Acceptance Sampling

Sampling Concepts

By

John A. Conte, P.E.
John A. Conte, P.E.

- University of Missouri, College of Engineering, BSIE and MSIE
- 35 years in the Telecommunications Industry including 25 years at AT&T Western Electric
- Nine ASQ Certifications including CQE, CRE
- Currently teaches a course for ASQ entitled CQE Exam Preparation
- Starts with CQE Body of Knowledge (BoK)
IV Product and Process Control

C. Acceptance Sampling

1. Sampling Concepts
   - Define, describe, and apply the concepts of producer and consumer risk and related terms, including operating characteristic (OC) curves, acceptable quality limit (AQL), lot tolerance percent defective (LTPD), average outgoing quality (AOQ), average outgoing quality limit (AOQL), etc.

2. Sampling standards and plans
   - Interpret and apply ANSI/ASQ Z1.4 ...
   - Identify characteristics of Dodge-Romig sampling tables ..
Acceptance Sampling

- Inspection of “Lots” of either incoming raw materials or outgoing product
- Decision to accept or reject based on sample
- All sampling plans have two components
  - The sample size (n)
  - The maximum number of defectives allowed in the sample (c or Ac) for acceptance of the lot
Producer’s Risk

- The risk of making an incorrect decision by rejecting a “good” lot
- For sampling plans in Z1.4 that risk is set at about 5% for a given AQL
- AQL is the Acceptable Quality Limit formally known as the Acceptable Quality Level
Consumer’s Risk

- The probability of making an incorrect decision by accepting a “bad” lot
- RQL – Rejectable Quality Level
- RQL - percent defective considered “bad”
- RQL - must have a defined Beta risk
- For Dodge-Romig sampling plans that risk is set at about 10% for a given LTPD
- LTPD - Lot Tolerance Percent Defective
Acceptance Sampling Risks

- **Correct Decision**: Type II Error, Beta (β) Risk, "Consumer's Risk"
- **Incorrect Decision**: Type I Error, Alpha (α) Risk, "Producer's Risk"

Confidence = (1 - α)

Power = (1 - β)
Operating Characteristic Curve

- First text given to me as a new engineer at Western Electric Company in 1966
- “Sampling Inspection Tables” by Harold Dodge and Harry Romig
- 115 out of 200 pages devoted to OC curves
The Operating Characteristic Curve

- Allows a sampling plan to be almost completely evaluated at a glance
- Gives a pictorial view of the probabilities of accepting lots submitted at varying levels of percent non-conforming.
- The OC Curve illustrate the risks of acceptance sampling
The Operating Characteristic Curve

- Curves are based either the Binomial or Poisson distribution
- Poisson approximation to the binomial was often used as the binomial computations were quite complex before the age of electronic calculators
Probability of Acceptance ($P_a$)

- Formula or statistical tables
- Most Poisson tables are cumulative and provide the probability for $c$ or fewer given $np$ ($\lambda$)

$$P_a = \sum_{x=0}^{x=c} \frac{(np)^x e^{-np}}{x!}$$
## OC Curve with Poisson Probabilities (n=40, c ≤ 3)

<table>
<thead>
<tr>
<th>Percent defective</th>
<th>np or $\lambda$</th>
<th>$P(\text{Acceptance}) = P(\text{finding 3 or fewer defectives in the sample})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>.02</td>
<td>40(.02)=.80</td>
<td>0.991</td>
</tr>
<tr>
<td>.04</td>
<td>40(.04)=1.6</td>
<td>0.921</td>
</tr>
<tr>
<td>.06</td>
<td>40(.06)=2.4</td>
<td>0.779</td>
</tr>
<tr>
<td>.08</td>
<td>40(.08)=3.2</td>
<td>0.603</td>
</tr>
<tr>
<td>.10</td>
<td>40(.10)=4.0</td>
<td>0.433</td>
</tr>
<tr>
<td>.12</td>
<td>40(.12)=4.8</td>
<td>0.294</td>
</tr>
<tr>
<td>.14</td>
<td>40(.14)=5.6</td>
<td>0.191</td>
</tr>
</tbody>
</table>

**TABLE 3: POISSON PROBABILITY DISTRIBUTION**

$$ P(x; \lambda) = \frac{e^{-\lambda} \lambda^x}{x!} $$
# OC Curve with Poisson Probabilities

