GE Plastics Color Matching

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Introduction to Color Matching

GE is one of the world’s largest producers of plastics
Customers specify the color they want the plastic
GE needs to create a formula that matches the customers color
- 10,000 color matches per year globally ($500 per match)
- colorants are the most expensive component of plastic

<table>
<thead>
<tr>
<th>Customers Color</th>
<th>Formula</th>
<th>Chip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green_332</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>Yellow_102</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>White_107</td>
<td>.63</td>
<td></td>
</tr>
<tr>
<td>Black_203</td>
<td>.025</td>
<td></td>
</tr>
</tbody>
</table>

Outline

Introduction to Color Matching
FormTool - lab color matching tool
ColorXpress - web customer tool
Customer Innovation Center
ProductXpress - product selection and research
Conclusion

There are 40 possible pigments that can be used. Choose 4 to 7.
The color of pigments can change with concentration
Concentration

<table>
<thead>
<tr>
<th></th>
<th>1%</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>yellow</td>
<td>tan</td>
<td>orange</td>
<td>red</td>
<td></td>
</tr>
</tbody>
</table>

The effect of small changes in colorant loadings can be predicted, but large changes are more difficult.
Easier to select a close match and adapt than create new.

Introduction to Color Matching

Filing Cabinet contains 2000 chips
2000 formulas
Experience used to select
Read color requested
search filing cabinet
Inspect physical chip
match?

match?

adapt loadings

save in filing cabinet

make trial chip

match?

match?

End

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Digitize Knowledge

- create case for each chip in filing cabinet
  - problem: numerical representation of color
  - solution: formula of color
- algorithm for selecting best case
- algorithm for adapting case selected
- process for learning new cases

Case base contains 10,000 cases
Automated selection

Selection is NOT just finding the most similar case
Best previous case meets all of the following attributes
Color must match under multiple lighting conditions
Pigments must hide the color of the plastic
The cost must be as low as possible
A limited amount of light can go through plastic
Color should not change when plastic is molded
The selection needs to provide a consistent meaning throughout all attributes
The consistency is achieved by using linguistic terms, such as
Excellent, Good, Fair, and Poor, which are associated with measured differences in each attribute
1) A method to search for a better solution
   - Greedy search which modifies colorant loadings
   - Modify each loading individually and test
   - Select best modification

2) A good method to evaluate if you are closer to the solution
The case selection calculation

<table>
<thead>
<tr>
<th>Color</th>
<th>Blue</th>
<th>Red</th>
<th>BlueViolet</th>
<th>Black</th>
<th>Gray</th>
<th>White</th>
<th>Formulas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Key 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Key 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Key 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Key 4</td>
</tr>
</tbody>
</table>

What to do if there is no good case?

Find patterns from case base that can guide heuristic search

For each color, what are most likely combinations

<table>
<thead>
<tr>
<th>Colorant</th>
<th>Color of that type</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>Ivory, Pure, Bright</td>
</tr>
<tr>
<td>Black</td>
<td>Coal, Midnight</td>
</tr>
<tr>
<td>Red</td>
<td>Crimson, Garnet, Wine, Fire</td>
</tr>
<tr>
<td>Orange</td>
<td>Orange, Pumpkin</td>
</tr>
<tr>
<td>Yellow</td>
<td>Canary, Lemon, Sunflower</td>
</tr>
</tbody>
</table>

Adaptation Needs

Costs are different for different colors

Case Selection

Cost Linguistic Value

E = [(L1 - L2)^2 + (a1 - a2)^2 + (b1 - b2)^2]

Aggregation of Linguistic Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Value</th>
<th>Weight</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>color match</td>
<td>Excel</td>
<td>95</td>
<td>.2</td>
</tr>
<tr>
<td>hide plastic</td>
<td>Good</td>
<td>8</td>
<td>.16</td>
</tr>
<tr>
<td>cost</td>
<td>Good</td>
<td>2</td>
<td>.16</td>
</tr>
<tr>
<td>light transmitted</td>
<td>Excel</td>
<td>1</td>
<td>.2</td>
</tr>
<tr>
<td>color change</td>
<td>Fair</td>
<td>5</td>
<td>.20</td>
</tr>
<tr>
<td>Total</td>
<td>Good</td>
<td>83</td>
<td></td>
</tr>
</tbody>
</table>

What to do if there is no good case?

Start

Read color requested

Retrieve Next Key

Yes

Retrieve Next Colorant Combination

Yes

Another Combination

Save best match

Yes

Another Key

Save best match

No

End
**FormTool - Benefits**

**Productivity**
- average number of test chips created decreased from 4.2 to 2.7
- savings of $2.25 million per year

**Colorant Cost**
- reduced amount of colorants
- cost part of selection algorithm
- average of $2.4 million per year

**Global Consistency**
**Speed**

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**Conclusion**

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**ColorXpress Select**

**Internet Color Matching and Ordering**
Customers use our pallet to select colors
Existing color samples delivered in 48 hours

- Step 1
- Step 2
- Step 3

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**ColorXpress Select - Benefits**

ColorXpress Select has been in use since 1999.
It is one of the first customer service tools that GE Plastics has made available over the web.
Simplified the process for customers to submit orders over the web.
GE now leads the plastic industry in on-line sales.

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**Innovation Center**

Brings together all information needed to select colors
- Chip room
- FormTool
- Small lot manufacturing
- Experienced color matchers
Create custom color and effects in one day
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GE ProductXpress - In development

Application -> ProductXpress Wizard
Specify all needs:
- color
- thermal
- molding
- strength
- etc.

Search global knowledge base of products

Research

Existing Solution or

New Solution

Search global knowledge base of experiments

Conclusion

One Possible CBR Project Life Cycle
- start as internal productivity tool
- expand to customer web tool
- allow greater customer interaction
- expand to a wider range of uses

The end