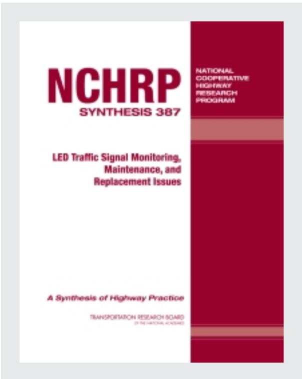

LED Traffic Signal Monitoring, Maintenance, and Replacement Issues

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 387

LED Traffic Signal Monitoring, Maintenance, and Replacement Issues

A Synthesis of Highway Practice

CONSULTANT

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Knoxville, Tennessee

SUBJECT AREAS

Highway Operations, Capacity, and Traffic Control and Safety and Human Performance

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FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Donna Vlasak
Senior Program Officer
Transportation Research Board

This synthesis reports on the maintenance and replacement of light-emitting diode (LED) traffic signal modules. It suggests some successful practices to deal with the complexities of this new and evolving LED technology and concludes with suggestions for additional research to resolve outstanding technical issues. It is intended for those currently dealing with the technicalities of evolving LED technology. Although experience is building, LED traffic signals remain an improving product and the uncertainties in the life of LEDs from an economic, performance, and safety perspective are not well understood. This is natural given the nature of LED technology; nevertheless, uncertainties associated with these issues are a major impediment to the development of a sustainable replacement strategy. As the topic panel directed, this synthesis includes the results of a 2006 ITE Task Force survey effort of users and vendors/manufacturers of LED modules. The specific objectives of the synthesis are to familiarize readers with the history of LEDs as replacements for incandescent lamps, to facilitate an understanding of LED issues, to document lessons learned, and to present successful practices in order to minimize future problems.

ITE survey information presented includes 75 responses from public agency traffic engineers, consisting of ITE public agency members and AASHTO state traffic engineers, and 6 LED vendors/manufacturers [members of the National Electrical Manufacturers Association (NEMA)]. These survey responses were supplemented by follow-up discussions with various state agency officials who confirmed the initial survey results. A case study details more specific LED information gleaned from the Road Commission of Oakland County, Michigan's experience with LEDs dating back to 2000.

Thomas Urbanik, II, University of Tennessee, Knoxville, Tennessee, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

LED TRAFFIC SIGNAL MONITORING, MAINTENANCE, AND REPLACEMENT ISSUES

SUMMARY

Light-emitting diode (LED) traffic signal modules were first widely used in the 1990s because of their significant energy savings and their much longer service life relative to incandescent signals. The Energy Policy Act of 2005 mandated that traffic signal heads manufactured after January 2007 achieve energy consumption levels consistent with LED technology, effectively making obsolete any further manufacturing of incandescent traffic signals.

Although LEDs are being implemented on a widespread basis, there are concerns regarding monitoring, maintenance, and replacement of LED modules. These concerns are centered on several factors including long-term degradation of light output, their mode of failure, and issues, such as cost, associated with their replacement.

This synthesis includes the results of a 2006 Institute of Transportation Engineers (ITE) Task Force survey effort of users and vendors/manufacturers of LED modules. The specific objectives of the synthesis are to familiarize readers with the history of LEDs as replacements for incandescent lamps, to facilitate an understanding of LED issues, to document lessons learned, and to present successful practices to minimize future problems.

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The synthesis identifies technical issues associated with the operation and monitoring, maintenance, and replacement of LED traffic signal modules. It also suggests some best practices to deal with the complexities of this new and evolving technology. It concludes with suggestions for additional research to resolve outstanding technical issues.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Light-emitting diode (LED) traffic signal modules were first widely used in the 1990s. An LED signal module provides significant energy savings relative to an incandescent lamp, and the light source has a much longer service life. LEDs are now being implemented on a widespread basis and will see increased use as a result of the Energy Policy Act of 2005 (EPACT 2005). There are, nevertheless, concerns regarding monitoring, maintenance, and replacement of LED signal modules. These concerns are centered on several factors. It should be noted that many of the problems associated with LED traffic signal modules were the result of early implementations. As will be discussed in more detail, the ITE standards have gone through a major revision based on early experience and the improvements in LED technology. The traffic signal head application of LED technology is still in a process of continual improvements as a result of the increasing population of installed LED traffic signal modules, longer experience, and competition for business.

Whereas incandescent lamps fail in a catastrophic manner, LED signal modules generally lose luminous intensity on a gradual basis, creating uncertainty over when they should be replaced. LEDs are driven by electronics, which make detecting failures more complex.

Many LED signal modules were initially financed outside of the transportation agency as an energy conservation incentive. This has led to some challenges regarding replacement. Once installed, the cost burden for replacing LED signal modules typically lies with the transportation agency. The gradual reduction of LED light output, combined with the higher costs of replacement, may lead to LED signal modules remaining in service after falling below desirable performance levels unless the owning agency has an appropriate replacement strategy.

SYNTHESIS OBJECTIVE

This synthesis reports on current practices for operating, monitoring, maintenance, and replacement of LED traffic signal modules. It reviews research and documents national and international standards and practices pertaining to operating, monitoring, maintenance, and replacement of LED traffic signal modules. The synthesis includes the results of a 2006 Institute of Transportation Engineers (ITE) survey consisting of 75 responses from users and manufacturers of LED modules. The specific objectives of the report are

- Familiarize the reader with the history of LEDs,
- Facilitate an understanding of the issues associated with LEDs,
- Document lessons learned from the experiences of others, and
- Present successful practices to minimize future problems.

ORGANIZATION OF REPORT

The report is organized into three additional chapters plus two appendixes. Chapter two provides an overview of current practices. Chapter three provides examples of successful practices. Chapter four provides conclusions and suggestions for further research. The appendixes contain the results of the two 2006 ITE surveys, one of users and the other of vendors.

CHAPTER TWO

CURRENT PRACTICES RELATED TO LED TRAFFIC SIGNAL MONITORING, MAINTENANCE, AND REPLACEMENT ISSUES

This chapter focuses on current practices related to LED traffic signal monitoring, maintenance, and replacement. However, it is useful to understand how we progressed to the current set of issues.

EVOLUTION TO LEDs

Historically traffic signals were illuminated by turning on an incandescent (60 W to 150 W) lamp behind either an 8 in. or a 12 in. lens tinted red, yellow, or green. Conventional pedestrian and arrow signal indications are similarly illuminated by incandescent lamps.

Incandescent lamps produce light by passing electrical current through a (typically, tungsten) filament. The efficacy of light production depends on the temperature of the filament. Higher temperatures yield a greater portion of the radiated energy in the visible spectrum but may adversely affect filament life. The electrical resistance to the flow of electric current in tungsten is 12 to 16 times greater when hot than at cold temperatures. The lower cold resistance produces an inrush current that lasts about a tenth of a second. Light output (measured in lumens) depreciates over the life of the lamp; typically less than a 20% to 25% reduction at the end of rated life.

General purpose incandescent lamps typically have a rated life in the 750-h to 2,500-h range. Incandescent lamps sold specifically for traffic signals typically have a rated life of approximately 8,000 h. Typical initial lumen output for a 135 W traffic signal incandescent lamp is approximately 1,750 lumens.

While incandescent lamps have been used in a variety of applications for many years, alternatives have been slowly replacing incandescents in many homes as well as outdoor and industrial locations. In most cases, the change from incandescent has been driven by more efficient light sources. However, until the 1990s, the incandescent lamp was the primary light source in traffic signal control applications despite changes in other applications.

An LED is a semiconductor device that creates light using solid-state electronics. A diode is composed of a layer of electron-rich material separated by a layer of electron deficient material that forms a junction. Power applied to this junction excites the electrons in the electron-rich material leading to photon emission and the creation of light. Depending on the chemical composition of the semiconductor layers, the color of light emission will vary within the electromagnetic spectrum.

