Setting Appropriate Fill Weight Targets
A Statistical Engineering Case Study

William A. Brenneman

Research Fellow, Global Statistics Discipline Leader
Data and Modeling Sciences
The Procter & Gamble Company

Adjunct Professor of Practice
Stewart School of Industrial and Systems Engineering
Georgia Tech University

European Network for Business and Industrial Statistics
Nancy, France
September 3, 2018

Outline

- Introduction – size and complexity of problem
- Net Content Regulations
- Target Setting Tool Requirements
- Company Task Force and Statistical Engineering Decisions
- Model Assumptions and Existing Methodology
- Why Lot-Lot Variability Matters
- Details of a Solution
- Target Setting Tool Requirements
- Deployment and Evolution of the Application
- Conclusion

P&G Products


IVORY
Pampers
Crest
Oral-B
Secret
MVP
Gillette
Fusion
BRAUN
The Gillette Company
Pepto-Bismol
Puffs
Charmin
VICKS
Vapo Steam
Sinex
VapoRub
NyQuil
DayQuil
Tide
DAWN
Cascade
OLAY
regenerist
head & shoulders
Old Spice
Bounty

P&G Facts

- Established in 1837; Soap and Candle Company, Cincinnati, Ohio
- 140 Countries
- 95,000 Employees Worldwide
- 70+ Brands
- $65 Billion in Sales

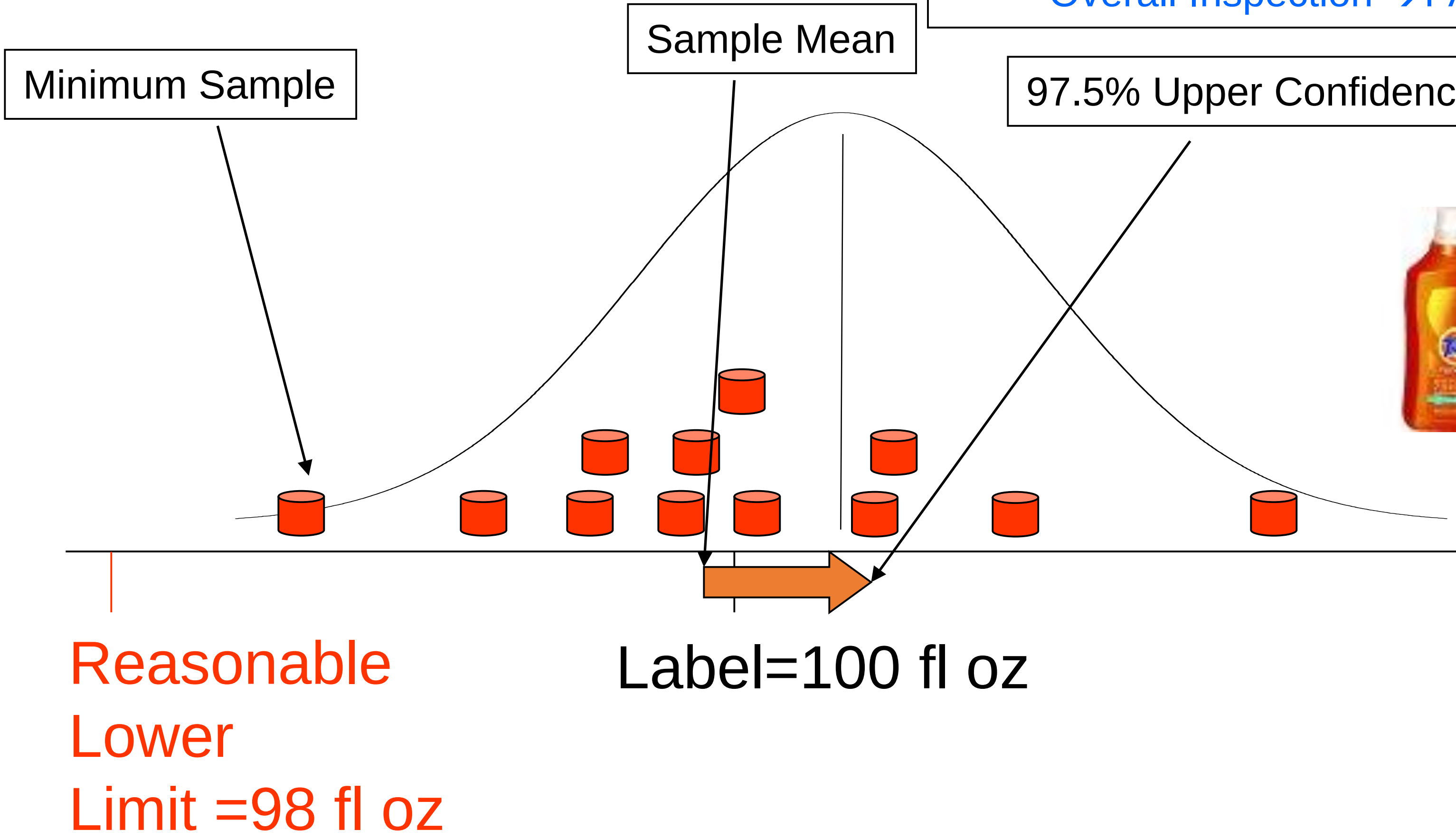
Introduction to Fill Weight Regulations

US Regulations
NIST Handbook 133

Example Result

- Sample n = 12
- Mean = 99.8 oz
- UB = 101.4 oz → PASS Average
- Min = 98.4 oz → PASS Individuals

