ATTACHMENT E

EVALUATION OF LIFE EXPECTANCY OF LED TRAFFIC SIGNALS AND DEVELOPMENT OF A REPLACEMENT SCHEDULE IN THE DISTRICT OF COLUMBIA
(57 PAGES)

Technical Report Documentation Page

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10. Abstract This research details a field study of LED traffic signals in the District and presents a replacement schedule based on the analysis of the data obtained. Most of the initial installation of the City's LED traffic signals occurred between December 2002 and December 2004.The study involved field testing of LED Traffic Signals with a Spectra III LED Degradation Tester. This equipment was used to measure the intensity of the LED Traffic Signals. The luminous intensity tests were conducted at 30 study intersections between April and May 2011. The intersections provided only had 12" ball traffic signal indicators. At each intersection, 2 signal heads were chosen and tested which yielded 60 sample points for each LED signal indicator. Analysis of the data showed that approximately 73% of the circular Red LED indicators and 80% of the circular Green LED indicators were found to be below their respective minimum ITE thresholds. All of the yellow LED indicators were found to be below the minimum ITE threshold of 910 candela (cd). Based on the degradation rates computed for each LED traffic signal indicator, an overall average replacement period of 7 to 9 years is recommended. Thus, a phased replacement program has to be scheduled and implemented between 2009 and 2011. It is also recommended that a program for testing of the luminous intensities of at least 60 signal heads be conducted on a quarterly basis. This will enable DDOT to keep track of the intensities of the signals to insure that they meet the ITE minimum standards.				
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1.0 EXECUTIVE SUMMARY

The goal of this study is to conduct field measurements for the evaluation of the current luminous intensities of LED Traffic Signals in the District of Columbia based on which a replacement schedule can be recommended. This study provides a replacement schedule based on the degradation rates of the LED traffic signals which will be implemented by the District Department of Transportation (DDOT) to manage and operate an effective traffic signal system.

The study involved field testing of LED Traffic Signals with a Spectra III LED Degradation Tester. This equipment was used to measure the intensity of the LED Traffic Signals. DDOT provided *Sammat Engineering Services* with 30 study intersections. The intersections provided only had 12" ball traffic signal indicators. The field luminous intensities of the LED traffic signals were conducted in coordination with *M.C. Dean, Inc.*, who also provided traffic control during the field data collection. At each intersection, 2 signal heads were chosen and tested which yielded 60 sample points for each LED signal indicator. The field tests were collected between April 14th and May 15th, 2011.

The installation dates of the LED signals for the selected study intersections was obtained from DDOT while the initial luminous intensities of the signals was obtained from the manufacturer, GE. Most of the initial installation of the City's LED traffic signals occurred between December 2002 and December 2004.

Based on the results of the analysis of the sample of intersections, the average luminous intensities of the LED signal indicators were all found to be below the minimum ITE thresholds. This is shown in the summary presented in following table.

Comparing Average LED Traffic Signal Intensities (for 12" Circular Indicators)

LED Signal Indicator	2011 Average Intensities	ITE Minimum Intensities
RED	315.30	**365**
GREEN	306.47	**475**
YELLOW	203.39	**910**

The average degradation rates for each of the signal indicators were also computed using the initial luminous intensities and the field-measured intensities. The results showed that the yellow signal indicator has the highest degradation rate followed by the green indicator. Approximately 73% (44 out of 60) of the red LED indicators and 80% (48 out of 60) of the green LED indicators were found to be below their respective minimum ITE thresholds. All of the yellow LED indicators were found to be below the minimum ITE threshold of 910 candela (cd).

Based on the analysis, the average replacement time for the LED traffic signals are presented in the following table:

Average LED Traffic Signal Replacement Schedule

LED Indicator	Average Replacement Period
Circular, Green, GE	(7 - 9 years)
Circular, Red, GE	(6 – 8 years)
Circular, Yellow, GE	**
Arrow, Green, GE	(8 - 9 years)*
Arrow, Green, GE	(7 - 8 years)*
Arrow, Yellow, GE	(5 - 7 years)*

***Replacement Period could not be estimated since the intensity levels were below ITE minimum threshold*

**Replacement Period estimated from literature reviews from other similar studies*

From the field reviews and analysis of the data, the following recommendations are presented:

1. **Replace LED traffic signal indicators within the next year**: Since almost all the LEDs were initially installed between 2002 and 2004, and with an average replacement period of 7 to 9 years, the existing LED signals should be replaced within the next year to meet the minimum ITE luminous intensity standards.
2. **Use phased replacement program**: It is recommended that a phased replacement of the LED signals be implemented, with the oldest intersections replaced first. A phased replacement system is typically more cost-effective than a system-wide replacement due to budget and resource constraints.
3. **Acquire LED Degradation Testers**: DDOT should consider acquiring a number of the LED Traffic Signal Degradation testers for maintenance purposes.

4. **Obtain benchmark luminous intensities**: The initial luminous intensity of at least 60 traffic signal heads (all indications) of the replaced LED signal indicators should be obtained in the field during the process of replacement in order to obtain the benchmark intensities levels.
5. **Quarterly Luminous Tests**: A quarterly field test of the luminous intensities of the same traffic signal heads (in No. 3) should be conducted in order to keep track of the intensity levels. This will provide a database which can be analyzed to insure that the LED signal indicators meet the minimum ITE thresholds.
6. **Conduct Periodic Random Checks**: Random checks of LED traffic signal luminous intensities should also be conducted at critical intersections not included in the sample study intersections.

