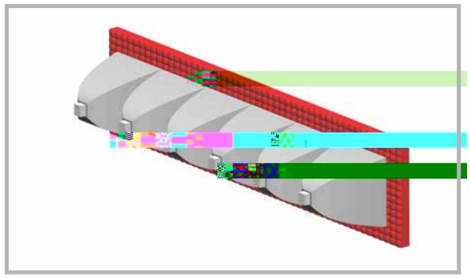
Introduction

The automotive industry makes a lot of cars—73 million passenger cars worldwide in 2017 alone—and the industry loves using light-emitting diodes (LEDs) in those cars. If you've purchased a new

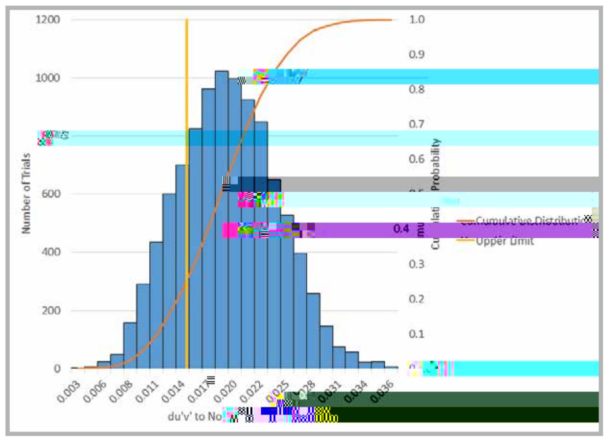


Working in the Red...

For a CHMSL to be legal, as far as the color of emitted light is concerned, its 1931 CIE chromaticity must lie within a specification-defined region known as the colorbox. Historically, this has been a very important consideration, because the light source was a warm white light bulb that was filtered by a lens to create red light. If you used the wrong thickness of lens or the wrong dye, you could very easily get a chromaticity that doesn't pass. With LEDs, it's a little bit easier, because the light from the LED is already red. For the most part, a designer just has to make sure that the optical elements in the system—the reflector and the lens—don't shift the chromaticity outside of the colorbox. In our case, this is true. Neither the spectral reflectivity of the aluminumized reflector nor

As stated, the ranges and statistics associated with perturbations to the LED spectrum are also needed. Several LED manufacturers were contacted for this information, but all of them declined to provide it. The reason for this might be very simple: they probably

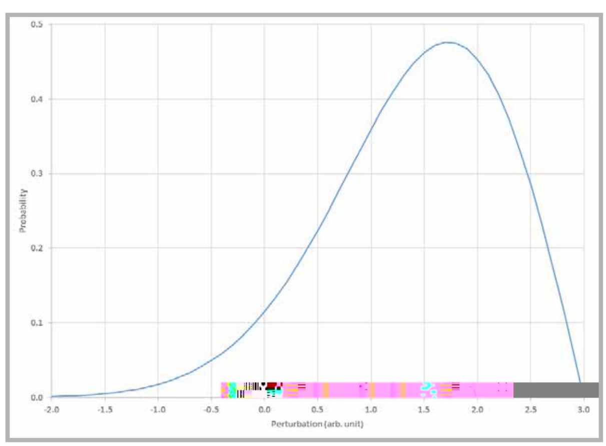
For the legality metric, 100% of the trials resulted in a legal lamp. Great! For the dominant wavelength metric, only 67% of the trials resulted in an LED that was in our color bin. Even though we set the ranges of the spectral parameters to ensure that the dominant wavelength was within one color bin, 33% of the trials were outside that range. Why? The simple answer is cross-terms. The sensitivity analysis used to set the ranges only considers the effect of perturbing each spectral parameter individually. The Monte Carlo analysis perturbs all three spectral parameters at the same time, so the effect of multiple perturbations is considered for each trial. One solution to keep the dominant wavelength within one bin is to reduce the ranges of the spectral parameters. As for the noticeability metric, only 25% of the trials resulted in a du'v' below our acceptable level. That means 75% of the lamps produced will have at least one LED whose color is noticeably different from the others. The following figure shows the results of the Monte Carlo tolerance analysis for the noticeability metric. Most of the trials, shown by the blue histogram, fall above the upper limit for this metric.



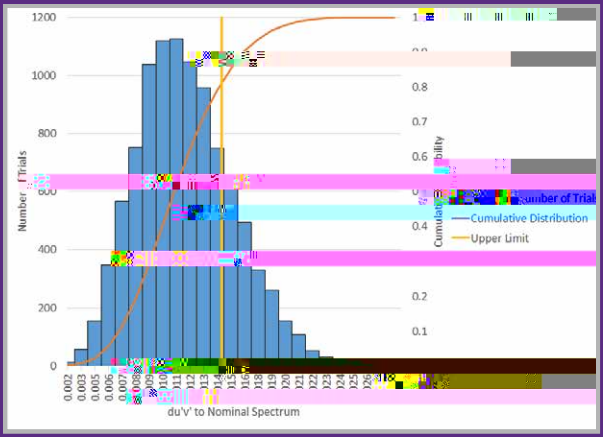
Performance of the Best-Guess Scenario

For the hypothetical best-guess scenario, we kept the perturbation ranges the same and adjusted the probability distributions to something that “might” be more realistic. For the peak wavelength parameter, we assume that the probability distribution is normal,

parameters, we assume that the value tends to broaden, and a narrower spectrum is less likely. To model this effect, we use a negative Weibull distribution, shown in the following figure, for each.



As with the worst-case scenario, we ran 10,000 iterations for the Monte Carlo analysis. As before, 100% of the trials resulted in a legal lamp. The dominant wavelength range for the trials was significantly better. 91% of the trials are now within one color bin. The noticeability metric is also better—only 20% of the lamps are more colorful than we would like. The following figure shows the results of this Monte Carlo analysis for the noticeability metric. The distribution of trials has clearly shifted so that more of the histogram area is to the left of the upper limit.



Understanding the tolerances of a design is important for any system that goes into production. Tools for tolerancing illumination systems for important optical performance metrics are now making inroads and giving designers the ability to virtually prototype the bad systems as well as the nominal ones. Understanding where problems lie before going into production will reduce iterations and increase production yields. In our example, we showed how simply changing the probability distribution for a given perturbation within a fixed range can have a significant impact on the throughput in production.

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