Overall Inspection →PASS



Motivation for Setting Appropriate Targets

Setting Fill Weight Targets on Products that have a Label Net Content Declaration – almost everything we sell!

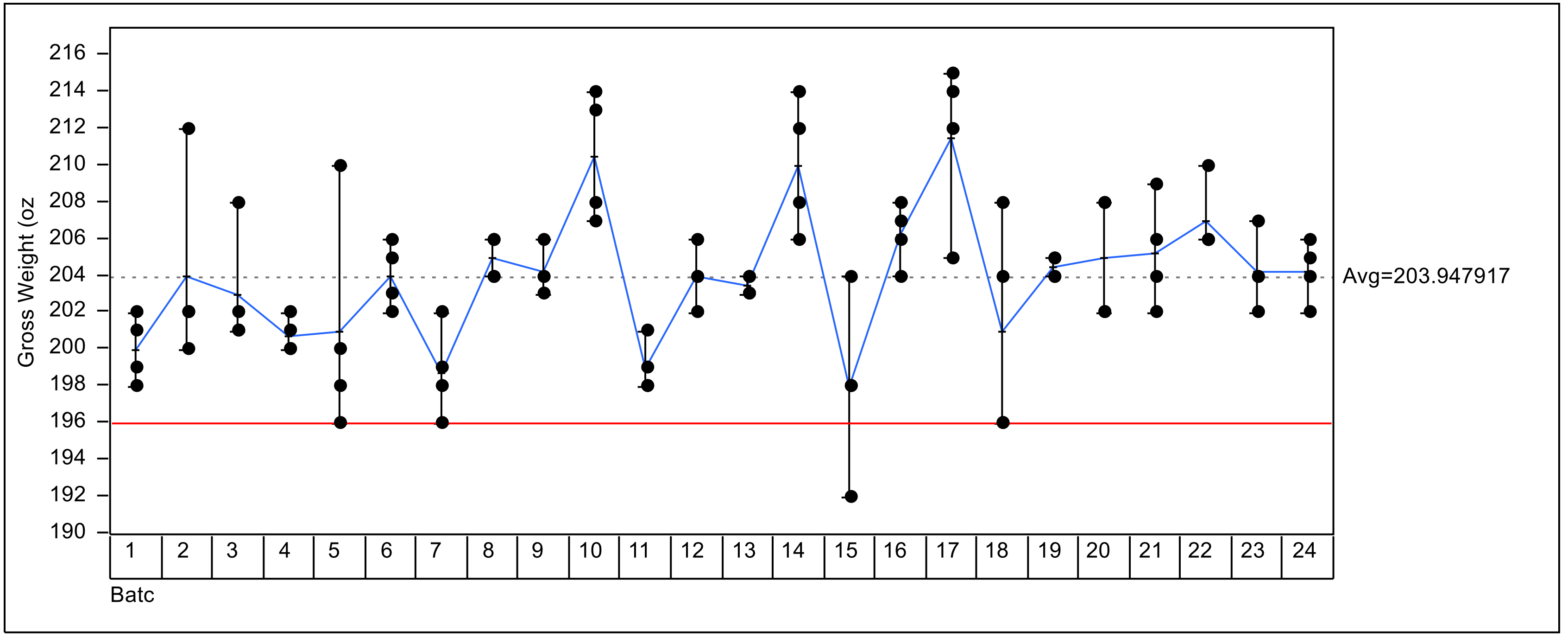
Motivation for this work:

1. Various ways for calculating fill weight targets in the company
2. No way currently to quantify the risk of failing a government inspection
3. No standard format for determining the loss due to over pack
4. Theoretical work for probability of passing regulations does not handle
    a. New Regulations
    b. Processes where Lot-to-Lot (Batch-to-Batch) variation is present
5. Overfill is very Costly

