Quality Improvement of a Plastic Injection Molder

Iowa State University
March 19, 1999

Kevin Dodd
Salvador Neaves
Kendall Ney
Matt Raine
Why An Injection Molding Corporation?

• Large industrial facility
• Injection Molding demands precision
• Injection molding is the wave of the future
Objectives

• Attempt a logical statistical quality analysis in a real world situation
• Provide a useful assessment of the variability in an injection molding process
• Characterize the current process performance
• Work to improve unsatisfactory performance
What?

• Analyze the variability of pre-form weights for a 48-cavity injection molding machine
Inside an Injection Molding Plant
Initial Analysis

• We began by benchmarking the current process to determine how the machine is currently running

• Based on these findings and past performance, four variables with the greatest potential impact on pre-form weight were chosen for an experiment
Factors Analyzed in an Injection Molding Process Experiment

• Hold Time (2.5 - 7 sec)
• Hold Pressure (600 - 1400 psi)
• Injection Time (1.5 - 3.5 sec)
• Injection Pressure (60 - 100 % of 2800 psi)
Data Collection

• Five cavities were selected to represent performance throughout the mold
Data Collection

• Keeping these five cavities constant, the mean and variability across cavities could be observed.
• Pre-forms were taken from these same cavities for each of 33 different set-ups and weighed on the same scale.
Data Collection

Set-ups

• All 16 combinations of High and Low values
• 1 All-nominal run (combination of Medium values)
• 16 combinations of High-Medium-Low values

• Total number of set-ups = 33
Data Collection

Total pre-forms analyzed

- 33 set-ups $\times$ 5 runs/set-up $\times$ 48 pre-forms/run = 7920 pre-forms manufactured

- 33 set-ups $\times$ 5 runs/set-up $\times$ 5 pre-forms/run = 825 pre-forms weighed
<table>
<thead>
<tr>
<th>Setup #</th>
<th>Hold Pressure</th>
<th>Hold Time</th>
<th>Injection Time</th>
<th>Fill Pressure</th>
<th>Cavity 3</th>
<th>Cavity 9</th>
<th>Cavity 18</th>
<th>Cavity 37</th>
<th>Cavity 47</th>
<th>Y-bar</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>1400</td>
<td>2.5</td>
<td>3.5</td>
<td>60</td>
<td>23.36</td>
<td>23.36</td>
<td>23.19</td>
<td>23.30</td>
<td>23.38</td>
<td>23.32</td>
<td>0.0776</td>
</tr>
<tr>
<td>1-2</td>
<td>1400</td>
<td>2.5</td>
<td>3.5</td>
<td>60</td>
<td>23.37</td>
<td>23.36</td>
<td>23.20</td>
<td>23.32</td>
<td>23.39</td>
<td>23.33</td>
<td>0.0760</td>
</tr>
<tr>
<td>1-3</td>
<td>1400</td>
<td>2.5</td>
<td>3.5</td>
<td>60</td>
<td>23.33</td>
<td>23.33</td>
<td>23.28</td>
<td>23.32</td>
<td>23.37</td>
<td>23.33</td>
<td>0.0321</td>
</tr>
<tr>
<td>1-4</td>
<td>1400</td>
<td>2.5</td>
<td>3.5</td>
<td>60</td>
<td>23.34</td>
<td>23.34</td>
<td>23.29</td>
<td>23.34</td>
<td>23.36</td>
<td>23.33</td>
<td>0.0261</td>
</tr>
<tr>
<td>1-5</td>
<td>1400</td>
<td>2.5</td>
<td>3.5</td>
<td>60</td>
<td>23.35</td>
<td>23.35</td>
<td>23.23</td>
<td>23.32</td>
<td>23.37</td>
<td>23.32</td>
<td>0.0555</td>
</tr>
<tr>
<td>2-1</td>
<td>600</td>
<td>7</td>
<td>3.5</td>
<td>60</td>
<td>23.56</td>
<td>23.56</td>
<td>23.57</td>
<td>23.55</td>
<td>23.59</td>
<td>23.57</td>
<td>0.0152</td>
</tr>
<tr>
<td>2-2</td>
<td>600</td>
<td>7</td>
<td>3.5</td>
<td>60</td>
<td>23.56</td>
<td>23.55</td>
<td>23.57</td>
<td>23.55</td>
<td>23.60</td>
<td>23.57</td>
<td>0.0207</td>
</tr>
<tr>
<td>2-3</td>
<td>600</td>
<td>7</td>
<td>3.5</td>
<td>60</td>
<td>23.56</td>
<td>23.56</td>
<td>23.58</td>
<td>23.55</td>
<td>23.60</td>
<td>23.57</td>
<td>0.0200</td>
</tr>
<tr>
<td>2-4</td>
<td>600</td>
<td>7</td>
<td>3.5</td>
<td>60</td>
<td>23.56</td>
<td>23.55</td>
<td>23.57</td>
<td>23.55</td>
<td>23.59</td>
<td>23.56</td>
<td>0.0167</td>
</tr>
<tr>
<td>2-5</td>
<td>600</td>
<td>7</td>
<td>3.5</td>
<td>60</td>
<td>23.55</td>
<td>23.55</td>
<td>23.58</td>
<td>23.54</td>
<td>23.59</td>
<td>23.56</td>
<td>0.0217</td>
</tr>
</tbody>
</table>
Data Analysis

