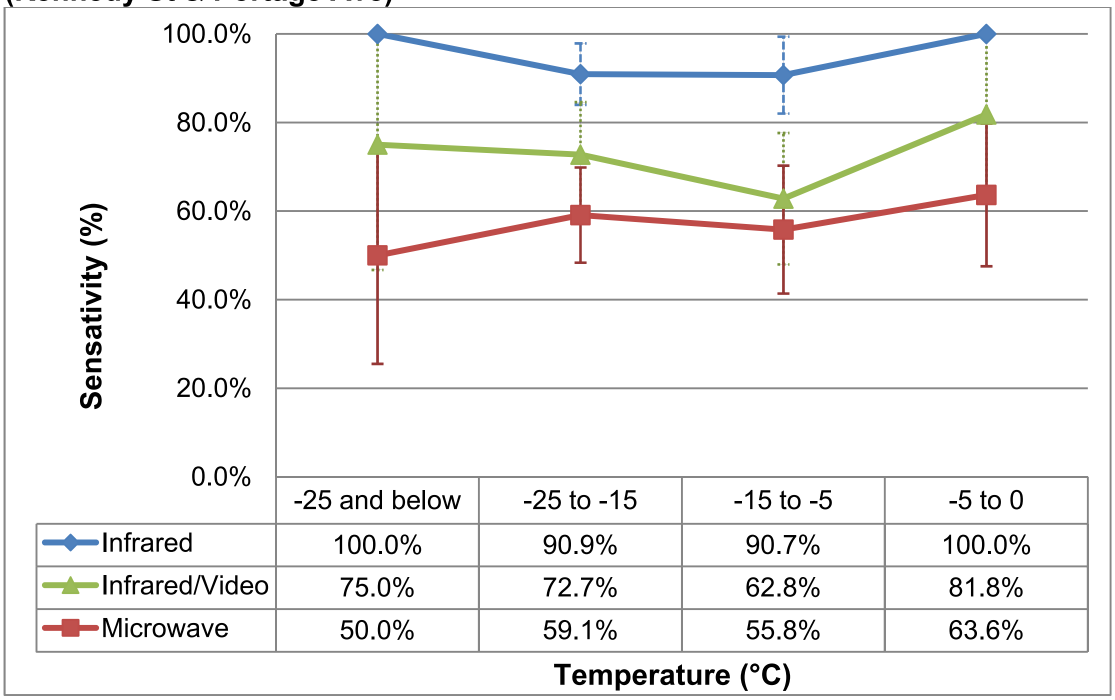
	-25 and below	-25 to -15	-15 to -5	-5 to 0
Infrared	97.6%	98.4%	98.9%	99.0%
Infrared/Video	86.2%	92.5%	89.0%	82.5%
Microwave	43.9%	47.3%	58.8%	80.4%

Figure 19: APD Selectivity as a Function of Temperature (Donald St & Portage Ave)



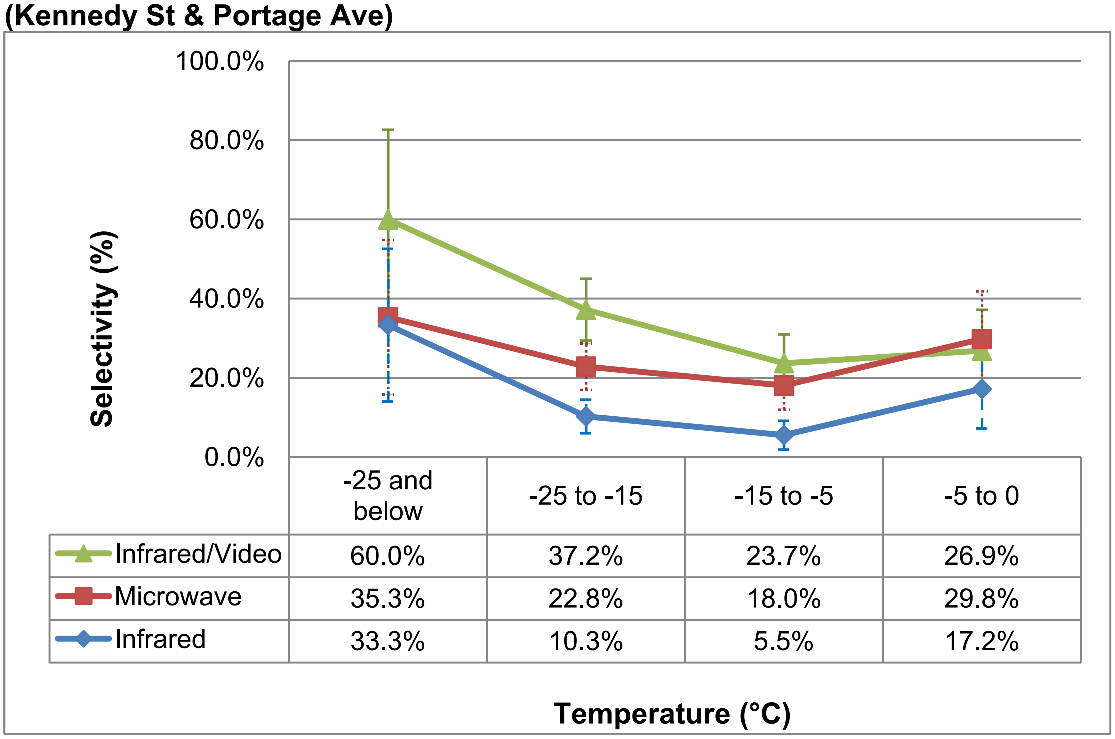
	-25 and below	-25 to -15	-15 to -5	-5 to 0
Infrared/Video	68.8%	55.8%	47.1%	46.8%
Microwave	19.3%	24.4%	17.4%	29.9%
Infrared	10.7%	15.5%	12.1%	21.9%