Example of Statistical Engineering

Example Data – Ice Cream Production

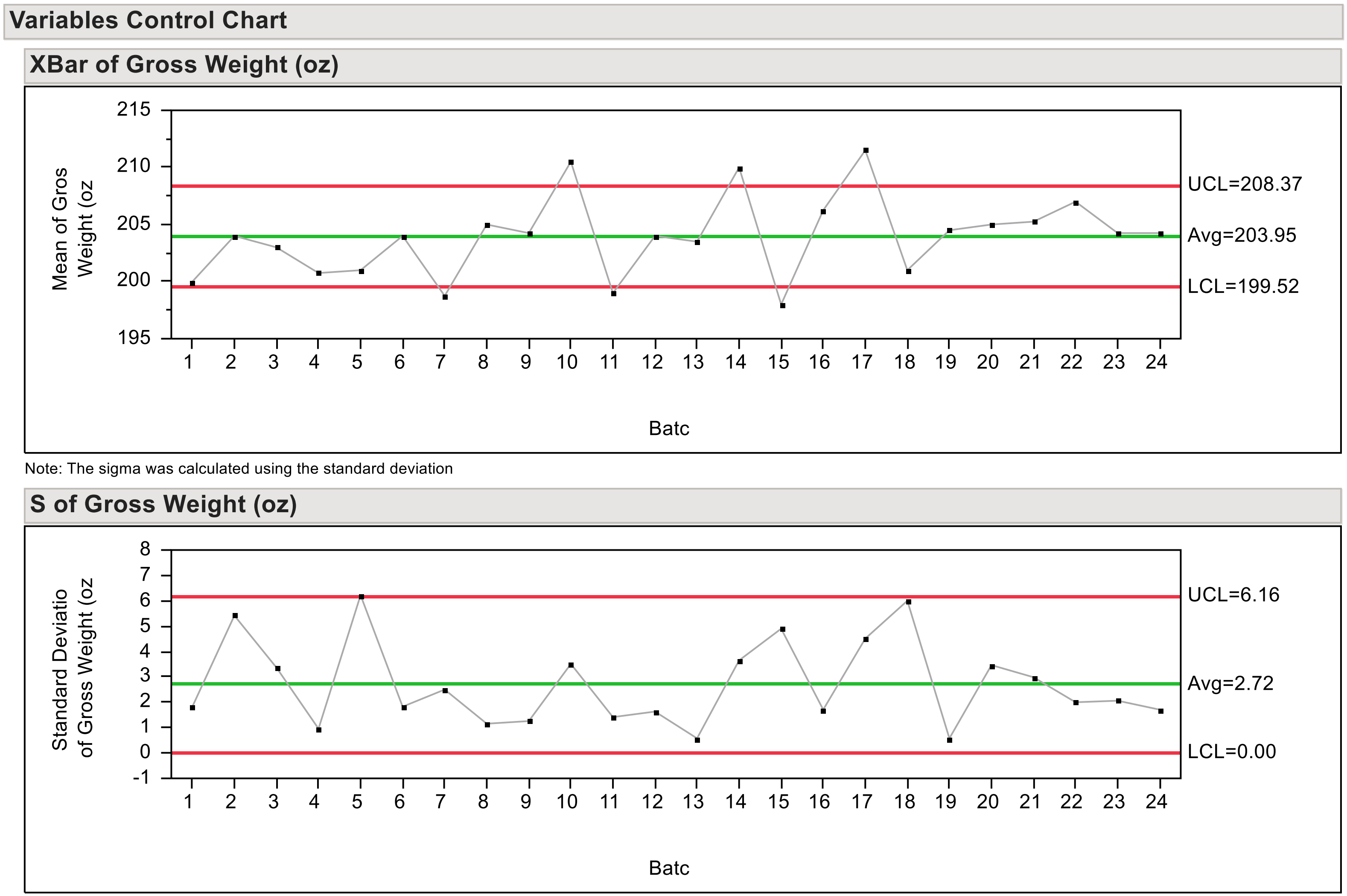
- Ott et. Al. (2005, p. 80) - 200 oz. French Style ice cream production
- Data collected from 24 Batches, 4 samples per Batch



Variance Components

Component	Var Component	% of Total	20 40 60 80	Sqrt(Var Comp)
Batch	9.947539	49.6		3.1540
Within	10.100694	50.4		3.1782
Total	20.048234	100.0		4.4775

Example Data – Ice Cream Production



Fill Weight Task Force and Statistical Engineering Decisions

- Task Force Makeup
  - Engineering
  - Manufacturing
  - Quality Assurance
  - Regulatory
  - Statistics
- Objective: Develop a Target Setting Tool to …
  - Assess *past* fill quality by determining the probability of passing government inspections
  - Establish *future* target fill that leads to an acceptable probability of passing government inspections while also complying with company-specific criteria
  - Provide loss analysis

Fill Weight Task Force and Statistical Engineering Decisions

- Defining an Acceptable Probability of Passing
  - In a perfect world would like close to 100% probability of passing (requires 100% inspection or substantial overfill)
  - An input to the target setting tool is the acceptable probability of passing
  - Interpretation and business ramifications led by statisticians
  - Critical to have QA and Regulatory members as part of the team
  - Target setting tool will provide a target that meets or exceeds this pre-defined probability