(\(\lambda = 1.6, \ c \leq 3\))

<table>
<thead>
<tr>
<th>Percent defective</th>
<th>np or (\lambda)</th>
<th>(P(\text{Acceptance})=P(\text{finding 3 or fewer defectives in the sample}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>.02</td>
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</tr>
</tbody>
</table>
### OC Curve with Poisson Probabilities

\( (\lambda = 2.4, 3.2, 4.0, 4.8, 5.6, c \leq 3) \)

<table>
<thead>
<tr>
<th>Percent defective</th>
<th>( np ) or ( \lambda )</th>
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<td>0.02</td>
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<td>0.191</td>
</tr>
</tbody>
</table>
# Operating Characteristic (OC) Curve

Sample Size = 40, Acceptance Number = 3

<table>
<thead>
<tr>
<th>Percent defective</th>
<th>np or λ</th>
<th>P(Acceptance)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.191</td>
</tr>
</tbody>
</table>
Acceptable Quality Level (AQL)

- From Z1.4 – Acceptance Quality Limit (AQL)
- “4.2 Definition: The AQL is the quality level that is the worst tolerable process average when a continuing series of lots is submitted for acceptance sampling.”
- “Note: The use of the abbreviation AQL to mean Acceptable Quality level is no longer recommended.”
Acceptable Quality Level

- From Z1.4 - “Although individual lots with quality as bad as the AQL can be accepted with a fairly high probability, the designation of an AQL does not suggest that this is necessary a desirable quality level. The AQL is a parameter of the sampling scheme …”
- The probability of acceptance of a lot with a process average equal to the AQL is normally set at 0.95
### Operating Characteristic (OC) Curve

For a sample size of 40 and an acceptance number of 3, the probabilities of acceptance are calculated as follows:

<table>
<thead>
<tr>
<th>Percent defective</th>
<th>np or λ</th>
<th>P(Acceptance)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>40(0.14)=5.6</td>
<td>0.191</td>
</tr>
</tbody>
</table>

Graph: Operating Characteristic (OC) Curve

- Sample Size = 40
- Acceptance Number = 3

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Minitab Software
Create or Compare a Sampling Plan

- **Stat**
  - Quality Tools
    - Acceptance Sampling by Attributes

- **Default Screen**
  - *Create* based on input of AQL, LTPD, and N
  - Or *Compare* based on input of n, c, and N
  - Measurement type *percent defective*
  - Acceptable Quality Level (AQL) 0.05
  - Rejectable Quality Level (RQL or LTPD) 0.10

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Minitab Example - Compare

- **Acceptance Sampling by Attributes**
- Measurement type: Go/no go
- Lot quality in percent defective
- Lot size: 100000
- Use binomial distribution to calculate probability of acceptance

- **Compare User Defined Plan(s)**
- Sample Size 40
- Acceptance Number 3

  Accept lot if defective items in 40 sampled <= 3; Otherwise reject.
  Average outgoing quality limit (AOQL) = 4.860 at 7.241 percent defective.

- **Graphs - Acceptance Sampling by Attributes**
Minitab Example – Compare Input of n, c, and N

Sample Size = 40, Acceptance Number = 3
Mintab Example – Create Plan

- Acceptance Sampling by Attributes
- Measurement type: Go/no go
- Lot quality in percent defective
- Lot size: 1000
- Use binomial distribution to calculate probability of acceptance
- Acceptable Quality Level (AQL) 1
- Producer's Risk (Alpha) 0.05
- Rejectable Quality Level (RQL or LTPD) 5
- Consumer's Risk (Beta) 0.1
- Generated Plan(s)
- Sample Size 132
- Acceptance Number 3
- Accept lot if defective items in 132 sampled <= 3; Otherwise reject.
- Percent Defective Probability Accepting Probability Rejecting AOQ ATI
  - 1 0.956 0.044 0.830 170.4
  - 5 0.099 0.901 0.431 913.9
- Average outgoing quality limit (AOQL) = 1.278 at 2.220 percent defective.
- Graphs - Acceptance Sampling by Attributes

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Minitab Create (AQL=1%, LTPD=5%)

Operating Characteristic (OC) Curve

Average Outgoing Quality (AOQ) Curve

Average Total Inspection (ATI) Curve

Sample Size = 132, Acceptance Number = 3
AOQ and AOQL

- Average Outgoing Quality (AOQ)
- AOQ dependent on the Incoming Quality
- Average Outgoing Quality Limit
- AOQL highest value of AOQ
AOQ - Average Outgoing Quality

- The expected average quality of all products, including all accepted lots, plus all rejected lots that have been sorted 100% and have had all defective units replaced
- Will always be less than the submitted quality
- \( \text{AOQ} = P_a \times p \times (1 - n/N) \)
- AOQL is the maximum value of AOQ
### AOQL in Z1.4 – Table V-A

**Table V-A—Factors for Determining Approximate Values for Average Outgoing Quality Limits for Normal Inspection (Single Sampling)**

(See 11.4)

<table>
<thead>
<tr>
<th>Code Letter</th>
<th>Sample size</th>
<th>Acceptance Quality Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.010 0.015 0.025 0.040 0.065 0.10 0.15 0.25 0.40 0.65 0.1 1.5 2.5 4.0 6.5 10 15 25 40 65 100 150 250 400 650 1000</td>
<td></td>
</tr>
<tr>
<td>A 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E 13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H 50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J 80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K 125</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M 315</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N 500</td>
<td>0.074</td>
<td></td>
</tr>
<tr>
<td>P 800</td>
<td>0.067</td>
<td></td>
</tr>
<tr>
<td>Q 1250</td>
<td>0.029</td>
<td></td>
</tr>
<tr>
<td>R 2000</td>
<td>0.042</td>
<td></td>
</tr>
</tbody>
</table>

Note: For a more accurate AOQL, the above values must be multiplied by \(\frac{1 - \text{Sample size}}{\text{Lot or Batch size}}\). (See 11.4)
**Minitab Create** (AQL=1%, LTPD=5%)
(look at AOQ and AOQL)

Sample Size = 132, Acceptance Number = 3
(etc.) ATI

- Average Total Inspection
- Concept associated with Dodge-Romig
- Plans were designed to minimize ATI
- ATI is the total of all units inspected including the sample size $n$ and 100% of all units in rejected lots
Minitab Create (AQL=1%, LTPD=5%)  
(look at AOQ and AOQL)
CQE Exam Question Example 1

- Z1.4 sampling tables and procedures have the fundamental principle of providing:
  - A. Low probability of acceptance of poor product
  - B. High probability of acceptance of good product
  - C. Low probability of acceptance of good product
  - D. High probability of acceptance of poor product
CQE Exam Question Example 2

The best way to evaluate a sampling plan for risk protection is to:

- A. Evaluate the $\alpha$ risk
- B. Evaluate the $\beta$ risk
- C. Examine the OC curve
- D. Determine how well it conforms to ASQ Z1.4
A single sampling plan calls for a sample size of 80 with an acceptance number of 5 and a rejection number of 6. If the quality of the submitted lots is ten percent defective, then the percent of lots expected to be accepted in the long run is approximately:

- A. 6%
- B. 10%
- C. 30%
- D. 0%
- E. 20%
CQE Exam Question - Answer

- Prob \( (c \leq 5 / \lambda = np) \)
- Prob \( (c \leq 5 / \lambda = 80 \times 0.10) \)
- Prob \( (c \leq 5 / \lambda = 8.0) \)
CQE Exam Question Example 3

- A single sampling plan calls for a sample size of 80 with an acceptance number of 5 and a rejection number of 6. If the quality of the submitted lots is ten percent defective, then the percent of lots expected to be accepted in the long run is approximately:

- A. 6%
- B. 10%
- C. 30%
- D. 0%
- E. 20%
CQE Exam Question Example 4

- Which of the following sampling plans gives the greatest protection against accepting lots of poor quality?
  - A. Sample size = 200, c = 14
  - B. Sample size = 100, c = 7
  - C. Sample size = 200, c = 21
  - D. Sample size = 200, c = 12
  - E. Sample size = 125, c = 7
CQE Exam Question Example 4

- Which of the following sampling plans gives the greatest protection against accepting lots of poor quality?
  - A. Sample size = 200, c = 14 \( \frac{14}{200}=0.07 \)
  - B. Sample size = 100, c = 7 \( \frac{7}{100}=0.07 \)
  - C. Sample size = 200, c = 21 \( \frac{21}{200}=0.105 \)
  - D. Sample size = 200, c = 12 \( \frac{12}{200}=0.06 \)
The two quantities that uniquely determine a attribute sampling plan are:

- A. AQL and LTPD
- B. sample size and rejection number
- C. AQL and producer's risk
- D. LTPD and consumer's risk
CQE Exam Question Example 6

- The diagram shows operating characteristic (OC) curves for two sampling plans. The dashed curve is:
  - A. Better.
  - B. Worse.
  - C. Better for the consumer.
  - D. Better for the producer.
CQE Exam Question Example 7

- The AOQL for the single sampling plan with sample size of 200, an acceptance number of 14 and rejection number of 15 for a lot size of 4000 is approximately:
  - A. 10.0%
  - B. 4.5%
  - C. 4.0%
  - D. 7.2%
Table II-A—Single sampling plans for normal inspection (Master tab...
Table V-A—Factors for Determining Approximate Quality Limits for Normal Inspection

<table>
<thead>
<tr>
<th>Code Letter</th>
<th>Sample size</th>
<th>Acceptance Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>7.4</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>4.6</td>
</tr>
<tr>
<td>E</td>
<td>13</td>
<td>6.5</td>
</tr>
<tr>
<td>F</td>
<td>20</td>
<td>4.2</td>
</tr>
<tr>
<td>G</td>
<td>32</td>
<td>6.9</td>
</tr>
<tr>
<td>H</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

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Note: For a more accurate AOQL, the above values must be multiplied by \(1 - \frac{\text{Sample size}}{\text{Lot or Batch size}}\) (See 11.4).

- 4.7% times \((1-200/4000)\) = 4.7 x 0.95 = 4.5%
The AOQL for the single sampling plan with sample size of 200, an acceptance number of 14 and rejection number of 15 for a lot size of 4000 is approximately:

- A. 10.0%
- B. 4.5%
- C. 4.0%
- D. 7.2%
Where to find out more

- The Certified Quality Engineer Handbook, Connie M. Borror, editor, ASQ Press, pages 193 to 226
- ANSI/ASQ Z1.4
- MIL-STD-105E public domain copy of Z1.4
- www.contesolutions.com

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Questions
Interpret and apply ANSI/ASQ Z1.4
Lot size and Inspection level yields Code Letter (page 10)

<table>
<thead>
<tr>
<th>Lot or batch size</th>
<th>Special inspection levels</th>
<th>General inspection levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-1</td>
<td>S-2</td>
</tr>
<tr>
<td>2 to 8</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>9 to 15</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>16 to 25</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>26 to 50</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>51 to 90</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>91 to 150</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>151 to 280</td>
<td>B</td>
<td>C</td>
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<td>281 to 500</td>
<td>B</td>
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<td>C</td>
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<td>D</td>
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<td>3201 to 10000</td>
<td>C</td>
<td>D</td>
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<td>10001 to 35000</td>
<td>C</td>
<td>D</td>
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<td>35001 to 150000</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>150001 to 500000</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>500001 and over</td>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

*(See 9.2 and 9.3)*
Interpret and apply ANSI/ASQ Z1.4
Sample size code letter and AQL yields plan

Table II-A—Single sampling plans for normal inspection (Master table)

(See 9.4 and 9.5)

<table>
<thead>
<tr>
<th>Sample size code letter</th>
<th>Sample size</th>
<th>Acceptance Quality Limits, AQLs, in Percent Nonconforming Items and Nonconformities per 100 Items (Normal Inspection)</th>
</tr>
</thead>
</table>
|                         | Ac Re       | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               | Ac Re                                               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Interpret and apply ANSI/ASQ Z1.4
Sample size code letter and AQL yields plan

Switching Rules for ANSI Z1.4 System

START

REduced

• Preceding 10 Lots Accepted, with
• Total Nonconforming less than Limit Number (Optional), and
• Production Steady, and
• Approved by Responsible Authority

NORMAL

• Lot not Accepted, or
• Lot Accepted but Nonconformities found lie between Ac and Re of Plan, or
• Production Irregular, or
• Other Conditions Warrant

Tightened

• 2 of 5 or fewer Consecutive Lots are Not Accepted

• 5 Consecutive Lots Accepted

• 5 Lots not Accepted while on Tightened Inspection

• Discontinue Inspection Under Z1.4

FIGURE 1

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