Decision Support Tool for SSL Luminaire Reliability

RTI International, Research Triangle Park, NC

Cree, Racine, WI, Research Triangle Park, NC; **SAS Institute**, Cary, NC; **Auburn University**, Auburn, AL; **PPG Industries**, Pittsburg, PA; **Marc Chason and Assoc.**, Schaumburg, IL

1. Introduction

- LM-80 data provides insights into lumen maintenance and color stability for LEDs, but does not take into account changes in the larger luminaire system.
- An early prototype of a system-level modeling tool for lumen maintenance of SSL luminaires has been developed. This tool takes into account changes in optical components and the electrical system.
- The goal of the SSL Reliability Decision Support Tool (SSL-DST) is to provide a central platform in which to investigate the impact of different system component choices on the lumen maintenance of SSL luminaires.
- The SSL-DST allows the creation of simple but informative reports about lumen maintenance for an entire luminaire.
- The long-term aging models for LEDs and luminaire optical components (e.g., lenses and reflectors) developed by RTI are programmed into the tool to provide users with the option to either analyze the stored data or provide their own data.
- Reports showing reliability and survival curves can be generated to aid users in decision-making processes related to SSL luminaire design, selection, and testing.

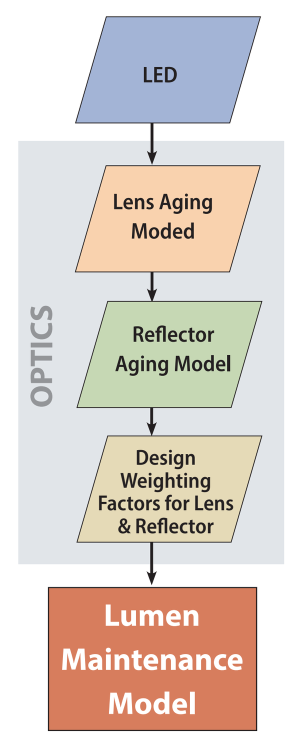
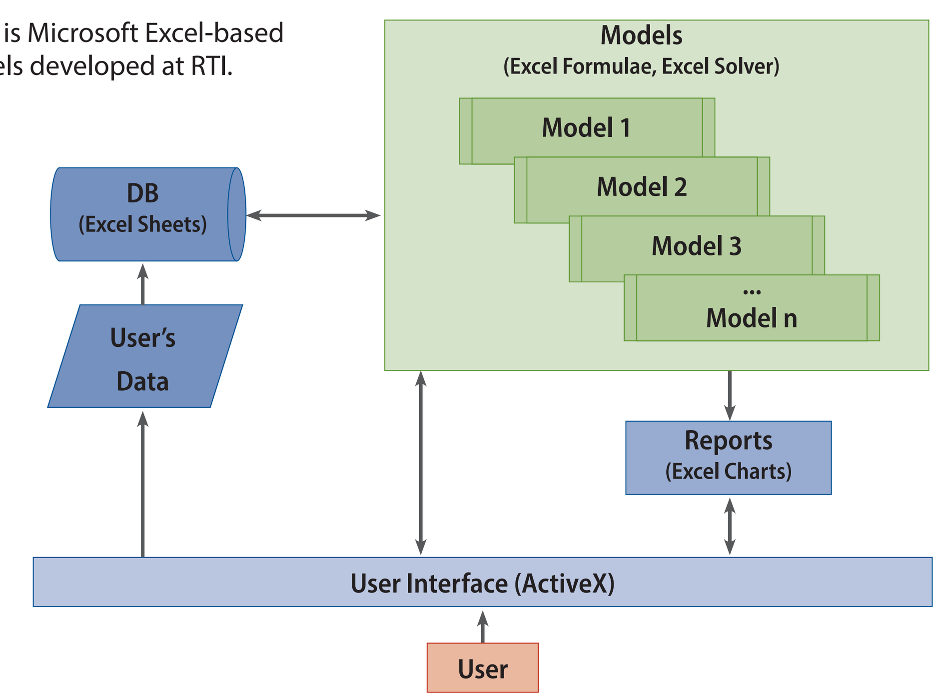


Figure 1 Data and models encompassing the aging of all luminaire parts are used to create the Lumen Maintenance Model.