Fill Weight Task Force and Statistical Engineering Decisions

- Distribution Theory
  - Traditional assumptions are independent and identically distributed (iid) processes
  - Not always a valid assumption
  - Need a target setting tool that handles more complex assumptions
- Simulation
  - Elected to create a system that uses simulated inspections to calculate the probability of passing
  - Decision of number of simulations (N) is a tradeoff between simulation error and amount of time to simulate N inspections

Fill Weight Task Force and Statistical Engineering Decisions

- Estimation of Variance Components
  - Need to determine assumptions around inspection sampling
  - What defines a lot
  - Decided to use restricted maximum likelihood (REML) techniques to estimate variance components from historical data
  - Improved using Winsorization techniques for robust extimates
- Determine Amount of Historical Data Required
  - In essence a sample size calculation
  - e.g., if just lot-lot assumption, then how many lots and how many products within each lot is sufficient to estimating the variance components
  - Solution through a simulation DOE on variables that can affect the precision of the estimated variance components and resulting probabilities and targets

Fill Weight Task Force and Statistical Engineering Decisions

- Miscellaneous Considerations
  - Tool will house regulations from around the world
    International Standards
    - US National Conference on Weights and Measures – NIST Handbook 133
    - International Organization of Legal Metrology – OIML

    Other Country Specific Standards
  - Allow for company-specific criteria
  - Calculate the cost of overpack and break down the overall cost into specific improvement areas
  - Easy to use interface that is accessible to all P&G sites globally

Fill Weight Task Force and Statistical Engineering Decisions

- Deployment of Solution
  - Pilot tool in several plants
  - Clear that stand alone tool will not be sufficient
  - Needed to embed the process of setting fill-targets into the work process
  - Plant scale automated tool required
    - Develop a program that can read fill weight data directly from plant databases
    - Execute the statistical algorithms automatically
    - Allow user to schedule quarterly (or some other frequency) assessments of production lines and target setting
- Training Requirements
  - Developed a training course

Model and Assumptions

Assumption: Need to handle in-control and out-of-control processes. Want to handle the case when the inspection samples are taken from one lot of production or mixed lots

$$X_{jk} = \mu + \alpha_j + \varepsilon_{jk}$$

where $\alpha_j \overset{iid}{\sim} N\left(0, \sigma_L^2\right)$, $\varepsilon_{jk} \overset{iid}{\sim} N\left(0, \sigma_W^2\right)$,
α_j and ε_{jk} are independent and represent *Lot-to-Lot* variability and *Within-Lot* variability, respectively.

Model and Assumptions

The probability we want to calculate is the probability of passing both the average criteria and the individual criteria:

$$P(\mu_T, n) = P_{\mu_T, n}(\bar{X}_n + t_{q,n-1}\frac{s}{\sqrt{n}} > \mu_0 \text{ and } I = 0) \geq p$$

where the sample of size *n* comes from one lot of production under the model

$$X_{jk} = \mu + \alpha_j + \varepsilon_{jk}$$

Extension of problem solved by Elder & Muse (*Technometrics*, 1982)

$$P(\mu_T, n) = P_{\mu_T, n}(\bar{X}_n > \mu_0 \text{ and } I = 0) \geq p$$

under simplified model assumption $X_k = \mu + \varepsilon_k$

How Lot-to-Lot Variability Matters

<u>Setup</u>

100 g label   Total Variance = σ_T^2 = 4 g^2

MAV = 7.2 g   MAV = 3.6σ_T

Case 1: An iid process with no lot-to-lot variance

$$\sigma_\alpha^2 = 0,\ \sigma_\varepsilon^2 = 4$$

Probability of Passing = 97.5%

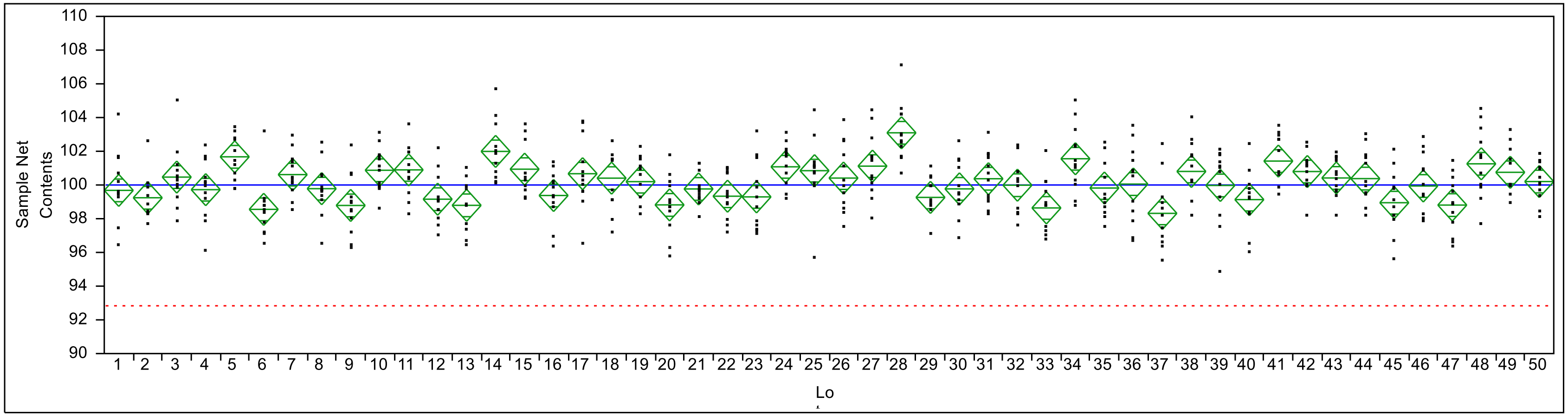
Case 2: A process with lot-to-lot variance equal to 25% of the total variance