Figure 20: APD Sensitivity as a Function of Temperature (Kennedy St & Portage Ave)



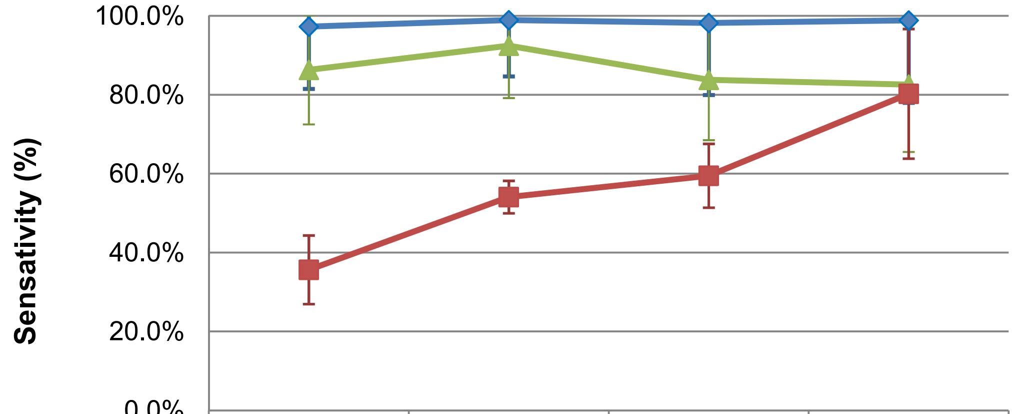
	-25 and below	-25 to -15	-15 to -5	-5 to 0
Infrared	100.0%	90.9%	90.7%	100.0%
Infrared/Video	75.0%	72.7%	62.8%	81.8%
Microwave	50.0%	59.1%	55.8%	63.6%

Figure 21: APD Selectivity as a Function of Temperature (Kennedy St & Portage Ave)



	-25 and below	-25 to -15	-15 to -5	-5 to 0
Infrared/Video	60.0%	37.2%	23.7%	26.9%
Microwave	35.3%	22.8%	18.0%	29.8%
Infrared	33.3%	10.3%	5.5%	17.2%

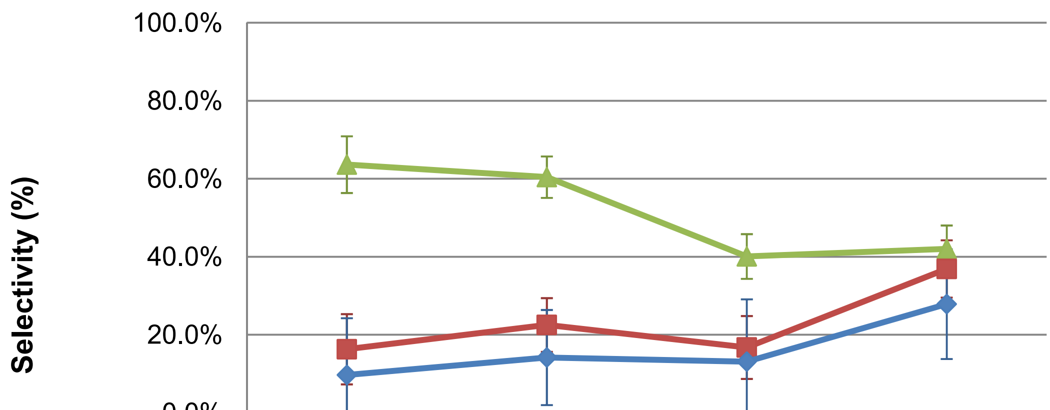
Figure 22: APD Sensitivity as a Function of Wind Chill (Donald St & Portage Ave)



	-30 and below	-30 to -20	-20 to -10	-10 to 0
Infrared	97.3%	98.9%	98.2%	98.8%
Infrared/Video	86.3%	92.4%	83.8%	82.6%
Microwave	35.6%	54.1%	59.5%	80.2%

Wind Chill (°C)

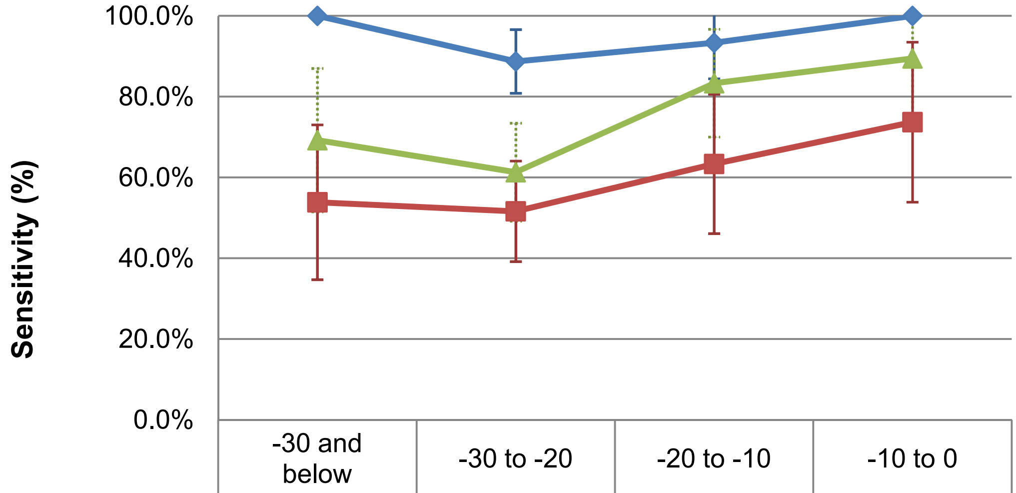
Figure 23: APD Selectivity as a Function of Wind Chill (Donald St & Portage Ave)