2.0 BACKGROUND OF LED TRAFFIC SIGNALS

In the past 10 years, Light-Emitting Diodes (LEDs) have replaced incandescent bulbs in traffic signals due to their energy savings in addition to their longer service life [1]. Most Departments of Transportation (DOT) have implemented programs to convert incandescent traffic signals to LEDs. Since the implementation, only a handful of DOTs have developed and implemented a LED Traffic Signal Replacement Plan. The standard practices of maintaining and replacing incandescent lamps cannot simply be transferred and applied to LED signals. Therefore, traffic engineers and technicians have to deal with the differences in long term performance between the two technologies and develop new practices that reflect these differences. There is still much uncertainty related to the monitoring, maintenance and replacement of LEDs over the course of their useful life. DOTs have a need for sustainable replacement strategies, but lack a comprehensive understanding of LEDs from an economic, performance and safety perspective.

There are number of inherent problems with LEDs. One critical issue is degradation. Instead of burning out catastrophically, like the incandescent lamps they replace, LED light output continuously degrades (dims) as a function of time and temperature. Rarely does an LED lamp exhibit complete burnout. As an example, the subtle, continuous decrease in light output of a red stoplight eventually results in impaired visibility, leading to a potential traffic safety hazard.

In 2006, due to the lack of knowledge involving the maintenance and replacement of LEDs, a special task force to address the issue was created by the Institute of Transportation Engineers (ITE). To ensure that LEDs aren't left in the field with light output below the recommended values, DOTs are still searching for a reliable method to monitor the light output of LEDs which degrade over time. Determining when an LED signal has reached the end of its useful life is not as clear-cut as it was in the past with incandescent bulbs and therefore new evaluation methods must be created. Whereas incandescent bulbs simply burned out instantly upon failure, LED light output slowly degrades over time, typically between 5 to 10 years. By definition, LED traffic signals reach their end of life when the light output is insufficient as detected by a driver. The ITE provides standards on minimum light output and light distribution and measures this minimum threshold in candelas (cd). Most DOTs use the ITE specifications as the standard.

The differences between the two traffic signal light technologies, together with their associated cost and safety concerns clearly show a need for a sustainable, systematic replacement schedule. Most LED traffic signals are often left in use beyond their end of life. This is due to the fact that they usually still function although their output is below the minimum light output threshold.

In the 1990's LEDs showed the ability to provide huge energy savings for agencies because they consumed a lot less energy (watts). As a result, agencies began replacing traffic signal indicators which have older bulb technology. The LEDs cost several hundred dollars compared with incandescent bulbs, but their longer life expectancy and proven energy saving capabilities suggests that they could still yield lower total life cycle costs. Previous studies conducted on the life cycle of LEDs showed that, despite the huge upfront equipment costs, their benefits still led to lower life cycle costs. DDOT first conducted an economic analysis of LED Streetlights which showed that the benefits of operating LEDs outweigh that of incandescent bulbs.

3.0 CAUSES OF LED DEGRADATION

The primary failure mechanism of conventional incandescent-lamped traffic signals is the catastrophic breaking of the lamp filament, immediately ending light output. However, the primary failure mode of LED-lamped traffic signals is not so obvious. Rather, it is a continuous, gradual degradation in light output over time. This subtle degradation eventually results in a potential safety issue (Hutchinson, 2001). Since any one signal color is ‗on' for 50% of the time or less, signal lights may operate for five to ten years or more before completely burning out. Without accurate field measurement instrumentation, maintenance personnel would be oblivious to the safety hazard caused by a degraded signal light level, and traffic engineers would not know when to replace a critically dim LED module. A traffic accident may result, for example, if the visibility of a dim red ‗stop' signal is impaired in a bright sun situation.

High ambient temperature is the primary cause of LED degradation; however, the design, installation site power, materials, humidity and time are also important factors. Oxygenation of aluminum in the LED junction, corrosion of the many module electrical connections, aging of the electrical drive circuits, dirt accumulation on the module lens, or deterioration of the module lens, such as pitting, warping, fading or the like--are some additional reasons for field degradation.

Empirical data indicate that LED lamp life decreases exponentially with operating temperature. In other words, as operating temperature gradually increases, overall lamp light output decreases at an increasing rate. These changes are gradual, but at some point, the light output level will no longer comply with the required minimum. And eventually, the light level will be so low that visibility may be impaired.

At room temperature (25°C), the lifetime of LEDs may in fact approach one hundred thousand hours, while operation at close to 90°C may reduce LED light life to less than seven thousand hours. Actual data collected in solar heating studies of traffic signals show that internal temperatures approaching 85°C may be rather common in the southwestern region of the United States for at least a significant part of the day. This is particularly true if amber and green incandescent lamps are retained, since the heat from incandescent lamps greatly increases the temperature surrounding the LED light module.

4.0 ITE LED SPECIFICATIONS

ITE released the LED purchase specification, —Vehicle Traffic Control Signal Heads Part 2," in 1998. 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). 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.

The ITS supplements have been adopted into the Federal Highway Administration's (FHWA) *Manual on Uniform Traffic Control Devices* (MUTCD). In 2007, the ITE published an additional supplement for arrow indicators (Institute of Transportation Engineers, 2007) and a third supplement in 2009 for pedestrian countdown signals.

The peak minimum maintained luminous intensity values for circular and arrow LED traffic signals for 8" (200mm) and 12" (300mm) modules are respectively presented in Tables 1 and 2. Standards for arrow traffic signal indicators are not defined. These values represent the intensity values of LED traffic signals when measured in the laboratory or at the signal, with a vertical angle of -2.5 degree and a horizontal angle of 0 degrees. These minimum values are required to provide throughout service as a traffic control signal.