Tools Used in the analysis

• Minitab “DOE” quadratic regression used to identify the most influential variables and model response
• Minitab for contour and surface plots
## Example Regression Analysis

### Response Surface Regression

Estimated Regression Coefficients for **Y-bar**

<table>
<thead>
<tr>
<th>Term</th>
<th>Coefficients</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>22.2283</td>
<td>387.347</td>
<td>0.000</td>
</tr>
<tr>
<td>Hold Pressure</td>
<td>0.0010</td>
<td>24.738</td>
<td>0.000</td>
</tr>
<tr>
<td>Hold Time</td>
<td>0.2631</td>
<td>36.314</td>
<td>0.000</td>
</tr>
<tr>
<td>Injection</td>
<td>-0.1447</td>
<td>-3.327</td>
<td>0.001</td>
</tr>
<tr>
<td>Fill Pre</td>
<td>-0.0046</td>
<td>-3.834</td>
<td>0.000</td>
</tr>
<tr>
<td>Hold Pre*Hold Pre</td>
<td>-0.0000</td>
<td>-16.371</td>
<td>0.000</td>
</tr>
<tr>
<td>Hold Tim*Hold Tim</td>
<td>-0.0116</td>
<td>-17.368</td>
<td>0.000</td>
</tr>
<tr>
<td>Injectio*Injectio</td>
<td>0.0303</td>
<td>3.614</td>
<td>0.000</td>
</tr>
<tr>
<td>Fill Pre*Fill Pre</td>
<td>0.0000</td>
<td>2.263</td>
<td>0.025</td>
</tr>
<tr>
<td>Hold Pre*Hold Tim</td>
<td>-0.0000</td>
<td>-14.852</td>
<td>0.000</td>
</tr>
</tbody>
</table>

**S** = 0.01406  \[ R-Sq = 99.7\% \]  \[ R-Sq(adj) = 99.7\% \]
Summary of Quadratic Regression Analyses

- All 4 variables as predictors of Y-bar
  R-Sqrd = 99.7%

- Hold Time - Hold Pressure as predictors of Y-bar
  R-Sqrd = 97.7%

- All 4 variables as predictors of log(StDev)
  R-Sqrd = 69.3%

- Hold Pressure as predictor of log(StDev)
  R-Sqrd = 53.5%
Fitted Regression Equation for Log (StDev)

(measuring within-die variability)
Results

• From the contour plot for Y-bar we are able to choose values for Hold Time and Hold Pressure to produce an ideal mean weight (23.4gr)

