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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

REVISION TO MILITARY STANDARD 414, SAMPLING
PROCEDURES AND TABLES FOR INSPECTION BY
VARIABLES FOR PERCENT DEFECTIVE

by

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September 1983

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Revision to Military Standard 414, Sampling
Procedures and Tables for Inspection by
Variables for Percent Defective

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Submitted in partial fulfillment of the
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3

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The procedural changes involve eliminating the Form 1 procedure of the present standard and eliminating the average range method of estimating the lot standard deviation. The format changes involve relabeling the inspection levels, regrouping the lot size ranges, and relabeling the sample size code letters. Additions to the switching procedures for tightened and reduced inspection are also suggested.

TABLE OF CONTENTS

5

LIST OF TABLES

7

I. INTRODUCTION

A major area in statistical quality control is acceptance sampling. Acceptance sampling is used to determine a course of action, either accepting a given "lot" of manufactured items as conforming to some set standard, or rejecting this lot as being below that standard. "The purpose of acceptance sampling is to determine a course of action, not to estimate lot quality. Acceptance sampling prescribes a procedure that, if applied to a series of lots, will give a specified risk of accepting lots of a given quality. In other words, acceptance sampling yields quality assurance" [Ref. 1].

It is not an attempt to control quality but to merely accept and reject lots, although the indirect effects of acceptance sampling may influence the quality of production. The supplier may take steps to improve his production methods in order to experience a higher rate of acceptance of his product or even to maintain a contract to supply his product.

According to Duncan [Ref. 1], acceptance sampling is warranted under the following conditions:

1) The cost of inspection is high and the loss arising from the passing of a defective unit is not great. (It is possible in some cases that no inspection at all will be the cheapest plan.)

8

2) 100 percent inspection is time consuming. (A care-
   fully worked-out sampling plan will produce as good
   or better results than full inspection of the lot.)

3) The inspection process is destructive. (In this
   case, sampling must be employed.)

A. SAMPLING PROCEDURES

The Department of Defense has two well known sampling
plans, Military Standard 105D (MIL STD 105D) and Military
Standard 414 (MIL STD 414). MIL STD 105D is a set of
sampling procedures for inspection by attributes for percent
defective while MIL STD 414 is a set of sampling procedures
for inspection by variables for percent defective. Presently
the most widely used standard is MIL STD 105D, which was
last revised in April 1963. MIL STD 414 was issued in June
1957 and has not been revised since. MIL STD 105D is pre-
ferred because of its ease of use and understanding.

1. Inspection By Attributes

Military Standard 105D [Ref. 2], describes attri-
bute inspection as follows. "Inspection by attributes is
inspection whereby either the unit of product is classified
simply as defective or nondefective, or the number of
defects in the unit of product is counted with respect to a
given requirement or set of requirements."

A sampling plan based on sampling inspection by
attributes, where the item is classified as good or bad

only, does not rely on assumed underlying probability distributions. It only relies on being able to judge whether an item taken from a random sample can be classified as defective or nondefective. The sample percent defective is then found by dividing the number of items that were defective by the total number in the sample and multiplying this quotient by 100. This number is a basis for estimating the lot percent defective.

2. <u>Inspection By Variables</u>

Inspection by variables is inspection wherein a specific quality characteristic of a unit of product is measured on a continuous scale. This measurable quality characteristic has an absolute limit, known as the specification limit, marking the boundary between defective and nondefective.

Sampling plans based on sampling inspection by variables are described by Military Standard 414 [Ref. 3], as "The variable sampling plans apply to a single quality characteristic which can be measured on a continuous scale, and for which quality is expressed in terms of percent defective. The theory underlying the development of the variables sampling plans...assumes that the measurements of the quality characteristic are independent, identically distributed, normal random variables."

In a variable sampling plan, a random sample of the items in the lot is taken and the quality characteristic of

each item is measured and recorded. The sample average of these measurements, with the specification limit, is used to determine whether the lot should be accepted or rejected. Also, when the measurements are independent, identically distributed, normal random variables, an estimate based on the distribution of these measurements can be made as to the lot percent defective.

3. Comparison of Attributes and Variables

Attributes sampling is the simpler method of sampling for percent defective from an operational point of view in that the inspector only has to use a "go no-go" type of gauging. This makes it easier to keep track of the defectives and make acceptance decisions based on simple binary type data [Ref. 4].

The advantages of a variables sampling plan is that, for the same quality assurance obtained by an attributes plan, the size of the random sample for the variables plan may be much smaller than that of the attributes plan. Similarly, for the same sample sizes in both plans, a better quality assurance may be obtained by the variables plan. Inspection by variables makes greater use of the information concerning the lot than does the inspection by attributes [Ref. 5]. It must be remembered that variables sampling plans cannot be used indiscriminately since the assumption of independent, identically distributed, normal random variables is a part of the basis for these plans.

