A Survey of Maintenance Practices of Light-Emitting Diode Traffic Signals and Some Recommended Guidelines

TO DETERMINE THE STATE OF KNOWLEDGE AND UNDERSTANDING OF LED TRAFFIC SIGNAL MAINTENANCE AND REPLACEMENT AND TO IDENTIFY ANY ASSOCIATED ISSUES, ITE ASSEMBLED A TASK FORCE CONSISTING OF INDIVIDUALS FROM PUBLIC AGENCY TRAFFIC ENGINEERING DIVISIONS, TRANSPORTATION CONSULTANTS, SAFETY COUNCILS, THE ITE LED SPECIFICATION COMMITTEE AS WELL AS AASHTO, IMSA AND NEMA.

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LIGHT-EMITTING DIODE (LED) traffic signals have been used widely since the mid-1990s. Some agencies either are considering or are in a cycle of replacement. In the early years of the technology, there were issues of early failures and appreciable loss of light output (degradation). However, since the late 1990s, with the use of high-brightness AlInGaP LEDs for red (and, later, yellow) signals and with better designs and power supplies, most LED traffic signal modules have been performing well in the field.

It is not common today to encounter a very dim or partially lit LED traffic signal in the field. Because LED traffic signals do not "burn out," agencies currently face a different maintenance issue, which is to determine when it is time to replace the modules.

An important factor for all U.S. public agencies is the Energy Policy Act of 2005, which requires that all traffic signal modules manufactured and sold in the United States as of January 1, 2007 meet the U.S. Energy Star Requirements for traffic signal modules. This basically implies that all traffic signals manufactured and sold in the United States from January 1, 2007 must be LED modules. The act does not require agencies to retrofit traffic signals; however, as existing stocks of incandescent signals are exhausted, those agencies that have delayed retrofitting their traffic signals with LED modules will be required to do so.

In August 2006, the ITE International Board of Direction discussed the issue of maintenance and replacement of LED traffic signals and decided that it merits more attention and research due to the absence of a collated body of knowledge or existing guidance on the matter.

To start the process, ITE assembled a task force consisting of individuals from public agency traffic engineering divisions, transportation consultants, safety councils, the ITE LED Specification Committee among its membership, as well as the American Association of State Highway and Transportation Officials (AASHTO), the International Municipal Signal Association and the National Electrical Manufacturers Association (NEMA), to ensure a wide variety of expertise, experience and input in this area.

This task force decided that to determine the state of knowledge and understanding of LED traffic signal maintenance and to identify any associated issues, it was best to ask those actually involved in manufacturing or selling and using or maintaining the LED modules. A survey was developed to solicit this information from the two most important groups: public agency traffic engineers (consisting of ITE public agency members and AASHTO state traffic engineers) and vendors or manufacturers of LED traffic signals (sent mainly through NEMA to its members). The two types of surveys also were important in understanding the gap, if existing, of both information/knowledge and expectations among these two principal groups.

The survey questionnaire was developed carefully so that it would be applicable to agencies varying in size and capability, geographic location, type, experience with LED signals and other parameters, but it would not identify the agency in the results that were obtained. The survey also was kept short to elicit a higher response. The actual surveys and results were not included with this feature because of space constraints but may be viewed online.

A total of 76 agency and six industry responses were received to the survey sent by ITE. The agency results were well distributed by agency type and signal system size. A brief summary of some of the specific results is presented in Table 1. In summary, the following statements can be inferred from the survey results:

- There is a legitimate and growing issue with the adequacy of the current state of the practice of LED traffic signal monitoring and replacement.
- Although agencies have gained experience in procuring and installing LED traffic signals, their practices and procedures for maintenance have not been defined consistently.
- Guidelines for LED traffic signal monitoring and replacement would be useful.
- There appear to be inadequate funding support and resources for the ongoing maintenance and operation of LED traffic signals. Funding resources would be needed for sustained compliance with specifications and to ensure high standards for public safety.

Table 1. Some specific results of the survey on maintenance practices.

