Transportation Technology Tournament-2019

University of South Florida

Improving Pedestrian Safety Through ITS Solutions

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NOCoE National Operations Center of Excellence

University of South Florida

FDOT TSM&O Transportation Systems Management & Operations

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11	Abstract	Providing pedestrian safety and making facility much convenient and safer for pedestrian are the top most priorities and transportation goals in Florida. Our first solution will utilize a mobile function similar to the Emergency Alerts that will warn the pedestrian attempting to cross the intersection. This trigger will warn the pedestrian of the impending danger of crossing an intersection when the pedestrian cross signal is RED. The research team also proposes a second solution, namely an automated pedestrian detection system that utilizes sensors to detect pedestrian arrival at the crosswalk. In this situation, the pedestrian is not required to press the push- button as the sensor detects their presence and alerts the signal system to activate the pedestrian crossing signal. Past iterations of this technology have utilized automated pedestrian detection systems only at mid-blocks but we propose to incorporate these solutions at signalized intersections. Future iterations of these solutions could also utilize the advancements in connected vehicle technologies to warn the drivers of impending danger while approaching intersections. We believe that the application of both the above-mentioned ITS solutions will produce drastic positive results that will reduce pedestrian fatalities in the state of Florida.
12	Original Problem Statement	Distracted pedestrians and drivers at intersections lead to a large share of crashes, fatalities, and even near misses. Our team has identified pedestrian safety at intersections to be of utmost priority and will propose ITS solutions with an aim to reduce pedestrian fatalities, crashes, and even near-miss encounters.

Table of Contents:

List of Figures:

List of Tables:

1. Background and Motivation

Providing pedestrian safety by making roadway facilities convenient and accessible for pedestrians and other road users are of most importance for the Florida Department of Transportation. According to Smart Growth America from 2008 to 2017, the state of Florida saw the highest average annual pedestrian fatality rate of any other state at 2.73 fatalities per 100,000 residents (1). The Florida DOT has identified pedestrians, bicyclists and distracted driving, as two of the 13 emphasis areas under the 2016 Strategic Highway Safety Plan (SHSP) (2). The Florida Department of Highway Safety and Motor Vehicles (DHSMV) releases an annual traffic crash fact report which summarizes crash rates for vulnerable road users such as, pedestrians and bicyclists. In 2017 alone, the state of Florida saw an increase in pedestrian crashes and fatalities from previous years to 9,420 crashes and 659 fatalities. In addition to this, the fact sheet gives information on crash location and driver actions. It was found there were 689 fatalities on local roadways and 559 fatalities due to drivers failing to yield the right of way (3). From this, it can be stipulated that a high volume of pedestrian fatalities occur at intersections when a driver fails to adhere to the pedestrian right of way while making a right-hand turn. In addition to this, the National Highway Traffic Safety Administration (NHTSA) released a nationwide pedestrian fact sheet that indicated in 2016, 45% on the weekday and 54% on the weekend of all pedestrian fatalities occurred between 6 pm and 9 pm (4). Other results also showed an alarmingly high rate of pedestrians (24%) crossing the intersection when the pedestrian crossing signals were flashing red, and a further 8% who crossed the intersection when the cross signal prohibited this maneuver.

2. Project Objectives

The overall objective of this project is to research and develop an accurate and reliable automated pedestrian detection system at signalized intersections with internally illuminated in-pavement markers (IIIPM) integrated with pedestrian detection technologies. This proposed project has three primary objectives:

- Research and review on pedestrian detection technologies, in-pavement markers and available pedestrian detection systems and obtain detailed information
- Integrate or develop a preliminary automated pedestrian detection system at signalized intersections with communication using currently deployed traffic controllers to adequately place a pedestrian call when a pedestrian is present and remove the pedestrian call when the pedestrian(s) leave the intersection.
- Finalize the development of an accurate automated pedestrian detection system and provide recommendations.

3. Approach

To address our project objective, two solutions were developed, and the general approach to each part of the solution is summarized below:

1. The research team will propose a solution, namely an automated pedestrian detection system that utilizes sensors to detect pedestrian arrival at the crosswalk. In this situation, the pedestrian is not required to press the push- button as the sensor detects their presence and alerts the signal system to activate the pedestrian crossing signal. Past iterations of this technology have utilized automated pedestrian detection systems only at mid-blocks, but we propose to incorporate these solutions at signalized intersections.
2. Our second solution is for the future iterations of the integrated automated pedestrian detection with IIIPMs and also utilize the advancements in connected vehicle technologies to warn the drivers of impending danger while approaching intersections. We believe that the application of both the above-mentioned ITS solutions will produce drastic positive results that will reduce pedestrian fatalities in the state of Florida.

4. Problem Statement

Distracted pedestrians and drivers at intersections lead to a large share of crashes, fatalities, and even near misses. Our team has identified pedestrian safety at intersections to be of utmost priority and will propose ITS solutions to reduce pedestrian fatalities, crashes, and even near-miss encounters.