	-30 and below	-30 to -20	-20 to -10	-10 to 0
Infrared/Video	63.6%	60.4%	40.1%	42.0%
Microwave	16.3%	22.5%	16.8%	36.9%
Infrared	9.7%	14.2%	13.1%	27.9%

Wind Chill (°C)

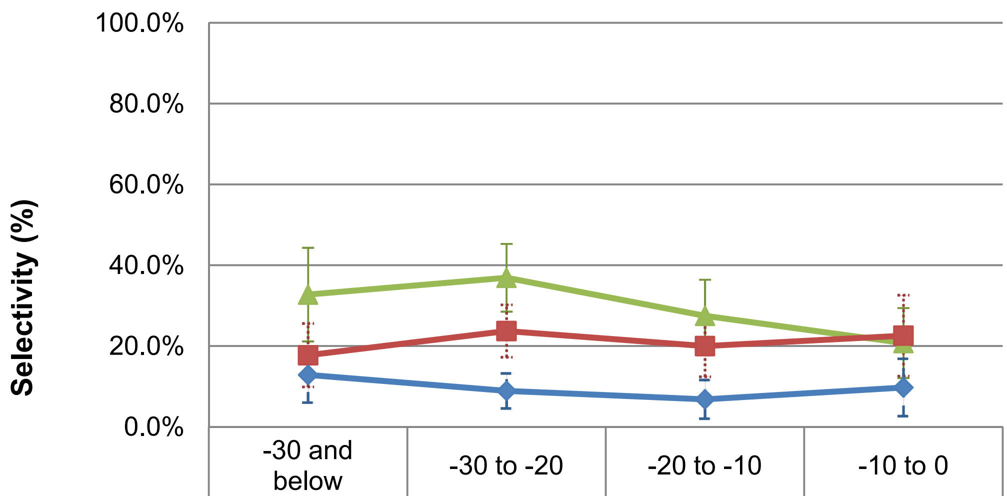
Figure 24: APD Sensitivity as a Function of Wind Chill (Kennedy St & Portage Ave)



	-30 and below	-30 to -20	-20 to -10	-10 to 0
Infrared	100.0%	88.7%	93.3%	100.0%
Infrared/Video	69.2%	61.3%	83.3%	89.5%
Microwave	53.8%	51.6%	63.3%	73.7%

Wind Chill (°C)

Figure 25: APD Selectivity as a Function of Wind Chill (Kennedy St & Portage Ave)



	-30 and below	-30 to -20	-20 to -10	-10 to 0
Infrared/Video	32.7%	36.9%	27.5%	20.7%
Microwave	17.7%	23.7%	20.0%	22.6%
Infrared	12.9%	8.9%	6.8%	9.7%

Wind Chill (°C)

4.7 SENSITIVITY AND SELECTIVITY AS A FUNCTION OF TIME OF DAY

Table 14 illustrates the recorded APD sensitivity and selectivity rates for day and night operation. Day operation is defined as the time period between sunrise and sunset, whereas night operation is defined as the time period between sunset and sunrise. The times of sunrise and sunset by date were obtained from Environment Canada’s website.

As Table 14 illustrates, all detectors maintain consistent sensitivity rates in day and night operation at both sites. The infrared detector has the highest sensitivity rate and lowest selectivity rate in both day and night operation. The infrared/video detector has the highest selectivity rate in both day and night operation.

All detectors at the Donald St & Portage Ave site experience an increase in selectivity rates when comparing day operation to night operation. The infrared/video detector has the largest selectivity rate increase of 11 percent when comparing day to night operation. The infrared/video APD’s increase in selectivity during the day may be due to changing shadows within the zone of detection caused by the headlights of passing vehicles. No clear differences are noted at the Kennedy St & Portage Ave site between day and night selectivity rates.

Table 14: APD Sensitivity and Selectivity by Day and Night (Donald St & Portage Ave and Kennedy & Portage Ave)

	Sensitivity (%)		Selectivity (%)	
	Day	**Night**	**Day**	**Night**
Donald St & Portage Ave				
Infrared	97.9 ± 1.4	97.9 ± 1.4	15.9 ± 3.7	13.3 ± 3.2
Microwave	58.9 ± 4.9	65.5 ± 4.5	26.0 ± 2.9	19.2 ± 2.0
Infrared / Video	87.2 ± 3.4	90.0 ± 2.8	55.4 ± 2.6	44.2 ± 2.3
Kennedy St & Portage Ave				
Infrared	94.0 ± 5.1	94.3 ± 4.8	12.1 ± 3.9	8.7 ± 3.6
Microwave	54.8 ± 10.6	61.4 ± 10.2	19.6 ± 4.7	27.3 ± 5.7
Infrared / Video	82.1 ± 8.2	67.0 ± 9.8	29.0 ± 5.6	35.3 ± 6.7

4.8 DETECTOR SELECTIVITY AND FALSE CALL CAUSATION

The analysis reveals that the selectivity rate of these detectors was below 50 percent. Further examination of the data reveals that false calls result from six different situations as follows:

1. Completed crossing: In this type of situation a pedestrian completes the intersection crossing in the direction opposite to the direction governed by the APD. As the pedestrian completes the crossing, the pedestrian is detected within the APD's detection zone and a call is erroneously sent for pedestrians who do not require the phase actuation.