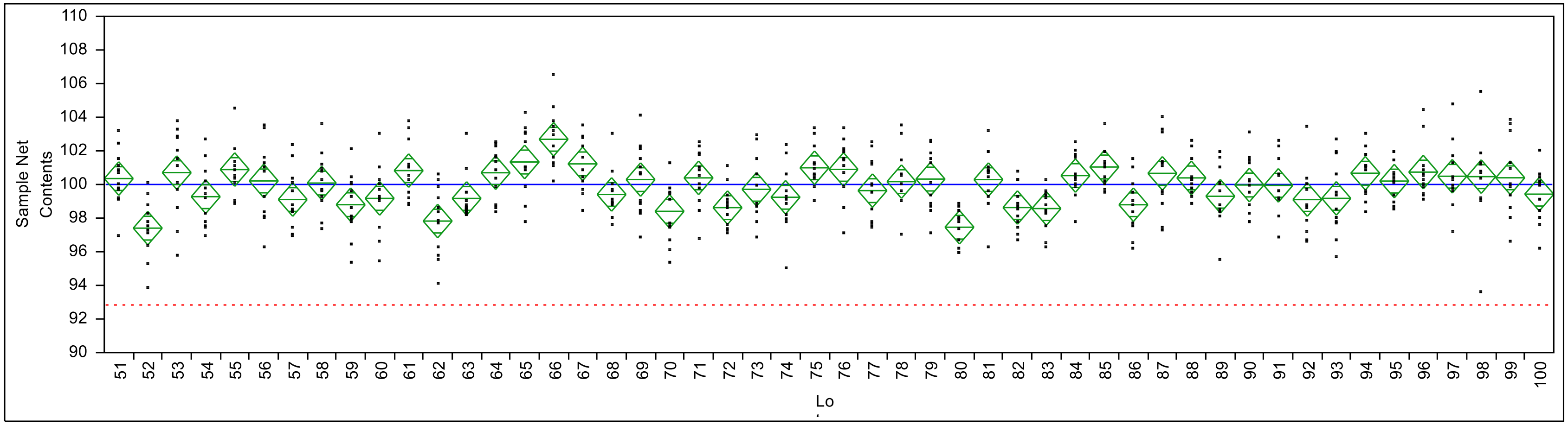
$$\sigma_\alpha^2 = 1,\ \sigma_\varepsilon^2 = 3$$

Probability of Passing = 82.8%

Brenneman, W.A. and Joner, M.D. (2012), "Setting appropriate fill weight targets – a statistical engineering case study, " *Quality Engineering*, to appear.