- 59 percent of respondents indicate that more than 50 percent of their signal modules are LEDs
- 82 percent use the ITE LED specification
- The majority (73 percent) use a 5-year warranty period (10 percent do not specify a warranty).
- Total failure rate (dark face) of LED modules is low (less than 5 percent) and decreasing as product quality improves.
- 33 percent do not use a qualified products list
- 85 percent do no compliance testing
- 60 percent have no monitoring/replacement procedure
- Half use the ITE specification for minimum light output; half use no specification for minimum light output. (Note: This indicates a lack of understanding of the 1998 and 2005 ITE specifications because it includes minimum light output.)
- The number of responses dropped considerably on all questions related to agency practices/procedures for monitoring and replacement. This is an indication of the number of agencies with no replacement program and is consistent with survey results.
- Replacement approach results:
  - 35 percent: no replacement program
  - 35 percent: complaint driven
  - 24 percent: routine, scheduled replacement
  - 3 percent: replace on vendor product life cycle
  - 3 percent: based on in-service test results
- Results for scheduled replacement:
  - 52 percent: greater than 6 years
  - 38 percent: 5 years
  - 10 percent: 6 years
- 55 percent prefer national guidelines (not standards) for minimum light output with 60 percent preferring to adhere to the guidelines based on agency-established procedures
- 78 percent have inadequate or no funding for monitoring/replacement programs

The survey found that the use of LED traffic signals is now common and growing, but there is not a good understanding of the ITE LED specifications, which include minimum values for maintained light output. Therefore, although the use of the 2005 ITE LED specification is prevalent (82 percent of respondents), minimum maintained light output values specified therein are of little value without a corresponding routine monitoring and replacement program.

For example, the survey found that 70 percent of the respondents have, at best, a reactive or passive replacement program; 35 percent have no routine replacement program; and 35 percent are driven by complaints. It must be noted that complaints are less likely with LED modules as they gradually dim over time. The survey also found that most agencies require a 5-year warranty on their LED products but, for the few with scheduled replacement programs, the replacement cycle tends to be greater than 6 years.

Therefore, the likelihood is that an increasing number of LED traffic signals in the field will perform below the specified minimum light output. Although there is interest in a national guideline for minimum light output, there is less support for a national standard.

Related to the lack of understanding of minimum light output requirements and the corresponding lack of maintenance practices is the issue of budgeting and funding. The survey shows that at least 78 percent of respondents do not have adequate funding for monitoring and replacement of LED traffic signals.

It is important to grasp the reasons behind the lack of understanding of the maintenance requirements of LED traffic signals for the traffic and transportation engineering community to address the underlying issue(s) properly. First, LED traffic signals were marketed and sold for the last 10 years as "long-lived" and requiring little maintenance. This was an important factor in the sales of these products because this lowered the life-cycle cost, especially in the early to mid-1990s when the modules were priced in the range of $100 to $200.

Also, in many early cost-benefit analyses used by purchasing agencies, the "lives" of these modules were assumed to be between 7 to 10 years. These impressions have somehow sustained among the traffic engineering community, or at least influenced the state of maintenance practices. In fact, neither of these assumptions is entirely correct.

A second important factor is budgeting (as opposed to funding). A number of agencies do not have adequate funding defined or planned for a routine maintenance and replacement program. When an agency retrofits its incandescent traffic signal heads with LED modules, it can justify a large capital program because the savings from reduced energy costs can pay for the program within a few years.

Often, such programs are funded by outside grants or utility companies. Accordingly, department budgets for power and signal maintenance are reduced or diverted elsewhere. This is due to existing departmental budget constraints, budget cuts and policies that, in hindsight, may appear short-sighted.

When it comes to maintenance or replacing a citywide installation of LED traffic signal modules, funding is scarce and modules often are left in place longer than they should be. This is not a difficult decision for many agencies because the module still emits light and appears adequate under visual inspection.

The first step to implementing a solid and dependable LED traffic signal maintenance program is to understand the benefits and limitations of the LED traffic signal module and the requirements of the LED traffic signal specifications.

For an agency planning to either replace its existing LED modules or convert its incandescent signals to LED modules, the specification to use is ITE's June 2005 *Vehicle Traffic Control Signal Heads—Light Emitting Diode Circular Signal Supplement* (VTCSH LED). This specification derives its authority from the *Manual on Uniform Traffic Control Devices* and is the current national standard for all circular (ball) LED traffic signal modules. *Vehicle Traffic Control Signal Heads—Part 3: Light Emitting Diode Vehicle Arrow Traffic Signal Modules* also has been completed by ITE and should be available for public comments and review around February 2007. The ITE LED Specification Committee will be releasing its *LED Pedestrian Supplement* and *Pedestrian Countdown Supplement* later in 2007.

It is very important to understand that these standards, among other aspects, include minimum light output and (angular) light distribution requirements at specified operational temperatures, as well as color (wavelength) ranges that have been derived from a number of national and international studies and human factors research. They account for signal visibility, driver reaction time, color recognition (including those of color-vision deficient drivers), nighttime conditions, glare and other aspects of driving.

IT IS IMPORTANT TO GRASP THE REASONS BEHIND THE LACK OF UNDERSTANDING OF THE MAINTENANCE REQUIREMENTS OF LED TRAFFIC SIGNALS FOR THE TRAFFIC AND TRANSPORTATION ENGINEERING COMMUNITY TO ADDRESS THE UNDERLYING ISSUE(S) PROPERLY.

The minimum standards also take into effect the loss of light output over time and with temperature. The percentage of drivers served begins to drop when a traffic signal module stops emitting the minimum required light output, and it should not be considered safe to leave it in operation. This is considered the end of the service life of the module, even though it will likely continue to emit light.

Once it is accepted that there is *a clearly defined* end of service life for an LED signal module based on the minimum light output requirements, two important conclusions follow. First, an agency should not specify, recommend, allow, or acquire any LED traffic signal modules that do not meet the minimum requirements.

Minimum requirements should not be altered or developed based on subjective decisions. This is especially true because it is next to impossible to determine whether a module meets the minimum requirements by visually inspecting it; each observer's perception of light output is different. Very few agencies have the resources, funding, or technical ability to conduct the kind of research needed to develop their own set of standards or variances. For this reason, although many agencies would prefer a national guideline, they should treat the ITE VTCSH LED as a national standard.

Second, an agency must be able to determine, with a relative degree of confidence, when its modules no longer meet specified requirements. Finding out when a module is "non-compliant" is not an easy task for agencies. Agencies often install such modules over time or in phases. This is complicated by the fact that many agencies install a number of different models of LED modules, some even from different manufacturers.

The most reliable method of determining whether a module is compliant with a specification is by removing it from the field and measuring the light output in a laboratory. A second method is field measurement, which may not be as reliable as lab measurement but still yields good results if done properly. A third method is statistical analyses based on time elapsed since installation. A crude version of this last method is to base a replacement cycle on the warranty period.

The indicator regarding module "life" that most agencies rely on is the warranty period offered by the manufacturers. Many agencies feel that the best time to replace the modules is at the end of the warranty period, especially in consideration of the potential liability issues involved for modules that do not meet the current ITE specification.

The warranty period in North America for LED traffic signal modules varies between 4 and 7 years, depending on location/climate, with 5 years being the average warranty offered. A warranty usually implies that, if the LED module has been used under normal operating conditions and the light output (luminous intensity) has fallen beyond a minimum specified by the manufacturer within the warranty period, the manufacturer will provide a new module.

Because manufacturers do not wish to risk funding the replacement of a large number of modules prematurely, a lot of calculation goes into offering these warranty periods, including historical information on LED lamp life, operating temperatures, climate conditions, voltage and current fluctuations and life of power supply. In addition, manufacturers usually include a margin of error in their consideration.

As a result, in many cases, LED modules may last 2 years or more beyond the warranty period offered. Some agencies feel that, with the current budget problems facing most public works departments, it is not worth replacing modules that are still functioning within specification.

The key issue for agencies that do not wish to rely on warranties or wish to extend the replacement interval beyond the end of the warranty period is to ensure that modules are actually within specification. As mentioned earlier, in terms of reliability, laboratory measurements are best. However, this is both a labor-intensive and expensive method and not entirely practical. Field-testing equipment available today is both easy to operate and useful when used properly. Although there may be a number of ways to implement a successful maintenance and monitoring program, in this author's experience, a combination of methods based on laboratory measurements, field tests and statistical sampling and analyses yields technically sound yet practical results.

Needless to say, a meticulous database or inventory of traffic signal modules (including incandescent lamps, if any) is the basis of any good maintenance program. A municipality should keep the following information in its database about each signal module: location (intersection, pole location, head number), color, type (arrow, circle, or programmed visibility), manufacturer's name, model number, serial number, date of purchase, date of installation and warranty end date, regardless of the maintenance regimen it selects. In addition, information such as replacements made or reasons for failure also should be noted.