• From the regression analysis for Log(StDev) we found that within die variability is minimum around 880psi Hold Pressure

• Predicted Log(StDev) for Hold Pressure in the range 600 - 1160psi is not substantially larger the minimum possible (minimum is at 880psi)
Results

• The company prefers a small Hold Time, so for a target value of 23.4 grams, using the contour plot we recommend:

  Hold Pressure = 1140psi
  Hold Time    = 3.95sec
### Initial Verification Study

**Benchmarking:** Average weight = 23.280gr  
**Verification Run:** Average weight = 23.405gr

<table>
<thead>
<tr>
<th>Run #</th>
<th>Hold Pressure</th>
<th>Hold Time</th>
<th>Injection Time</th>
<th>Fill Pressure</th>
<th>Cavity 3</th>
<th>Cavity 9</th>
<th>Cavity 18</th>
<th>Cavity 37</th>
<th>Cavity 47</th>
<th>Y-bar</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.40</td>
<td>23.39</td>
<td>23.39</td>
<td>23.39</td>
<td>23.44</td>
<td>23.40</td>
<td>0.0217</td>
</tr>
<tr>
<td>2</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.41</td>
<td>23.40</td>
<td>23.47</td>
<td>23.39</td>
<td>23.45</td>
<td>23.42</td>
<td>0.0344</td>
</tr>
<tr>
<td>3</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.40</td>
<td>23.38</td>
<td>23.41</td>
<td>23.39</td>
<td>23.44</td>
<td>23.40</td>
<td>0.0230</td>
</tr>
<tr>
<td>4</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.40</td>
<td>23.39</td>
<td>23.40</td>
<td>23.40</td>
<td>23.44</td>
<td>23.41</td>
<td>0.0195</td>
</tr>
<tr>
<td>5</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.41</td>
<td>23.40</td>
<td>23.41</td>
<td>23.39</td>
<td>23.44</td>
<td>23.41</td>
<td>0.0185</td>
</tr>
<tr>
<td>6</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.40</td>
<td>23.39</td>
<td>23.39</td>
<td>23.39</td>
<td>23.43</td>
<td>23.40</td>
<td>0.0173</td>
</tr>
<tr>
<td>7</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.40</td>
<td>23.38</td>
<td>23.40</td>
<td>23.40</td>
<td>23.43</td>
<td>23.40</td>
<td>0.0179</td>
</tr>
<tr>
<td>8</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.41</td>
<td>23.40</td>
<td>23.40</td>
<td>23.39</td>
<td>23.44</td>
<td>23.41</td>
<td>0.0192</td>
</tr>
<tr>
<td>9</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.41</td>
<td>23.39</td>
<td>23.39</td>
<td>23.39</td>
<td>23.43</td>
<td>23.40</td>
<td>0.0179</td>
</tr>
<tr>
<td>10</td>
<td>1140</td>
<td>3.95</td>
<td>1.99</td>
<td>66</td>
<td>23.40</td>
<td>23.39</td>
<td>23.39</td>
<td>23.39</td>
<td>23.43</td>
<td>23.40</td>
<td>0.0173</td>
</tr>
</tbody>
</table>
Further Verification

• Compare historical machine output against weights produced using set-up taken from the contour plot (all 48 cavities)
(Routine process monitoring done on the basis of 6 randomly selected pre-forms each hour)
Histogram of Historical Data

Y-bar = 23.28gr.
StDev = 0.035gr.
Histogram of Current Data

Y-bar = 23.38gr.
StDev = 0.037gr.
Histogram of Historical Production Data

Histogram of Current Production Data
Recommendations

• We suggest the company use contour plots as a guide to setting the values of the Hold Time and Hold pressure and move Hold Pressure toward 880psi to whatever extent is possible (and is consistent with low cycle time goals)

-These values will help provide the company with an optimal set-up for pre-form weights near 23.4gr
??? Questions ???