2. Perpendicular crossing: In this situation a pedestrian crosses the intersection in the direction perpendicular to that being monitored. However, this is done from the same corner where the APD has a zone of detection. When the pedestrian crosses through the APD's zone of

detection a call is sent even though the pedestrian is crossing in the perpendicular direction of the APD's governed direction.

3. Pedestrian detected but does not wait: In this type of situation a pedestrian crosses the intersection in the direction governed by the APD without waiting for accommodation before crossing. Even though the pedestrian does not wait, a call has been sent for a pedestrian phase that is no longer required.

4. Pedestrian redirected: In this situation a pedestrian approaches the intersection corner as if to cross in the direction governed by the APD. However, instead of crossing in the direction governed by the APD, the pedestrian changes the original travel path to a direction other than the APD governed crossing direction (in other words, the pedestrian changes his/her mind about the direction of crossing).

5. Vehicle detected: This situation involves a vehicle moving adjacent to the APD's detection zone, causing a call to be sent even though no pedestrians require the associated phase actuation.

6. Unknown reason: In this case there is no obvious reason why a call is recorded by the APD.

Table 15 shows the number of false calls associated with each of the six situations previously discussed, for each of the two locations being monitored, and by type of APD. Figure 26 and Figure 27 illustrate these results graphically.

Table 15: Number of False Calls by APD

Reason for False Call	Infrared	Infrared/video	Microwave
Donald St & Portage Ave			
Completed crossing	1506	254	752
Pedestrian interference	933	108	254
Pedestrian detected (no wait)	1218	183	450
Pedestrian redirected	112	48	50
Vehicle detected	722	121	257
Unknown	219	42	57
TOTAL	**4710**	**756**	**1820**
Kennedy St & Portage Ave			
Completed crossing	318	67	65
Pedestrian interference	348	88	96
Pedestrian detected (no wait)	409	79	120
Pedestrian redirected	23	9	13
Vehicle detected	276	23	30
Unknown	64	11	9
TOTAL	**1438**	**277**	**333**

Table 15, Figure 26, and Figure 27 show that the Donald St & Portage Ave site has a greater proportion of false calls as a result of pedestrians having completed the crossing, relative to Kennedy St & Portage Ave (about 35 percent at Donald St & Portage Ave site compared to about 20 percent at Kennedy St & Portage Ave). However, Kennedy St & Portage Ave has a greater proportion of false calls as a result of pedestrians crossing in the perpendicular direction (i.e., perpendicular crossing). This may be attributed to the diagonal curb ramp for two directions of crossing available at Kennedy St

& Portage Ave versus the individual curb ramp per direction available at Donald St & Portage Ave.

Figure 26: Percent of False Calls by Type (Donald St & Portage Ave)

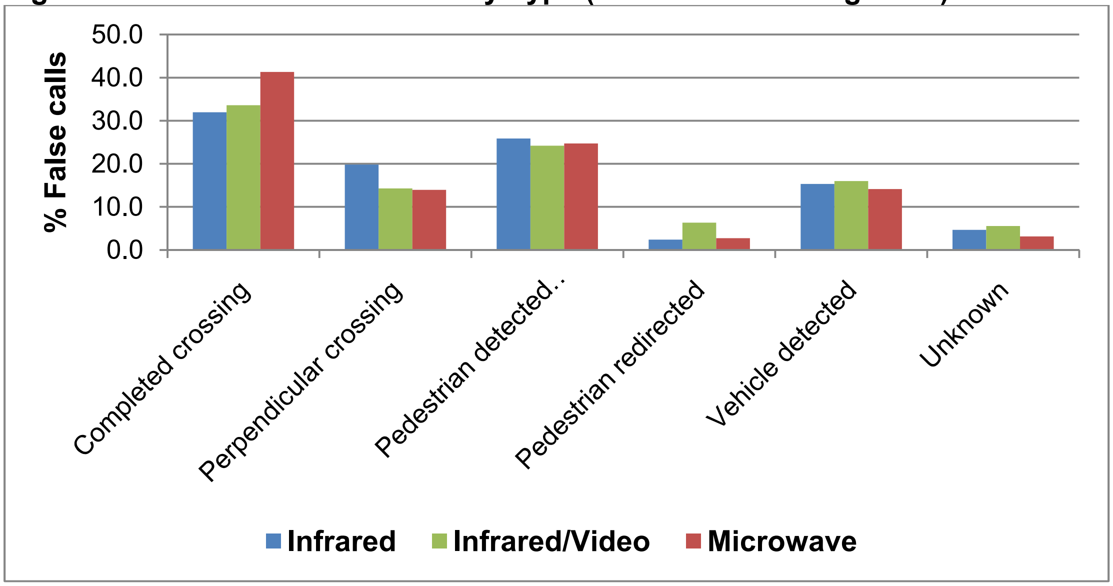
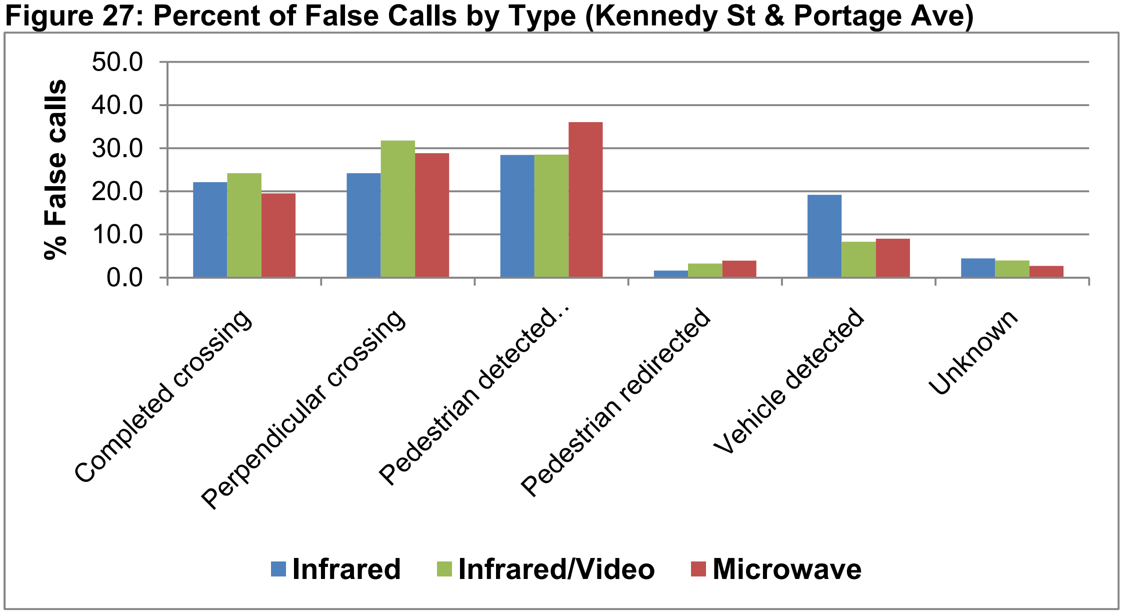