5. Description of the Solution

5.1 Automated Pedestrian Detection

Table 1: Summary of Existing Automated Pedestrian/Bicycle Detection Technologies [16-30]

Technology Used	Dura-tion	User Type	Pros	Cons
Laser Scanner	Short or long		• High accuracy • Easy installation • Laser scanners can differentiate according to height information • Larger coverage area	• Different model setup application used to monitor pedestrians and vehicles • More than one scanner plane needs to compensate vehicle pitch motion • More complex in signal processing • Limits detection in severe weather condition
Active Infrared Sensor	Short or long		• Portability • Relatively low cost • Easy installation • High accuracy and high precision	• Subject to interference in outdoor settings • Occlusion effects
Passive Infrared Sensor	Short or long		• Low cost • Commercially widely available • Not affected by wet or foggy weather • Can be mounted perpendicular to pedestrian movement and can track the direction of movement • Multiple sensor arrays can distinguish pedestrians walking in groups	• Single or double sensor counter cannot differentiate between individual or pedestrians in group • Temperature can affect counter performance • Limited coverage area • The tendency to undercount groups or side-by-side travelers • Possible undercounting due to occlusion • Differences between products
Microwave Radar Sensors	Long		• Great precision • Insensitive to inclement weather at relatively short ranges encountered in traffic management applications • Direct measurement of speed • Multiple lane operations available	• Continuous wave, Doppler sensors cannot detect stopped vehicles
Computer Visioning	Long		• Easy installation • Data verification • Automated process • Ideal for crowded environments • Large coverage area • Potential to count accurately in various conditions (crowded pedestrians, different lighting conditions) • Possible to review to collect pedestrian characteristics • Video can be recorded for manual review	• Most products intended for indoor settings • Development complexity • Non-standard and non-transferable approaches • Malfunctions after installation of equipment • The difficulty of counting pedestrians in crowded environments not yet resolved • Poor weather conditions can affect product performance if device not adequately designed

Thermal Imaging	Long		• Easy installation • Bicycle detection can be used to adapt green time for people bicycling • Large detection area • Automatic data extraction • Long durations count at one or more intersections	• Poor weather at night can affect the accuracy
Radio Beam Sensors	Long		• Some devices count bicyclists/ pedestrians separately • Highly portable • Equipment can be hidden easily • More accuracy under proper weather conditions	• Not previously tested in the literature • Occlusion errors • Product Differences • Temperature, lighting, rain possibly issues results not highly conclusive • False counts possible when bicycles move side-by-side

5.1.1 Description of the device

Automated pedestrian detection uses thermal technology, which is a combination of passive and automated image processing. Thermal cameras operate similar to passive infrared sensors and generate images by detecting body temperature. They are mounted above the detection zone (as shown in the figure 4) which allows both detection and movement monitoring functions. This detection device is connected to the traffic signal controller via dry contact outputs or TCP/IP network communication which will allow for enhanced dynamic control of traffic signals based on presence or volume information. A significant advantage of thermal sensors is that they are not affected by variations on ambient light. It is also capable of thermal detection in complete darkness, through shadows, and under sun glare and, therefore, can provide real-time detection and monitoring regardless of time. The summary of technical specifications for the proposed device are located in the APPENDIX.

5.2 Internally Illuminated In-Pavement Markers (IIPM)

Background: Internally illuminated in-pavement markers (IIIPM), also known as in-road warning lights (IIIRWL) or recessed pavement markers (IIRPM) have seen an increase in roadway applications throughout the United States. Initially, IIIPMs was developed for airport runway and taxiways. However, they have had more frequent use for pedestrian crosswalks, school and construction zones and highway-rail crossings. (Nambisan, Pulugurtha, & Karkee 2006) (Hofer and Yim 2018). Studies have found that crosswalks with active IIIMPs, compared to those with no additional pedestrian safety features outside of what is required, have seen an increase in driver yield compliance by 70-100 percent (Hamood et al. 2015). At signalized intersections, IIIPMs have also been used to increase driver compliance to red lights by locating the IIIPMs just before the stop bar. A previous study in Houston, Texas, collected data from multiple sites between 2006 and 2009 that implemented an IIIPM system which operated in a continual red burn mode when the signal was also red. The study identified over a 90 percent decrease in the number of right turn on red violations after installing the IIIPM system (Tydlacka 2010).

5.2.1 Description of the device

IIIPMs consists of a light-emitting diodes (LED), a power source and a system controller that are all housed in a compact, durable shell. The color of the LED can come in blue, red, amber, or white, and depending on the vendor, it can be bi-colored. IIIPMs power source is comprised of buried low voltage, parallel DC currents, but have sometimes utilized solar power (NCHRP S-380). Solar powered IIIPM devices have had luminosity constrictions, to which when there is an external power source available, hardwired IIIPMs are preferred (Baker 2002). An example of an IIIPM and its specifications are displayed in Figure 5, in the Appendix.