2. Intended Audience

When completed, the SSL-DST is intended for lighting-industry professionals, including those that design, manufacture, and specify SSL luminaires. These professionals have worked on the development and implementation of effective lighting solutions within the commercial, industrial, institutional and government market sectors.

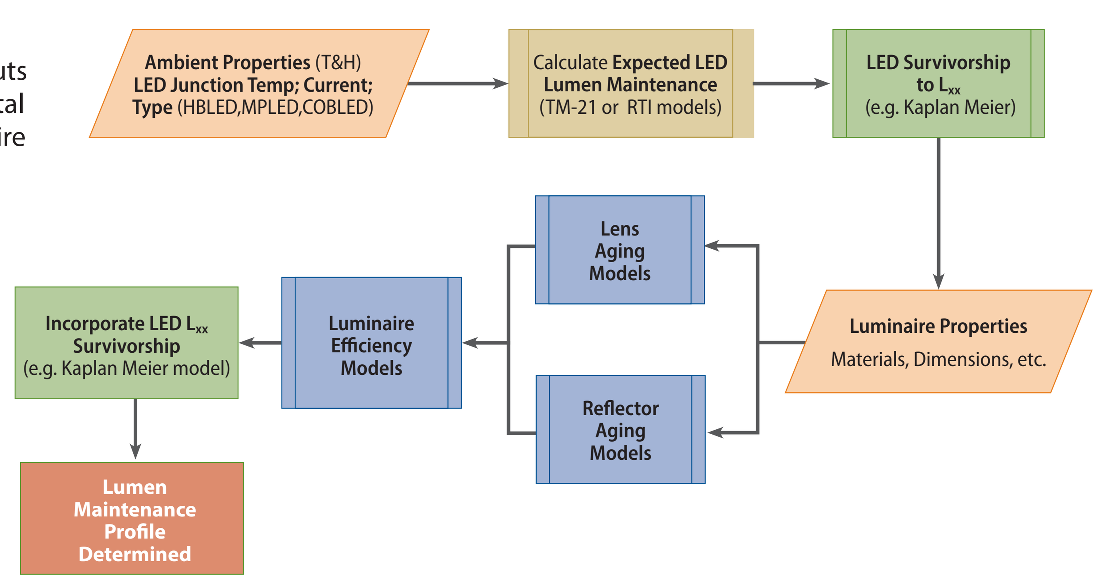
Figure 2 The SSL-DST is Microsoft Excel-based and runs several models developed at RTI.



Parameter Inputs:

i. Ambient properties (temperature and humidity)
ii. LED junction temperature; LED current; LED type (HBLED, Mid-power, COB)
iii. Luminous flux decay rate (entered from LM-80 report or estimated from RTI models)
iv. Lens materials
v. Reflector materials
vi. Luminaire geometry

Figure 3 The SSL-DST can accept several inputs related to environmental conditions and luminaire construction.



3. Models for LEDs

We analyzed 119 difference LM-80 datasets, broken out as shown in **Figure 4**. In reality, α values of LEDs are dependent upon multiple variables including:

- Temperature
- Current
- Manufacturer (not used in these models)
- LED type (e.g. HBLED, Mid-power, COB)
- LED package materials

The multivariate regression models used by RTI to describe the decay rate, α, as a function of current and junction temperature are of the general form:

$$\propto = \beta_0 + \beta_1 * T_j + \beta_2 * I + \varepsilon$$

where:

$\propto$: decay rate
T_j: junction temperature
I: current
$\beta_0, \beta_1, \beta_2, \beta_3$: regression parameters
ε: residual error