To use the ITE label on LED traffic signal modules, manufacturers must keep data on the initial light output of a traffic signal module design (qualification testing) and must conduct production testing of individual modules. The qualification testing includes a full measurement of the light output at various angles (as measured using a goniometer). Production testing usually includes only a single point sample measurement that is correlated to the light distribution pattern established during qualification.

It is in the public agency's interest to acquire the qualification and production data from manufacturers and use it to reduce maintenance costs. In addition to reviewing manufacturer-provided test data, it is highly recommended that an agency randomly select a small number of modules for testing at a qualified photometric laboratory, especially when making a sizeable purchase.

If such data are correlated to a value the agency can use, the agency can track a module's light output degradation by taking field measurements. While installing, the agency also may take initial measurements on a given number of modules with a handheld field-testing instrument, then track the performance of those same modules in the field over time.

For example, assume that the initial value of total light output as measured with such a handheld instrument (like an integrating photometer with a funnel) on a module is "X" at 25°C. Second, assume that at some time later the same module reads "Y" in the field with the same type of test instrument but at a different temperature. Y must be adjusted to compensate for what the reading would be at 25°C, the original temperature at which the data were collected. If this reading is Y^1, the percentage decrease (degradation) from X can be determined. This percentage change, when compared to previously measured data derived from the supplied manufacturer's initial module values, provides a good indication of whether or not the module is still within specifications.

Of course, a lot depends on the accuracy, repeatability and ease of operation of the field-testing instrument, the skill of the technician and the quality of the data stored in the first place. In addition, this method is recommended for sampling use only, not for determining absolute intensity values on individual modules. If a large number of such readings on various modules indicate they are below specifications, it is a statistical probability that the population it represents is failing and needs to be replaced.

It must be noted that the above is not the only type or method of field data collected on module light output. Various field instruments and methods are available in the market today. Besides price, agencies should look for factors including ease of use, accuracy (as determined by laboratory calibration), repeatability, durability (hardiness) and usefulness when deciding on an instrument. The ability to upgrade the instrument over time, as newer technology modules become available, is an additional consideration.

It is a common misconception among many agencies and departments of transportation in North America that once LED traffic signals are installed, they may be left alone until it is time to replace them. Agencies assume that the regular re-lamping cost incurred on incandescent lamps may be saved when switching to LED modules. It is strongly recommended that every agency adopt a lens cleaning program at regular intervals (between 1 and 2 years on average, based on individual climates and surroundings). This implies a traffic signal technician must access the signal housing in the field and physically clean the lenses (currently, this step is the largest cost component of a re-lamping program).

In this author's experience, this cleaning is the best opportunity for signal technicians to obtain field data on light output for a given (representative) number of modules. Currently, most agencies provide laptops to their signal technicians, where the information can be entered into the database directly in the field. Hardcopies of maintenance logs also may be used for later data entry. Some field equipment also may be available with memory banks, thermometers and temperature adjustments on readings, which may make the collection of such data easy.

Agencies must also be mindful of LED modules that are temperature-compensating or degradation-compensating (the module is driven harder as ambient temperature rises or time passes), which may require additional considerations.

Once an agency has started collecting and processing such data from its traffic signals, it will see a pattern emerging in its light output data collected over time. This will provide the best indication of when it is time to consider replacement. Most reputable LED module manufacturers will assist agencies in this regard, as will some experienced consultants. This also implies that it is important to acquire modules from reputable manufacturers who will be around when the warranty period is coming to an end.

To achieve such a maintenance goal, an agency must also budget for servicing and replacement. As mentioned earlier, too often, agencies provide the capital to purchase and install LED modules but do not consider maintenance aspects or replacement costs. For a new installation, one way to retain a maintenance fund is to reprogram a portion of the energy budget to the maintenance program; an initial recommendation is the equivalent of 5 to 10 percent of the capital outlay for maintenance. Another fact to consider is a phased implementation and replacement program that would become a part of the annual budget so the agency need not replace all its modules together every 5 or 6 years.

In this author's experience, a good sampling method, inventory database, lab testing program, purchase of field-testing equipment and proper training of signal technicians are important components of a good maintenance program. In turn, a good maintenance program, by providing the opportunity to obtain the requisite data to determine optimal field replacement of LED modules, can reduce agency liability. ■

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