PPG Automotive Coatings
Overview
Project for excellence in color matching
Wellcome!

Global Color Technology Platform
Color Management Services

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Agenda

- Performance Monitoring
- Application Optimization
- Application Correlation
- Standard Derivation and Control
- Color Formulation
- Tolerance Derivation
- Instrument Validation
- Production Approval
- Visual Audits
Components of Color Management

- Application Correlation
- Color Formulation
- Performance Monitoring
- Tolerance Derivation
- Production Batch Approval
- Instrument Validation
- Color Standard Derivation and Control
- Visual Audit
- Application Optimization
Performance Monitoring

Central to any control system is the necessity to objectively track the performance of a given process. When it comes to controlling color in the Automotive Industry, in particular where effect pigments are present, this truth is two-fold. Color is an artifact of both the pigments contained in the material and the application process.

The presence of effect pigments and their directional light-scattering abilities is the origin of the phenomenon of “travel.” Travel is defined as the change in the appearance of a material as it is viewed over a range of aspecular angles. Because effect pigments scatter light preferentially, the originating direction the impinging light and the observers position relative to it play a large role in the perceived color.

Effect pigments scatter light preferentially because they are somewhat two-dimensional; they have a large surface dimension in which the majority of the interaction with light takes place, and a smaller “thickness” dimension which scatters light in small glints and sparkles.

The large surface scatters light directionally depending on its reflective and/or interference properties. But the direction it sends the light also will depend on the orientation of this surface relative to the light source and/or observer.
Performance Monitoring

The orientation of the effect pigments in the film is an artifact of the application process. Many variables impact this, including atomization energy, fluid flow rate, temperature, humidity, etc.

The application process contributes to apparent color in two ways: In the amount of material deposited and in the way effect pigments are oriented within the film. The former is important due to the concept of hiding – if the film layer of the coating is too thin, the substrate and/or sub-layers will show through, potentially changing the apparent color.

If the effect pigments are not oriented in a consistent manner, travel is impacted. This is the phenomenon behind “mottling,” where the color has a blotchy, inconsistent appearance. The most common cause of mottling is localized areas of differently-oriented effect pigments. Severe mottling illustrates just how wildly different the same material can appear due to effect pigment orientation issues. Effect pigment orientation defines how a color travels, and two specimens that travel differently will appear to be different colors, even when compositionally identical.
Performance Monitoring

Because of this, it is necessary to understand the cause of a perceived color difference in order to take corrective action. Is the problem flake orientation? Or is it material-related? If it is the former, no amount of pigment additions can rectify it. Our corrective action has to concentrate on flake alignment. If it is the latter, then perhaps we can improve color through pigment additions. Either way, if the average outcome of the process isn’t known, we will never know which is the problem.

Also, without understanding the average output of a process, it is a matter of guesswork to replicate it in a spray laboratory. And if we are guessing on the spray methodology, we are also guessing on color formulation. Monitoring the performance of a given process involves sampling and measurement. Visual audits cannot help us here; they are point-in-time samplings of one and are based on subjective opinions.

In order for us to understand the process that creates color, we must measure color using accepted statistical sampling techniques. We then need to look at the data in ways that will provide clues as to the origins of color variation, and be able to use it in order to improve the process.

The best way to do this is by measuring and tracking Travel. Changes in travel can be directly attributed to changes in flake orientation.
A normal data distribution is represented by a bell curve. The highest point is at the mean (average) and the width is dependant on the amount of variation in the process. ≈99.99% of all data points will fall within ±3σ (standard deviations) of the mean.

Normal Distribution

-3σ  -2σ  -σ  Mean  +σ  +2σ  +3σ

-67%

-95%

-99.99%
The more repeatable a process is, the more narrow and steep the bell curve will be. The standard deviation will be smaller because the data points will be contained within a tighter distribution.
Taking multi-angle color measurements of multiple body and fascia samples allows us to calculate the amount of travel exhibited by each. If we were to plot the distribution curves of the Flop Index or color travel metric from a body line and a fascia line, we might see something like the representation above.
In order to increase the chances that the body and fascia will travel similarly, and therefore exhibit better color harmony towards one another, we need to take steps to bring the mean values of each distribution closer to one another.
Efforts to bring the means of each distribution closer will greatly increase our chances of the different parts traveling similarly to one another. However, it will not guarantee that every vehicle will have acceptable color harmony.
The width of the distributions (size of the $\sigma$) could still lead to a situation where contiguous parts will not match in travel, although this occurrence would be much rarer than when the means were widely separated.
Acting upon this situation by altering the material or process parameters could lead to the means drifting apart again, decreasing the chances of an acceptable color harmony match.
This illustrates the danger involved in “point-in-time” assessment, or rather judging a material or process based upon one unit rather than an appropriate sampling.
Instead of drawing conclusions based upon one vehicle, a better method might be to use multiple vehicles. An alternative would be to select which vehicle to assess by first measuring its color to ensure both the body and bumper are representative of the average (within $\pm \sigma$ of the mean perhaps).
Efforts to improve the reproducibility from vehicle to vehicle would narrow the distributions and further increase the chances of achieving acceptable color harmony.
In this example, the means of each distribution are very close to one another and we have improved our process consistency to narrow the distributions. The chances of producing unacceptable color harmony are extremely slim.
Performance Monitoring

XYZ

Body

LFF
RFF
LRLQ
RRLQ
STD
Performance Monitoring

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XYZ

Right Rear Corner
Performance Monitoring

XYZ

Average Body & Fascia

Smyrna Fascia

STD

Smyrna Body

Average Body & Fascia
Performance Monitoring

XYZ Fascia – Color Travel ΔE
Performance Monitoring

XYZ

Customer vs. PPG

S  Fascia
PPG Fascia
S  Body
PPG Body
STD
PPG Fascia Std
PPG Body Std
Performance Monitoring

XYZ Fascia – Color Travel $\Delta E$

Mean

$+1\sigma$

$+2\sigma$

$+3\sigma$

UCL

$-1\sigma$

$-2\sigma$

$-3\sigma$

LCL

Std
Performance Monitoring – What Have We Learned?

1. Fascia, on average, travels less than the standard at the Customer
2. Body, on average, travels more than the standard at the Customer
3. The four corners of Fascia are similar in average travel
4. The four corners of Body differ from one another more than Fascia, on average
5. The Left Rear Corner of the vehicle is least variable on both Body and Fascia
6. Fascia has less variability than Body, on average
7. Coating supplier applications Fascia and Body travel very similarly, on average
8. Coating supplier Body and the Customer Body applications are somewhat correlated
9. Coating supplier Fascia and the Customer Fascia application are not correlated
10. Coating supplier standards (or the instrument used to measure them) are different than the Customer’s
11. Coating supplier standard for Fascia is slightly different than that for Body
12. Coating supplier has more variation than the Customer on both Body and Fascia
Lab-to-Line Correlation

Why?

1. If a coating supplier is unable to replicate the customer results with the same material, formulating for travel is guesswork.
2. Without proper travel, body and fascia harmony is impossible.

How?

1. Must be based on average performance on line. Online travel is not perfectly consistent. There is point-to-point variation around the vehicle and job-to-job variation between vehicles.
2. Traditional methods involve a dry-film sample from online. This is point-in-time sampling and statistically invalid.
3. Traditional methods use visual inspection of point-in-time the Customer samples versus coating supplier point-in-time samples. Visual is inconsistent, and point in time is statistically invalid.
4. Monitoring methods must be put in place at both the Customer and coating supplier.
Performance Monitoring

If this were based on sufficient sampling, how do we move towards improvement?

1. The Customer
   a. Work on application variables to improve consistency in all critical areas
   b. Work on application variables to improve consistency from job to job
   c. Collect objective data in statistically significant quantities for all colors, calculate travel indices, plot control charts, and share inform with coating supplier

2. The Customer and coating Supplier
   a. Establish a Critical Match Point (CMP) where application correlation and visual audits take place.
   b. Establish numerical standards that take into account instrument variation
   c. Establish objective production approval tolerances that take harmony into account.

3. Coating Supplier
   a. Establish application correlation for body and fascia
   b. Establish tracking mechanism to monitor the Customer and Coating Supplier application performance.
   c. Re-formulate body and fascia color to the same standard under correlated application processes.
   d. Approve production batches to established standards and tolerances.
Color Standard Derivation and Control

Why?

1. Physical plaques differ from one another, if even slightly.
2. Physical plaques change over time. They get damaged (scratches, scuffs, etc.) and this changes the overall impression of color. Pigments will often change after lengthy exposure to light and fluctuations in environmental conditions (temperature, humidity, etc.)
3. Instruments have inherent differences and these can inject variation around the margins unless accounted for.

How?

1. Actual standards must be numeric.
2. Numeric standard should come from measurements of a central, pristine plaque that is kept in this condition perpetually.
3. The central plaque should only be used to measure. All instruments in the supply chain should measure this panel using identical, statistically valid sampling techniques.
4. All other physical plaques are ranked relative to the central plaque and become visual reference plaques.
Visual Considerations – Standards

Using measurements of different physical plaque standards will inject variation into the system, in particular near the margins, or approval limits.

Again, the black circle represents the ideal color position, the green ellipse represents our visually-derived tolerance.

The red circles represent measurement of a physical plaque standard at various points in the supply chain, and the dotted ellipses represent the tolerance from each of these.
Visual Considerations – Standards

Simply by ensuring that each location measures the exact same physical plaque, using good, identical technique, significantly reduces the amount of variation.

In terms of absolute values, there will still be some variation, primarily due to inter-instrument agreement. However, because this system takes the same physical plaque and measures it on all the instruments in the supply chain, color differences are potentially very similar.

Instrument verification activities helps to ensure that this agreement does not drift out of control.
Color Formulation

Why?
1. Current formulas have potential for travel issues because they may or may not have been originally formulated against correlated application conditions.
2. Current formulas have potential for travel issues because they may or may not have been originally formulated against offset or otherwise insufficient standards.

How?
1. Color formulation must focus on travel relative to the numeric standard under correlated application conditions.
2. Both body and fascia must be formulated to the same numeric standard.
Color Tolerance Derivation

Why?

1. Visual approval to physical plaque standards does not have the repeatability or reproducibility necessary for consistent color.
2. Visual approval to physical plaque standards does not have the precision or accuracy to ensure that multiple batches and/or body and fascia materials are close enough to each other to ensure material contribution to color harmony is minimized without skewing overall color to one side of standard.

How?

1. Set numerical tolerances that take visual impression into account.
2. Utilize multiple observers, and if possible, multiple evaluations to determine the “average” level of acceptability using physical plaques of historic specimens.
3. Determine those specimens that are visually acceptable.
4. Measure these specimens.
5. Using an ellipsoidal formula, set the weighting factors to “fit” the data.
6. Measure the unacceptable specimens and ensure they fail on one angle minimum.
Color Tolerance Derivation
Color Tolerance Derivation
Color Tolerance Derivation

We can measure those panels that are visually acceptable to standard and then, using an ellipsoidal equation, adjust weighting factors until it “fits” the data.

We then measure those panels that are visually unacceptable to ensure that they fall outside the ellipsoid on at least one angle.

We have now created an objective means to improve consistency, based on average visual opinions.

But is it optimal for color harmony?
Color Tolerance Derivation

Would we expect these two specimens to be acceptable to one another? Possibly not.

We have more work to do...
Color Tolerance Derivation
Color Tolerance Derivation

Measuring those panels that are deemed acceptable versus one another, we can adjust our ellipsoid downward.

Re-centering it on the standard, we have created an objective tolerance, based on average visual assessment, that takes color harmony into account.
Instrument Validation

Why?

1. Instruments have the potential to deviate in performance due to overuse (lamp life), damage (dropping, knocking around, etc.), and various wear and tear.
2. A verification program can help minimize instrument variation contributions to material variation.

How?

1. Acquire a traceable verification tile.
2. Establish a protocol for measuring the tile and monitoring the result.
3. Establish guidelines for evaluating the data and procedures for corrective action.
Production Batch Color Approval

Why?

1. Visual approval to physical plaque standards does not have the repeatability or reproducibility necessary for consistent color.
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How?

1. Ensure instrument is verified as performing properly.
2. Measure the specimen using statistically-relevant sampling and consistent techniques in terms of direction, mar avoidance, etc.
3. Ensure that the color passes the tolerances for each angle under consideration.
4. Utilize the visual reference plaque and controlled visual techniques to establish that the color is acceptable.
Visual Color Audit

Why?
1. Visual techniques have the potential to bring about variation.
2. Sampling techniques for visual audits do not take into account mean performance and control limits.
3. Reaction to unacceptable-yet-in-control results increases variation exponentially – Deming’s Funnel.

How?
1. Understand the average performance through a monitoring and tracking program.
2. Establish that either the specimen under inspection is in control.
3. Evaluate visual results relative to process variation.
4. Establish corrective action based on:
   a. Root cause.
   b. Statistical control techniques.
Total Program

If all these processes were put into place, what could we expect?

1. Would every vehicle have perfect color harmony?
   a. There would still potentially be some vehicles with unacceptable color harmony, depending on how successful we were in our efforts to reduce application variation. A body that is $+2\sigma$ matched to a fascia that is $-2\sigma$ might produce less than acceptable harmony, yet still be within process capability.
   b. If we use only a visual appraisal to decide harmony quality, there could be times where visual variation or lack of control of the visual experiment rates a match substandard when on a different occasion it may be acceptable.

2. Would overall harmony be improved?
   a. The consistency of harmony would be improved, but there may still be individual jobs that are unacceptable. These would be much more rare than they currently are, however.
   b. The foundation for actual continuous improvement would be laid.

3. How can we ensure that the system performs in perpetuity?
   a. Only make changes where SPC techniques suggest they will improve things.
   b. Practice discipline. Trust the system. Eliminate knee-jerk reactions to visual impressions.
Questions?