Specifying In-Road Lights and In-Pavement Markers for Traffic Operations and Safety

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ABSTRACT

In-road lights (IRLs) are a viable option for primary and supplemental pavement markings, being identified as acceptable for use by the United States Manual on Uniform Traffic Control Devices (*MUTCD*). The durability of the in-pavement markers is the key to the success of the deployment of these devices. Engineering study of the durability, failure modes, and performance and output over time, and equipment degradation due to environmental factors is a means of assessing the state of the practice for in-pavement markers and identify appropriate device specifications.

This paper describes how wireless IRWL or Internally-Illuminated-Pavement Markers (IIPMs) may be a seizure hazard, devices protruding over 1/2" may be a breakaway hazard, and certain materials and designs are maintenance-intensive due to inherent design weaknesses in shape and technology. The authors propose that agencies review their specific application needs and specify physical, electronic, and warranty characteristics of IRWL and/or IIPM to ensure that industry-leading design practices are being used by prospective and pre-approved manufacturers.

INTRODUCTION

In-Road Warning Lights (IRWL) are effective traffic control and warning devices. [1] [2] [3] [4] Officials are looking for ways to increase visibility on crosswalks especially with the rise in pedestrian fatalities and the implementation of the Vision Zero campaigns. [5] Innovative technologies such as In-Road Warning Lights (IRWL) have been implemented in various locations across the United States and Canada. [4] [6]

Distracted driving is one of the leading causes of pedestrian fatalities. [7] According to the Center of Disease Control and Prevention (CDC), the main types of distraction include:

1. Visual: the driver's eyes are off the road
2. Manual: the driver's hands are not touching vehicle controls
3. Cognitive: the driver's mind is not focused on the task of driving

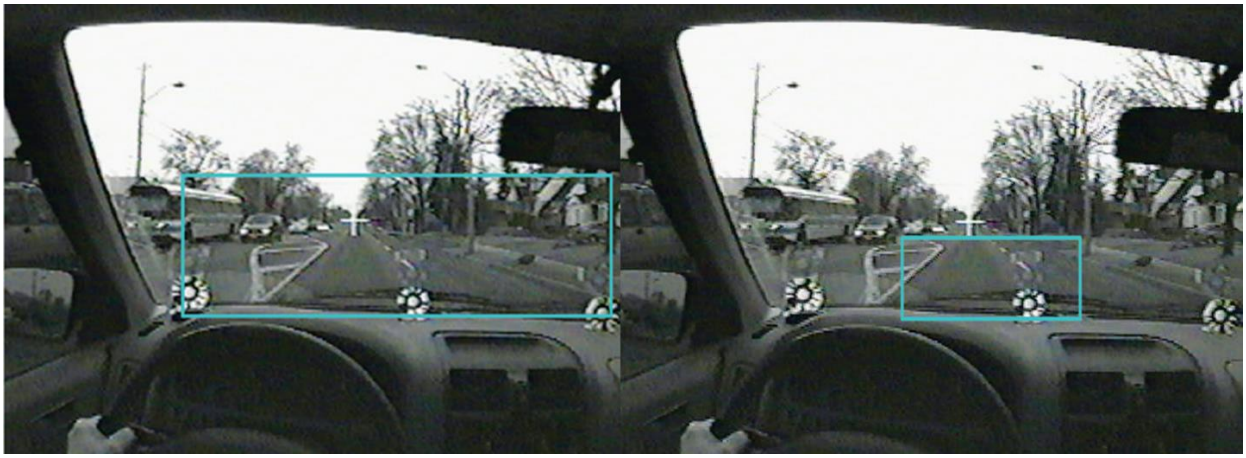

Figure 1 Average attention zone for control group (LEFT) and average attention zone for drivers using hands-free phone (RIGHT) [1]

Often multiple types of distracted driving are occurring simultaneously; for example, while texting, or eating and driving. [7] Cognitive research found a decrease in the attention zone of driver using a hands-free phone when compared to an alert driver, with the attention zones shown in Figure 1, illustrating on the right the decreased area subject to visual scanning by the driver. [1] IRWL technology is effective in

reducing accidents because it targets distracted drivers by placing the warning device directly in the limited field of vision typically encountered with distracted drivers. [1] [2] [3] [4]