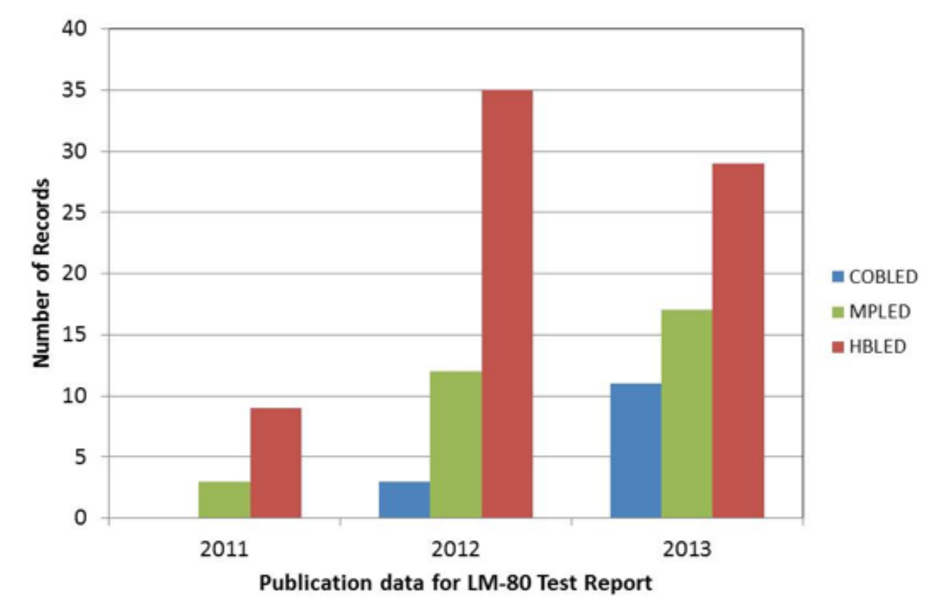


Figure 4 Breakout by year of LM-80 data included in this analysis.

An examination of LED α values by package types allows the creation of general models based on industry trends.

- The LED decay rate constant, α, is most accurately represented in a multi-dimensional graphic with a planar fit.

- Fortunately, distribution about the mean for most manufacturers has similar shape although averages may vary.
- This allows an estimate of the distribution about the median value.