Table 1: Minimum ITE Thresholds for Circular LED Traffic Signals

COLOR	**INTENSITY (Vertical = -2.5 degrees, Horizontal = 0 degrees)**	
	8" (200 mm)	**12" (300 mm)**
Circular Red	165	365
Circular Yellow	410	910
Circular Green	215	475

Table 2: Minimum ITE Thresholds for Arrow LED Traffic Signals

COLOR	INTENSITY (Vertical = -2.5 degrees, Horizontal = 0 degrees)	
	8" (200 mm)	12" (300 mm)
Arrow Red	-	58
Arrow Yellow	-	146
Arrow Green	-	76

The ITE LED traffic signal standards also include requirements for manufacturers to warrant their modules for at least 5 years. Thus, they must repair or replace any traffic signal indicators whose minimum luminous output levels fall below the ITE threshold (Institute of Transportation Engineers, 2005).

5.0 SURVEY OF AGENCIES USING LED TRAFFIC SIGNALS

In 2006, the ITE conducted a survey of public agencies and vendors or manufacturers of LEDs. Seventy-five responses from public agencies were received from 6 vendors. The following is a summary of the principal findings from the survey:

- 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 its occurrence is decreasing as quality of LED traffic signals improve
- 33% do not use a qualified products list
- 85% do no compliance testing
- 60% have no monitoring/replacement procedure
- 50% use the specification for minimum light output while 50% use no specification for minimum light output

The number of responses was considerably low for all questions related to agency practices or procedures for monitoring and replacement. This is possibly an indication of the number of agencies with no replacement program which 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%
  – Based on in-service test results: 3%
- Results for scheduled replacement:
  – Greater than 6 years: 52%
  – Five years: 38%
  – 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 the ITE 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.

6.0 CURRENT REPLACEMENT AND MONITORING PRACTICES

Generally, an agency has two options when it comes to identifying a replacement strategy:

1. Replace individual LEDs as they fall below the minimum lighting intensity threshold one at a time, or
2. Segment the signals into groups, either by intersection or signal indication type and replace entire groups at a time.

Based on the above strategies, an agency may either execute the replacement at a pre-defined interval (usually based on vendor warranty), or after they receive a complaint. Without any guidelines based on realities of long term LED performance, agencies that practice scheduled replacement often use the manufacturer's warranty as the interval rate.

Generally, replacement plans which are based on a manufacturer's warranty are a safe bet, but may not be cost-effective. A truly sustainable solution for an agency is to seek to extend the use of an LED past the warranty period as much as possible. To date, several studies and analyses have attempted to determine the best practices for replacing LEDs. A study was conducted to compare the life cycle costs of a spot replacement plan and a group replacement plan. The study found that group replacement has a greater cost benefit although the results relied heavily on an estimation of useful life and expected failure rates. Although LEDs degrade gradually over time, a limited amount of spot replacements will inevitably be needed even if a group replacement plan is undertaken. The study recommended testing LEDs in a lab after the decision has been made to replace them, and setting aside a small percentage of the LEDs with the most useful life still remaining for quick replacement purposes. These partially used but not dead LEDs could be used as a stockpile for spot replacing other LEDs that fail before their replacement period.

In summary, a monitoring program that seeks to understand the degradation rate could therefore provide accurate estimations of useful life that will help develop a sustainable replacement strategy.

7.0 PROJECT OBJECTIVES

The goal of this study is to provide a repeatable methodology that can be used by the District Department of Transportation (DDOT) to evaluate the life expectancy of LEDs and develop guidelines for a cost-effective replacement schedule based on these findings. The study is based on field testing of LED intensities, data collection and statistical analysis.

In particular, this project conducted the following:

1. Compile LED Traffic Signal light intensities at 30 intersections (provided by DDOT)
2. Gather information on dates on when the LEDs were installed at the 30 intersections
3. Compile and reduce the data obtained at the signalized intersections
4. Conduct analyses on the data compiled
5. Develop a replacement plan for the LEDs based on the results of the analysis.

8.0 DATA COLLECTION AND ANALYSIS

This section presents the field data collection process and methodology used in conducting the analysis.

8.1 STUDY INTERSECTIONS

Sammat obtained the list of the study intersections from the DDOT project Manager. In order to ensure a good sample size for this study, 30 signalized intersections were selected. At least three intersections were selected from each of the 8 Wards in the District. The intersections provided only have circular LED traffic signals indications. The intersections selected are presented in Table 3. None of the intersections provided for this project had arrow LED traffic signal indicators.

8.2 DATA COLLECTION EQUIPMENT

The Spectra Candela III Traffic Signal Light (TSL) Tester was used to measure the in the lighting intensities at the intersections. The Tester measures luminous intensity and light output degradation of Red, Yellow and Green LED signal modules in order to meet mandated minimum safety standards. Spectra Candela III Traffic Signal

Light Tester Model 2000 is a versatile, precision, portable multiple channel Photometer/Radiometer. Presented in Figure 1 is a photograph of the TSL Tester used in the field data collection.

TABLE 3: STUDY INTERSECTIONS

WARD	INTERSECTIONS
1	• 15th – New Hampshire Ave / Florida Ave NW • 15th /16th – Irving St NW • 14th – Kenyon St / Park Rd NW
2	• 10th D St / Pennsylvania Ave NW • 14th – Thomas Circle NW • 18th – M St Conn. Ave / M St NW • 22nd – Q St / Massachusetts Ave & Florida Ave NW
3	• Western Ave – Military Rd NW • 29th St – Calvert & Cleveland St NW • Ward Circle NW • 41st – McKinley St / Western Ave & Cedar Pkwy NW
4	• Georgia Ave - Missouri Ave NW • Georgia Ave – Kansas Ave / Upshur NW • New Hampshire Ave – Rittenhouse / 3rd NW • 16th – Missouri Ave NW
5	• Taylor St & 7^{th} St & Puerto Rico Ave • Rhode Island Ave, South Dakota Ave & 24th St, NE • Rhode Island Ave – New Jersey Ave & S St, NW
6	• 14 St & 15th St & Massachusetts Ave & Independence Ave & South Carolina Ave, SE • 1st St & Constitution Ave, NW • 11th St & F St, NW • 2nd St & Maryland Ave & Constitution Ave, NE
7	• Sheriff Rd & 45th St & 45th Place, NE • Pennsylvania Ave & L'Enfant Square, SE • Nannie Helen Burrough Ave & Kenilworth Ave, NE • East Capitol St & 56th Place
8	• Pennsylvania Ave & Branch Ave, SE • Alabama Ave & Stanton Rd, SE • East Capitol St & Stoddert Place • Martin Luther King Ave & Howard Rd & Sheridan Rd, SE