How Lot-to-Lot Variability Matters





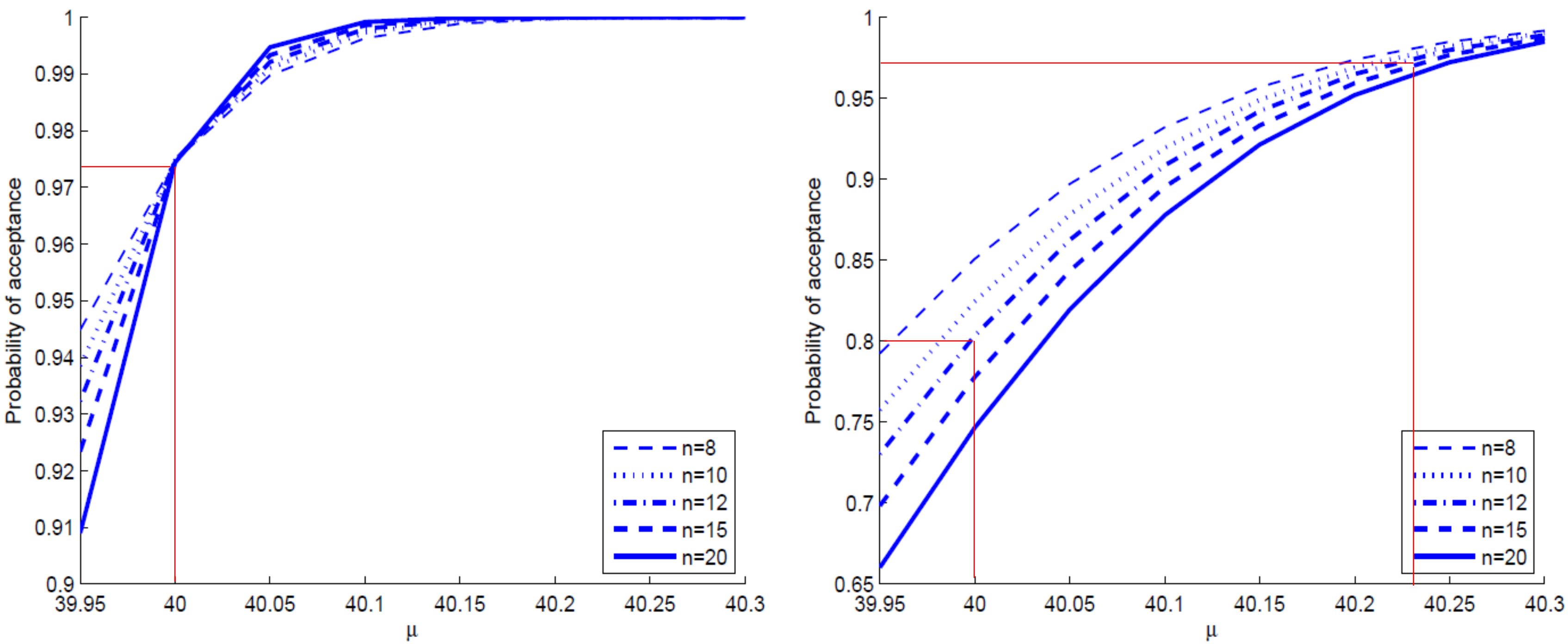
Average Requirement = 83/100
Individual Requirement = 100/100
→ Observed Probability of Passing = 83/100 (83%)

How Lot-to-Lot Variability Matters

Marked Weight = 40 oz, σ^2 = 0.118 oz^2, MAV = 1.376 oz,   MAV/σ = 4

(a) One Variance Component: $X_k = \mu + \varepsilon_k$, $\varepsilon_k \sim N(0, \sigma^2)$

(b) Two Variance Components: $X_{jk} = \mu + \alpha_j + \varepsilon_{jk}$, $\alpha_j \sim N(0, 0.3\sigma^2)$, $\varepsilon_{jk} \sim N(0, 0.7\sigma^2)$



(a) One variance component   (b) Two variance components

Probability of Acceptance as a function of Target = μ

Linkletter, C.D., Ranjan, P., Lin, C.D., Bingham, D.R., Brenneman, W.A., Lockhart, R.A. and Thomas, T.M. (2012), "Compliance Testing for Random Effects Models with Joint Acceptance Criteria," *Technometrics*, to appear.

Solution through Simulation

***Simple** algorithm for illustrative purposes*

I. Estimate Variance Components

II. Target 1 – Passing Government Inspection(s)

1. Set target
2. Calculate probability of passing inspection (via simulation)
3. Repeat 2 and 3 until probability converges to *p* (*p*=0.9, 0.95, 0.975, 0.99)
4. Resulting target = T_1

III. Target 2 – Passing Internal P&G Criteria

IV. Overall Target = $\max\{T_1, T_2\}$

Target Setting Tool Requirements

- Diversity of Production
  - P&G sells a wide variety of products
  - Labeled by volume, weight, dimensions
  - Target setting tool must adapt to all of these products
- Understand Consumer’s ability to Access Product
  - Some products lose weight over time – needs to be accounted for
    - NIST Handbook 133 allows for 3% weight loss of dry pet food
  - Some package designs retain residual product (e.g., aerosol cans may not spray our all contents)
- Units of Measurement and Measurement Systems Analysis
  - Label in Volume, Product controlled by weight
  - Checkweigher online (yes,no)

Target Setting Tool Requirements

- Assess Cost-Saving Opportunities
  - Overpack can be very costly
  - Break down to “types” of overpack
    - Due to weight loss over time
    - Additional product fill
    - Lot-to-Lot variation
  - Helps management to determine if engineering resources should be placed around a project to reduce these types of overpack
- Allow and Account for Lot-to-Lot Variation

Able to link reducing variation (statistical thinking principle) directly to cost

Deployment and Evolution of the Applications

- AccuTarget™
  - Web based application
  - Server based approach
  - Upgrades are made on server and immediately globally accessible (e.g., robust estimators)
  - Changes in regulations made on server and immediately globally accessible (NIST changed some portions of Handbook 133 in 2005)
  - Adoption is quicker when a new application is branded (could just be internally branded)