The individual diodes are grouped together to form a traffic signal where, depending on the individual LED size, up to several hundred "lamps" are packaged into an array to form a traffic signal head. The "Vehicle Traffic Control Signal Heads: Light Emitting Diode (LED) Circular Signal Supplement," July 27, 2005 (VTCSH LED 2005), the current ITE performance specification for circular signal indications, specifies a light display more consistent with traditional incandescent lamps and lens (*1*). A specification for arrows, "Vehicle Traffic Control Signal Heads: Light Emitting Diode (LED) Vehicle Arrow Traffic Signal Supplement," has also been published (*2*).

LEDs are much more energy efficient than their incandescent counterparts for several reasons. LEDs are very energy efficient, producing light output with very little heat while incandescent lamps use a lot of energy generating heat. Incandescent lamps only produce white light, which must be filtered for traffic signal use, and this leads to an additional loss in energy. LEDs, on the other hand, produce colored light that quite often does not need to be filtered—all of the energy is concentrated around one color band and none is "wasted" on undesired colors.

One significant difference in LEDs is that they rarely experience catastrophic failure, as do all incandescent lamps, although their light output continuously degrades over their significantly longer life. This has the potential to have a "dim" indication that will not be detected by electrical current monitoring methods that determine failure by a total lack of output resulting from a failed filament in an incandescent lamp. Also, because of the electronics powering the LEDs, the LED traffic signal design must account for a number of electrical issues including turn-on time, turn-off time, and failed impedance state in order for the safety monitoring device [conflict monitor (CM) or maintenance malfunction management unit (MMU)] to perform satisfactorily.

ENERGY POLICY ACT OF 2005

The Energy Policy Act of 2005 Title I, Subtitle C, Section 135 (z), applies to the manufacture and import of traffic signal and pedestrian modules (*3*). The sections of the EPACT 2005 relevant to traffic signals appear below.

(a) DEFINITIONS—
(43) The term "traffic signal module" means a standard 8-inch (200mm) or 12-inch (300mm) traffic signal indication that—
(A) consists of a light source, a lens, and all other parts necessary for operation; and
(B) communicates movement messages to drivers through red, amber, and green colors.
(b) TEST PROCEDURES—
(11) Test procedures for traffic signal modules and pedestrian modules shall be based on the test method used under the Energy Star program of the Environmental Protection Agency for traffic signal modules, as in effect on the date of enactment of this paragraph.
(c) STANDARD SETTING AUTHORITY—
(z) TRAFFIC SIGNAL MODULES AND PEDESTRIAN MODULES—
Any traffic signal module or pedestrian module manufactured on or after January 1, 2006, shall—
(1) meet the performance requirements used under the Energy Star program of the Environmental Protection Agency for traffic signals, as in effect on the date of enactment of this subsection; and
(2) be installed with compatible, electrically connected signal control interface devices and conflict monitoring systems.
(d) GENERAL RULE OF PREEMPTION—
(B) is an amendment to a regulation described in subparagraph (A) that was developed to align California regulations to changes in the Institute for Transportation Engineers standards, entitled "Performance Specification: Pedestrian Traffic Control Signal Indications."

ENERGY STAR REQUIREMENTS

The Environmental Protection Agency Energy Star Program Standard in place at the time of EPACT 2005 became the criteria for traffic signal modules. The energy efficiency criteria for Energy Star Qualified Traffic Signal Modules appear in Table 1.

TABLE 1
ENERGY EFFICIENCY CRITERIA FOR ENERGY STAR QUALIFIED TRAFFIC SIGNAL MODULES

Module Type	Maximum Wattage (at 74°C)	Nominal Wattage (at 25°C)
12-in. Red Ball	17	11
8-in. Red Ball	13	8
12-in. Red Arrow	12	9
12-in. Green Ball	15	15
8-in. Green Ball	12	12
12-in. Green Arrow	11	11
Combination Walking Man/Hand	16	13
Walking Man	12	9
Orange Hand	16	13

The net effect of the Energy Policy Act of 2005 is that it effectively eliminates the use of incandescent traffic signal modules on new installations and facilitates the transition of traffic signal modules to more energy efficient LED technology by placing energy consumption criteria on red and green LED traffic signal modules. The EPACT 2005, Title 1, Subtitle C, Section 135 (z) applies to Traffic Signal and Pedestrian Modules manufactured on or after January 1, 2007. This act effectively overrides earlier Energy Star requirements for LED traffic signal modules.

It should be noted that the focus on green and red indications resulted from their longer duty cycle. The early cost of LEDs made it difficult to justify the electrical savings from the change-out of the yellow indication. As costs have come down and practical considerations of having to maintain two different types of technology have come into play, LEDs are now typically used for all colors.

ITE LED SPECIFICATIONS

ITE released the LED purchase specification, "Vehicle Traffic Control Signal Heads Part 2," in 1998 (*4*). The VTCSH Part 2 was released as an interim purchase specification to meet the needs of public agencies in light of the rapid expansion of LEDs into traffic signal modules. The VTCSH Part 2 was intended to provide interim specifications while further human factors and photometric tests were completed on LED traffic signal modules. Studies on the effects of luminous intensity, chromatic variation, and degradation of light output needed to be fully understood before the ITE specification could be updated. Span wire-mounted LED traffic signal modules were implicitly excluded from the VTCSH Part 2 as luminous intensity was not addressed at an adequate variation of vertical and horizontal angles to encompass this mounting technique.

ITE replaced the VTCSH Part 2 in June 2005 with a performance specification published under the name "Vehicle Traffic Control Signal Heads: Light Emitting Diode Circular Signal Supplement" (VTCSH-LED) (*1*). Full adoption of the new ITE 2005 VTCSH-LED occurred 1 year from the effective date of the specification making the 1998 VTCSH Part 2 obsolete. The VTCSH-LED supplement states that agencies should use this specification as a minimum performance specification or document alternative requirements based on an engineering study.

Arrow modules are addressed in an ITE-approved specification entitled "Vehicle Traffic Control Signal Heads—Part 3: Light Emitting Diode (LED) Vehicle Arrow Signal Modules—A Purchase Specification." ITE also adopted specifications on March 19, 2004, entitled "Pedestrian Traffic Control Signal Indications—Part 2: Light Emitting Diode (LED) Pedestrian Traffic Signal Modules." While these pedestrian signal specifications are approved ITE standards, it is the intent of ITE to further refine these specifications by harmonizing the language and content of these specifications with that of the new ITE 2005 VTCSH-LED.

TECHNICAL ISSUES

Many technical issues have been overcome since the initial implementation of LED traffic signals. The 2005 ITE specification addresses many of the early problems with LEDs. The following discusses the issues that have been addressed, as well as some issues that are still outstanding.

Traffic signal safety monitors continually look for potential problems in the operation of the traffic signal. The monitoring logic is designed around the field indication circuit and electrical characteristics of a simple incandescent lamp. An incandescent circuit is simply a filament that is connected across the hot and neutral leads of the field wiring to that particular indication. When power is applied, the filament quickly heats up and the lamp emits light. When power is removed, the filament quickly cools and the lamp no longer emits light. If the lamp fails, the circuit is open. It is very simple and very predictable. An LED module is a system of transformers, electronic circuitry, and light-emitting diodes. Unlike a filament, the electrical characteristics of an LED module are component- and design-dependent. The slow voltage decay can be interpreted by the signal monitor as two conflicting indications being energized simultaneously causing the monitor to place the signal into conflict flash. This condition has been addressed and corrected in the new specification.