Figure 1: Spectra Candela III Traffic Signal Light (TSL) Tester

Its specifically configured calibrated channels are used to measure luminous intensity [Candlepower in candelas (Cd)] of Red, Yellow, and Green LED traffic signal modules and Photometric brightness Red, Yellow and Green Arrows (foot-lamberts/cd/m^2). Its custom configuration allows the tester to measure luminous intensity, illuminance, luminance, irradiance, radiance, radiant energy, and many other special parameters. Calibration and indication of the proper readout unit is accomplished automatically when the switches are set and the proper accessories/attachments are installed.

The TSL tester can measure luminous intensity of LED signal modules and photometric brightness of LED signal arrows. The measuring capability and sensitivity range of the instrument is given in Instrument Specifications.

8.3 DATA COLLECTION AT SIGNALIZED INTERSECTIONS

Most LED monitoring programs involve removing the indicator and testing it in a laboratory. In some instances, a luminance or intensity meter is used to take readings of the LED signal from the side of the road. Others also obtain readings of luminance or intensity ―from the driver's perspective".

In this study, since the original intensity of the LED traffic signals were obtained from manufacturer's laboratory testing, it is essential to measure the intensity levels under ―similar" conditions. Thus, the Spectra Candela III Traffic Signal Light (TSL)

Tester, which covers the entire signal indicators during the measurement process, mimics the readings taken under laboratory conditions.

Sammat's technicians conducted the field measurements from April 14 through May 15, 2011. For each intersection, two signal heads were selected. The technicians used a truck which has a bucket in order to get access directly to the signal head (see Figure 2 for site and laboratory LED luminous tests). Appropriate traffic control was put in place to ensure the safety of the technicians. Measurements were taken twice for each signal color indication.

Figure 2: Field Data Collection

The data was recorded in the following format presented in Table 4 for each signal head.

Table 4: Sample Data Collection Sheet

SIGNAL HEAD # ***LED SIGNAL TYPE***	***Measurement 1***	***Measurement 2***
Circular RED	R1	R2
Circular GREEN	G1	G2
Circular YELLOW	Y1	Y2

Presented in the Appendix is the raw data collected from the field. DDOT also provided the project team with information on the installation dates of all the LED Traffic signals in the City to date. All the selected study intersections are equipped with LED Traffic Signal indicators manufactured by GE. The research team contacted the vendor who provided the luminous intensities of the LEDs at the time of installation. This is presented in the cut-sheet in Figure 3.

Product Information

Model Number	Size (in)	AC Voltage	Power (W)	Wavelength (nm)	Maintained Intensity (Cd)
		Nominal	Nominal	Dominant	Minimum
DR4-RTFB-20A	8	120V - 60 Hz	5	626	133
DR4-YTFB-20A	8	120V - 60 Hz	13	589	267[3]
DR4-GTFB-20A	8	120V - 60 Hz	6	508	267
DR4-GCFB-20A	8	120V - 60 Hz	6	508	267
DR6-RTFB-20A	12	120V - 60 Hz	10	626	339
DR6-YTFB-20A	12	120V - 60 Hz	22	589	678[3]
DR6-GTFB-20A	12	120V - 60 Hz	12	508	678
DR6-GCFB-20A	12	120V - 60 Hz	12	508	678

Options:
- Q : Quick Connect
- S : Medium Base Socket
- F : In-line Fuse

Standard product equipped with spade connectors.
[2] Measured at +2.5°H -2.5°V, T_a = 25°C.
[3] Actual intensity less than ITE specification.

Figure 3: LEDs Intensities at Installation in 2002 - 2004

8.4 *DATA REDUCTION AND ANALYSIS*

I. Current Traffic Signal Lighting Intensities for Red, Yellow and Green Indicators

From the data collected, the average light intensities for each type of signal indicators were compared with the minimum ITE Lighting thresholds presented in Table 1. The luminous Intensity (LI) is a measure of the power emitted by a light source in a particular direction per unit solid angle (based on the luminosity function which is a model of the sensitivity of the human eye). The SI unit of luminous intensity is the candela (cd). It was assumed that the age of an LED is the number of months of non-stop operation since installation. A scatter plot was prepared to display the current light intensities for the red, yellow and green indicators which were compared with the minimum lighting output for each color indicator.

Descriptive statistics of the luminous intensities were also computed. These included the mean, median and standard deviation for each LED traffic signal indicator.

II. Degradation Rate

The rate of degradation *D*, was determined using the formula as shown:

where:

LI (c) = current luminous intensity in *cd* for a given LED

LI (i) = initial luminous intensity (at installation) in *cd* for a given LED

t = duration of usage in years.

The numerator measures the difference in luminous intensity at time *t* and the same at the time of installation, and the denominator measures the number of hours of operation. The degradation rate for each LED signal indicator was then computed. This yielded 60 sample points for which the average degradation rate was computed for the red, green and yellow indicators. The standard deviation was also computed to determine the spread of the degradation rates. A probability distribution fit was used to predict the probability of failure of an LED at a given point of time in its lifetime. These probabilities were critical for developing a cost-effective replacement plan for the LEDs that ensures safety of the traffic. It is important to note that the LED traffic signals become less visible to drivers once its luminous intensity falls below the ITE thresholds.

III. Development of Replacement Schedule

From the average degradation rates computed, the average time it would take for each type of LED indicator to fall below the corresponding ITE thresholds was projected based on which the replacement timeframe was projected. This projection was made for each type of indicator.

9. RESULTS

9.1 Current Traffic Signal Lighting Intensities

RED LED INDICATORS

Presented in Figure 4 is a plot of the luminous intensities of the Red LED signal indicators at the selected study intersections. The figure also shows the minimum ITE threshold (365 cd) for Red LED indicator.

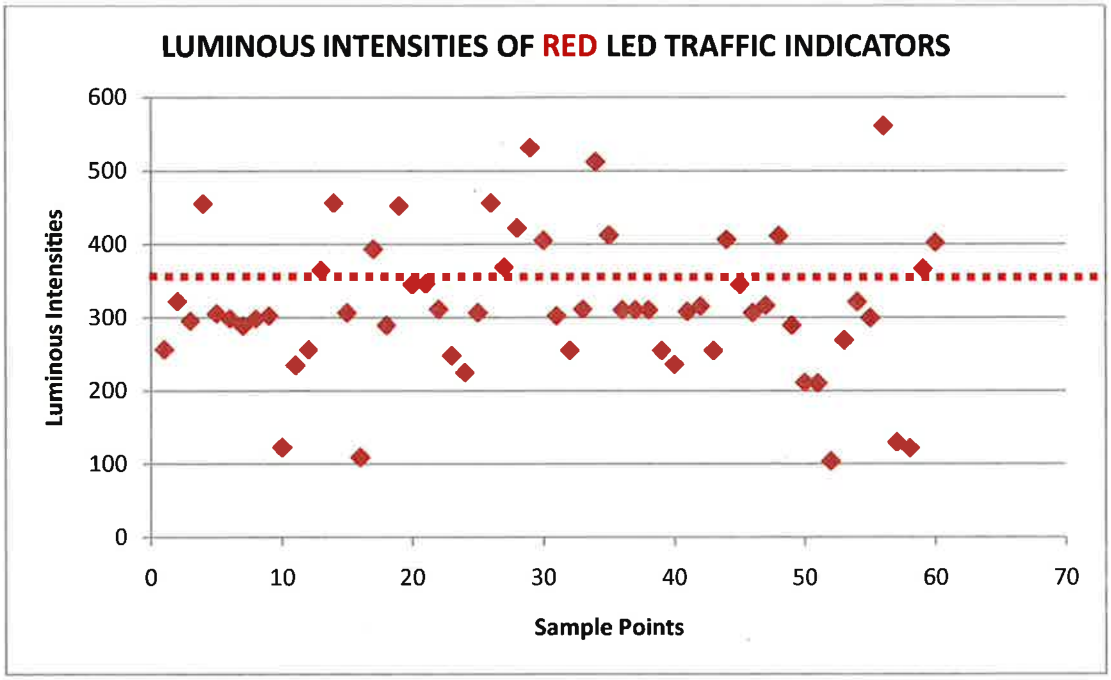

Figure 4: Luminous Intensities of Red LED Indicators

From the analysis, approximately 73% (44 out of 60) of the red LED indicators measured in the field were found to be below the minimum ITE threshold. The average and standard deviation of luminous intensity of the red signal indicators measured at the sites were respectively 315.3 cd and 67.89 respectively.

GREEN LED INDICATORS

Figure 5 presents a plot of the luminous intensities of the Green LED signal indicators at the selected study intersections which include the minimum ITE threshold (475 cd).

The analysis shows that 80% (48 out of 60) of the green LED indicators measured in the field were found to be below the minimum ITE threshold. The average and standard deviation of luminous intensity of the green signal indicators measured at the sites were respectively 306.47 cd and 195.89 respectively.

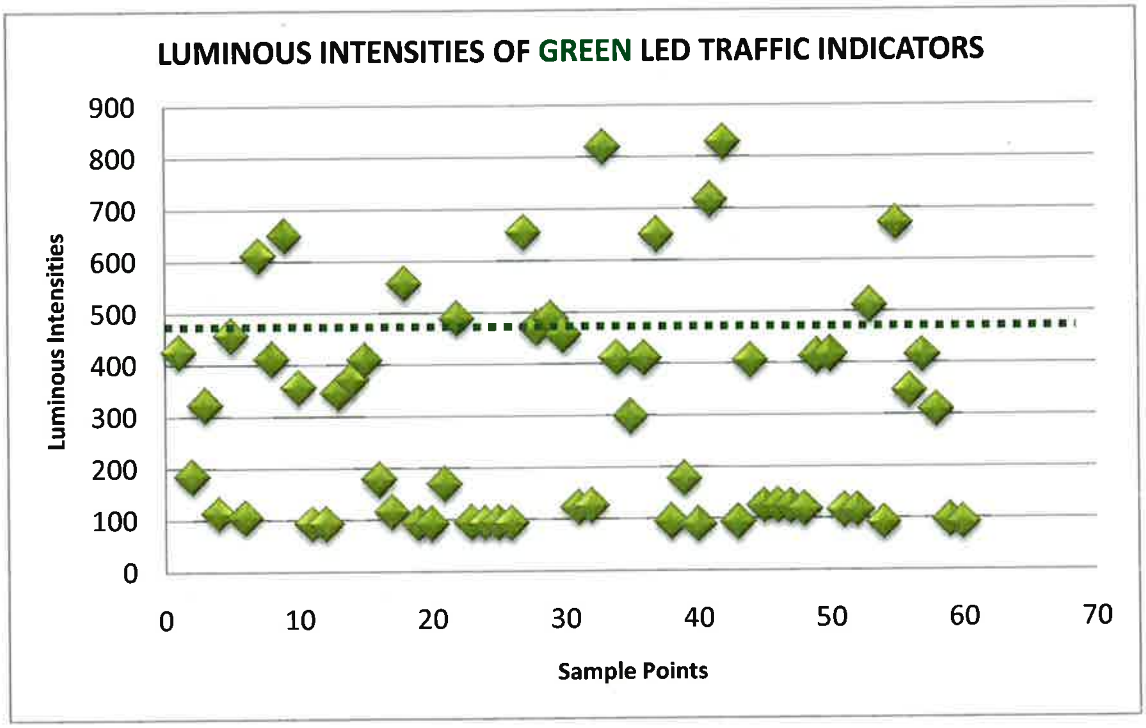

Figure 5: Luminous Intensities of Green LED Indicators

YELLOW LED INDICATORS

In Figure 6, the luminous intensities of the Yellow LED signal indicators at the selected study intersections are presented including the minimum ITE threshold (910 cd). Comparing the minimum threshold with the sample data obtained in the field shows that all the yellow indicators are below the ITE minimum maintained luminous intensity values.

The average and standard deviation of luminous intensity of the green signal indicators measured at the sites were respectively 306.47 cd and 195.89 respectively.

9.2 Degradation Rates

The rate of degradation *D*, was determined using the formula as shown:

$$D = [LI\ (i) - LI\ (c)]\ /\ t$$

where:

LI (c) = current luminous intensity in *cd* for a given LED

LI (i) = initial luminous intensity (at installation) in *cd* for a given LED

t = duration of usage in years.

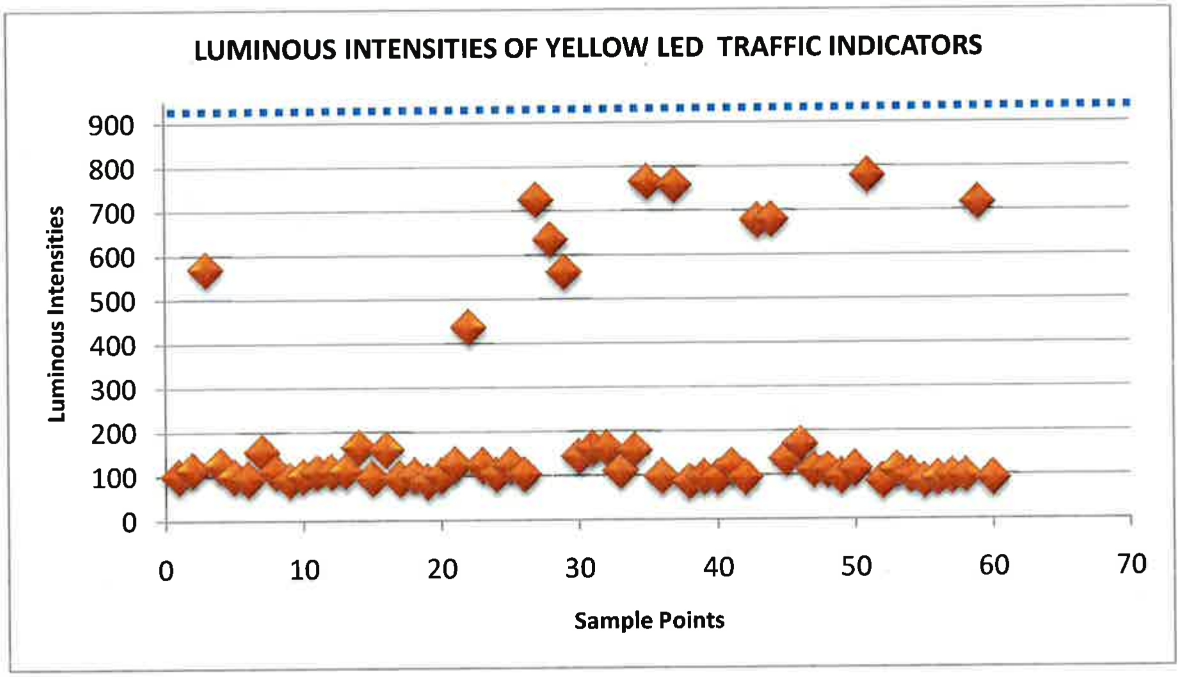

Figure 6: Luminous Intensities of Yellow LED Indicators

The summary results of the average degradation rates of the LED traffic signal indicators are presented in Table 5. From the table, the yellow signal indicator has the highest degradation rate followed by the green indicator.

Table 5: Summary of Average Degradation Rates for LED Traffic Signal Indicators

LED Signal Indicator	Average Degradation Rate (cd/yr)	Standard Deviation
RED	11.98	3.29
GREEN	25.78	3.22
YELLOW	90.31	13.50

9.3 Development of Replacement Schedule

Using the average degradation rate, the following table (Table 6) presents a conservative timeframe for which the LED traffic signal indicators should be replaced.

This timeframe was projected using the reported initial luminous intensity and the computed average degradation rate per year in Table 5. The average time it would take for each LED indicator to degrade to the minimum ITE standards was then computed. For each LED traffic signal indicator, the standard deviation was used to obtain a timeframe for replacement.

Table 6: Replacement Timeframe for LED Traffic Signal Indicators

LED Signal Indicator	Average Replacement Time	Average Replacement Timeframe
RED	7 years	6 – 8 years
GREEN	8 years	7 – 9 years
YELLOW	-	-

10. DISCUSSION OF RESULTS

Several studies have proved that LED traffic signal indicators are a superior economic choice as compared to the incandescent bulbs. They offer significant benefits in terms of operations, maintenance costs and useful life. Generally, the failure of an LED indicator is defined by its luminous intensity falling below the ITE's minimum maintained luminous intensity. Based on the results of the analysis of the sample of intersections, the average luminous intensities of the LED signal indicators were all found to be below the minimum ITE thresholds. This is shown in the summary presented in Table 7.

Table 7: Comparing Average LED Traffic Signal Intensities (for 12" Circular Indicators)

LED Signal Indicator	Average Intensities	ITE Minimum Intensities
RED	315.30	**365**
GREEN	306.47	**475**
YELLOW	203.39	**910**

The average degradation rates for each of the signal indicators also showed that the yellow signal indicator has the highest degradation rate followed by the green indicator. Approximately 73% of the red LED indicators and 80% (48 out of 60) of the green LED indicators were found to be below their respective minimum ITE thresholds. All of the yellow LED indicators were found to be below the minimum ITE threshold of 910 cd.

12. CONCLUSIONS AND RECOMMENDATIONS

- From the results of the analysis, it is recommended that an implementation program be implemented to replace all circular and arrow indicators installed within the past seven to eight years.
- Due to limited observed degradation patterns, it is recommended that a phased replacement of the LED signals be implemented, with the oldest intersections replaced first. A phased replacement system is typically more cost-effective than a system-wide replacement due to budget and resource constraints.
- The research team recommends that DDOT acquire a number of the LED Degradation Testers for maintenance tests and routine checks purposes. The tests should be conducted on a quarterly basis with the intention of developing a comprehensive LED luminous intensity database.
- It is also strongly recommended that DDOT develop a database system to manage the LED traffic signal luminous intensities to achieve an effective replacement plan. This database will allow the effective monitoring of traffic signals for ITE threshold compliance.
- Based on enhanced degradation information gained through quarterly LED intensity tests, a replacement program interface application could be developed to analyze and predict future funding levels needed, check manufacturer warranties for potential replacement and lead to a comprehensive performance-based specifications for LED products.

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APPENDIX

RAW DATA FROM FIELD TESTING

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 15th St & New Hampshire Ave & Florida Ave NW

DATE OF INSTALLATION OF LED: 05/15/2003

DATE: 05/15/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	455	453
Circular GREEN	345	346
Circular YELLOW	101	98

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	236	425
Circular GREEN	184	184
Circular YELLOW	114	116

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 10th St & D St & Pennsylvania Ave NW

DATE OF INSTALLATION OF LED: 06/17/2003

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	461	467
Circular GREEN	443	356
Circular YELLOW	568	571

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	412	421
Circular GREEN	114	111
Circular YELLOW	124	126

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Western Ave & Military Rd. NW

DATE OF INSTALLATION OF LED: 12/13/2002

DATE: 05/14/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	500	498
Circular GREEN	389	456
Circular YELLOW	101	98

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	336	339
Circular GREEN	104	106
Circular YELLOW	92	94

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Georgia Ave & Missouri Ave NW

DATE OF INSTALLATION OF LED: 05/02/2003

DATE: 05/15/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	459	456
Circular GREEN	564	564
Circular YELLOW	154	154

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	584	582
Circular GREEN	571	571
Circular YELLOW	110	112

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 7th St & Taylor St & Puerto Rico Ave NE

DATE OF INSTALLATION OF LED: 12/23/2004

DATE: 05/15/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	456	456
Circular GREEN	355	355
Circular YELLOW	92	92

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	456	460
Circular GREEN	365	366
Circular YELLOW	98	101

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 14th St & 15th St Massachusetts Ave & Independence Ave & South Carolina Ave

DATE OF INSTALLATION OF LED: 07/28/2003

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	355	355
Circular GREEN	93	93
Circular YELLOW	108	110

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	521	522
Circular GREEN	92	92
Circular YELLOW	110	110

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Sheriff Rd & 45th St & 45th Pl NE

DATE OF INSTALLATION OF LED: 07/31/2003

DATE: 05/14/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	523	524
Circular GREEN	448	448
Circular YELLOW	112	111

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	644	696
Circular GREEN	728	734
Circular YELLOW	166	168

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Pennsylvania Ave & Branch Ave SE

DATE OF INSTALLATION OF LED: 10/01/2002

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	540	544
Circular GREEN	625	622
Circular YELLOW	96	97

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	108	110
Circular GREEN	177	177
Circular YELLOW	159	161

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 15th St & 16th St & Irving St

DATE OF INSTALLATION OF LED: 03/19/2003

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	394	388
Circular GREEN	118	111
Circular YELLOW	94	95

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	658	661
Circular GREEN	797	788
Circular YELLOW	99	101

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 14th St & Thomas Circle NW

DATE OF INSTALLATION OF LED: 04/19/2003

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	552	543
Circular GREEN	94	93
Circular YELLOW	87	87

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	514	511
Circular GREEN	92	92
Circular YELLOW	101	100

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 29th St & Calvert & Cleveland St. NW

DATE OF INSTALLATION OF LED: 08/10/2004

DATE: 05/15/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	323	324
Circular GREEN	168	168
Circular YELLOW	124	126

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	542	544
Circular GREEN	784	784
Circular YELLOW	436	436

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Georgia Ave & Kansas Ave & Upshur Ave NW

DATE OF INSTALLATION OF LED: 04/03/2003

DATE: 05/14/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	***Measurement 1***	***Measurement 2***
Circular RED	480	482
Circular GREEN	92	95
Circular YELLOW	123	123

SIGNAL HEAD 2

LED SIGNAL TYPE	***Measurement 1***	***Measurement 2***
Circular RED	577	575
Circular GREEN	93	93
Circular YELLOW	102	104

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Rhode Island Ave & South Dakota Ave NE

DATE OF INSTALLATION OF LED: 06/12/2004

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	469	467
Circular GREEN	782	786
Circular YELLOW	720	730

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	541	537
Circular GREEN	815	811
Circular YELLOW	572	697

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 1st St & Constitution Ave NW

DATE OF INSTALLATION OF LED: 07/06/2004

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	527	531
Circular GREEN	718	721
Circular YELLOW	558	564

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	661	664
Circular GREEN	772	775
Circular YELLOW	141	144

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 14th St & Kenyon St & Park Rd NW

DATE OF INSTALLATION OF LED: 05/12/2003

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	631	634
Circular GREEN	122	123
Circular YELLOW	164	161

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	675	675
Circular GREEN	124	128
Circular YELLOW	165	161

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 18th St & M St & Connecticut Ave NW

DATE OF INSTALLATION OF LED: 02/13/2003

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	580	577
Circular GREEN	820	820
Circular YELLOW	110	112

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	672	658
Circular GREEN	815	810
Circular YELLOW	155	159

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Ward Circle

DATE OF INSTALLATION OF LED: 08/12/2004

DATE: 05/14/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	466	468
Circular GREEN	831	835
Circular YELLOW	764	764

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	306	307
Circular GREEN	836	837
Circular YELLOW	95	97

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: New Hampshire & Rittenhouse & 3rd St NE

DATE OF INSTALLATION OF LED: 08/14/2003

DATE: 05/14/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	529	528
Circular GREEN	817	817
Circular YELLOW	759	758

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	577	577
Circular GREEN	93	94
Circular YELLOW	85	84

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Pennsylvania Ave & L'Enfant Sq SE

DATE OF INSTALLATION OF LED: 10/08/2002

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	576	577
Circular GREEN	178	177
Circular YELLOW	94	94

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	521	520
Circular GREEN	89	89
Circular YELLOW	93	93

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Alabama Ave & Stanton Rd SE

DATE OF INSTALLATION OF LED: 08/06/2003

DATE: 05/14/11

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	612	614
Circular GREEN	788	789
Circular YELLOW	117	119

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	597	597
Circular GREEN	827	829
Circular YELLOW	93	93

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Rhode Island Ave & New Jersey Ave

DATE OF INSTALLATION OF LED: 06/25/2004

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	624	567
Circular GREEN	92	93
Circular YELLOW	666	687

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	528	524
Circular GREEN	797	802
Circular YELLOW	689	675

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 11th St & F St NW

DATE OF INSTALLATION OF LED: 06/30/2004

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	537	532
Circular GREEN	123	123
Circular YELLOW	134	137

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	301	311
Circular GREEN	124	124
Circular YELLOW	168	171

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 22nd St & Florida Ave & Q St & Massachusetts Ave NW

DATE OF INSTALLATION OF LED: 06/09/2003

DATE: 05/14/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	664	666
Circular GREEN	122	122
Circular YELLOW	109	111

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	623	623
Circular GREEN	116	118
Circular YELLOW	111	109

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 41 St & McKinley/Western & Cedar Pkwy

DATE OF INSTALLATION OF LED: 08/20/2004

DATE: 05/14/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	586	588
Circular GREEN	631	634
Circular YELLOW	97	95

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	618	619
Circular GREEN	627	631
Circular YELLOW	114	111

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 16th St & Missouri Ave NW

DATE OF INSTALLATION OF LED: 03/24/2003

DATE: 05/14/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	681	680
Circular GREEN	115	116
Circular YELLOW	779	778

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	104	103
Circular GREEN	116	116
Circular YELLOW	84	86

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: 2nd St & Maryland Ave & Constitution Ave NE

DATE OF INSTALLATION OF LED: 12/06/2004

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	447	449
Circular GREEN	513	511
Circular YELLOW	111	109

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	318	324
Circular GREEN	91	91
Circular YELLOW	99	97

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: Nannie Helen Burrough Ave & Kenilworth Ave NE

DATE OF INSTALLATION OF LED: 04/19/2004

DATE: 05/17/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	102	103
Circular GREEN	102	101
Circular YELLOW	136	137

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	702	681
Circular GREEN	118	116
Circular YELLOW	101	102

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: East Capitol St & Stoddert Pl

DATE OF INSTALLATION OF LED: 07/11/2003

DATE: 05/15/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	586	588
Circular GREEN	668	672
Circular YELLOW	86	84

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	567	568
Circular GREEN	674	676
Circular YELLOW	92	92

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: East Capitol St & 56th Pl

DATE OF INSTALLATION OF LED: 07/11/2003

DATE: 05/15/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	628	626
Circular GREEN	564	564
Circular YELLOW	96	96

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	586	588
Circular GREEN	644	646
Circular YELLOW	96	98

DDOT LED DEGRADATION EVALUATION STUDY

FIELD DATA COLLECTION SHEET

INTERSECTION: M.L, King Ave & Howard Rd & Sheridan Rd SE

DATE OF INSTALLATION OF LED: 03/05/2004

DATE: 04/16/2011

MANUFACTURER OF LED: GE

SIGNAL HEAD 1

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	531	534
Circular GREEN	96	95
Circular YELLOW	717	717

SIGNAL HEAD 2

LED SIGNAL TYPE	*Measurement 1*	*Measurement 2*
Circular RED	543	544
Circular GREEN	91	91
Circular YELLOW	90	91