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A Comparison of In-Service Statistical Test Programs

North Carolina Electric Meter School & Conference

June 30, 2004

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Program Background

Advent Design Corporation has conducted numerous studies of in-service and new meter testing procedures and practices among both gas and electric utilities. For in-service testing, these studies reviewed both current practices based on state regulations and testing programs prescribed in ANSI C12.1-2001, *American National Standard for Electric Meters, Code for Electricity Metering*.

The goal of the studies was to develop a testing programs that would improve the information gathered from in-service testing, and help reduce the overall amount of testing and operating costs.

Based on the studies, in-service testing programs based on ANSI/ASQC Z1.9-1993, *Sampling Procedures and Tables for Inspection by Variables for Percent Nonconforming, have been recommended*.

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Testing Plans Considered

- Periodic Interval Plans
- Variable Interval Plans,
  sometimes called Selective Test Plans
- Statistical Sampling Plans

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Requirements - Nationally

- Of 51 jurisdictions (50 states and the District of Columbia):
  - 5 states mandate periodic testing and allow no alternative: AL, CO, MS, OR, & TX
  - 3 states allow for periodic testing or variable interval / selective testing but no other alternative: HI, NY, & RI
  - Of the remaining 43 jurisdictions, statistical sample testing is possible in all. Specifically:
    - 7 states normally require periodic testing but allow waivers for statistical sample testing programs: CT, DE, MO, NH, NJ, ND, & OK
    - 16 states directly allow for statistical sample testing programs, normally with pre-approval by the commission: AR, FL, IL, IN, IA, KY, ME, MI, NM, NC, PA, SC, TN, UT, WV, and WI
    - 5 states prescribe no specific plan but require an in-service testing plan to be filed with the commission: AK, AZ, MD, WA, & WY
    - 15 jurisdictions have no specific in-service testing requirements. In-service testing plans are simply incorporated into rate or tariff filings or otherwise filed with the commission: CA, DC, GA, ID, KS, LA, MA, MN, MT, NE, NV, OH, SD, VT, & VA

Requirements - Nationally

- Of states allowing for statistical sample testing:
  - 8 specifically reference MIL-STD 414 or ANSI/ASQC Z1.9 as a suitable plan:

    FL, IL, IN, MI, TN, WA, WV, & WI

  - 8 specifically reference ANSI C12.1 or ASA C12 as the guidance for in-service testing plans:

    AZ, AR, CT, IA, NM, OH, PA, & UT

  - One state allows for statistical sample testing but only using ANSI/ASQC Z1.4: MD

  - Of the remaining 26 jurisdictions, no specific guidance is given for the choice of statistical sample testing plans:

    AK, CA, DC, DE, GA, ID, KS, KY, LA, ME, MA, MN, MO, MT, NE, NV, NH, NJ, NC, ND, OK, SC, SD, VT, VA, & WY

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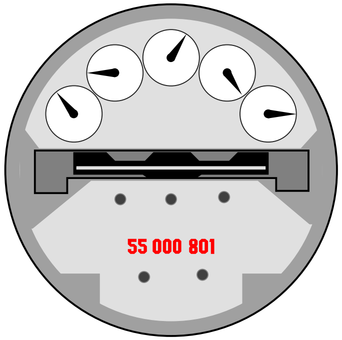
What is Statistical Testing?

Statistical testing is the testing of a population or group for specific characteristics or parameters using a valid statistically-derived sampling plan.



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Features of a Statistical Testing Plan

- Homogeneous Population(s)
- Sample(s) of a Suitable Size for the Plan
- Random Sample Selection of Items to Be Tested
- Expectation that the Group or Population Being Tested Fits the Statistical Model

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Homogeneous Population(s)

- The groups or populations being sampled and tested are made up of the same or similar items, items which operate in the same way and were made in the same manner.
- For electric meters, this has traditionally been interpreted as being meters of a specific meter type from a manufacturer (i.e. AB1, J5S, MX, etc.).

Suitably Sized Samples

- The sample size for each group must be large enough to provide a statistically valid sample for the group's population.
- The larger the group's population, then the larger the sample will be up to a certain point.

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Random Sample Selection

- Every item within the group or population has an equal chance of being selected as part of the sample for testing.
- Random sample selection is critical to providing for a statistically valid sample.