A far worse condition than a signal monitor falsely placing a signal in conflict flash is a scenario that would warrant a conflict flash condition that is ignored or missed. There have been reports of malfunctioning LED modules that no longer emit light, which continue to present an electrical load to the conflict monitor, giving the monitor the appearance of normal operation. This potential problem has been identified and addressed in the new ITE 2005 VTCSH-LED specification by requiring a failed state impedance circuit that will sense a problem and effectively appear as an open circuit to the signal monitor similar to an incandescent lamp. However, it must be realized that the only true test is observation of the presence or absence of adequate light output, which can only be inferred from LED electronics. Although the failure mode issue is addressed by the 2005 VTCSH-LED, it is not clear whether the requirements are sufficient to provide the most practically reliable systems.

A different conflict occurs when the LED emits light when *not* energized. This can occur as a result of the design of the LED electronics. Some designs may discharge stored energy in a means that could allow the energy to be stored and discharged in an unintended manner. This issue, which is highly technical in nature, suggests an independent assessment of current standards requirements and designs to ensure that only the most fault-tolerant approaches are used. This technical review should consider all aspects of the electrical designs of LEDs with a focus on potential failure modes (including failing on and off).

Another technical issue is the harmony between the ITE standard for LEDs and the NEMA standard for the signal monitor portion of the MMU in TS 2 or the Conflict Monitor (CM) in TS 1. The MMU or CM specifies operation down to 60 ± 10 volts, while LEDs are only required to operate at 80 volts. This creates an inconsistency in the expectation of two devices that should operate in harmony.

A load switch is a solid state device, containing triacs, which is designed to use the traffic signal controller's low voltage DC outputs to switch on high voltage AC outputs to the signal heads. The load switch requires a minimum current flow to trigger and hold the output in the "on" state. In some cases, extremely low wattage LED modules may not draw the necessary load current to satisfy the trigger current or hold current requirements of the load switch, resulting in flickering of the signal indication and/or permanent damage to the load switch. This issue is a practical constraint on the usage of low wattage LEDs. Current NEMA load switch specifications provide an operating range of 0.1 to 10 amps, effectively requiring a 12 W minimum load to operate. This is problematic in some applications such as single arrow application for left turns where the load could be as little as 5 W. This has lead to the practice by some of installing a load resistor in the output circuit, which can defeat the conflict monitoring process. This is an example of the lack of harmony between load switches that were designed for incandescent lamps that draw higher currents and LEDs whose purpose is to reduce load. While there are technical solutions such as designing a new load switch, there are issues of cost and interchangeability that make an interim solution difficult in practice.

Transient voltage protection is also an issue in areas with lightning strikes. Although the 2005 ITE VTCSH-LED specification makes reference to the NEMA TS 2-2003 voltage surge protection, the environment of the LED signal head electronics is significantly different from that with the roadside cabinet. These differences bring into question, as noted in the standard, the effectiveness of the current specification. Some users, most notably Texas DOT, have had concerns with LEDs and lightning strikes.

Since LED modules are extremely energy efficient, they do not generate waste heat and do not melt snow and ice from their lenses like their incandescent counterparts. This can be a problem and may require some additional maintenance work to clear the faces after a driving snow storm. Some agencies have had success using products that are designed to repel rain from automobile windshields to mitigate this effect.

Early LEDs were designed to the old ratio of red:yellow:green of 1:4.6:2 based on circa 1933 standards developed based on glass lens. The new 2005 ITE LED performance specification changes the ratio to 1:2.5:1.3, which was based on human factors issues.

While LED measurement issues are largely beyond the scope of this synthesis, some mention of the complexities is worth noting. LED clusters are unique light sources differing greatly from incandescent lamps in physical size, luminous flux (the measure of the perceived power of light), spectrum (colors), and spatial distribution (LED clusters are not point sources like incandescent lamps). Temperature of measurement also affects the result; therefore, LED measurement results differ considerably in various laboratories. LEDs' unique characteristics therefore require new methods. The Commission Internationale De L'Eclairage (CIE), a standards body involved in the development of standards for measuring the optical properties of LEDs, has been recommending new definitions and new measurement conditions to reduce discrepancies. However, the standards have not kept up with LED technology as it continues to evolve. The net result is difficulty in assessing LED performance in the field. There is also an expectation that CIE will come up with a new edition of CIE 127-1997, which is the foundation of LED measurements (*5*). However, CIE 127-1997 did not cover sufficiently the measurement of total luminous flux and color of LEDs, which are very important in traffic signal applications.

ITE SURVEY

In 2006, the ITE conducted a survey of public agencies and vendors/manufacturers of LEDs. There were 75 responses from public agencies and 6 from vendors. The complete results of the survey are included in Appendices A and B. The following is a summary of the principal findings:

- 59% of respondents indicated that more than 50% of their signal modules are LEDs.
- 82% use or plan to use the ITE LED specification.
- The majority (73%) use a 5-year warranty period (10% do not specify a warranty).
- Total failure rate (dark face) of LED modules is low (less than 5%) and is decreasing as product quality improves.
- 33% do not use a qualified products list.
- 85% do no compliance testing.
- 60% have no monitoring/replacement procedure.
- Half use the specification for minimum light output; half use no specification for minimum light output.
- The number of responses dropped considerably on all questions related to agency practices/procedures for monitoring and replacement. This is possibly an indication of the number of agencies with no replacement program and is consistent with survey results.
- Replacement approach results:
  - No replacement program: 35%;
  - Complaint-driven: 35%;
  - Routine, scheduled replacement: 24%;
  - Replacement on vendor product life cycle: 3%; and
  - Based on in-service test results: 3%.
- Results for scheduled replacement:
  - Greater than 6 years: 52%;
  - Five years: 38%; and
  - Six years: 10%.
- Fifty-five percent prefer national guidelines (not standards) for minimum light output with 60% preferring to adhere to the guidelines based on agency-established procedures.
- Seventy-eight percent have inadequate or no funding for monitoring/replacement programs.

The following is a summary of the main points ascertained from the survey:

- Current usage of LED signal modules is prevalent and growing.
- Many agencies are now approaching the life span of their initial installations.
- Most use a 5-year warranty, but scheduled replacement tends to be on a greater than 6-year cycle; therefore, there is a growing likelihood of old LED signal modules in the field with light output that is below specification.
- Most have no routine replacement program or they are driven by complaints (complaints are less likely with LEDs as they gradually dim over time).
- Although use of the 2005 ITE LED specification is strong, the minimum values for light output are of little use without routine monitoring/replacement programs.
- Most do not have adequate funding for monitoring/replacement of LED signal modules.

RESULTS OF FOLLOW-UP DISCUSSIONS WITH AGENCIES FROM ITE

Many of the follow-up discussions with agencies confirmed the basic issues discussed previously. The following adds some additional comments.

- Indiana DOT has programmed replacement on a 6-year replacement schedule, subject to refinement as their experience base with the newer LEDs adds to their understanding. At this time, they do not plan to replace yellow LEDs on a 6-year cycle. They also plan aerial inspection and cleaning on a three-year cycle. At this time, they do not anticipate monitoring LED performance.
- Texas DOT has had issues with transients. They have not been able to specifically pinpoint the cause. The problems appear to be less with new designs. Texas

DOT reviews LED designs and does failure testing as part of their acceptance testing process.

- Louisiana DOTD had historically required a special circuit in their LEDs that monitored light output. At 85% ITE minimum output, the circuit caused the LED to go dark and a breaker to create an open circuit. One manufacturer met this specification with a photocell on red, yellow, and green balls. The manufacturer has stopped making this LED due to Energy Star requirements for wattage. Louisiana DOTD is concerned that the lack of output monitoring can lead to an unsafe condition.

CHAPTER THREE

SUCCESSFUL PRACTICES

The development of successful practices has many complexities owing to the differences in how agencies operate and maintain their traffic signals. Further, while experience is building, LED traffic signal modules are an evolving product. The following contains insights developed from several agencies.