Figure 27: Percent of False Calls by Type (Kennedy St & Portage Ave)



The Donald St & Portage Ave site has fewer false calls caused by pedestrians crossing without waiting. This is expected as the vehicular flow perpendicular to the pedestrian crossing direction is greater at Donald St & Portage Ave site than at Kennedy St & Portage Ave site. The lower the vehicular volume, the greater the potential for gaps between vehicles, which allows pedestrians to cross without the need of proper accommodation by the traffic signal.

The proportion of false calls as a result of vehicles driving in lanes adjacent to the APDs is, on average, greater at Donald St & Portage Ave than at the Kennedy St & Portage Ave site (about 15 percent false calls at Donald St & Portage Ave compared to about 10 percent at Kennedy St & Portage Ave). This may be due to the detectors being aligned inadvertently closer to the road at the Donald St & Portage Ave site than at Kennedy St & Portage Ave site. Another reason may be due to blowing snow tracking through the detection zones of the infrared/video and microwave detectors when a vehicle passes adjacent to the detection zone at a speed typically greater than experienced at the Kennedy St & Portage Ave site. The infrared detector, however, recorded a greater percentage of false calls associated with vehicles passing by at the Kennedy St & Portage Ave site than at the Donald St & Portage Ave, which may be due to the detector setup.

4.9 APD ESTIMATED COSTS

Table 16 illustrates the estimated installation and setup costs per APD in this research. The cost is given per departure zone as some APDs are capable of monitoring more than one curbside departure zone. However, no analyzed detector in this research is capable of monitoring more than one curbside departure zone.

Table 16: APD Cost Estimate per Departure Zone for Detectors Used in this Research (US$)

	IR 207 (Infrared)	Smartwalk XP (Microwave)	AGD 640 (Infrared/Video)
Capital Cost ^	$ 550.00	$ 500.00	$ 1,200.00
Installation and Setup ^	$ 325.00	$ 350.00	$ 150.00
Total (US$)	***$ 875.00***	***$ 850.00***	***$ 1,350.00***
Maintenance per year	0	0	$ 25.00*

^ Capital costs are based on prices quoted to Texas Transportation Institute, and discussions with manufacturers during equipment acquisition. Installation and setup cost is based on two electricians and one line truck at $145/hr.

* During this research there was no need to provide any maintenance to this equipment other than lens cleaning twice per year (5 minutes per detector per instance). This may not be the case under regular operation as there may be a need to realign the devices once they are in operation for more than one year.

For the research's use, the cost per departure zone for the AGD 640 is US$1,500 as the detectors supplied are final prototypes. Once the detectors are in full production, the estimated cost per detector quoted by AGD Systems was US$1,200.

The costs to install and setup the detectors are based on the ease by which the detectors are installed and setup. Installation, setup, and maintenance costs are based on the hourly rates of two traffic signal service staff and a service truck. The cost estimate assumes that power and detector communication wiring such as compatible pushbutton wiring are available in an existing pole adjacent to the required departure zone. The cost estimate assumes that the existing pole with appropriate wiring has room to mount the detector free of viewing obstructions and does not need to be relocated. The initial installation cost is the same for all the detectors as the mounting and wiring are similar. The IR 207 and Smartwalk XP detectors require more time to setup than the AGD 640.

The IR 207 and Smartwalk XP do not provide visual representation of their respective zones of detection. To setup the detector with the most optimal detection zone, the following must be done:

1) The cover of the detector must be removed to view the detection status LED or a digital read out device needs to be supplied and connected to the detector’s output relays to provide an alternative means of viewing the detection status of the detector.

2) Walk tests through the perceived detection zone are to be conducted from multiple approaches to verify the detector’s detection zone.

3) Adjustments are made to the detector’s mounting to minimize detection in the intersection or outside of the required zone of detection.

4) Adjustments are made to the detector’s configuration settings to adjust range, directionality, detection thresholds, and onset delay.

All adjustments are followed by walk tests for zone verification with further adjustments of the detector's mounting and configuration.

The AGD 640, equipped with two cameras, has the capability to provide a visual representation of the detector's field of view and preset zone of detection. The AGD 640 requires the use of a laptop or PDA with Bluetooth or serial communications. To setup the AGD 640 detector with the most optimal detection zone, the following takes place:

1) The detector is mounted and aligned by the installer's eye to the approximate position for optimal definition of the detection zone.

2) The detector is powered on, and a serial or Bluetooth connection created.