Population Fits the Statistical Model

- The statistical model being used for the sampling/testing plan needs to match the actual distribution of the population.
- In most circumstances, one is looking at a normal or Gaussian distribution (i.e. a Bell curve).
- This can be checked using a histogram plot or a chi-square analysis. For mechanical and electromechanical meters, a normal distribution fits the actual data very well.
- For electronic or solid-state meters, there is some question due to the failure modes of these meters. These meter types are fairly recent designs, and not enough data has been seen yet to verify a normal distribution.

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Why Use a Statistical Testing Plan?

- Focuses testing on the proper meters.

- Minimizes number of meters to be tested; usually requires less than 30% of what a periodic testing plan requires.

- Can provide data and analysis tools for use in understanding what is happening with meters installed in the field or for use in the purchasing of new meters.

What Statistical Testing Plan to Use?

ANSI C12.1-2001 Code for Electricity Metering Guidance

Paragraph 5.1.4.3.3 Statistical sampling plan

"The statistical sampling plan used shall conform to accepted principles of statistical sampling based on either variables or attributes methods. Meters shall be divided into homogeneous groups, such as manufacturer and manufacturer's type. The groups may be further divided into subdivision within the manufacturer's type by major design modifications."

NOTE - Examples of statistical sampling plans can be found in ANSI/ASQC Z1.9, the ANSI version of MIL-STD-414 and ANSI/ASQC Z1.4, the ANSI version of MIL-STD-105.

- Based on MIL-STD-105
- Uses attributes (pass/fail, yes/no, etc.) as the basis for its analysis
- Variety of special and general inspection levels
- Various sampling plans (single, double, & multiple)
- Wide range of Acceptable Quality Levels (AQL's)

- Based on MIL-STD-414
- Use variables (a measured parameter or characteristic) as the basis for its analysis. This is normally weighted average for electric meters.
- Variety of special and general inspection levels
- Selection of Acceptable Quality Levels (AQL's)

- Various methods (Variability Unknown - Standard Deviation Method, Variability Unknown - Range Method, and Variability Known Method)
- All methods can be used with single or double specification limits.
- For electric meters, the Variability Unknown - Standard Deviation Method with Double Specification Limits is normally used.

ANSI/ASQC Z1.4 & ANSI/ASQC Z1.9Comparison

- ANSI/ASQC Z1.4:
  - Simpler and quicker analysis
  - Analysis can be done manually
  - Limited data on actual meter performance

- ANSI/ASQC Z1.9:
  - Much more complicated analysis
  - Best done with automated data gathering and analysis
  - Provides good feedback on meter performance
  - Much smaller sample sizes

Reasons for Selection of an ANSI/ASQC Z1.9 Testing Plan

After reviewing the possible choices of statistical plans, variable interval plans, and periodic plans, the an ANSI/ASQC Z1.9 testing plan for the following reasons:

- Improved quality and collection of performance data for in-service meters
- Improved ability to monitor meter performance trends
- More informed decision-making on meter remediation issues
- Better decision-making on new meter purchasing
- Improvements in the accuracy of the overall meter population
- Overall customer service improvements through fewer customer interruptions
- Improved operating efficiencies

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In-Service Testing Requirements - Neighboring States

- Connecticut - Periodic testing prescribed, but selective or statistical testing programs can be approved by the Connecticut DPUC
- Maine - Periodic testing prescribed, but sample testing can be approved by Maine PUC. Largest electric utility, Central Maine Power, has used sample testing since 1962 and an ANSI Z1.9 program since July 2003.
- Massachusetts - No specific state regulations for in-service electric meter testing. Massachusetts Electric and Nantucket Electric started using an ANSI Z1.9 program in 2004.
- New Hampshire - Periodic testing or a selective test program prescribed. Granite State Electric granted a waiver for an ANSI Z1.9 plan in February 2004.
- New York - Various non-statistical programs used. An ANSI Z1.9 program is being proposed for the new operations manual which will govern meter testing under new regulations before the NY PSC. MIL-STD 414 program in use for in-service gas meter testing.
- Vermont - No specific state regulations for electric meter testing

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Use of ANSI/ASQC Z1.9 Testing Plan

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ANSI/ASQC Z1.9 Calculation Steps

For the Variability Unknown Standard Deviation Method, the following calculation steps are used:

- Select appropriate inspection level
- Determine AQL value to be used for application
- Determine sample size(s) for population(s)
- Select random sample from population(s)
- Test samples and record desired parameter(s)
- Determine mean and standard deviation for each population
- Determine Quality Indexes (Qu and Ql)
- Determine Pu and Pl values using Qu and Ql
- Add Pu to Pl to get actual percent nonconformance (% ncf)
- Compare actual % ncf with allowed % ncf to determine population pass/fail status

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ANSI/ASQC Z1.9 Inspection Levels

Inspection Levels:

- Special Levels S-3 and S-4
  - Used for quick sampling and testing in certain circumstances
  - Small sample sizes
  - Not used for meter testing
- General Inspection Levels I, II, and III
  - Level I is reduced inspection
  - Level II is normal inspection (This level is the one that is normally used.)
  - Level III is tightened inspection
- Inspection level is used in conjunction with group size in Table A-2 to determine sample size code letters.

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Acceptable Quality Level (AQL's)

- AQL is the maximum percent nonconforming that, for purposes of sampling inspection, can be considered satisfactory as a process average.
- For ANSI/ASQC Z1.9, AQL's vary from 0.10 to 10.00 with 11 pre-defined AQL values.
- For use with electric meter testing, either in-service testing or receipt inspection, AQL's of 0.25 to 2.50 are normally utilized.

ANSI/ASQC Z1.9 - Table A-2

TABLE A-2[2]

Sample Size Code Letters[1]

Lot Size			Inspection Levels				
			Special		General		
			S3	S4	I	II	III
2	to	8	B	B	B	B	C
9	to	15	B	B	B	B	D
16	to	25	B	B	B	C	E
26	to	50	B	B	C	D	F
51	to	90	B	B	D	E	G
91	to	150	B	C	E	F	H
151	to	280	B	D	F	G	I
281	to	400	C	E	G	H	J
401	to	500	C	E	G	I	J
501	to	1,200	D	F	H	J	K
1,201	to	3,200	E	G	I	K	L
3,201	to	10,000	F	H	J	L	M
10,001	to	35,000	G	I	K	M	N
35,001	to	150,000	H	J	L	N	P
150,001	to	500,000	H	K	M	P	P
500,001	and	over	H	K	N	P	P

[1]Sample size code letters given in body of table are applicable when the indicated inspection levels are to be used.

[2]The theory governing inspection by variables depends on the properties of the normal distribution and, therefore, this method of inspection is only applicable when there is reason to believe that the frequency distribution is normal.

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ANSI/ASQC Z1.9 - Table B-3

Table B-3 — Standard Deviation Method

Master Table for Normal and Tightened Inspection for Plans Based on Variability Unknown
(Double Specification Limit and Form 2—Single Specification Limit)

Sample size code letter	Sample size	Acceptable Quality Levels (normal inspection)											
		T	.10	.15	.25	.40	.65	1.00	1.50	2.50	4.00	6.50	10.00
		M	M	M	M	M	M	M	M	M	M	M	M
B	3	↓	↓	↓	↓	↓	↓	↓	↓	7.59	18.86	26.94	33.69
C	4							1.49	5.46	10.88	16.41	22.84	29.43
D	5					0.041	1.34	3.33	5.82	9.80	14.37	20.19	26.55
E	7		0.005	0.087	0.421	1.05	2.13	3.54	5.34	8.40	12.19	17.34	23.30
F	10	0.077	0.179	0.349	0.714	1.27	2.14	3.27	4.72	7.26	10.53	15.17	20.73
G	15	0.186	0.311	0.491	0.839	1.33	2.09	3.06	4.32	6.55	9.48	13.74	18.97
H	20	0.228	0.356	0.531	0.864	1.33	2.03	2.93	4.10	6.18	8.95	13.01	18.07
I	25	0.250	0.378	0.551	0.874	1.32	2.00	2.86	3.97	5.98	8.65	12.60	17.55
J	35	0.253	0.373	0.534	0.833	1.24	1.87	2.66	3.70	5.58	8.11	11.89	16.67
K	50	0.243	0.355	0.503	0.778	1.16	1.73	2.47	3.44	5.21	7.61	11.23	15.87
L	75	0.225	0.326	0.461	0.711	1.06	1.59	2.27	3.17	4.83	7.10	10.58	15.07
M	100	0.218	0.315	0.444	0.684	1.02	1.52	2.18	3.06	4.67	6.88	10.29	14.71
N	150	0.202	0.292	0.412	0.636	0.946	1.42	2.05	2.88	4.42	6.56	9.86	14.18
P	200	0.204	0.294	0.414	0.637	0.945	1.42	2.04	2.86	4.39	6.52	9.80	14.11
		.10	.15	.25	.40	.65	1.00	1.50	2.50	4.00	6.50	10.00	
		Acceptable Quality Levels (tightened inspection)											

Calculations For Standard Deviation Method

- Determine the mean and the standard deviation for the sample results.
- Determine Quality Indexes

  Qu = (Upper Limit - mean)/standard deviation

  Ql = (mean - Lower Limit)/standard deviation

  Upper Limit is normally 102, and Lower Limit is normally 98.
- Use Qu and Ql to determine estimate of percent nonconformance above the Upper Limit (Pu) and below the Lower Limit (Pl) using Table B-5.

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ANSI/ASQC Z1.9 - Table B-5 (portion)

Table B-5—Continued

Table for Estimating the Lot Percent Nonconforming Using Standard Deviation Method[1]

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
.70	29.27	26.67	25.74	25.03	24.67	24.46	24.38	24.33	24.31	24.29	24.26	24.24	24.23	24.22	24.21
.71	28.92	26.33	25.41	24.71	24.35	24.15	24.06	24.02	23.99	23.98	23.95	23.92	23.91	23.90	23.90
.72	28.57	26.00	25.09	24.39	24.03	23.83	23.75	23.71	23.68	23.67	23.64	23.61	23.60	23.59	23.59
.73	28.22	25.67	24.76	24.07	23.72	23.52	23.44	23.40	23.37	23.36	23.33	23.31	23.30	23.29	23.28
.74	27.86	25.33	24.44	23.75	23.41	23.21	23.13	23.09	23.07	23.05	23.02	23.00	22.99	22.98	22.98
.75	27.50	25.00	24.11	23.44	23.10	22.90	22.83	22.79	22.76	22.75	22.72	22.70	22.69	22.68	22.68
.76	27.13	24.67	23.79	23.12	22.79	22.60	22.52	22.48	22.46	22.44	22.42	22.40	22.39	22.38	22.38
.77	26.76	24.33	23.47	22.81	22.48	22.30	22.22	22.18	22.16	22.14	22.12	22.10	22.09	22.08	22.08
.78	26.39	24.00	23.15	22.50	22.18	21.99	21.92	21.89	21.86	21.85	21.82	21.80	21.78	21.79	21.78
.79	26.02	23.67	22.83	22.19	21.87	21.70	21.63	21.59	21.57	21.55	21.53	21.51	21.50	21.49	21.49
.80	25.64	23.33	22.51	21.88	21.57	21.40	21.33	21.29	21.27	21.26	21.23	21.22	21.21	21.20	21.20
.81	25.25	23.00	22.19	21.58	21.27	21.10	21.04	21.00	20.98	20.97	20.94	20.93	20.92	20.91	20.91
.82	24.86	22.67	21.87	21.27	20.98	20.81	20.75	20.71	20.69	20.68	20.65	20.64	20.63	20.62	20.62
.83	24.47	22.33	21.56	20.97	20.68	20.52	20.46	20.42	20.40	20.39	20.37	20.35	20.35	20.34	20.34
.84	24.07	22.00	21.24	20.67	20.39	20.23	20.17	20.14	20.12	20.11	20.09	20.07	20.06	20.06	20.05
.85	23.67	21.67	20.93	20.37	20.10	19.94	19.89	19.86	19.84	19.82	19.80	19.79	19.78	19.78	19.77
.86	23.26	21.33	20.62	20.07	19.81	19.66	19.60	19.57	19.56	19.54	19.53	19.51	19.51	19.50	19.50
.87	22.84	21.00	20.31	19.78	19.52	19.38	19.32	19.30	19.28	19.27	19.25	19.24	19.23	19.23	19.22
.88	22.42	20.67	20.00	19.48	19.23	19.10	19.05	19.02	19.00	18.99	18.98	18.96	18.96	18.95	18.95
.89	21.99	20.33	19.69	19.19	18.95	18.82	18.77	18.74	18.73	18.72	18.70	18.69	18.69	18.68	18.68

Calculations For Standard Deviation Method

- With the values of Pu and Pl determined from Table B-5 using Qu and Ql, estimated percent nonconformance equals to Pu plus Pl.
  (% ncf = Pu + Pl)
- Acceptance is based on whether the estimated percent nonconformance is below the allowed percent nonconformance given in Table B-3.