ROAD COMMISSION OF OAKLAND COUNTY, MICHIGAN, CASE STUDY

The Road Commission of Oakland County (RCOC), Michigan, began installing LEDs in 2000. The total number of intersections maintained is 1,300, with 680 on LEDs. The LEDs are projected to last between 5 and 10 years (LEDs last longer in cooler climates). RCOC in 2006 received lab tests back on sample LEDs installed in 2000. These tests showed that 10 years is a reasonable life span for LEDs. Therefore, RCOC expects that their LEDs will last from 8 to 10 years.

Given the above results and the existing age of RCOC LEDs, the following schedule for LED replacing has been undertaken.

Replacement of First Wave of LEDs

- Year 2008—Replace 36 locations installed in 2000 and 2001 at a cost of $150,000.
- Year 2009 to 2016—Replace about 81 per year at a cost of $350,000 per year.

On-Going Replacement Schedule

- Years 2017 and beyond—Start replacing 10% per year, estimated to be about 95 and ramp up to 200 by year 2026 when all signal heads will use LED modules. This replacement schedule will provide for incremental upgrades from incandescent to LEDs as well as for the addition of new signal installations.

Table 2 shows the estimated funding that is recommended to meet this schedule. This schedule assumes that in years 2006 and 2007 the $200,000 in the budget will not be used to install new LEDs, but will instead be rolled over to provide future funding for replacement. Also, in years 2008 to 2010 (assuming a continued $200,000 budgeted), the remaining monies not used to replace LEDs will be rolled over. In years 2012 to 2016, $250,000 will be needed in the RCOC budget.

This plan will allow three things to occur:

1. A mostly uniform and known budget amount will be established.
2. The budget amount will not be increased over what has been established over the last few years.
3. In several years, a large number of LEDs were installed. This schedule allows for a smoothing of the replacements so no year will see a big budget increase.

Essentially, by looking a few years out and developing a plan that allows more consistent funding, the RCOC has developed a strategy that puts them on what is essentially a 10-year replacement cycle. However, it should be noted this is not based on wishful thinking, but on evaluation of what they expect will be the performance of their LEDs based on manufacturers' specifications and known degradation curves.

ASPECTS OF SUCCESSFUL PRACTICES

Synthesis study efforts revealed that there are several aspects to successful LED traffic signal module practices including purchasing, monitoring, maintaining, and replacing LED modules. Each of these issues is interrelated and cannot be considered in isolation. Understanding successful practices is an evolving science and users of LEDs should continue to monitor industry practices. Purchase specifications should also consider requesting degradation information from manufacturers under varying operating conditions.

There is clearly a need for an LED replacement schedule that routinely replaces a portion of the LED signal modules every year so that agencies are not placed in a position of infrequent, but expensive, replacement programs that tend to postpone replacement of LEDs that have passed their useful life. This problem is likely to be most challenging in agencies that replaced their incandescent lamps all at one time.

Purchasing, as a minimum, LEDs compliant with ITE specifications will address a number of issues associated with early LED implementations. When making large purchases, it may be desirable for a sample of the product to be sent out for conformance testing. It would also be desirable to test in

TABLE 2
RCOC REPLACEMENT STRATEGY

Year	LED Repl. Cost	RCOC Cost	Local Cost	RCOC Budget	Roll-Over Monies
2006				$200,000	$200,000
2007				$200,000	$400,000
2008	$150,000	$135,000	$15,000	$200,000	$450,000
2009	$350,000	$325,000	$25,000	$200,000	$300,000
2010	$350,000	$300,000	$50,000	$200,000	$150,000
2011	$350,000	$275,000	$75,000	$200,000	$0
2012	$350,000	$250,000	$100,000	$250,000	
2013	$350,000	$250,000	$100,000	$250,000	
2014	$350,000	$250,000	$100,000	$250,000	
2015	$350,000	$250,000	$100,000	$250,000	
2016	$350,000	$250,000	$100,000	$250,000	

the shop the LEDs with the specific brands of load switches and MMUs and/or CMs being used by the agency.

Monitoring the maintenance experience with LEDs and keeping records will assist the agency in identifying trends and developing a proactive approach to replacement. While the life of LEDs is long compared to incandescent lamps, LEDs are more susceptible to variations in the environment (heat and cold) than are incandescent lamps. This is another reason for developing a maintenance history of LEDs including the color and type (circular or arrow) of the display, make and model, date of manufacture, date of installation, and the type of operation. Yellow indications have shorter duty cycles than reds and greens. Likewise, some reds and greens may have long duty cycles due to the traffic patterns. A rural traffic signal may have long green times on the arterial and long red times on the cross street. Failure to understand these varying conditions could lead to erroneous conclusions with regard to LED module life.

Maintenance intervals are naturally going to increase because of the longer life of LEDs. This reduced maintenance interval is likely to lead to a lack of cleaning of the LEDs. This lack of cleaning will lead to a maintenance depreciation of the light output in addition to the normal degradation owing to usage and age. To determine if intermediate cleaning is necessary, a systematic monitoring program, as previously mentioned, is essential. Testing of light output with and without cleaning will assist in determining if lens cleaning is a cost-effective strategy to increase service life. This would require a program where samples of modules (cleaned and not cleaned) were sent for laboratory testing.

The replacement strategy for LEDs is the most complex and currently least understood aspect of LEDs. While the early generations of LEDs are reaching their useful life, they do not represent current technology and are at best only an indicator of what may be experienced with newer technology and designs. Agencies will have to be proactive if they are to avoid being driven to costly reactive maintenance.

The simplest form of replacement strategy would be to begin by not doing a systemwide replacement program. The most conservative and potentially most costly approach is to have a maintenance program based on the LED warranty period. Assuming a 5-year warranty, 20% of the traffic signal modules would be replaced each year. This would allow an initial establishment of a worse-case budget. At the end of 5 years, an experience base of failures at 1 through 5 years would be established. At the end of 5 years, the budgeting process would be established that would allow for the complete replacement of 5-year-old LEDs. However, at this point, laboratory testing could be undertaken to determine the light output (before and after cleaning) for a representative sample of LEDs in different operating environments.

Based on the results of testing, a revised maintenance schedule could be developed. It would be speculative to suggest what adjustment should be made, but consideration should be given to the fact that LEDs are different from incandescent lamps. It might be desirable to experiment with different strategies that reflect the duty cycle, operating environment, and relative importance of the indication. Reds might be replaced where duty cycles are high and yellows and greens cleaned if testing showed the approach to be cost-effective. Therefore, until an adequate history is developed, careful experimentation may be a cost-effective strategy to not prematurely replace LEDs that have additional useful service life. However, just waiting until the LEDs can no longer be seen is not a recommended strategy.

CHAPTER FOUR

CONCLUSIONS

SUMMARY OF FINDINGS

Light-emitting diodes (LEDs) are widely used and becoming more so as the result of the Energy Policy Act of 2005. The quality of the product has been steadily improving and the ITE 2005 LED specification addresses many of the early problems experienced by first adopters of LEDs. Users of LEDs appear to be largely satisfied with the performance of LEDs. Nevertheless, there are some concerns that have not been totally addressed.

Issues remaining to be addressed include the following:

- Definition of a sustainable LED replacement strategy:
  - Determining appropriate replacement schedule,
  - Determining funding for replacements.
- Need for improvement of technical standards:
  - Better failure detection,
  - Harmonization with related standards,
  - Ability to further reduce energy consumption.

The life of LEDs from an economic, performance, and safety point of view is not well understood. This is natural given LEDs are a new and improving technology. However, the uncertainty associated with these issues is a major impediment to development of a sustainable replacement strategy.