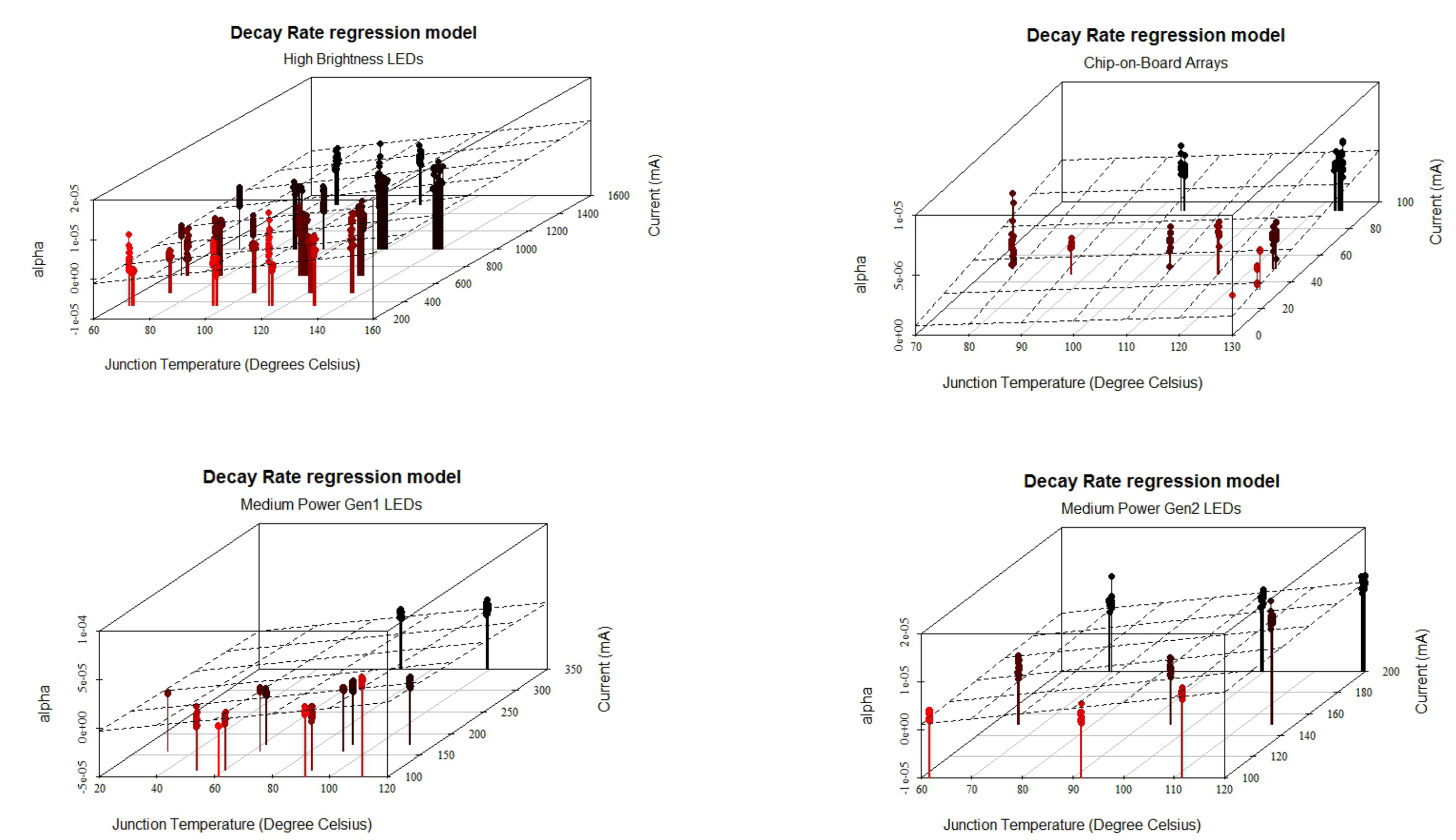


Figure 5 Three-dimensional graphs of average α values for HBLEDs, Mid-power LEDs, and COB LEDs in this study. The least squares fit plane is also shown in each graph.

While a single α value is convenient for each LED product, there is a distribution in values about the mean.

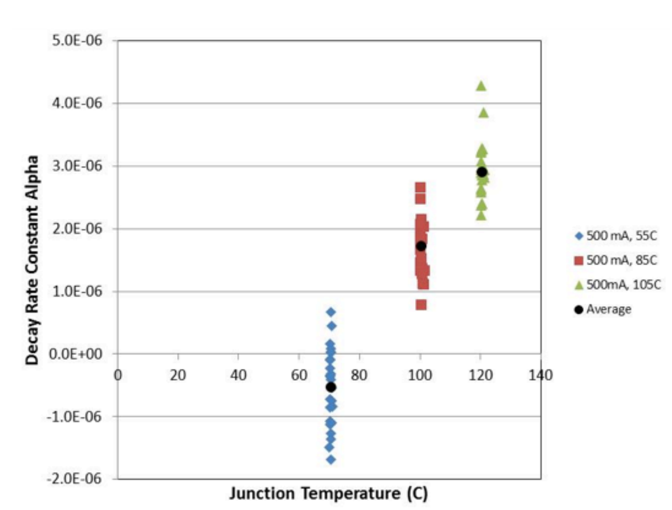
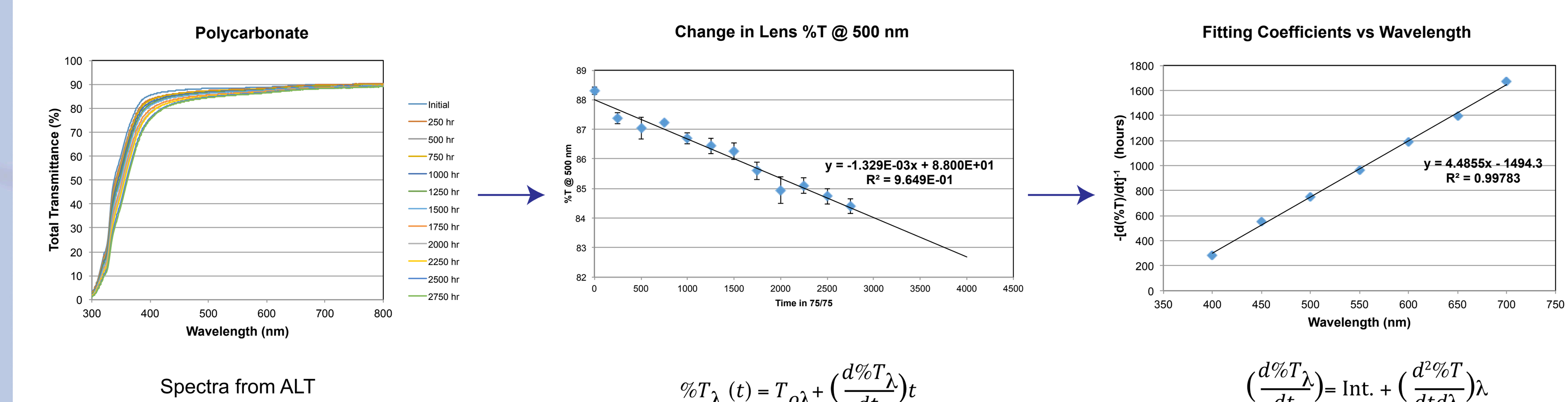


Figure 6 Graph of the average α value (shown in black) for three different HBLED populations tested at three different ambient temperatures. The calculated α value for each LED in the population is shown as either blue diamonds (55C and 500 mA), red squares (85C and 500 mA), or green triangles (105 C and 500 mA).

4. Lens And Reflector Aging Models

Process for building models of changes in lens and reflector materials:

1. Conduct ALTs on sample lenses and reflectors in luminaires at 75°C/75% RH.
2. Measure exposure of the materials to the environment (e.g., temperature, light flux).
3. The change in optical properties (x = %T or %R) is roughly linear at each λ with time, dx/dt.
4. The magnitude of dx/dt values depends on λ in a predicable manner.
5. Acceleration factors are essential to convert ALT findings to expected operational conditions.
6. To accurately model the change in luminous flux, the entire spectrum must be modeled.



$$\%T_{\lambda}(t) = T_{o\lambda} + \left(\frac{d\%T_{\lambda}}{dt}\right)t \qquad \left(\frac{d\%T_{\lambda}}{dt}\right) = \mathrm{Int.} + \left(\frac{d^2\%T}{dt\,d\lambda}\right)\lambda$$

Figure 7 Building a model for lens and reflector aging.

Since time $_{op}$ = t_{ALT} * Acceleration Factor, we can use our test results to predict spectral response of lenses and reflectors at any future time under any stress conditions.

$$\Phi(t) = K_m \int I_{o\lambda} \left\{ \%T_{\lambda}(t) \right\} V(\lambda) d\lambda.$$

5. Luminaire Efficiency Model

- Data from Photopia simulations were used to study the impact of optical material degradation on luminaire efficiency for a 6" downlight "virtual luminaire".
- This approach enabled models to be built of the impact of aging on the lumen maintenance of a 6" downlight.
- $\Phi(t) = \Phi_{init} G_{led} H_{lum}$
  - G_{led} = LED lumen maintenance
  - H_{lum} = Normalized luminaire efficiency
- $F_{tot} = F_{init} G_{led} F_{lens} (F_{reflector})^n$

RTI is now investigating what, if any, modifications are needed to extend this model to other luminaire designs (e.g. troffers).

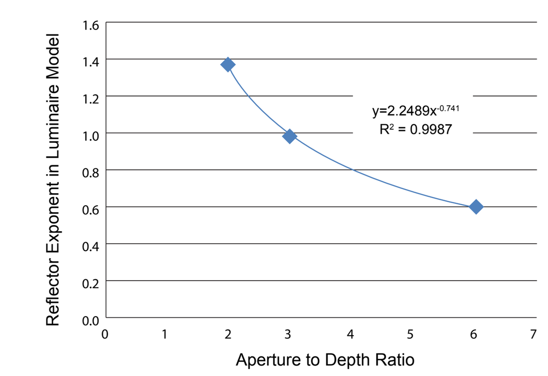


Figure 8 Dependence of reflector exponent in fitting equation upon downlight aperture to depth ratio.

6. Conclusion

- An Excel-based tool has been developed for examining lumen maintenance at the luminaire level. Alpha testing of the tool has begun.
- The tool includes models for the impact of luminaire design and the aging characteristics of major luminaire optical components:
  - LEDs
  - Lenses
  - Reflectors
- The tool demonstrates the importance of a system-level perspective to luminaire lumen maintenance.
- Additional refinements of the models will occur as more data becomes available. Some planned refinements include:
  - Inclusion of newer LEDs in the RTI models
  - Extension to troffer and other luminaires
  - Availability in other software platforms

More Information

Sources cited are available upon request.

Lynn Davis
Director, Engineering Research
919-316-3325
ldavis@rti.org

Karmann Mills
Project Manager
919-541-6884
kmills@rti.org

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RTI International
3040 E. Cornwallis Road
Research Triangle Park, NC 27709

www.rti.org