5.3 Integration of Automated Pedestrian Detection and IIIPMs

Although studies have proven the usefulness of IIIPM systems for stop bar reinforcement and pedestrian yield compliance, there has not been a system which links a pedestrian automated detection system to an IIIPM at an intersection. Moreover, the IIIPMs have only displayed one color that either indicates to stop or yield. It is for this reason that the University of South Florida Team 1 is proposing to link the existing IIIPM systems and the automated pedestrian detection systems together to provide a physical, visible, bi-colored indicator to the roadway users. The placement of the IIIPM system will be located at the right-hand turn stop bar of each approach in the intersection, due to most pedestrian crashes at intersections occurring at the right-hand turn movement.

6. Functional Architecture

The functional architecture, displayed in Figure 1, demonstrates how the system will operate. To prompt the system, pedestrians must remain in the sensors view for more than 4 seconds. The minimum 4 second wait time will insure that unnecessary pedestrian phases do not occur when no pedestrians are present. After 4 seconds has incurred, a signal will be sent to the traffic controller indicating a pedestrian phase needs to be initiated. When the pedestrian phase occurs, the conflicting right-hand turn approaches will have their IIIPMs glow red, which is shown in in the “yes” flow line to the in-pavement markers in Figure 1, reinforcing the stop bar and promoting the drivers to make a complete stop in order to increase their awareness of pedestrians in the intersection. In addition to this, the parallel, right hand turn approaches, will have their IIIPMs glow amber indicating that there is a pedestrian in the crosswalk, and that the pedestrians have the right of way, regardless if the traffic light is green, since the movement is considered permissive as seen in phases 2,6 4 and 8 in Figure 2.