LEDs are operating in an environment developed for incandescent lamps. This has led to LEDs being designed to "work" in a world defined by Thomas Edison in the 19th century. Resolving these issues is difficult because of the installed base of existing equipment and the lack of a clear path to specification of a new "system" to deliver traffic signal displays safely and efficiently.

CONCLUSIONS

LEDs are the likely de facto technology for traffic signal displays for the foreseeable future. They are generally meeting the needs previously met by incandescent lamps at greatly reduced energy consumption and reduced life-cycle cost. LEDs have a number of positive benefits including increased life that reduces the exposure of maintenance personnel to working in the roadway. However, a number of technical issues have not been completely addressed. The next section contains suggestions for further research to address current limitations in understanding and legacy issues emanating from standards developed for incandescent lamps.

SUGGESTIONS FOR FURTHER RESEARCH

Based on the results from this synthesis work, the most pressing LED need is to address the fundamental issue of a dark display not being sensed by the conflict monitor or malfunction management unit. This is a complex issue that includes both the harmonization of related standards and the fundamental issue that an LED display is not electrically the same as an incandescent lamp. This issue would best be addressed in a systematic manner involving the standards organizations (National Electrical Manufacturers Association and ITE) as well as the vendors. While this issue does not seriously affect current day-to-day operations, it does potentially impact future liabilities. The issue also limits the ability of LEDs to be more energy efficient in the future.

The issue of LED module life and LED module degradation also warrants national attention, but would be best done at the regional level, primarily because it is impractical for most individual agencies to undertake the research necessary to determine the most cost-effective maintenance strategy and because performance is affected by the operating environment. Future research would include development of a better understanding of LED module life by *color* under differing operation conditions including duty cycle and operating environment. Additional research would also include the development of suggested practices for monitoring and maintaining LED modules so that understanding of performance could be refined over time as LED modules continue to evolve.

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APPENDIX A

Agency LED Traffic Signals Survey

SURVEY DESCRIPTION

The Institute of Transportation Engineers (ITE) is seeking to better understand maintenance issues associated with light emitting diode (LED) traffic signals. LED traffic signals represent a fundamental shift in technology from incandescent traffic signals and have unique characteristics that must be taken into account in maintenance practices. Additionally, use of LED traffic signals is growing and will continue to grow due, in part, to the recent Department of Energy requirements on signal manufacturers. Therefore, more information is needed to enhance understanding of the maintenance issues faced by public agencies that own, operate, and maintain LED traffic signals.

ITE requests your assistance by completing the following short survey.

All individual information and responses will remain confidential.

RESULTS OVERVIEW

The following tables summarize the responses received.

TABLE A1
BACKGROUND

2. Please check one:			
City/Municipality		34	45%
County		17	23%
State/Province		20	27%
Other, please specify (see Table A7)		4	5%
Total		75	100%

3. How many traffic signals does your jurisdiction operate and maintain?			
Less than 50		11	15%
50 – 150 signals		16	22%
151 – 500 signals		20	27%
501 – 1000 signals		10	14%
More than 1000 signals		17	23%
Total		74	100%

4. What is your jurisdiction's population?			
Less than 50,000		9	12%
50,000 – 250,000		20	27%
250,000 – 500,000		9	12%
500,000 – 1,000,000		10	14%
More than 1 million		25	34%
Total		73	100%

5. What percentage of your individual traffic signal indicators (including pedestrian signals) use LED modules?			
Less than 10%		6	8%
Between 10 and 30%		16	22%
Between 30 and 50%		8	11%
Between 50 and 80%		15	20%
Between 80 and 99%		18	24%
100%		11	15%
Total		74	100%

6. Does your agency have plans for full conversion to LED traffic signals (See Table A8 for comments)			
Yes		60	85%
No		11	15%
Total		71	100%

TABLE A2
EXPERIENCE WITH LED TRAFFIC SIGNALS (All questions apply only to LED traffic signal installations)

7. How long has your agency been using LED traffic signals?			
Do not use LED traffic signals		1	1%
Less than 1 year		2	3%
Between 1 year and 5 years		31	42%
More than 5 years		40	54%
Total		74	100%

8. If your agency experienced total burn-outs (black face) of whole LED traffic signal modules within the warranty period or within 60 months of installation (if there is no warranty period), what percentage of the total LED traffic signal modules failed?			
None		9	12%
Less than 1%		24	33%
Between 1 and 5%		31	43%
Between 5 and 10%		7	10%
More than 10%		1	1%
Total		72	100%

9. The LED traffic signal modules failed because of which of the following (check all that apply):			
High ambient temperature		6	8%
Wet weather		7	10%
Electrical storms		14	20%
Compatibility of external hardware		3	4%
Poor quality utility power		3	4%
Faulty module		40	59%
Do not know		23	34%
Other, please specify (see Table A9)		10	14%

TABLE A3
PURCHASING LED TRAFFIC SIGNALS

11. Now that ITE has released the 2005 LED circular ball specification, does your agency plan to use it?			
Yes		61	82%
No		13	18%
Total		74	100%

12. If your agency does not use an ITE LED specification, how does your specification differ (check all that apply)?			
Extended viewing angles		6	21%
Higher light output values for red		1	3%
Higher light output values for green		2	7%
Higher light output values for yellow		1	3%
Lower light output values for red		1	3%
Lower light output values for green		2	7%
Lower light output values for yellow		2	7%
Other, please specify (see Table A11)		18	64%

13. What warranty time period does your agency require for LED traffic signals?			
No warranty is required		7	10%
3 year warranty		5	7%
4 year warranty		0	0%
5 year warranty		52	73%
6 year warranty		4	6%
More than 6 year warranty		3	4%
Total		71	100%

14. Is your agency purchasing LED traffic signals that have light output indicators that identify when light output falls below the specified level?			
Yes		4	6%
No		67	94%
Total		71	100%

TABLE A4
APPROVAL OF LED TRAFFIC SIGNALS FOR USE

15. Does your agency rely on a Qualified Products List (QPL) when making a purchase of LED traffic signal modules?			
Yes, the QPL is maintained by my agency		31	42%
No		24	33%
Yes the QPL is maintained by this other agency (see Table A12)		18	25%
Total		73	100%

16. Does your agency routinely conduct compliance testing on samples of newly purchased LED modules (either in-house or through a lab)?			
Yes		11	15%
No		61	85%
Total		72	100%

17. If your agency routinely conducts compliance testing on samples of newly purchased LED modules (either in-house or through a lab), which of the following tests do you run for LED traffic signals (check all that apply)?			
Photometric testing		5	10%
Chromaticity		3	6%
Drive current		4	8%
Power factor/total harmonic distortion		2	4%
Transient protection		2	4%
Compatibility with other signal equipment (MMU, load switches, etc.)		6	12%
We do not do compliance testing		37	77%

TABLE A5
ONGOING MAINTENANCE POLICIES AND PROCEDURES

18. What type of practice or procedure does your agency use for ongoing sample testing and/or scheduled replacement of LED traffic signals?			
We have a documented practice or procedure		6	8%
We have an informal practice or procedure		23	32%
We do not have a specific practice or procedure		44	60%
Total		73	100%

19. How is follow-up testing done?			
In the field only		35	88%
In the lab only		2	5%
In the field with follow-up lab tests		3	8%
Total		40	100%

20. What follow-up tests are run on LED traffic signals (check all that apply)?			
Photometric testing		11	39%
Chromaticity		2	7%
Drive current		1	3%
Power factor/total harmonic distortion		1	3%
Transient protection		1	3%
Compatibility with other signal equipment (MMU, load switches, etc.)		21	75%

21. Does your agency use a specification other than the ITE LED specification for minimum light output to determine replacement or failure?			
No, we use the ITE LED specification for minimum light output		34	52%
No, we do not have a specification for minimum light output to determine replacement/failure		27	41%
Yes, the specified minimum light output is (see Table A13)		5	8%
Total		66	100%