HISTORY OF TECHNOLOGY

The United States Federal Highway Administration's *Manual for Uniform Traffic Control Devices* (*MUTCD*) provided guidance concerning the use of IRWLs in the 2000 edition. [8] Researchers testing IRWLs and various agencies implementing IRWL technologies learned that many of the devices were maintenance-intensive and some required replacement at intervals that significantly degraded the cost benefit gained from their installation, relative to a reduction in crashes. [9] [10] [11] [12] A report shows the annual maintenance for one IRWL system was $15,000, roughly the cost of equipment for a new crosswalk installation. [13] [14] However, recent research shows some devices are designed better, last longer, and do not incur significant maintenance costs. [2] [3] [13] Additionally, there are different types of technologies and devices some of which are more suited for specific applications. [13] [15] In particular, the Federal Aviation Administration and Transport Canada have published advisory circulars and regulations that address the use of in-pavement lights [16], which find ubiquitous use at airports throughout North America, including those with extremely intensive use by heavy aircraft.

DEVICE DESIGN AND TOPOLOGY

IRLs, which include the IRWLs and IIPMs, are generally are embedded in the roadway surface and project light subject to the programming of a light controller, which is generally connected to a detection and activation system. IRWLs are a type of in-road light used specifically for crosswalk applications, in accordance with the U.S. *MUTCD*. [17] In-road lights may also be used to illustrate a regulation or provide guidance and may display static, simultaneous flashing, or sequenced indications. [13] The *MUTCD* refers to in-road light devices used for other applications as Internally Illuminated Pavement Markers (). [17] IRWLs are a warning device. IIPM may have regulatory functions such in contraflow operations, and stop bar or signal reinforcement. [13]

CROSSWALK APPLICATIONS

IRWLs are a niche crosswalk treatment in the United States and Canada, in comparison to other devices. [13] [15] IRWL crosswalks are often supplemented with flashing beacons, LED-enhanced flashing signs, or Rectangular Rapid Flashing Beacons (RRFB). [6]

All crosswalk warning lights (i.e. IRWLs and side flashers) must not flash at rate between 5 and 30 times per second to avoid seizure inducing frequencies. [17] The language in the MUTCD chapter 4N.02 specifies the flash rate for IRWLs only, but if IRWLs operate independently from accompanying side flashers the combined light flashed may create a seizure inducing frequency. One provider of these technologies, LaneLight™, produces a wired system specifically for the purpose of synchronizing all lights to the same seizure safe flash rate. Figure 2 shows a LaneLight™ IRWL and RRFB crosswalk warning system installed on a wide roadway instead of overhead mast arms. The system shown below may be solar powered from a small solar panel (50-85W) and cabinet assembly, and is wired for connection reliability, flash pattern synchronization, and ease of access and maintenance.

Figure 2 IRWL and RRFB Crosswalk on a Wide Roadway in California [18]

Wireless and solar IRWL devices have been designed and sold by at least two manufacturers: SPOT Devices Inc, and Silicon Constellations Inc. SPOT Devices' V2 wireless IRWL experienced a high failure rate and SPOT® V3, a wired device that performed better than V2, also suffered from harsh roadway conditions. [19]

Wireless devices may fall out of sync due to moisture, oils, metals, loss of communication due to other devices operating on the same frequency band. [20] Engineers and designers must design-in fail-safe modes and recovery protocols to ensure no IRWL device flashes independently if communication is lost. Wireless devices can be difficult to troubleshoot and maintain since radio spectrum analyzers are not common tools. Additionally, due to security reasons and encryption, vendor-specific software and hardware may be necessary to debug and maintain wireless systems.

Silicon Constellations, Incorporated, provides a device similar to SPOT's V2. Silicon Constellation's case study of SPOT Devices' unit concludes the that failure was a result of the device protruding sharply off the ground and was subject to high mechanical stress. [19] That vendor's analysis, and literature review of raised pavement markers (RPMs) indicates that in-road lighting devices are best kept under ¼-inch (6 mm) or less from the pavement surface and recessed flush for snowplowable applications. [21] [22]

Figure 3 Left - SPOT Devices V3; Right - SPOT Devices V2 [19]

Furthermore, plastic materials and polycarbonate lenses are not recommended in the roadway due to abrasion, pitting, and cracking causing moisture penetration and corrosion to the electronics inside the unit. [19] Rather, corrosion-resistant metals such as stainless steel are recommended for long term durability. [13]

OTHER APPLICATIONS

In-road lights are also used as IIPMs for guidance and regulatory operations. [6] [13] IIPMs may operate in steady burn and may have various colors including red. Some applications of IIPMs include:

1. Red traffic signal indication reinforcement
2. Activation and conspicuity of rail crossings for transit and transport
3. Wrong-way movement warning systems
4. Bike lane guidance and warning systems
5. Tunnel lane delineation and contraflow applications
6. Extensions of markings for multiple turn lanes
7. Delineation of horizontal curvature
8. Fog warning and visibility of roadway alignment
9. Runway Status Lights for taxiway holding and takeoff holding operations [23]
10. Runway and taxiway centerline delineation at airports of all sizes
11. Security gates for government and private operations
12. Parking garage systems for parking directions

In such applications IIPMs require high durability, duty cycle, and intelligent control systems to operate effectively. Many IIPM systems cannot be solar powered due to higher duty cycles, and special operation requirements, particularly at airfield operations and for many in-roadway operations where constant or recurring operations are encountered. [6] [13]

High voltage alternating current (AC) system that utilize induction are usually costly, and require special permits and expertise. While low voltage Direct Current (DC) systems (12-48 VDC) are relatively cheaper and easier to install and maintain they are not as reliable on long cable runs, generally considered those that exceed 1000 ft. (305 m.) Low voltage AC systems (12-36 VAC) combine reliability with long cable lengths, safety, ease of use and maintenance, and individual unit addressability and control.

Wired addressable low voltage AC systems are superior to conventional DC units for IIPM systems since they have a lower failure rate, and rely on two-way communication over power to send status reports and operation commands. [24] [25]

Addressable units use a fully digital data transceiver for communication over power lines using Frequency-Shift Keying (FSK) which is built around an Application Specific Integrated Circuit (ASIC). This ASIC is a very efficient solution for cost sensitive, medium data rate applications. Each addressable IRWL contains a microcontroller running software that together with the ASIC is used to implement the Physical (PHY) and Media Access Control (MAC) layers of the Open Systems Interconnection (OSI) networking model. The ASIC not only provides a way to efficiently modulate and demodulate data packets; it features collision detection, as well as automatic forward error correction and CRC-16 data integrity verification creating a very robust data communication link between each marker and the controller. It allows communicating over AC or DC power lines at any frequency between 50kHz and 2MHz with data rates up to 50kbps. [25] Figure 4 illustrates LaneLight's™ specification with the addressable chip as an optional add-on.

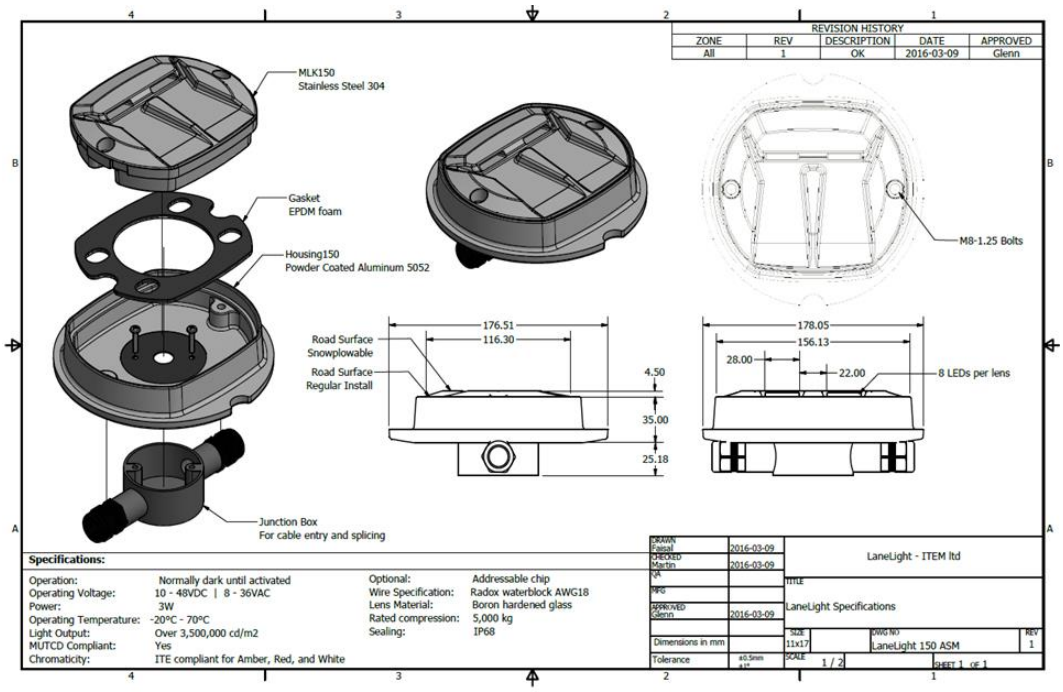

Figure 4 Sample of IRWL Design Specifications [26]