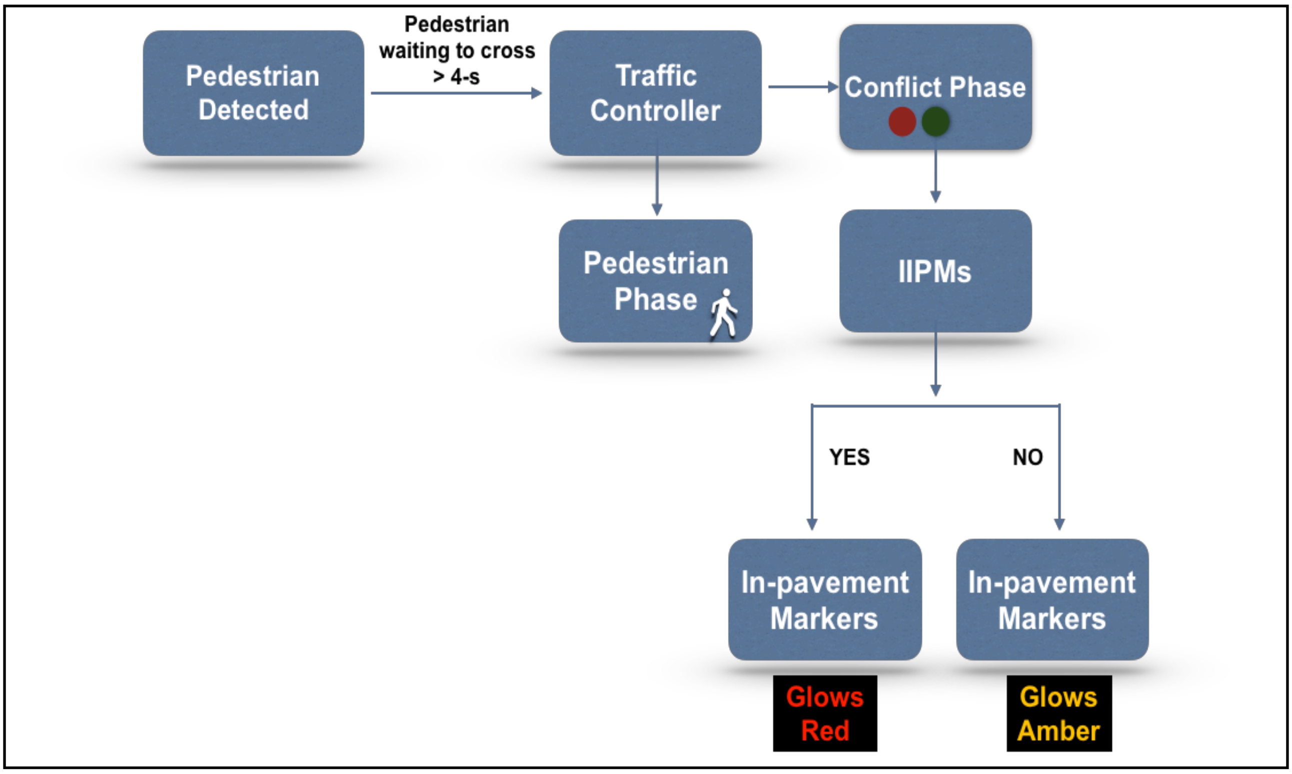

Figure 1: Functional Architecture

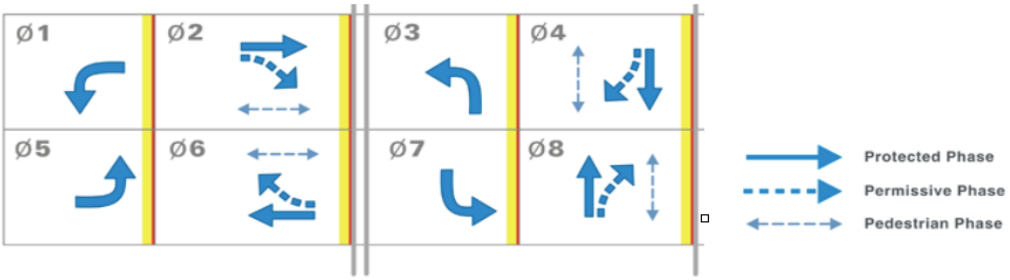

Figure 2: Typical Intersection Phase Diagram with Right-Turn Overlap

7. Physical Architecture

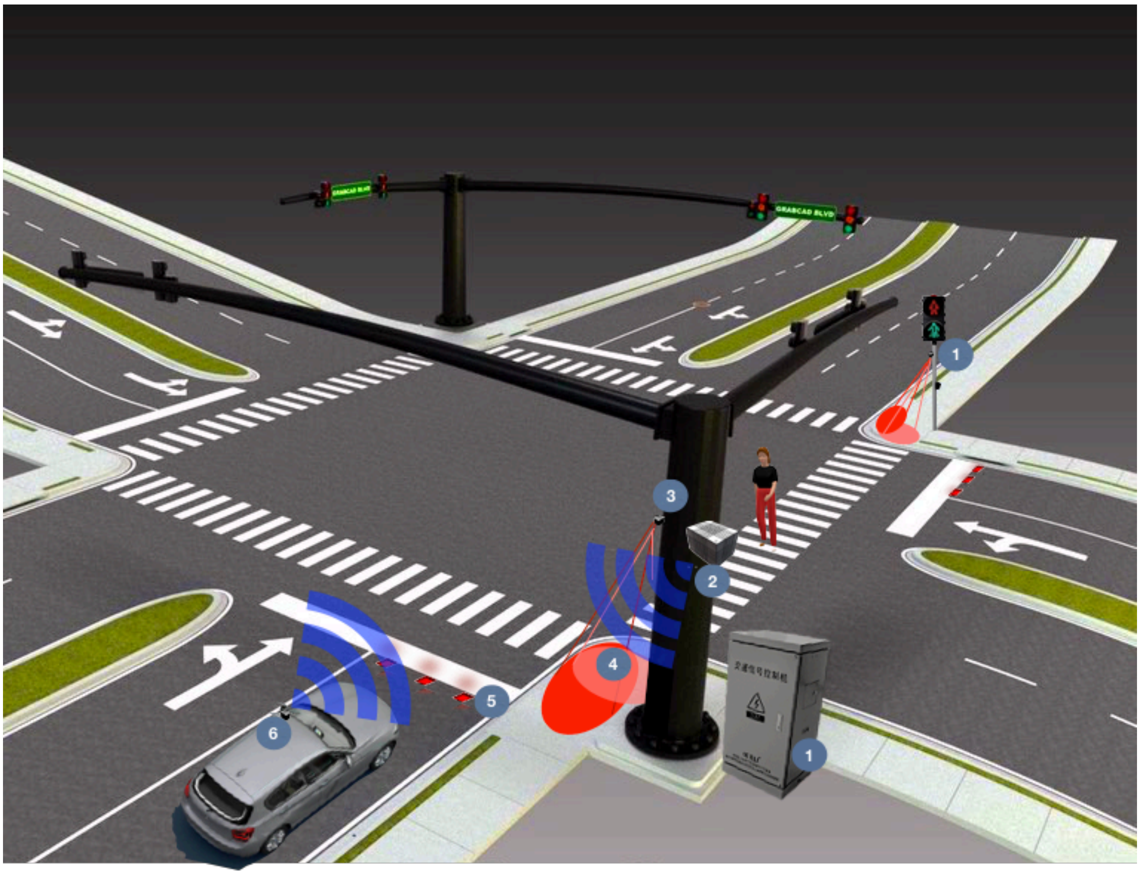

Figure 3: Physical Architecture

[1 and 3] Automated pedestrian detectors physical locations

[2] Dedicated short range communication (DSRC) (discussed later)

[4] Pedestrian detection zone

[5] Internally illuminated in-pavement marker location

[6] Connected vehicle transmission to the DSRC (discussed later)

[7] Traffic control cabinet, housing the signal system controller and the IIIPM controller

8. Cost Estimate

Table 2: Cost Estimate for the Automated Pedestrian Detection Sensor

Basis of Estimate					
Project: Automated Pedestrian Detection Internally Illuminated In-Pavement Markers			**Date: 4-30-2019**		
Internally Illuminated Bi-Colored In-Pavement Marker (IPM)					
Category	**Material**	**Labor**	**Base Cost**	**Total Cost**	**Duration (Hr)**
In-Pavement Marker	x16 Bi-Colored IPM		\$100 - \$250	\$1600 - \$4000	4 – 8
IPM Controller	x1 System Controller	X1 Electrician \$21.80/hr.	\$1000 - \$3000	\$1050 - \$3100	1-4
Pavement Removal - Groove	Concrete/Asphalt Diamond Saw	X1 Saw Operator & crew \$40/hr		\$160 - \$320	4 -8
Pavement Removal - Core	Asphalt Milling x16, 7"x7"x2" cores	Milling Crew \$50/hr		\$200 - \$400	4 -8
Groove and Core Fill	Epoxy	General Laborer \$11.71/hr	\$154/Ga.	\$330	2
Power Source and Fiber Optic	Power and Fiber Optic Cable/	x1 Electrician \$21.80/hr.	\$3.30 LF	\$396	4
Cost Description: In-pavement markers (IPM) are typically estimated based on the entire cost of installation. The IPM controller is usually housed in the traffic control cabinet and thus needs to be installed by an electrician. One controller is capable of service all 16 IPMs. The groove pavement removal is to allow for the power source and fiber optic cables to connect from the IPM that is embedded in the pavement to the pull box. The core pavement removal is the imbedded placement of all 16 IMPs. The epoxy is needed to fill the groove and core. The power source and fiber optic cables are the distance from the furthers IPM at each approach to the nearest pull box. In this case we used a linear distance of 30 feet for each approach. Costs for Labor and Fiber optic cable were obtained from Wage Determinations which compiles federal wages and from the Florida Department of Transportation Yearly Basis of Estimate for Hillsborough County.					

Table 3: Cost Estimate for the Internally Illuminated In-Pavement Bi- Colored Markers

Basis of Estimate					
Project: Automated Pedestrian Detection Internally Illuminated In-Pavement Markers			**Date: 4-30-2019**		
Automated Pedestrian Detection Sensor					
Category	**Material**	**Labor**	**Base Cost**	**Total Cost**	**Duration (Hr)**
Pedestrian Sensor	x4 Thermal Sensor		\$500 – \$4000	\$2500 - \$16000	4 – 8 hours
Power Source and Fiber Optic	Power and Fiber Optic Cable/	x1 Electrician \$21.80/hr.	\$3.30 LF	\$350	4
Brackets	x4 mount clamps and aluminum tubing	General Laborer \$11.71/hr	\$400	\$1650	4
Cost Description: The thermal sensors are estimates depending on the functionality of each sensor. The low end for each was identified as \$500 and \$4000 each for the more advanced versions available. The power source and fiber optic cables are assumed to be connected to local pull boxes at the intersection. The supplier vendor for the sensor often supplies the power cable, however the fiber optic cable will need to be purchased and installed to which there will be an electrician needed to connect the sensor into the pull box. Lastly, brackets will be needed for each sensor to hang from existing Mast poles at each corner of the intersection. (It is assumed there will be a pole to hang the device from to not incur addition costs for fabrication and installation of another pole.) Costs for Labor and Fiber optic cable were obtained from Wage Determinations which compiles federal wages and from the Florida Department of Transportation Yearly Basis of Estimate for Hillsborough County.					

9. Summary of Impacts

Automated pedestrian detectors integrated with illuminated in-pavement markers can provide significant operational and safety benefits when installed, especially at signalized intersections. These pedestrian sensors are programmed in such a way that it would detect the pedestrian only in the assigned zone and assigned direction. For example, if a pedestrian enters the detection zone from the opposite side of the crosswalk, the sensors would not detect those pedestrians. There are cases where pedestrian using sidewalks tend to pass by the detection zone, for this scenario, the sensors are programmed to reject the pedestrian call be having an underlying directional awareness.

10. Limitation

In some instances, there are false pedestrian triggers due to slow moving vehicles making right turns outside the detection zone. This can be solved by providing a proper setback (approx. 25-30 inches) between the curb and detection zone.

There might also be a case where pedestrian would intentionally stand outside the detection zone under a shade near a traffic signal while waiting to cross. This case is more observed in Florida especially during summer months where pedestrian would try to stay away from direct contact with the sun. This is a distinct instance where it becomes impossible for the sensors to detect the pedestrian since they have not presence in the detection zone. This is why, even though most individuals do not activate the push-button to cross the intersection should remain. If the pedestrian remains in close proximity to the intersection and does not receive the crossing phase, they will still have the option to physical institute the phase through the historic push-button

11. Future Work

In terms of reducing traffic accidents and using transportation networks efficiently, it is essential to use wireless communication technologies such as Dedicated Short-Range Communication (DSRC) systems between connected vehicles and infrastructure via Intelligent Transportation System (ITS) applications [12]. DSRC is an active safety application which provides high-speed data transfer in two-way short to medium range wireless communications. For public safety and traffic management, the DSRC system provides many transportation applications such as intersection collision avoidance, blind spot warnings, and electronic toll payment [13]. Integrating the proposed technology (i.e., automated pedestrian detection with illuminated in-pavement markers) with Connected vehicle through DSRC would provide significant operational and safety benefits when installed especially on the signalized intersection. As it would be a vital role in triggering the presence of pedestrian on the crosswalk inside the vehicle would create a powerful impact on reducing the pedestrian crashes.

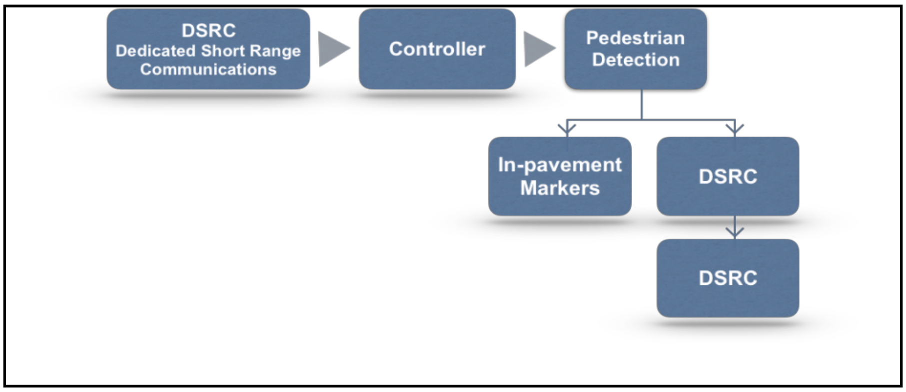

Figure 4: Future Connected Vehicle Framework

12. Stakeholders

City of Tampa

Traffic-related concerns such as traffic advisories, traffic signs, traffic signs repair, traffic signal timing concerns are taken care by city of Tampa with the involvement of other departments such as Florida department of transportation (FDOT).

Plan Hillsborough

The Planning Commission, the official local planning agency for all jurisdictions in Hillsborough County, provides consolidated planning services and makes independent recommendations to the Board of County Commissioners, Plant City Commission, Tampa City Council, Temple Terrace City Council and other agencies regarding smart growth and development of Hillsborough County.

Local and Regional Department of Transportation

The Florida Department of Transportation (FDOT or Department) is an executive agency, which means it reports directly to the Governor. FDOT's primary statutory responsibility is to coordinate the planning and development of a safe, viable, and balanced state transportation system serving all regions of the state, and to assure the compatibility of all components, including multimodal facilities.

13.Conclusion

In the United States it is expected that development and refinement of automated pedestrian detection systems with connected in-pavement markers will continue due to the potential benefits of this technology to road users. Improvements are required in the accuracy of the detections to reduce the number of false alarms and missed calls at the interaction. The combination of an automated pedestrian detection system with illumined in-pavement markers will result in positive changes in the driving behavior of drivers and thus decrease the negative statistics of pedestrian-motor vehicle incidents

Operational and Safety benefits: Since right-turns require the driver to pay attention to oncoming traffic, and the potential for there to be a pedestrian at two locations, one at each crosswalk, IIIPMs will provide a preemptive indication of pedestrians present in the crosswalk. This will give the driver an increased awareness of their presence in the crosswalk. The merged sensor system provides automation, which is conventionally done by manual efforts.

It is expected that the induction of IIIPMs and automated detection devices will reduce the number of incidents and near-misses for vehicle-on-pedestrian scenarios. The pedestrian would be safer when crossing the street as the sensors automatically detect them, and also the driver will have increased compliance of performing a complete stop at the stop bar. The advisory, amber scenario, will prompt users to be more cautious at an intersection because it will be made apparent there is a pedestrian attempting to use the crosswalk.

Mobility benefits: Since the Automated pedestrian detection sensors and IIIMP system is easy to install, it can be applied in a wider area, extending beyond places with high crash rates. Pedestrians themselves would travel in less time within crossings with less perceived risk and more road user awareness.

Environmental benefits: The systems have limited environmental impact – the markers and pedestrian detection devices are strong and easy to produce, last for a long time and the parts can be recycled for new systems. IIPMs both physically and visually, it has a small footprint on the roadways. The system is appropriate for sensitive areas as causes less light pollution.