22. In an LED module with some dark pixels, what triggers the decision to replace the module?			
Primarily, a percentage of the total LEDs on the module that have failed		19	29%
Primarily, an alteration of shape		8	12%
Combination of percentage and change in shape		38	58%
Total		65	100%

23. Where a maintenance program is based on scheduled replacement of LED modules, some may be faded below specification levels prior to replacement. What maximum percentage of LED modules faded below specification levels does your agency consider acceptable with a scheduled maintenance program?			
Less than 1%		2	5%
1% to 5%		16	39%
5% to 10%		14	34%
10% to 15%		4	10%
Greater than 15%		5	12%
Total		41	100%

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TABLE A5
(*continued*)

24. What type of replacement approach does your agency use for LED traffic signals?			
Routine, scheduled replacement		17	24%
Complaint driven		25	35%
Replace when recommended by vendor product life cycle		2	3%
Module has an indicator that suggests it should be replaced		1	1%
Based on in-service maintenance test results		2	3%
No replacement program is established		25	35%
Total		72	100%

25. If your agency replaces LED modules on a scheduled basis, what is the time period between replacements?			
3 years		0	0%
4 years		0	0%
5 years		11	38%
6 years		3	10%
Greater than 6 years		15	52%
Total		29	100%

TABLE A6
POLICY ISSUES

26. In addressing the issue of minimum light output, which do you think is the preferred approach?			
Mandated national standard for minimum light output		16	22%
National guidelines on minimum light output		40	55%
Minimum light output defined by engineering judgment as determined by the agency		17	23%
Total		73	100%

27. If there were national standards for minimum light output, how would you recommend adhering to them?			
Field testing to a specified minimum light output value		10	14%
Replacement schedules based on product service life from the vendor		19	26%
Agency defined maintenance practices or procedures		43	60%
Total		72	100%

28. Does your agency have financing in place for ongoing monitoring and maintenance of LED traffic signals?			
Yes, we have adequate financing for monitoring and maintenance		16	23%
Some financing for monitoring and maintenance is available but is not adequate		21	30%
No, financing for monitoring and maintenance has not been arranged		34	48%
Total		71	100%

TABLE A7
QUESTION 2 COMMENTS

2. Please check one, other please specify.	
#	**Response**
1	Consultant (Prior City of Jackson, MS)
2	Consultant
3	Consultant

TABLE A8
QUESTION 6 COMMENTS

6. Does your agency have plans for full conversion to LED traffic signals?	
#	**Response**
1	When funding is available.
2	Over the next 3 years.
3	5 to 10 years.
4	All new installations will be LED. We've recently incorporated the New ITE LED specifications for circular indications.
5	Now complete.
6	We plan to use surplus 100% State maintenance funds. Under a letter of understanding municipalities or IDOT will carry out the retrofit and charge the other agency its proportionate share. Retrofit would be in two phases, Phase 1: within 12 months and Phase 2: within 30 months.
7	As halogen bulbs expire.
8	PennDOT does not own or operate signals. Municipalities do.
9	We are waiting for the approval of the yellow LED vehicle signal by ITE. After that we will implement them and should be 100% LED.
10	2008
11	Over the next 5 years.
12	Over the next two years, final 1%. A few yellow and walks to do.
13	On-going as budgets allow.
14	In 2007 we will have all LEDs. We are finishing the yellow balls so we can use battery backup UPS at all intersections.
15	We upgrade to LED lights during our signals during routine PM Program
16	Currently in year 3 of an 8 year program converting all except yellow. Yellow will be replaced in years 9 through 16 (when the first LEDs are replaced).
17	We are in the 3rd year of 6 year plan to fully convert.
18	We will be complete by the end of this year for locations we pay the electric bill. Total of maintained locations is 45%ish.
19	By 2011
20	When there is one that deals with snow accumulation issues.
21	Of the ~750 signals we maintain, ~250 are county owned. Our program deals only with these 250. We are half way through a 5 year program to convert these locations. The Maryland State Highway Administration owns the remaining ~500 signals in the county. Their program at present calls for LEDs as part of new builds and major modifications but not conversion of existing.
22	There are a couple of factors that will drive this change. Factor number one is the lack of availability/increased price for incandescent fixtures. Factor number two would be legislation to use LED modules only. Factor number three is a cost benefit analysis between incandescent and LED—taking into account the difference in maintenance needs and maintenance issues (e.g., snow removal from the lenses in winter)
23	Within two years.
24	Everything but amber.
25	Already 100% LED.
26	The only items left are pedestrian heads. They will be changed out as they wear out or the intersection is upgraded for other reasons.
27	We should be completed by mid 2008.
28	Full conversion by 2008.
29	Implemented over 10 year period ending in 2015.
30	When the financial budget allows.
31	Already done.
32	All existing traffic signals are retrofitted with LED. Future traffic signals will be designed and constructed with LED.
33	3 years
34	We have a five year conversion plan for all of our 4300 traffic signals.
35	This year we should be complete.
36	Program completed in 2005.
37	New installations and all replacements will be LED; no set time period.
38	New installs and upgrades.
39	In the process.
40	Due to LED module failures, the date is open; however, our intent was to be within 5 years.
41	Currently on-going as funding permits.
42	2008
43	As locations are modernized with annual projects or in new installations. This will take 10 years.
44	All state-owned vehicular indications, except in one major municipality, have been changed to LED. Will transition to pedestrian LED indications during future maintenance activities.

(continued on next page)

TABLE A8
(*continued*)

6. Does your agency have plans for full conversion to LED traffic signals?	
#	**Response**
45	Yellow modules are not cost beneficial. Will only be replaced if required by law.
46	We initialized this process for full conversion in all new construction 2003.
47	We do not plan on changing the yellow, they are too costly for the return, but we do have all reds, greens, and peds. LED at this time. Also all new signals will be completely LEDs at time of install.
48	Not sure at present.
49	As funds permit.
50	Current schedule is for completion by June 2007.
51	Within 2 years. Almost all vehicle indications have been converted. Remaining conversions will be done through maintenance as incandescent bulbs fail. A contract will soon be let out to convert remaining pedestrian indications.
52	Completed. Some signal heads that are incandescent will be replaced as part of maintenance activities over the next 3 years.
53	100% by the end of 2007.
54	As funds come available each budget year.
55	Already completed
56	As new signals are installed or replaced they go in as LED (began before this was required). No plan to do blanket replacement.
57	We are in the process.
58	TBD as part of maintenance and replacement program of existing heads. All new traffic signals are equipped with LED lights.
59	Eventually over time
60	Project kickoff is October 6, 2006, with completion by December 31, 2006.
61	Over the next 5 years, depending on continued capital funding.

