“Best in Segment” Strategy: Quality Pillars

Perceptual Quality

- Improve Surface Structure (Orange Peel)
- Improve Color Harmony
- Improve Secondary Surface Appearance
- Improve Exposed Sealer Appearance
- Evaluate Color Palette

Strategic Tasks:

- Initial Quality
- Long Term Quality
- Polymers and Add-On Parts
- Perceptual Quality

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Why Instrumental Color Measurement?

- Foundation for Process Control
- Need for Objective Assessment that can be Conducted in Paint Shop Lighting
- One Fascia Supplier Supplies Multiple Plants

Assembly Plant 1
BC/CC System
Supplier A
SBBC/2KCC

Assembly Plant 2
BC/CC System
Supplier B
WBBC/2KCC

Assembly Plant 3
BC/CC System
Supplier B
WBBC/1KCC

Fascia Supplier 1
BC/CC System
Supplier A
SBBC/2KCC

Fascia Supplier 2
BC/CC System
Supplier B
WBBC/2KCC
Objective Instrumental Measurement: Color Harmony

- Gage R&R Validated
- Multi-Angle Color Measurement
- Metallic Impact Characterized by Sparkle and Graininess
- Objective Data for Match to Standard or Adjacent Panel Harmony
- Obtain color harmony using tool for process control.
**Color Risk:** Likelihood of a Color to Change Sparkle, Grain, or Hue Due to Viewing Angle

- **LOW:** Non-Metallic or Dark Metallic Color with Minimal Travel & No Hue Shift
- **MEDIUM:** Light to Medium Metallic Color with Travel and No Hue Shift
- **HIGH:** Light to Medium Metallic Color with High Travel and Hue Shift

<table>
<thead>
<tr>
<th>Volt Color</th>
<th>Code</th>
<th>Risk Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>41 / GBA</td>
<td>Low</td>
</tr>
<tr>
<td>Crystal Claret Tintcoat</td>
<td>89 / GBE</td>
<td>Medium</td>
</tr>
<tr>
<td>Switchblade Silver Metallic</td>
<td>17 / GAN</td>
<td>Medium</td>
</tr>
<tr>
<td>Urban Fresh Tricoat</td>
<td>16 / GLC</td>
<td>High</td>
</tr>
<tr>
<td>White Diamond Tricoat</td>
<td>98 / GBN</td>
<td>High</td>
</tr>
<tr>
<td>Cyber Gray Metallic</td>
<td>57 GBV</td>
<td>High</td>
</tr>
</tbody>
</table>
**Design** = \( f(\text{Cut Line} \times \text{Gap Character} \times \text{Angle Interface}) \)

### Fascia Cut-Line

<table>
<thead>
<tr>
<th>Fascia Cut-Line</th>
<th>Color Category</th>
</tr>
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<tbody>
<tr>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>All Vertical 90°</td>
<td>Green</td>
</tr>
<tr>
<td>Short Verticals &amp; “Z” Joints</td>
<td>Green</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Green</td>
</tr>
<tr>
<td>Horizontal with Break</td>
<td>Green</td>
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</tbody>
</table>

### Angle Interface

<table>
<thead>
<tr>
<th>Angle Interface</th>
<th>Color Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>&lt; 4° Angle</td>
<td>Green</td>
</tr>
<tr>
<td>&gt; 4° Angle</td>
<td>Green</td>
</tr>
</tbody>
</table>

**Poor Color Harmony Example**
Service Bulletin: 2010 Chevrolet Camaro
Information on Door and Quarter Panel Paint Appearance

- **Background**
  - Paint on Doors May Appear as a Different Shade than Quarter Panels
  - Varies based on Viewing Angle and Light Conditions
  - More Apparent with Certain Colors

- **Design Intent**
  - Door to Quarter Panel Angle Match is the Design Intent
  - Wildfire Metallic (High Harmony Risk Color) Panels Demonstrate Impact of Angle on Apparent Color

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Flat Panel with Standard Indicating Color Consistency

Panel with Crease on Right Side Creates an Angle Similar to the Camaro Door-Quarter Interface

Standard Repositioned to the Right Side of the Panel Shifts Along with the Angled Side
Instrumental Color Process Control

3 Segments

1. Batch

1st Degree of control. Reduce batch to batch variation to minimize color impact.

2. Painted Body

In paint shop control – daily measurement to identify processing variations and maintain consistency.

3. Color Harmony

Measurement of assembled product for match point data and visual correlation.
BykMac Output

Total Color Difference
\( dSE \)

\( dS_t \)
Effect

Sparkle

\( 25^\circ, 45^\circ, 75^\circ \)

Graininess

Angle Independent

\( S_a \) Sparkle Area
\( S_i \) Sparkle Intensity

\( G \) Graininess
(Fine vs. Grainy Pattern)

\( dE_t \)
Color Difference

-15°, 15°, 25°, 45°, 75°, 110°

\( \Delta L \) Light to Dark
\( \Delta C \) Chroma (Saturation)
\( \Delta h \) Hue

\( \Delta a \)

\( \Delta b \)

Bright Light

Diffuse Light

High Sparkle

High Grainsness

Low Sparkle

Low Grainsness

Supports Benchmarking & Monthly Color Harmony Reviews

Supports Paint Shop and Paint Supplier Process Control

Batch & Component to Standard

Component to Component (Body to Fascia)
Measurement of Color:
Color Systems for Automotive Exterior Applications

- **DIN 6175-2 System**
  - $\Delta E_{\text{DIN}}$ Scales
  - Developed by European OEM's
  - Based on Metallics
  - Good $\Delta E_{\text{DIN}}$ Visual Correlation
  - Weighting Factors
    - Angle ($\gamma$)
    - Application ($g$)
    - Color ($S$)

\[ \Delta E_{\text{DIN}} > 1.7 \text{ STOP} \]
\[ 1.0 < \Delta E_{\text{DIN}} \leq 1.7 \text{ Evaluate} \]
\[ \Delta E_{\text{DIN}} \leq 1.0 \text{ GO} \]

<table>
<thead>
<tr>
<th>Application Factors:</th>
<th>$g_L$</th>
<th>$g_a$</th>
<th>$g_b$</th>
<th>$g_C$</th>
<th>$g_H$</th>
<th>Normalized Tolerance</th>
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<tbody>
<tr>
<td>Paint Batch Application</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>$\Delta E_C = 1.0$</td>
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<tr>
<td>Paint Line Body</td>
<td>2.0</td>
<td>1.2</td>
<td>1.2</td>
<td>1.8</td>
<td>1.2</td>
<td>$\Delta E_P = 1.0$</td>
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<tr>
<td>Repair Line</td>
<td>2.0</td>
<td>1.2</td>
<td>1.2</td>
<td>1.8</td>
<td>1.2</td>
<td>$\Delta E_P = 1.5$</td>
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<tr>
<td>Repair Line with Gap</td>
<td>2.0</td>
<td>1.2</td>
<td>1.2</td>
<td>1.8</td>
<td>1.2</td>
<td>$\Delta E_P = 3.0$</td>
</tr>
</tbody>
</table>

**Non-chromatic**:
\[ \Delta E_{\gamma}^c = \left( \frac{\Delta L_{\gamma}}{g_L S_L} \right)^2 + \left( \frac{\Delta a_{\gamma}}{g_a S_a} \right)^2 + \left( \frac{\Delta b_{\gamma}}{g_b S_b} \right)^2 \]

\[ s_L = 0.15 \sqrt{L} + \frac{31.5}{\gamma} \]
\[ s_a = 0.7 \max \left( 0.7, 0.48/\gamma - 0.35/L \right) \]
\[ s_b = 0.7 \max \left( 0.7, 0.14/\gamma - 0.20/L \right) \]

**Chromatic**:
\[ \Delta E_{\gamma}^r = \left( \frac{\Delta L_{\gamma}}{g_L S_L} \right)^2 + \left( \frac{\Delta C_{\gamma}}{g_C S_C} \right)^2 + \left( \frac{\Delta H_{\gamma}}{g_H S_H} \right)^2 \]

\[ C^* \geq 18 \text{ or} \]
\[ C^* \geq 10 \text{ and } L^* < 27 \]

DIN 6175-2 System Allows Use of **Red Yellow Green** Zones with a Single Tolerance
Process Control Time Allocation

Data Collection
- Batch
- Painted Bodies
- Full Vehicles

Data Analysis
- Trend Charting
- Individual vehicle tracking
- Scorecards

25% 75%
Data Analysis

Objective:
• Use process control charts to track changes and drive continuous improvement
• Not a Go/No Go Method.

Method
• Track Total Color, dE, Total Effect, dL, da, db averages over time.
• Look at individual vehicle data for visual correlation.
Data Analysis

Use Data to Excel to extract useful data for charting.
What Has Worked Well

- Measurement for Process Control
- Trend charting using Excel
- Ease of use for operators – software and equipment
- Repeatability of measurements
- Visual correlation on many colors
Success Story

Detected a special-cause variation in batch. Re-routed vehicles to prevent passing issue into production process.
Opportunities for Improvement

- Visual correlation for interference pigments and tri-coats.
- Difficulty correlating same colors between plants based on technology and formulation.
- Charting capabilities in software.
- Speed of software for download and data analysis.
Visually acceptable to standard.

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<tbody>
<tr>
<td>Panel Match</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass</td>
<td>02 Hood RF - 88 Hood LF</td>
<td>0.31</td>
<td>0.20</td>
<td>0.18</td>
<td>0.29</td>
<td>0.12</td>
<td>0.14</td>
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<tr>
<td>Pass</td>
<td>06 R Fdr F - 84 L Fdr F</td>
<td>1.17</td>
<td>1.01</td>
<td>1.19</td>
<td>0.72</td>
<td>0.74</td>
<td>0.98</td>
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<tr>
<td>Pass</td>
<td>12 RF Dr Upr - 75 LF Dr Upr</td>
<td>0.75</td>
<td>0.68</td>
<td>0.94</td>
<td>0.59</td>
<td>0.59</td>
<td>0.60</td>
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<tr>
<td>Pass</td>
<td>34 R Qtr Lwr - 56 L Qtr Lwr</td>
<td>1.13</td>
<td>0.97</td>
<td>1.28</td>
<td>0.51</td>
<td>0.64</td>
<td>1.11</td>
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Visually acceptable to standard.

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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass</td>
<td>02 Hood RF</td>
<td>1.63</td>
<td>1.63</td>
<td>2.67</td>
<td>1.15</td>
<td>0.62</td>
<td>2.03</td>
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<tr>
<td>Fail</td>
<td>06 R Fdr F</td>
<td>2.68</td>
<td>2.54</td>
<td>4.95</td>
<td>1.97</td>
<td>1.83</td>
<td>0.97</td>
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<tr>
<td>Fail</td>
<td>34 R Qtr Lwr</td>
<td>2.45</td>
<td>2.68</td>
<td>4.78</td>
<td>1.85</td>
<td>1.33</td>
<td>0.65</td>
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<tr>
<td>Fail</td>
<td>34 R Qtr Lwr</td>
<td>2.06</td>
<td>2.06</td>
<td>3.78</td>
<td>1.66</td>
<td>1.35</td>
<td>1.18</td>
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<tr>
<td>Fail</td>
<td>88 Hood LF</td>
<td>1.63</td>
<td>1.63</td>
<td>2.78</td>
<td>1.01</td>
<td>0.74</td>
<td>1.08</td>
</tr>
</tbody>
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Color Travel Chart

Check Zone: 02 Hood RF;06 R Fdr F;12 RF Dr Upr;34 R Qtr Lwr;56 L Qtr Lwr;78 L

Date: from 3/21/2011 to 3/31/2011

Model:  

n = 9
Understanding DIN6175

- Internal tolerances may not suit 100% of colors
  - “False Feel Good” - Solids
  - “False Reaction Required” – some interference pigments

- Partner with suppliers to identify “trouble” colors for DIN6175.
Partnering with Suppliers

- Add-on part suppliers, paint suppliers.
- Integrate common equipment and capabilities across supply base.
- Data-sharing partnership to improve color harmony.
- Variation reduction and process control.
Partnering with Suppliers

Plant A and Supplier B dE Overlap and Min/Max Zones

Overlap Min
Max
Min
Overlap Max

dE

dE Angle

dE15
dE25
dE45
dE75
dE110
Plant A and Supplier B dL* Overlap and Min/Max Zones

Plant A and Supplier B da* Overlap and Min/Max Zones

Plant A and Supplier B db* Overlap and Min/Max Zones
Color Measurement: Future Opportunities

- Work with suppliers to further understand DIN 6175
- Continue to improve visual correlation for interference and tri-coat paints.
- Integrate color process control across supply base
- Include color measurement from beginning stages of color development