14. Acknowledgement

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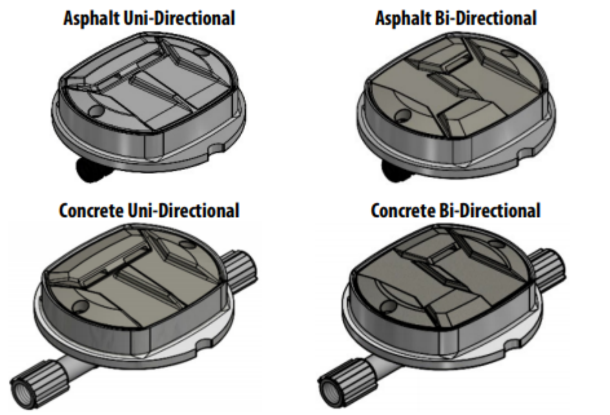
15. References

1. Smart Growth America. Dangerous By Design 2019. https://smartgrowthamerica.org/dangerousby-design/
2. Florida DOT. Florida Strategic Highway Safety Plan, 2016. https:// fdotwww.blob.core.windows.net/sitefinity/docs/default-source/safety/safety/shsp2016/ fdot_2016shsp_final.pdf?sfvrsn=3c118f35_0
3. The Florida Department of Highway Safety and Motor Vehicles (DHSWV) Traffic Crash Facts Annual Report 2017. https://firesportal.com/Pages/Public/DHSMVDocuments.aspx
4. National Highway Traffic Safety Administration (NHTSA). Traffic Safety Facts 2016 Data. DOT HS 812 493.
5. National Cooperative Highway Research Program (NCHRP S-380). "*Applications of Illuminated, Active, In-Pavement Marker Systems."* NCHRP Synthesis 380. https://www.lightguardsystems.com/wp-content/uploads/2013/02/NCRH-ApplicationsOfIlluminatedActiveIPMSystems1.pdf
6. Wage Determinations OnLine.gov (WDOL) "Selecting DBA Wage Decisions". https://www.wdol.gov/dba.aspx
7. Nambisan, S. S., Pulugurtha, S. S., & Karkee, G. (2006). An evaluation of the effectiveness of an inpavement flashing light system. In Transportation Research Board 85th Annual Meeting (No. 06- 1972).
8. Hofer, J. Yim, L. (2018). Experiment 8(09)-8 (E). Los Angeles Metro. http://www.dot.ca.gov/trafficops/ctcdc/docs/Final-Report-IIRPM-Los-Angeles-091018.pdf
9. Baker, T. (2002). National Electrical Code Requirements for In-Roadway Lights. IMSA Article Form. IMSA Journal Article Aug 2002.
10. Hamood, F., Parentela, E.M., Mustafa, Z., Killian, C. (2015). In-Road Warning Lights: Revisiting Pedestrian Crosswalk Application. https://www.westernite.org/annualmeetings/15_Las_Vegas/Papers/5A-Killian.pdf
11. Tydlacka, J. (2010). Evaluation of Lighted Pavement Marker Stop Bard and LED Outline Trarffic Signal Backplates. Texas Transportation Institute. IMSA Journal.
12. Liu, Y., Dion, F., & Biswas, S. (2005). Dedicated short-range wireless communications for intelligent transportation system applications: State of the art. *Transportation research record*, *1910*(1), 29-37.
13. National Highway Traffic Safety Administration (NHTSA). *Traffic Safety Facts: 2015*. U.S. Department of Transportation, August 2015, pp. 1–9. https://doi.org/DOT HS 812 409.
14. Zeeger, C. V., D. Nabors, P. Lagerwey, C. Sundstrom, D. Lovas, T. Huber, R. Eldridge, and M. Bushell. *PEDSAFE 2013: Pedestrian Safety Guide and Countermeasure Selection System*. Washington, DC, 2013.
15. Foord, J. G. Operating Performance of Automated Pedestrian Detectors at Signalized Intersections. Master Thesis. University of Manitoba, 2010.
16. Federal Highway Administration. University Course on Bicycle and Pedestrian Transportation, Lesson 10: Pedestrian Facility Signing and Pavement Markings. Washington, DC, 2006.
17. Somasundaram, G., V. Morellas, and N. P. Papanikolopoulos. Practical Methods for Analyzing Pedestrian and Bicycle Use of a Transportation Facility. Reprot No. MN/RC 2010-06. Minnesota Department of Transportation. Minneapolis, MN, 2010.
18. Bu, F., and C.-Y. Chan. Pedestrian Detection in Transit Bus Application: Sensing Technologies and Safety Solutions. *In:IEEE Proceedings Intelligent Vehicles Symposium,* 2005.
19. Viola, P., M. J. Jones, and D. Snow. Detecting Pedestrians Using Patterns of Motion and Appearance. In: *Proceedings Ninth IEEE International Conference on Computer Vision,* 2003.
20. BEA: A Halma Company. LZR-130 Laser Scanner for Industrial Door and Gate Safety. https://www.beainc.com/en/product/lzr-i30/. Accessed Feb. 15, 2018.
21. Hughes, R., H. Huang, C. Zegeer, and M. Cynecki. Evaluation of Automated Pedestrian Detection at Signalized Intersections. *REPORT NO. FHWA-RD-00-097.* Highway Safety Research Center, University of North Carolina. Chapel Hill, NC, 2001.
22. Noyce, D. A., and R. Dharmaraju. An Evaluation of Technologies for Automated Detection and Classification of Pedestrians and Bicyclists. *Web Document.* Amherst, MA, 2002.
23. Hotron Ltd. Active Infrared Sensor Technology. http://www.hotron.com/active-infrared-sensor-technology. Accessed Feb. 15, 2018.
24. Eco-Counter. CITIX-IR. https://www.eco-compteur.com/en/products/citix-ir. Accessed Feb. 15, 2018.
25. Steindel, M. Technologies for Automated Pedestrian Detection at Signalized Intersections.
26. Manitoba, Canada, 2008.
27. Gavrila, D. M., M. Kunert, and U. Lages. A Multi-Sensor Approach for the Protection of Vulnerable Traffic Participants the PROTECTOR Project. *In: Proceedings of the 18th IEEE Instrumentation and Measurement Technology Conference. Rediscovering Measurement in the Age of Informatics,* 3, 2001, pp. 2044-2048.
28. Dharmaraju, R., D. A. Noyce, and J. D. Lehman. An Evaluation of Technologies for Automated Detection and Classification of Pedestrians and Bicycles. *Web Document,* 2011.