TABLE A9
QUESTION 9 COMMENTS

9. The LED traffic signal modules failed because of which of the following, other please specify:	
#	**Response**
1	Moisture within LED unit
2	Manufacturer problem with green
3	Primarily yellow LEDs have had high failure rates
4	I believe some go out because of power surges
5	Aging
6	Power supplies, capacitors
7	Industry has yet to provide an explanation
8	Cold weather
9	Poor quality LED modules
10	Do not have traffic signal modules in the RM

TABLE A10
QUESTION 10 COMMENTS

10. Approximately what percentage of your LED traffic signal modules was purchased using the following specifications?

#	1995 ITE Specification	1998 ITE Specification	2005 ITE Specification	Other Specification (not ITE)
1		100%		
2		100%		
3				We called for screw in units for vehicle signals
4		80 – 100%		
5		100%	0%	Used Caltrans specs in interim on yellow intensity
6		50%	50%	
7		80%		
8		100%		
9		100%		Had to meet ITE or Caltrans specification
10		100%		
11	5%	95%		
12	25%	50%	25%	
13	0%	85%	15%	
14				FDOT approved products lists
15		100% with additional Toronto requirements		
16	100%			
17	3%	95%	2%	
18	0%	75%	25%	0%
19		30%	20%	
20		100%		
21		25%	75%	
22	Don't know	Don't know	Don't know	
23	25%	60%		Caltrans
24	?	?	?	?
25				We have always used a specific mfr.'s spec
26				100%
27		90%	10%	
28		100%		
29	0%	0%	100%	
30		95%	5%	
31	80%	20%		
32		100%		
33		75%	25%	
34				FDOT
35				Our own City of LA specification
36	35%	65%		
37	Tested			Did a big install in 2001 (red & green), 2 years later yellow
38		65%	35%	
39	50%		50%	
40		1998 spec & ALDOT spec		
41	20%			80%
42	20%	80%		
43		Most have been purchased with this spec		We had our own spec and referenced the 1998 spec
44		All red and green circular		All arrow and yellow circular
45			50%	50% Caltrans spec
46		100%		
47		100%		
48		90%	10%	
49	0%	10%	90%	

(continued on next page)

TABLE A10
(*continued*)

#	1995 ITE Specification	1998 ITE Specification	2005 ITE Specification	Other Specification (not ITE)
50				100%
51	<1%	>99%	None	
52		100% of red LEDs (2001-2003), all other LEDs 2003+	100% all LEDs since 2005	
53		50%	50%	
54		100%		
55		80%	20%	
56	70%	20%	10%	
57				Caltrans specs
58				100% Caltrans & customized LA County specs
59	10%	90%		
60	Don't know	Don't know	Don't know	100% Caltrans
61	10%	85%	5%	
62		100%		
63				one purchased
64	0%	?	?	
65		80%		
66	30%	60%	10%	
67		90%	10%	
68				Internal spec
69	33%	10%	57%	
70		100%	100%	

TABLE A11
QUESTION 12 COMMENTS

12. If your agency does not use an ITE LED specification, how does your specification differ, other please specify:

#	Response
1	Will use the ITE specification when we replace
2	
3	6 year warranty
4	N/A
5	FDOT does certification & testing of vendor
6	N/A
7	N/A
8	I don't believe it differs—we just want the mfr.
9	Don't know what the ITE specs are. Update as B.O.
10	Heat tolerance
11	Caltrans for arrows and yellow circular
12	See #11
13	Still using Caltrans specs
14	Non-pixelized appearance required
15	However the Caltrans specs compare
16	We use ITE Standards
17	Do not use
18	Internal spec

TABLE A12
QUESTION 15 COMMENTS

15. Does your agency rely on a Qualified Products List (QPL) when making a purchase of LED traffic signal modules; identify maintenance by other agency?	
#	**Response**
1	ODOT
2	Caltrans QPL
3	FDOT
4	State, FDOT
5	Maryland State Highway Administration
6	Caltrans
7	GDOT
8	FDOT
9	Caltrans
10	We use NCDOT's QPL
11	FDOT
12	WSDOT
13	NCDOT

TABLE A13
QUESTION 21 COMMENTS

21. Does your agency use a specification other than the ITE LED specification for minimum light output to determine replacement or failure?	
#	**Response**
1	FDOT specification
2	Per Caltrans specifications
3	Caltrans specification
4	1998 ITE spec with expanded viewing angles

TABLE A14
QUESTION 29 COMMENTS

29. Thank you for taking the time to complete the above survey on your jurisdiction's experiences with LED traffic signals. As a final item, please describe any other experiences (good or bad) that you have encountered that were not asked about in this survey.	
#	**Response**
1	My power company refused to give a rate reduction to realize savings on LED installations. My information is about a year old since I left the City of Jackson in August 2005.
2	Kansas DOT purchases, installs, and then turns over all traffic signal operations & maintenance to the local jurisdiction or authority.
3	We have incorporated ITE LED specifications and have been pleased with the results. ITE specs provide minimum requirements to all vendors.
4	It is too bad that this is only for agencies. Many consultants have observations and thoughts with respect to LEDs that cannot be entered. This is especially true with respect to potential liability. This is a major consideration that is not included.
5	Different type of technologies (e.g., non-pixelated appearance LEDs) use less LEDs and when they start to go bad do not have half or part of the module not lighted. Aesthetically, they look better and in my opinion they operate better.
6	Good experiences—no more maintenance calls that one of the red, yellow, or green indications is out (dark). Now the crew can focus on other maintenance tasks. Signals don't go into flash as often because all bulbs of the same color on an approach out. Major cost savings in electric bills. Bad experiences—Convincing upper management when creating budgets why we need $80 instead of $2 to buy a light bulb. Determining how long to wait before changing an LED and how to make sure money is available when things need replacement.
7	Rely greatly on FDOT for specifications & certification of vendors. Have local signal maintenance group that notifies FDOT of common vendor problems &/or trends; whereby, FDOT will investigate. Our experience is generally as a relatively new LED user. However, we are pleased so far and like the LED signals.
8	You should adopt a two spec approach, the same as TS-1 and TS-2.
9	Dialight LED modules have many issues and are not recommended by Pinellas County from install to return for warranty. We recommend GELcore for all installs as they stand by the product and have never had problems with returns. Even when they discovered they had a bad batch of greens they delivered free replacements with no questions asked.
10	We use only Red and Green LEDs. There are currently no Yellow LEDs on the FDOT's QPL; this makes the purchase and use unbeneficial to our agency. There is also the added expense of using incandescent bulbs and the eventual cost of adding the yellows in the future. LED units are warranted through the manufacturer for 10 years which conflicts with the guidelines for life expectancy. The unit is warranted for 10 years but weather conditions in our area (FL) shortens the average life expectancy to 3-5. Also, the manufacturer's warranty period begins at the date of purchase, not installation date. This makes it difficult for agencies to store quantities of units in inventory. Warranties can expire while LED units remain in inventory (never being used in the field) if large quantities are purchased at one time.
11	I believe that you need to address the problems with snow accumulation and snow sticking in areas that this may happen. This will be a significant issue in the future.
12	We are in the third year of a four year plan to replace all red LEDs that were installed in 1998-1999. This phased-in approach establishes a routine replacement schedule to make sure that at least 80% of the red LEDs are under warranty in any given year. There is no scheduled replacement policy for green LEDs due to inadequate funding and higher replacement cost. Yellow incandescent signals still being used in 60% of our intersections are scheduled to be replaced by LEDs beginning this year. We do not plan to establish a time-based replacement schedule for these. Our history of LED usage since 1998 has shown that there are more complete failures of red LED modules than fading, and more partial LED failures in green modules than others. Also, some vendors have a higher failure rate than others, which creates a problem in purchasing based on low bid only.
13	Screw-in type green modules are really not working well in our county. We have had an extremely high failure rate with these units.
14	They have created substantial added work for staff and our maintenance contractor when they fail during the warranty period. You don't just toss them out like you would an incandescent bulb.