3) Verification by an external LED informs the installer that a connection has been made to the correct detector.

4) The detector takes an image of its field of view and illustrates the preset detection zone with a polygon superimposed upon the image.

5) Calibration of the two cameras, modification of the polygon vertices to fit the intersection, fine tuning by the removal of detection blocks within

the detection zone polygon if required, onset delay, and other settings are set via a user interface on a laptop or PDA.

6) Verification of the optimal detection zone setup occurs either by the indication on the user interface visible on the laptop, PDA, or by the detector's bottom mounted external LED detection indicator which is clearly visible to the installer from the curbside as walk tests are conducted.

Table 17 shows the recorded installation time per detector at each of the two sites where data was collected. As the table shows, from a time investment perspective, the field crew spent 2.25 hours installing the infrared detector, 2.50 hours installing the microwave detector, and one hour installing the infrared/video detector at each site. This translates into significant installation and setup cost savings associated with the AGD 640 detector.

Table 17: APD Installation Time for Detectors Used in this Research

	IR 207	Smartwalk XP	AGD 640
Installation Time (hrs)	0.75	0.75	0.75
Setup Time (hrs)	1.50	1.75	0.25
Total Time (hrs)	***2.25***	***2.50***	***1.00***

4.10 DISCUSSION

This section discusses key observations from this research regarding the following: (1) previous research; (2) detector selectivity; and (3) limitations of the field test.

4.10.1 Previous Research

The results from this research are different from the results obtained in the Texas field evaluation, where the microwave detector had results of 83 to 93 percent sensitivity and 92 to 98 percent selectivity, and the infrared detector had a sensitivity of 69 to 90 percent and 93 to 100 percent selectivity. The Texas field evaluation used the same infrared detectors and a previous model of the microwave detector used in this research. Possible explanations for the difference in results are as follows: (1) the selection of a greater onset delay through the detectors or by an external device; (2) the detectors performing better in warmer and drier climate than in winter weather; (3) the curbside geometry at the corners of the test intersection (the Texas evaluation occurred at curbsides where sidewalks were delineated and separated according to the crossing direction desired); (4) the complexity of pedestrian movements was different in Texas due to pedestrians crossing predominately in one direction.

4.10.2 Detector Selectivity

Based on the causation of false calls (as illustrated in Table 15, Figure 26, and Figure 27), Table 18 shows a number of options that could help reduce the number of false calls experienced by these detectors under the given conditions of this type of field test.

Table 18: Actions to Mitigate APD False Calls

Actions to Reduce False Calls (Increase Selectivity)	Consequences	Mitigated Reason(s) for False Calls
Increase onset delay	This reduces detector sensitivity as continuous detection criteria may cause fewer RPCs to be accommodated (intermittent detection or pedestrians who only need to wait for a few seconds.)	• Completed crossing • Pedestrian detection (no wait) • Pedestrian redirected • Vehicle detected
Provide directional detection	This may result in possible issues with pedestrians who make a 90-degree turn, stop, and wait for phase actuation in the governed direction. Since directional detection is not available with the tested APDs the performance is unknown.	• Completed crossing • Perpendicular crossing • Pedestrian redirected • Vehicle detected
Make detection zone depth smaller	This would create a smaller detection zone to detect pedestrians who require phase actuation, which may lead to lower sensitivity.	• Completed crossing
Make detection zone width smaller	Similar to the option of reducing detection zone depth, this would create a smaller detection zone available to detect pedestrians who require phase actuation, which may lead to lower sensitivity.	• Completed crossing
Move Detection zone away from curb	This may reduce the detection zone available to detect pedestrians who require phase actuation, which may lead to lower sensitivity.	• Vehicle detected

4.10.3 Limitations of the Field Test

Although the scope of this research is for winter months, there was extensive work required in preparation for the data collection and analysis. The equipment was setup in September 2009 and data was collected on a regular basis each week. The following are considered to be limitations of the field test, which could have either affected the data itself, or the analysis. However, the extent of impact is unknown. It is useful to consider these issues in further work related to this topic.

- The weather and temperature values used in the research are from Environment Canada's website for the weather station located at the James A. Richardson International Airport in Winnipeg, Manitoba. As weather and temperature are location specific the geographic separation of the two sites in Winnipeg's central business district from the airport weather station (up to 6 km) may create situations where differences exist between the actual weather or temperature conditions at the research sites and the recorded data at the airport weather station.

- Weather and temperature data recorded by the airport weather station was collected on a 15-minute interval in order to capture recorded weather and temperature data changes as they were made available by the Environment Canada website. Weather and temperature data was matched to the corresponding APD timestamp with the assumption that the weather and temperature remained constant until the time when Environment Canada's recorded weather and temperature data changed.

- Weather conditions are composed of a variety of climatic conditions. As an example, snow conditions occur when certain combinations of temperature, humidity, barometric pressure, and cloud cover exist. The research provides infield weather performance data that is a function of combined climatic conditions without isolating specific climatic conditions.

- A held call occurs when an APD fails to release the call four consecutive seconds after the last perceived detection event has left the surrounding vicinity of the APD's detection zone. In many instances the held call concludes before the onset of a new detection event, however in instances where an APD continues to hold a call during a new detection event the APD call (valid, false, or missed) cannot be determined. In the instances where an APD continues to hold a call during a new detection event the APD call status is recorded as "Off" which may increase the APD's number of false or missed calls depending on the detection event classification.

- Onset delay was set at two seconds for all APDs where possible (Infrared/Video and Microwave). The two-second onset delay was determined by walk tests during the initial setup of the APDs. The onset delay was maintained throughout the research to ensure consistency of data. Increasing onset delay may increase the capability of the APD to minimize false calls but conversely may decrease the capability to detect and send a call for pedestrians requiring accommodation (i.e., increasing detector selectivity but decreasing its sensitivity).