This technology was used in LA Metro, California's rail crossings and Sugar Land, Texas' multiple left turn lanes. [25] [27] LaneLights™ replaced a continuously failing SPOT Devices® system. The SPOT units were replaced on average 3 times over a 2-year period. [24]

CONCLUSION

IRWLs and IIPMs are approved and effective traffic devices. [1] [2] [3] [4] However, not all devices are durable and lasting. [10] [11] [12] [24] If specified properly IRWLs and IIPMs can last over a decade without significant maintenance ($1000/3yrs). [3] When specifying an IRWL or IIPM our recommendations are:

1. Wireless in-road lights may lose communication in certain conditions and if not designed properly may become a seizure hazard and a source of liability. [19] [20]
2. Devices that protrude off the ground more than 1/2in are a safety hazard (may break away and fly off the road), require maintenance, and are not snowplowable. Snowplowable markers must be installed flush with the pavement surface. [19] [21] [22] [24]
3. Plastic structure, polycarbonate lenses, solar panels, batteries, and non-round structures are subject to abrasion, pitting, corrosion, high mechanical stress, and failure. [13] [19] [24]
4. For long cable run applications addressable low voltage AC (12-36VAC) systems are the cheapest, most reliable, and versatile solution. [25]
5. Electrical and electronic connections must be sealed with at least 3 layers of moisture protection using special hydrophobic gel and connectors as shown in Figure 5.
6. 5-year manufacturer warranty.

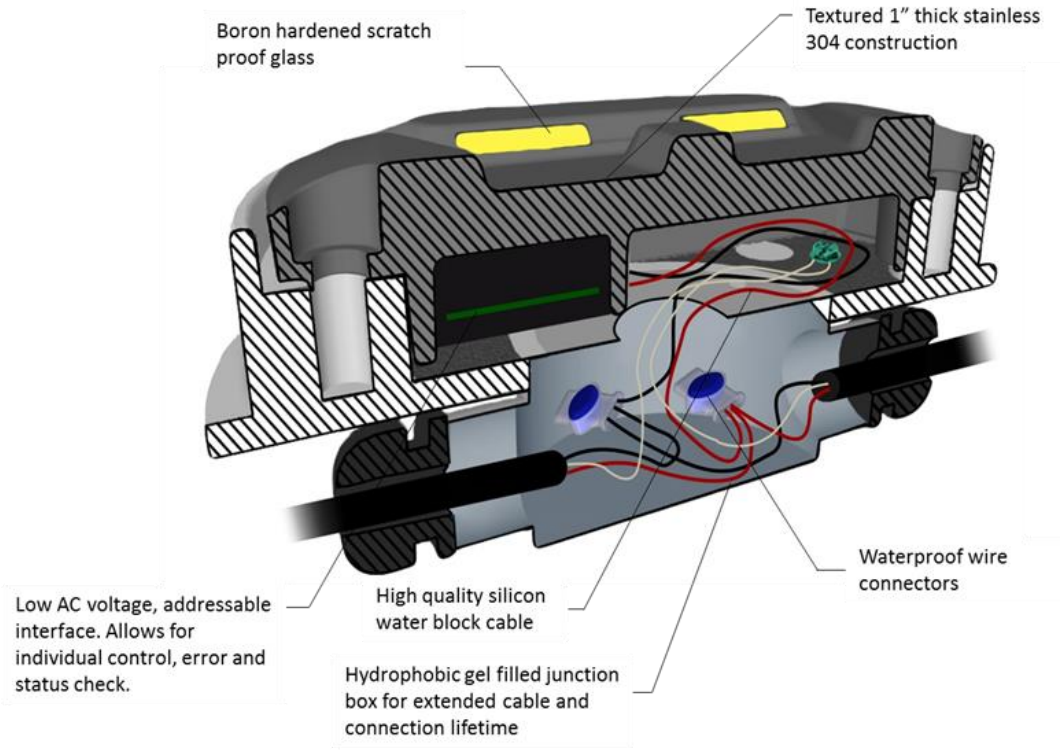

Figure 5 Section View of LaneLight™ electrical connections [6]

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