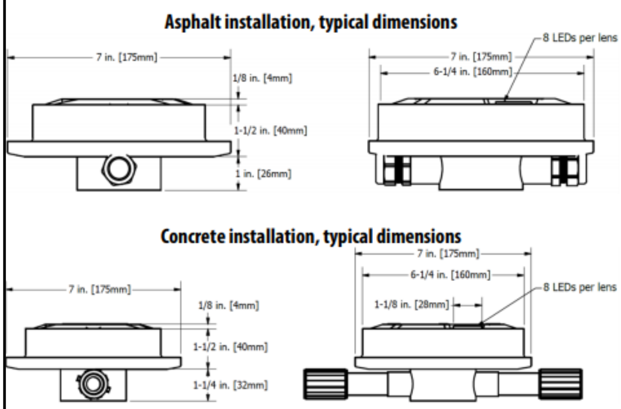
Table 4: Pedestrian Detection Sensor Specifications

Input power	12 – 42 V AC/DC
Power consumption	3 Watt
Outputs	1 N/O and 1 N/C dry contacts direct, 16 N/C dry contacts via TI BPL2 interface
Ethernet	10/100 MBps
PoE	PoE A and PoE B
Powerline communication	Up to 2 MBps via TI BPL2 interface
Wi-Fi	IEEE 802.11
Shock & vibration	NEMA TS2 specs
IP Rating	IP67
Temperature range	-40°C to +60°C (-40°F to +140°F)
FCC	FCC part 15 class A
Housing materials	Aluminum housing with PC GF10 sunshield
Bracket	PA GF30 mounting clamps and aluminum tube
Visual sensor resolution	1080 x 1920 HD color CMOS
Visual sensor frame rate	30 fps
Visual sensor lens	HFOV 95°
Visual sensor streaming Video	RTSP
Visual sensor compression	H.264, MPEG-4, MJPEG
Thermal sensor resolution	160 x 120
Thermal sensor frame rate	9 FPS
Thermal sensor detector type	Focal Plane Array (FPA) uncooled VOx microbolometer LWIR sensor, 8 to 14 µm wavelength
Thermal sensor streaming video	RTSP
Visual sensor compression	H.264, MPEG-4, MJPEG
# detection zones	8 vehicle presence zones, 8 pedestrian presence zones
Configuration	Web page via secure Wi-Fi or Ethernet

CONFIGURATIONS



DIMENSIONS



IN-ROAD PROFILES

SPECIFICATIONS

Technology	LED
Dimensions - LED Module	6-1/4 in. L x 5 in. W x 1-1/4 in. H [160mm L x 125mm W x 32mm H]
Dimensions – Housing, Including Junction Box	∅ 7 in. x 2-1/2 in. H [∅ 175mm x 65mm H]
In-Road Profiles	Non-Snow-Plowable: Fixture protrudes above finished road surface 1/8-1/4 in. [4-6mm] Snow-Plowable: Flush mount installation, leveling plates are provided
Snowplow Compatible	Yes, with flush mount installation
Housing - LED Module	Stainless steel
Housing - Base	Aluminum, sea water grade
IP Code	IP68
Load Rating	5.5 tons [5,000 kg] compression
Operating Temperature	-13°F to +167°F [-25°C to +75°C]
LED Face	Uni-directional or bi-directional options
LEDs Per Unit	16
LED Colour	Yellow, red, green, blue, white or bi-colour
Light Intensity	Over 3,500,000 cd/m2
Daytime Visibility	3000 ft. [914m] Dimmable by PWM at night
Operating Voltage	24VDC or 36VAC
Power Consumption	2.5W (nominal)
Wiring	3-wire for VDC installation 2-wire for VAC installation 18 AWG direct burial or drain equipped conduit
Controller	LaneLight Mk4 or Mk5 system controller
Lens	Borosilicate glass
MUTCD Compliance	YES
Warranty	5 year limited warranty for defects in manufacturing, factory assembly and materials only; excludes batteries and damage caused by vehicles or vandalism

Figure 5: Internally Illuminated In-Pavement Specifications