(continued on next page)

TABLE A14
(*continued*)

#	**Response**
15	Winter storms cause problems when wet snow builds up and sticks to the LED lenses. The heat generated by the LEDs is not enough to melt the snow and ice.
16	Our LEDs (red) have been in the field for 9 years and we are not experiencing a significant failure rate. We do not have a replacement program funded. We are doing replacement on a failured basis.
17	No real questions. I have noticed that some manufactures are a lot better than others.
18	If LED wattage keeps getting lower, MMU, conflict monitors will not operate properly. My understanding now is that the monitor is reading the transformer for the LED insert.
19	I feel on the warranty it should be 5 years replacement only. We have had some Pedestrian LED's that were repaired and they failed again within a couple of weeks of being reinstalled. We own a couple of LED testers and the district personnel run some random tests. At this time we don't have an official maintenance and testing procedure in place.
20	LEDs are necessary for UPS use. Undefined failures have caused us to discontinue use of a reputable manufacturer.
21	Almost all signals in the State are maintained by the City or County. The State provides tech and monitoring. We may have problems with smaller cities replacing the LEDs when they fail after the 7 year warranty because of added expense.
22	While market competition is increasing resulting in lower costs, the evolving specs and general lack of knowledge regarding LED technologies and photometric measurement have slowed the establishment of maintenance practices for these items.
23	After the failure rate of one type of LED exceeded the manufacturer's standard, he replaced 100% of the units.
24	Many agencies, including ours, do not yet have sufficient experience with LEDs. As time goes on, we will have better honed practices and policies in place. This is also likely true for other agencies. As an example, we have not yet experienced our first complete replacement of modules.
25	Sorry, I cannot provide more information for your survey since we do not have any traffic signals in our jurisdiction.
26	It would be nice if someone could come up with a reasonable method of checking LEDs in the field. Maybe something that could be done from the ground without disrupting traffic.
27	We like using the LEDs for the signals, especially the newer ones with a wider visual cone.
28	1. Yellows fade quickly it seems and do not have the brilliance of a light bulb and do not attract as much attention. (Plastic clouds over.) 2. Power Savings—It takes a long time to recoup cost. 3. LEDs tend to be "directional" and lose brilliance quickly if observer not in limited cone in front of signal; head timing is more critical; engineering design, more often than we prefer, places heads outside an optimal 20 degree cone of vision—this can be done with bulb not LED. 4. High winds in Reno area may etch plastic faces more quickly than LEDs are expected to last. Winds have blasted paint off cabinets at Mt. Rose highway.

APPENDIX B

Vendor LED Traffic Signals Survey

SURVEY DESCRIPTION

The Institute of Transportation Engineers (ITE) is seeking to better understand maintenance issues associated with light emitting diode (LED) traffic signals. LED traffic signals represent a fundamental shift in technology from incandescent traffic signals and have unique characteristics that must be taken into account in maintenance practices. Additionally, use of LED traffic signals is growing and will continue to grow due, in part, to the recent Department of Energy requirements on signal manufacturers. Therefore, more information is needed to enhance understanding of the maintenance issues faced by public agencies that own, operate and maintain LED traffic signals.

ITE requests your assistance by completing the following short survey.

All individual information and responses will remain confidential.

RESULTS OVERVIEW

The following tables summarize the responses received.

TABLE B1
BACKGROUND

2. The primary role of my company is:			
LED manufacturer/vendor		1	17%
Traffic signal manufacturer/vendor		5	83%
Total		6	100%

TABLE B2
EXPERIENCE WITH LED TRAFFIC SIGNALS (All questions apply only to LED traffic signal installations)

3. How long has your company been supplying LED traffic signals?			
Less than 6 months		0	0%
Between 6 months and 1 year		0	0%
Between 1 and 5 years		0	0%
More than 5 years		6	100%
Total		6	100%

4. If you are aware of instances of total burn-outs (black face) of whole LED traffic signal modules within the warranty period or within 60 months of installation (if there is no warranty period), what percentage of the total LED traffic signal modules failed?			
None		0	0%
Less than 1%		5	83%
Between 1 and 5%		1	17%
Between 5 and 10%		0	0%
More than 10%		0	0%
Total		6	100%

5. The LED traffic signal modules failed because of which of the following (check all that apply):			
High ambient temperature		1	16%
Wet weather		2	33%
Electrical storms		4	66%
Compatibility of external hardware		0	0%
Poor quality utility power		1	16%
Faulty module		4	66%
Do not know		1	16%
Other, please specify (see Table B7)		2	33%

6. When considering the failed LED traffic signal modules above, what was the predominant root cause(s) of the malfunction (check all that apply)?			
Design inadequacy		2	33%
Poor product quality		3	50%
Act of god		2	33%
Poor power source		1	16%
Improper application		1	16%
Undetermined		1	16%
Other, please specify (see Table B8)		2	33%

TABLE B3
PROCUREMENTS FOR LED TRAFFIC SIGNALS

7. Of the LED traffic signal procurements you are familiar with, how many used the 1995 or 1998 ITE LED circular ball specification for purchasing LED traffic signals?			
All		0	0%
More than 75%		1	17%
Between 50 and 75%		3	50%
Between 25 and 50%		0	0%
Less than 25%		1	17%
None		1	17%
Total		6	100%

8. At this time, how many LED traffic signal procurements are using the 2005 ITE LED circular ball specification?			
All		0	0%
More than 75%		3	50%
Between 50 and 75%		0	0%
Between 25 and 50%		0	0%
Less than 25%		3	50%
None		0	0%
Total		6	100%

9. For procurements that do not use the ITE LED specification, how do these specifications differ (check all that apply)?			
Extended viewing angles		6	100%
Higher light output values for red		1	16%
Higher light output values for green		1	16%
Higher light output values for yellow		2	33%
Lower light output values for red		0	0%
Lower light output values for green		1	16%
Lower light output values for yellow		2	33%
Other, please specify (see Table B9)		2	33%

10. Of the LED traffic signal procurements that include a warranty period, what is the warranty time period			
3 year warranty		0	0%
4 year warranty		0	0%
5 year warranty		6	100%
6 year warranty		0	0%
More than 6 year warranty		0	0%
Total		6	100%

11. Of the LED traffic signal procurements you are familiar with, how many specify light output indicators that identify when output fails below the specified level?			
All		0	0%
More than 75%		0	0%
Between 50 and 75%		0	0%
Between 25 and 50%		1	17%
Less than 25%		5	83%
None		0	0%
Total		6	100%

TABLE B4
APPROVAL OF LED TRAFFIC SIGNALS FOR USE

12. When you do product testing, which of the following tests do you run for LED traffic signals (check all that apply)?			
Photometric testing		3	75%
Chromaticity		3	75%
Drive current		3	75%
Power factor/total harmonic distortion		3	75%
Transient protection		3	75%
Compatibility with other signal equipment (MMU, load switches, etc.)		2	50%

TABLE B5
ONGOING MAINTENANCE POLICIES AND PROCEDURES

13. In your experience, what types of practices or procedures do agencies have for ongoing sample testing and/or replacement of LED traffic signals?			
Most have a documented practice or procedure		1	17%
Most have an informal practice or procedure		2	33%
Most do not have a specific practice or procedure		2	33%
Do not know		1	17%
Total		6	100%

TABLE B6
POLICY ISSUES

14. In addressing the issue of minimum light output, which do you think is the preferred approach?			
Mandated national standard for minimum light output		2	33%
National guidelines on minimum light output		4	67%
Minimum light output defined by engineering judgment as determined by the agency		0	0%
Total		6	100%

15. If there were national standards for minimum light output, how would you recommend agencies adhering to them?			
Field testing to a specified minimum light output value		0	0%
Replacement schedules based on product service life from the vendor		2	33%
Agency defined maintenance practices or procedures		4	67%
Total		6	100%

TABLE B7
QUESTION 5 COMMENTS

5. The LED traffic signal modules failed because of which of the following, other please specify:	
#	**Response**
1	Improper handling during storage and installation
2	Various

TABLE B8
QUESTION 6 COMMENTS

6. When considering the failed LED traffic signal modules above, what was the predominant root cause(s) of the malfunction, other please specify:	
#	**Response**
1	Modules often discarded without failure analysis
2	LED electrical characteristics—variability

TABLE B9
QUESTION 9 COMMENTS

9. For procurements that do not use the ITE LED specification, how do these specifications differ, other please specify:	
#	**Response**
1	Custom pedestrian signal requirements
2	Light degradation warning device

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation