LED Dirt Depreciation from Roadway Luminaires
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Light Loss Factor (LLF)

LLF is a factor applied to lighting design to compensate for depreciations over time. Factors are:

- Lamp Lumen Depreciation (LLD)
- Luminaire Dirt Depreciation (LDD)
- Ambient Temperature Factor (ATF) – LED only
- Equipment Factor (EF) – HPS only

Important Consideration: Light loss factor should be based on end of lamp life at re-lamp not mean lumen value.
Light Loss Factor (LDD)
Light Loss Factor (LLD) for HPS

* 4,000 hours of use is approximately one year
HPS Light Loss Factor for HPS

Three-Year - Maintenance Cycle LLF Calculation:
0.77 (LLF) = 0.9 (LLD) x 0.9 (LDD) x 0.95 (EF)

Four-Year - Maintenance Cycle LLF Calculation:
0.71 (LLF) = 0.84 (LLD) x 0.89 (LDD) x 0.95 (EF)

Five-Year - Maintenance Cycle Calculation, or Maintenance by Spot Re-lamping LLF Calculation:
0.65 (LLF) = 0.78 (LLD) x 0.88 (LDD) x 0.95 (EF)
Typical Test Method

• Method
  – Photometer dirty luminaire
  – Clean the luminaire
  – Photometer again

Result: Spatially distributed dirt depreciation estimates
Before Cleaning
Percentage Difference
(Clean – Dirty)/Clean
Does this work for LED?

Issues:

• No Lamp replacement
  – Reduces Maintenance Cycle

• Optics
  – How does the light generation method change the dirt depreciation?
Luminaire Dirt Depreciation

Are we adequately accounting for the changes in the luminaire intensity due to dirt?

• What is overall Luminaire Dirt Depreciation?
• Is a single factor enough?
• What is the best way to clean an LED luminaire?

We have taken on 2 research projects to investigate this issue:

Sponsored by:
The Virginia Center for Transportation Innovation and Research
The Illuminating Engineering Society
VCTIR Project - LED Lifetime Performance Evaluations

Parking Lot with 6 different Luminaire types
Evaluation of Luminaire performance over a 2 year period
Measure Grids and Performance in a VDOT parking lot every 3 months for 24 months
VCTIR Approach

Measure Light Source Performance over time

• Monitor:
  – Overall Light Output
    • Average Light Output
    • Light Loss Factor
    • Overall Distribution Changes
  – Color Changes
  – Temperature Issues
  – Visual Inspection
    • Water Issues
    • Animal Intrusion
    • Dirt Build Up
VCTIR Test Protocol

Lab setting - VTTI grid evaluation
  • completed summer 2012

Field setting - Woodbridge Park-and-Ride evaluations
  • Every 3 months

Lab setting - VTTI grid evaluation
  • Measure removed luminaires dirty, then clean
  • completed summer 2014
Testing Location

Illuminance mapping of Park-and-Ride area
Luminaires Evaluated
IES Project Objective

The primary objective of this research is to establish the performance of various types of LED luminaires in terms of dirt depreciation.

This performance will be established for various:

- luminaire optics types
- material types
- environment types
- luminaire IP ratings

A secondary outcome of this research may be a specification for the cleaning of LED luminaires.
Approach – IES Project

Measure Performance of Luminaires in-situ using the VTTI Roadway Lighting Mobile Measurement System

- Measure
- Clean
- Re-measure
## Tested Materials – IES Project

<table>
<thead>
<tr>
<th>Num Luminaires</th>
<th>Led Optics</th>
<th>Luminaire Optics</th>
<th>Installation Age (yrs)</th>
<th>Location</th>
<th>Data</th>
<th>Cleaning Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Individual Acrylic</td>
<td>None</td>
<td>3</td>
<td>Hampton, VA</td>
<td>RLMMS</td>
<td>IPA wipe</td>
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<td>Individual Acrylic</td>
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<td>3</td>
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<td>3</td>
<td>Individual Acrylic</td>
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<td>RLMMS</td>
<td>Dry Wipe</td>
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<td>Individual Acrylic</td>
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<td>Smart Road</td>
<td>RLMMS</td>
<td>IPA wipe</td>
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<tr>
<td>5</td>
<td>Individual Acrylic</td>
<td>None</td>
<td>6</td>
<td>Smart Road</td>
<td>RLMMS</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>Individual Acrylic</td>
<td>None</td>
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<td>Smart Road</td>
<td>RLMMS</td>
<td>Water Pressure Wash including Heat Sink</td>
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<td>Individual Acrylic</td>
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<td>Smart Road</td>
<td>RLMMS</td>
<td>Water Wipe</td>
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<td>Woodbridge, VA</td>
<td>Grid</td>
<td>IPA wipe</td>
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<tr>
<td>4</td>
<td>Individual Acrylic</td>
<td>None</td>
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<td>Woodbridge, VA</td>
<td>Grid</td>
<td>IPA wipe</td>
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<tr>
<td>2</td>
<td>Acrylic</td>
<td>Flat Glass</td>
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<td>RLMMS</td>
<td>IPA wipe</td>
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<tr>
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<td>Acrylic</td>
<td>Flat Glass</td>
<td>3</td>
<td>Woodbridge, VA</td>
<td>Grid</td>
<td>IPA wipe</td>
</tr>
<tr>
<td>2</td>
<td>Acrylic</td>
<td>Flat Glass</td>
<td>3</td>
<td>Woodbridge, VA</td>
<td>Grid</td>
<td>IPA wipe</td>
</tr>
<tr>
<td>4</td>
<td>Acrylic</td>
<td>Flat Glass</td>
<td>3</td>
<td>Woodbridge, VA</td>
<td>Grid</td>
<td>IPA wipe</td>
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<tr>
<td>2</td>
<td>None</td>
<td>Molded Individual Acrylic</td>
<td>3</td>
<td>Woodbridge, VA</td>
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<tr>
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<td>None</td>
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<td>3</td>
<td>Woodbridge, VA</td>
<td>RLMMS</td>
<td>IPA wipe</td>
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<tr>
<td>2</td>
<td>Acrylic</td>
<td>Flat Glass</td>
<td>3</td>
<td>Woodbridge, VA</td>
<td>Grid</td>
<td>IPA wipe</td>
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<tr>
<td>2</td>
<td>Acrylic</td>
<td>Flat Glass</td>
<td>3</td>
<td>Woodbridge, VA</td>
<td>RLMMS</td>
<td>IPA wipe</td>
</tr>
</tbody>
</table>
Results

Question 1

• What is overall Luminaire Dirt Depreciation?
VTTI | Transportation safety is our #1 priority
Field Testing Results

General trends show luminaires performing as expected.
Field Test Results – Light Loss

![Graph showing field test results for light loss.](#)
Laboratory Test Results

Average Horizontal Illuminance – Initial Testing and Second Testing

Light Loss based on Horizontal Illuminance

LED Average LED Average
(with D (2)) (w/o D (2))

-10% -9% -8% -7% -6% -5% -4% -3% -2% -1% 0%

Lumen Depreciation  Dirt Depreciation  Overall
Dirt Differences

- Impact of emissions from bus traffic in concrete area
- Compare 4 luminaires from 2 manufacturers
Asphalt and Concrete Comparison

-Differences most likely due to individual differences in luminaires and not due to ground surface type or vehicle emissions.
Relationship to Optical Design

-12%
-10%
-8%
-6%
-4%
-2%
0%
2%

Design C (2)  HPS 250 (2)  Optic Average (A, D, E w/o D(2))  Design B Average

Graph showing the relationship to optical design with bars for Lumen Depreciation, Dirt Depreciation, and Overall.
Efficacy

Design A
Design B
Design C
Design D
Design E
HPS 250W

Initial Efficacy
After Efficacy (Dirty)
After Efficacy (Clean)
CCT

Relative Irradiance

Wave Length (nm)

- Design A (1) Initial
- Design A (2) Initial
- Design B (1) Initial
- Design B (2) Initial
- Design C (1) Initial
- Design C (2) Initial
- Design D (1) Initial
- Design D (2) Initial
- Design E (1) Initial
- Design E (2) Initial
- HPS 250W (1) Initial
- HPS 250W (2) Initial

VTTI | Transportation safety is our #1 priority
Field Test Results – CCT
## Luminaire Inspection - Summary

<table>
<thead>
<tr>
<th></th>
<th>Wildlife intrusion device installed</th>
<th>Level of presence of wildlife (ex. Insects)</th>
<th>Level of rust in component housing</th>
<th>Level of dirt inside component housing</th>
<th>Level of dirt buildup on optics cover</th>
<th>Level of damage to electrical component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta</td>
<td>No</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
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</tr>
<tr>
<td>Dialight</td>
<td>Yes</td>
<td>Red</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>Philips</td>
<td>Yes</td>
<td>Red</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>Lighting Science</td>
<td>No</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
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<tr>
<td>GE</td>
<td>No</td>
<td>Red</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>HPS</td>
<td>No</td>
<td>Red</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
</tbody>
</table>
Summary

The average loss seems to be about 4% over 2 years. The specific dirt depreciation factor seems to be related to the optical design.

It appears that a single value for all LED is not possible.

There is also a color shift – Only about 200K – Not significant.
So ... In the Meantime

Calculation should be based on luminaire life 15 to 20 years.

LLF (Will vary for each luminaire) =

• LLD Based on IES LM80 and TM21 extrapolation method. Factors range from 0.85 to 0.95
• LLF based on 8 to 10 year cleaning (use factor of 0.9)
• ATF – Based on ambient temperature available from supplier. Northern area can use factor above 1.

• LLF for LED typically around 0.8 to 0.9.
  – If you use a full L70 – Then it will be around 0.65

Assumptions

• The luminaires will be replaced before L70 is reached
• There is some form of maintenance
Results

• Question 2
• Is a single factor enough?
General Profile
Summary

No – The impact of dirt is Spatially distributed. A single factor should not be used.

The distribution seems to be related to the optical design of the luminaire

• Manufacturers may be required to provide a dirt depreciation function

• An accelerated dirt method would be required.
Results

• Question 3
• What is the best way to clean an LED luminaire?
Lit Review Results

Very few manufacturers provide maintenance information
• Typically
  – “Wipe down the luminaire”
  – No solvents
  – Isopropryl alcohol washes “tough stains”

Other roadway fixtures have maintenance
• Pressure washing and scrubbing in tunnels

Natural washing
• Spray in truck vortexes
• Rain
Cleaning Approach

A bucket truck was used to perform most of the cleaning procedures.

- Wiping Exterior
  - Dry
  - Isopropyl Alcohol
- Pressure Washing
## Cleaning on Smart Road

<table>
<thead>
<tr>
<th>Cleaning Method</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wipe with a dry microfiber rag.</td>
</tr>
<tr>
<td>2</td>
<td>Wipe with a microfiber rag wetted with water.</td>
</tr>
<tr>
<td>3</td>
<td>Wipe with a microfiber rag wetted with isopropyl alcohol (IPA)</td>
</tr>
<tr>
<td>4</td>
<td>Pressure wash the optics from a bucket truck with plain water.</td>
</tr>
<tr>
<td>5</td>
<td>Pressure wash the optics and the heat sink(s) from a bucket truck with plain water.</td>
</tr>
</tbody>
</table>
Measurements

Figure 1: Illuminance vs Latitude and Longitude on the smart road. Top trace is the illuminance before cleaning. Lower trace is the difference between before and after cleaning. Bottom trace was displaced downward 0.0005 longitude for display purposes. Color scale is in lux (lx).
All wiping methods were kept to no more than 1-2 minutes to simulate expected field performance of crews. Still took 10 min to setup, clean two luminaires per pole, and breakdown to move to the next pole.
Pressure Washing

- Pressure washing required a water truck, generator, lift, and pressure washer.
- Took 13-15 min to setup and clean two luminaires per pole.
Washing – From Below and From Above

- Pressure washing the heat sinks were challenging.
- Large debris would not be blown out with the pressure washer.
- 50 feet of pressure washer hose was not quite enough.
Data Analysis

This data represents Complete Light Loss Factors
- Not specifically dirt

Losses in 2 years are between 2 and 5%
- Perturbations with temperature and humidity
A little Dirt – 5 years
Dirt Residue

- All wipe methods resulted in accumulation of dirt on the microfiber rags.
- Methods 1 and 2 (dry and wet rag wipe – water) consisted of mostly dark grey “dirt”
- Method 3 (isopropyl alcohol wipe) consisted of a mixture of dark grey and brown dirt.
Before and After

Before (top) and after cleaning photos of the same luminaire

Before and after photos show clearer optics after cleaning

Clearer optics equate to less loss, proper light distribution.
Measurements – cont.

- Isopropyl rag (cleaning method #3) and pressure washing optics only (#4) give similar results
- Isopropyl rag is easier
In-situ Testing – Minneapolis
Before and After
Minneapolis Cleaned Horizontal Illuminance, lx
Summary

Wiping with alcohol seems to provide equivalent cleaning performance.

The impact of water pressure can damage the luminaire (IP ratings are for 18 psi)
Other Issues

Not sure what the impact of the “Big Optics” will be
  • Less surface area
  • Fewer vertical surfaces

Heat
  • LEDs are significantly cooler than HID
    – No dirt etching
    – Bug build up
Approach: Adaptive Lighting

With the advent of new control and ballast technology we have the ability to adapt a roadway lighting system to the needs of the environment.

- Traffic Volume
- Weather
- Lighting Condition
- Pedestrian Usage

Adaptive Lighting basically represents the lowering or raising of the light level based on the needs of the roadway and the drivers

- This requires dimming capabilities
Monitoring Light Level as an Asset

GIS systems are being used to monitor city assets

• Consider light level as an asset
The Immediate Future

Connected Vehicles
• V2V, V2I, V2X

Lighting on Demand
• DSRC and Cellular
  – Pedestrian Pickup
• Issues
  • Comfort Level
    – How many luminaires, how big a space
    – Driver Glance Behaviour
  – Object Detection / Safety
The Long Range Future

More and More Automation
  • Autonomous Vehicles
    – Do we need lighting?
    – Vision systems pickup pavement markings and Radar/Lidar detect other vehicles and obstacles

  • Pedestrians will always have legacy Vision Systems (eyeballs)

Vehicles on Demand
  • Lighting for Personal Safety
Land of Confusion
We need to control the visual environment
Questions?