- The APDs were not connected to the local signal controller as the performance and operation of the APDs were unknown. Additionally, no information on the walk, flashing don't walk, and don't walk indications were collected from the local signal controller for use in the data analysis.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses research findings and conclusions, and opportunities for further research.

5.1 CONCLUSIONS

The research analyzes the operating performance of three commercially available curbside automated pedestrian detectors (APDs) as a function of winter weather, temperature, and temporal variations at signalized intersections. This research forms the basis for future decision-making regarding the potential implementation of automated pedestrian detection at signalized intersections. The results from the analyses provide information to transportation engineers on how each studied APD works, and factors that should be considered when deciding whether to install an APD instead of a pedestrian pushbutton at signalized intersections.

The three detectors analyzed in this research are: (1) AGD 640, manufactured by AGD Systems Ltd. based in the United Kingdom; (2) Xtralis ASIM IR 207, formerly manufactured by ASIM Technologies Inc. in Switzerland, now owned by Xtralis; and (3) Smartwalk XP, manufactured by MS Sedco based in the United States. The AGD 640 is a pole-mounted passive infrared and stereovision curbside detector. The Xtrails ASIM IR 207 is a pole-mounted passive infrared curbside detector, and the Smartwalk XP is a pole-mounted microwave detector.

Based on a sample of 8,225 detections from November 2009 to March 2010, the research found the following:

- Overall, the three APDs are sensitive to sending valid pedestrian calls, but selectivity rates tend to remain below 50 percent.

- The infrared detector, in all analyzed conditions, consistently has the highest sensitivity and lowest selectivity of all detectors. The infrared/video detector has the second highest sensitivity and the highest selectivity of the analyzed APDs. The microwave detector has the lowest sensitivity and the second highest selectivity of the APDs.

- In the case of the microwave APDs, the sensitivity was observed to increase with increasing temperature, over the range of temperatures recorded during the field test (-34^{o}C (-29^{o}F) to 0^{o}C (32^{o}F)). This is not the case for the infrared and infrared/video APDs, whose performance were not affected by temperature changes.

- Selectivity rates for the infrared and microwave detectors seem to perform better at warmer than colder temperatures (over the range of winter temperatures applicable to this research), whereas the infrared/video detector performs better at colder temperatures ranging from 45 percent to 70 percent.

- The most common reasons for false calls were dependent upon the site. The Donald St & Portage Ave site experienced the most false calls (above 30 percent of all false calls) due to pedestrians who had already completed their crossings walk through the APD's zones of detection, causing erroneous calls to be made. The Kennedy St & Portage Ave site experienced the most false calls due to pedestrians who crossed without waiting (above 25 percent of all false calls), and crossed from the intersection curbside in the perpendicular direction of the APD governed crossing direction (also above 25 percent of all false calls).

- With respect to equipment installation, the research found that the infrared/video detector was the most time-efficient to install given that it has the capability to provide a visual representation of the APD's field of view and zone of detection. This resulted in an overall installation of less than one-half of the time required to install the other two detectors and a greater confidence in the known zone of detection.

5.2 RECOMMENDATIONS FOR FURTHER RESEARCH

This research has resulted in the following recommendations for research opportunities in the future:

- A continuation of this research at the two selected field locations for the months of April to October would complete the seasonal (spring, summer, fall) data collection. This data collection and analysis would provide information to a broader range of traffic signal engineers as it will address the additional weather and temperatures experienced in other climates.

- The analysis of the operating performance of the selected APDs as a function of recorded winter weather and temperature has revealed performance tendencies. It is important to understand and further investigate these tendencies to provide information to APD developers which will aid the continued development and improvement of detection technologies and detectors used for automated pedestrian detection. Further investigation of these tendencies will also provide information to traffic engineers located in various climates as they consider the suitability, benefits, and limitations provided by a particular APD.

- More research and analysis is required to understand additional factors that contribute to false and missed calls. Possible factors to consider are the availability/complexity of pedestrian movements in and around a given APD detection zone, the effect of curbside geometry at the intersection corner, and the effect of varied onset delay settings. Knowledge of these possible factors will provide information to APD developers and traffic engineers on how best to design the infrastructure to support potential APD use for the actuation of pedestrian calls at the curbsides of signalized intersections. Likewise, the information will also be useful to APD developers to address shortcomings due to varied intersection curbside geometry.

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Appendix A

Site Setup

Installation of detectors

Prior to installing the detectors at the selected intersection sites, 5.5 m poles were selected to replace the onsite 3.05 m poles. A 5.5 m pole was selected for mounting the camera at a sufficient height which would enable the video camera to have a full view encompassing beyond the installed APD's zones of detection. The mounting arm for the detectors and camera, data collection enclosure, and all other signage including pre-existing signal equipment, pedestrian pushbuttons, and pedestrian heads were installed at the City of Winnipeg Traffic Signals shop. The APDs were not installed prior to installation of a 5.5 m pole onsite to avoid damage to the APDs.

To ensure unhindered views by each APD, the use of a mounting arm was chosen. Standard City of Winnipeg pedestrian signal head mounting arm brackets consisting of extruded aluminum were used to provide unhindered view by the detectors. The overall length of the mounting arm is approximately 40.6 cm in length. The detectors selected for mounting on the standard mounting arms were the AGD 640 and the Smartwalk XP. The selection criteria used to determine which detectors were placed on the mounting arms was by the ease by which an APD's individualized mounting hardware would affix to the mount arm.