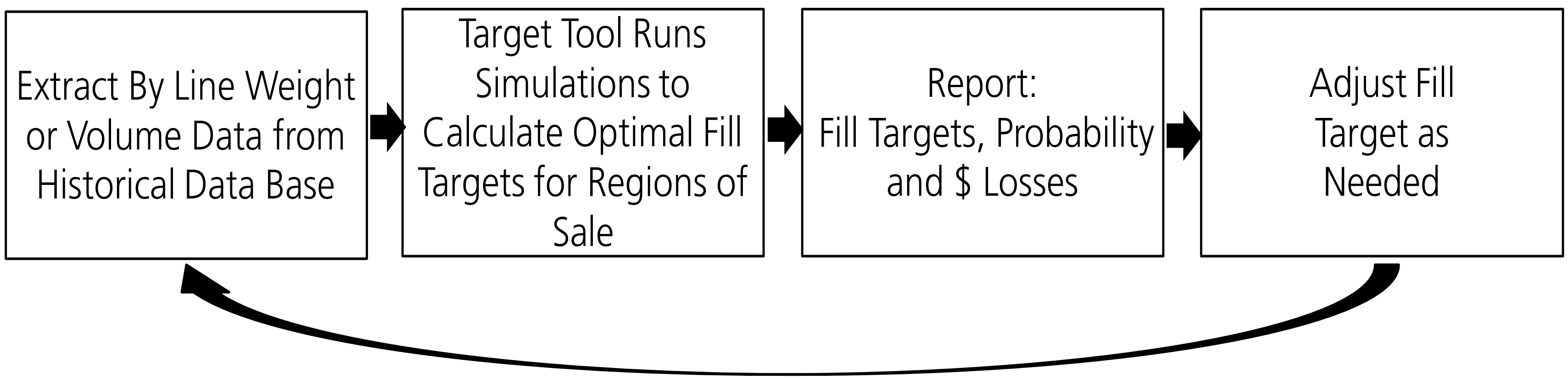
Deployment and Evolution of the Applications

- AccuTarget Express™
  - Plant scale automation tool
  - Single plant can have 200+ targets to set

Validation

- Extensive validation protocol
  - Extremely important
  - Needs to be done in some form prior to pilot!
  - Needs to be redone whenever changes are made to the program

Schematic of Target Setting Process



Screen Shots of AccuTarget™

AccuTarget Version 3.2 P&G

The AccuTarget tool is used to help establish fill weight targets that are consistent with internal policy and with governmental regulations. For technical details, please see the instructions.

Please Select Regulation Criteria (select all that apply):

- [x] US
- [ ] OIML
- [ ] Canada

Is a checkweigher used online to individually weigh each package?

- ○ Yes
- ◉ No

Do you have historical fill data to upload?

- ○ Yes
- ◉ No

Please Estimate the Following Historical Fill Process Parameters:

Variance Estimates:

Lot-to-Lot 9.95 Within-Lot 10.1

Median Weight: 203.95

Is the Product Dry Pet Food?