A 5.5 m pole with a roughly aligned and affixed camera mount and APD mounting arms was transported to one of the sites, and then removed from the City of Winnipeg Traffic Signal's line truck. The 3.05 m onsite pole was disconnected from power, and then removed from its position at the intersection and exchanged for the 5.5 m pole. Once exchanged, power was connected to the study equipment from pre-existing power cables. The detectors were installed at a height of 3.05 m.



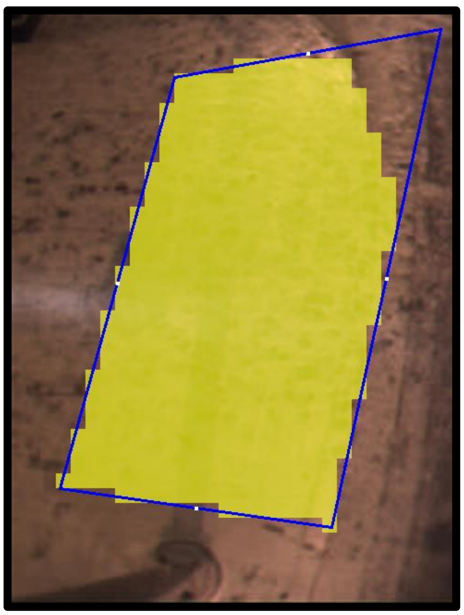
Alignment of the detectors

AGD 640

The onsite alignment and setup of the AGD 640 was the fastest of the three APDs. Communication to the AGD 640 was enabled through use of a Bluetooth dongle on an onsite laptop. Upon connection, a visual indicator by means of a visible blue/green LED on the exterior bottom side of the AGD detector, clearly visible from the curbside, illustrated that the laptop was connected to the correct AGD detector.

Once the AGD 640 was connected to the laptop, the supplied AGD software then proceeded to take a JPEG image of the detector's current field of detection. Knowing the present detection zone of the APD provided immediate feedback on how to position the APD for optimal performance and alignment at the curbside of the intersection.

The AGD software then allows the installer to inscribe a four-sided polygon on the image of the zone of detection which encompasses the area of detection the installer requires. The setting of fine adjustments then allow the installer the ability to remove areas within the polygon where detection is not required.



IR 207 and Smartwalk XP Detection Zone Identification

Visual indication for when the APDs are sending calls is important to know when an image of the detection zone is not provided. The IR 207 and the Smartwalk XP both have LED's which indicate when a detection is occurring. The Smartwalk XP and the IR 207 have indicator lights located within their personalized covers to indicate when detection is occurring. The IR 207 indicates when a call is sent by means of an illuminated red LED. The Smartwalk XP provides its notification of detection in three different ways:

1) A green LED light illuminates when no motion is detected by the detector.

2) A red LED light flashes when motion is sensed within the detection zone.

3) A red LED light illuminates and remains solid when the relay has sent a call.

The LED indication lights of the Smartwalk XP and IR 207 are located within the APD shells which do not allow the installers to see a clear indication from street level that the APD is detecting. Without detection knowledge, the setup of these detectors becomes extremely difficult as it is like turning on a flashlight from a height of 3.05 m without any batteries and trying to determine the shape, size, and location of the intended illumination area.

Knowledge of when detection occurs enables the installers to accurately set up the detector because the zone of detection for each detector can be determined by conducting walk tests within the zone of detection. The use of a datalogger within the data collection enclosure, connected by remote connection to a laptop, provided information to the installers about when an APD is making a call. Two installers, pylons and caution tape were required for the setup by walk testing. The pylons were set up around the APDs buffered zone of detection, with caution tape connected to each pylon to prevent calls from pedestrian movements, other than the installer's movements. Pylons were setup as to minimize interruptions to pedestrian traffic flow in the area. Once the detection zone was cordoned off, an installer would walk from multiple directions and stop when a call occurred marking their stopping points. The APDs mounting would then be adjusted to better align the APD to the curbside wait area. The IR 207 and Smartwalk XP both required more time to install in comparison to the AGD 640.

IR 207

The IR 207 has no configuration options and therefore is the least configurable of all the APDs. The IR 207 instantly sends a call when a change thermal energy in the detection zone has been identified. When there is a change in the detection zone, the IR 207 detector then send a signal that a pedestrian has been detected. Immediately after the change is no longer present within the detection zone the APD stops sending a call. The identification of the IR 207's detection zone by walk tests is aided by the APD's quick changes to the status of the call.

MS Sedco Smartwalk XP.

For the purpose of the walk testing setup, the onset delay potentiometer of the APD was set to zero seconds. The delay was set to zero so that so that detection noted on the laptop occurs immediately following the entrance of the installer within the APD's detection zone. The immediate detection notification allows the visualization of the ground area of detection. Once the detection zone is determined the APD is re-aligned and checked once again. This process occurs until the optimal detection zone as determined by the installer is present.

Site Configuration

The expected performance of the selected APDs in Winnipeg weather was unknown while the setup occurred. To ensure safety and reliability of the intersections, the APDs have not been wired into the local traffic signal controller for the actuation of pedestrian phases. The onset delay of the AGD 640 has been set to two seconds in order to detect waiting pedestrians, and minimize inadvertent false detections caused by pedestrians who are not crossing but walk through a portion of the detection zone. The risk of not detecting valid pedestrians increases as the onset delay increases. Conversely, the risk of a false detection due to inadvertent pedestrian presence is reduced when the onset delay is increased. Due to the large curbside wait area at the Donald site, the AGD detector was reverted to non-enhanced mode (single camera), the Kennedy site was able to maintain use of the enhanced dual camera detection mode. The onset delay for the Smartwalk XP is set to a similar time based upon detections of trial walk tests.