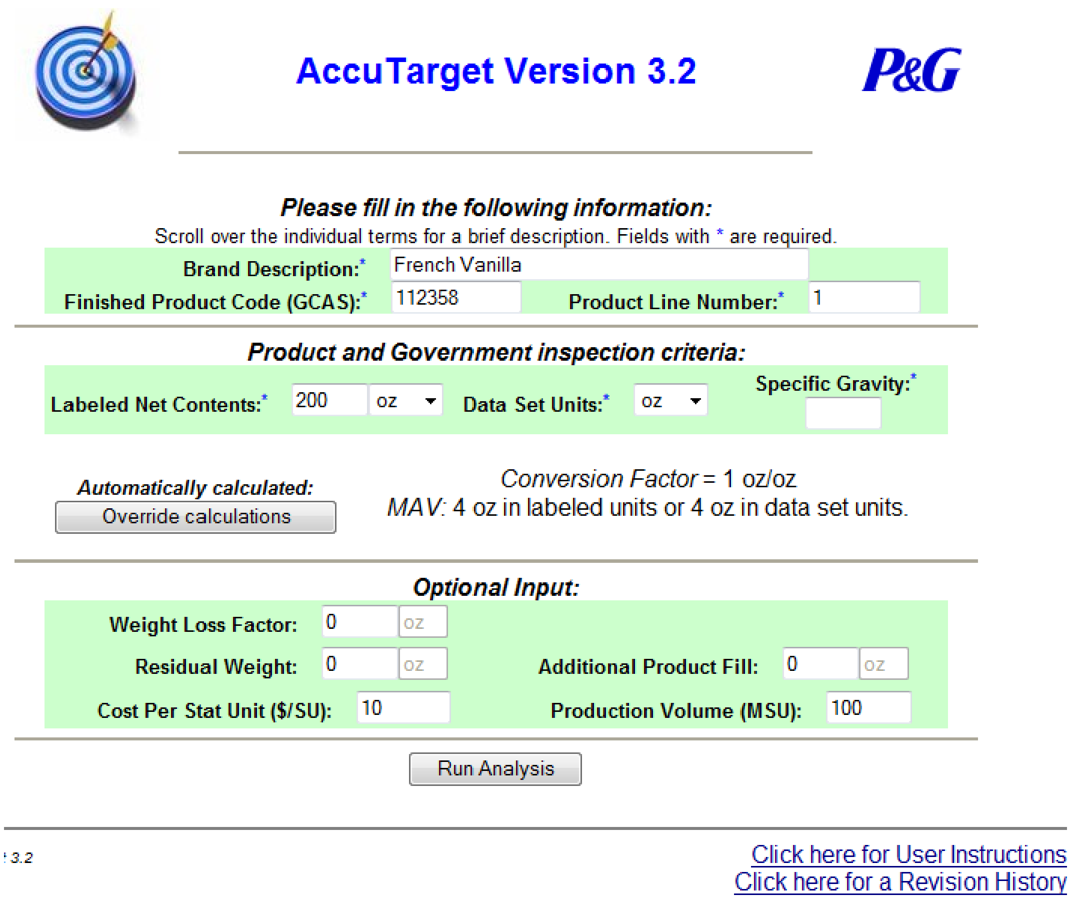
- ○ Yes
- ◉ No

Submit Reset

AccuTarget 3.2

Click here for User Instructions
Click here for a Revision History

Screen Shots of AccuTarget^{TM}



AccuTarget^{TM} Output

200 oz French Vanilla Example

- Estimate the Current Process Parameters

  Overall average = 203.95 oz

Variance Components

Component	Var Component	% of Total	20 40 60 80	Sqrt(Var Comp)
Batch	9.947539	49.6		3.1540
Within	10.100694	50.4		3.1782
Total	20.048234	100.0		4.4775

- Evaluate Current Probability of Passing (single lot inspected)

  78%

- Provide Appropriate Target

  207.16 oz for 95% probability of passing

- Provide Process Improvement Cost Analysis

  Eliminate lot-to-lot variance →Target = 204.34 oz

  Save ~ $14,000

Conclusion

- Setting fill weight targets and evaluating current processes satisfied a high-level need within P&G
- Probability calculation done under more realistic assumptions
- First solved through simulation, then worked on theoretically with academic collaborators
- Both technical and non-technical skills used to arrive at a meaningful solution
- Solution is embedded in work processes
- Web-based application provides a unified approach to solving this complex problem
- Saves time, resources and money
- This process for setting fill targets was granted a patent in 2009

References

1. **Brenneman, W.A. and Bumgarner, B.J. (December 8, 2009), "Systems and Methods for Analysis and Simulation of Package Net Content Decisions," Patent and Trademark Office, U.S. Department of Commerce, Patent No. 7630778.**

2. **Brenneman, W.A. and Joner, M.D. (2012), "Setting Appropriate Fill Weight Targets – A Statistical Engineering Case Study, "** ***Quality Engineering*****, 24:2, 241-250.**

3. Burns, P.J. (1992), "Winsorized REML Estimates of Variance Components," Technical Report, Statistical Sciences, Inc.

4. Elder, R.S. and Muse, R.L. (1982), "An Approximate Method of Evaluating Mixed Sampling Plans," *Technometrics*, 24, 207-211.

5. Hoerl, R.W. and Snee, R.D. (2010), "Moving the Statistics Profession Forward to the Next Level," The American Statistician, 64(1):10-14.

6. Insightful Corporation (2001), S-PLUS statistical analysis software.

7. Insightful Corporation (2002), S-PLUS StatServer.

8. King, D. (1997), "A Tutorial on Probabilistic Risk Assessment for Net Package Contents," *American Society for Quality Statistics Division Newsletter*, 16(7), 7-9. URL http://asq.org/statistics/2010/09/statistics/a-tutorial-on-probabilistic-risk-assessment-for-net-package-contents.html?shl=101593.

9. **Linkletter, C.D, Ranjan, P., Lin, C.D., Bingham, D.R., Brenneman, W.A., Lockhart, R.A. and Loughin, T.M., (2012), "Compliance Testing for Random Effects Models with Joint Acceptance Criteria,"** ***Technometrics*****, 54(3), 243-255.**

10. NIST Handbook 133 (2011), *Checking the Net Contents of Packaged Goods*, Department of Commerce, United States of America, URL http://www.nist.gov/pml/wmd/pubs/hb133-11.cfm.

11. Ott, E.R., Schilling, E.G. and Neubauer, D.V. (2005), Process Quality Control, 4th edition. Milwaukee, WI:ASQ Quality Press

12. R Development Core Team (2011), R: A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

13. Vangel, M.G. (2002), "Lot Acceptance and Compliance Testing Using the Sample Mean and an Extremum," *Technometrics*, 44, 242-249.

Acknowledgements

<u>P&G Colleagues</u>

Brent Bumgarner, Chris Guay, Michael Joner + many others

<u>Co-authors on papers related to this topic</u>

1. Michael Joner
2. Crystal Linkletter, Pritam Ranjan, C. Devon Lin, Derek Bingham, Richard Lockhart and Thomas Loughin