B. REVISION OF MILITARY STANDARD 414

MIL STD 414 was developed as a substitute for MIL STD 105D that would, through smaller sample sizes, significantly reduce the cost of inspection. At present "it is out of line with the attributes standard in several respects. This is partly due to MIL STD 105D being revised since MIL STD 414 was issued" [Ref. 1].

MIL STD 414 needs to be revised. In its present form it is difficult to use. Even after an accept or not accept decision has been made, there is confusion as the reason for the decision outcome and to the meaning of the figures obtained from the inspection [Ref. 4]. Also, there is a need to bring the variables plans more in line with the revised attributes plans in MIL STD 105D to allow the inspector or the contractor to decide which approach is more desirable or cost-effective.

Revision of MIL-STD 414 has been under study by the Department of Defense since 1974, but it has yet to be accomplished [Ref. 6]. Revision of complement standards has been made by other agencies. An international group representing the United States, the United Kingdom, Canada, and Australia has developed a counterpart, <u>Sampling Procedures and Charts for Inspection by Variables for Percent Defective</u> (QSTAG 330) [Ref. 7]. The main difference between QSTAG 330 and MIL STD 414 is the use of graphs instead of tables to determine acceptance or rejection of a lot [Ref. 4]. The

American Society For Quality Control has developed Sampling
Procedures and Tables for Inspection by Variables for Percent
Nonconforming (ANSI/ASQC Z1.9) [Ref. 8], and has proposed
this document be adopted by the Department of Defense as the
accepted standard for sampling by variables [Ref. 6]. The
proposal has been rejected, although ANSI/ASQC Z1.9 does
closely parallel the attributes plan of MIL STD 105D, with
the main exception being the use of different terminology.

C. PURPOSE OF THIS THESIS

The purpose of this thesis is to suggest changes to the
format and to certain procedures of MIL STD 414. It is
hoped that with these changes the standard will become
easier to use and understand and will be similar to the
attributes standard.

The mathematical and statistical principles underlying
inspection by variables is discussed in Chapter II. These
are the basis of MIL STD 414 and are used to support the
recommended changes to the standard.

MIL STD 414 uses two basic procedures for determining
acceptance or rejection of a lot. These two procedures are
referred to as "Form 1" and "Form 2" [Ref. 1]. Within these
two procedures are three different methods for determining
the outcome of the inspection procedure. This immediately
presents the inspector with six different choices as to
which method to employ for his inspection of the lot. Chap-
ter III proposes the elimination of one of the procedures

13

and suggests the removal of the average range method for determining the variability of the sample. This is a step in revising the variables standard to make it easier to use.

An easier comparison of a variables plan from MIL STD 414 and an attributes plan from MIL STD 105D could be made if the presentation of the two standards were similar. In Chapter IV, various ways of bringing the variables standard closer to the attributes standard are discussed. These revisions to MIL STD 414 would meet the original intention of making the variables standard the alternative to the attributes standard.

Chapter V summarizes the proposed changes to the variables standard.

II. STATISTICAL PROCEDURES OF MILITARY STANDARD 414

Variables sampling plans are based on the idea that the measurements of a single quality characteristic are independent, identically distributed, normal random variables with mean μ and standard deviation σ. These measurements constitute a random sample of size n drawn from a lot of size N. Associated with this quality characteristic are certain design specifications or tolerance levels that cannot be exceeded. A design specification may have an upper specification limit U, a lower specification limit L, or both upper and lower specification limits. When only one limit is given, it is referred to as a single specification limit, and when both are given they are referred to as double specification limits. An item is considered defective when its quality characteristic exceeds its specification limit (greater than U or less than L) such that the associated product will not satisfy its intended normal usage requirements.

Duncan [Ref. 1], writes, "If the items of a process or lot has a normal distribution, there exists an exact functional relationship between the fraction defective and the mean and standard deviation." The percent defective, expressed in terms of the probability distribution of the measurements,

for the different specification limits is given in Reference 9 as:

$$p_U' \;=\; 100(1 - \Phi\{(U-\mu)/\sigma\})$$

for an upper specification limit U,

$$p_L' \;=\; 100(1 - \Phi\{(\mu-L)/\sigma\})$$

for a lower specification limit L, and

$$p' \;=\; p_U' + p_L'$$

when both U and L are given [Ref. 9].   (In these equations $\phi(v)$ is the standardized normal density function

$$1/\sqrt{2\pi} \; \exp(-v^2/2),$$

and $\Phi(x)$ is the normal probability integral

$$\int_{-\infty}^{x} \phi(v)\,dv.)$$

The procedures of MIL STD 414 involve estimating

$$(U-\mu)/\sigma, \quad (\mu-L)/\sigma, \quad p_U', \quad p_L', \quad \text{or} \quad p'.$$

When sampling from a lot, the distribution variance may or may not be known. Sampling by variables may be categorized into three different types depending on the knowledge about the variance. In MIL STD 414 there are sampling plans for when the standard deviation is known, sampling plans for when the standard deviation is unknown but estimated by the sample standard deviation, and there are sampling plans for when the standard deviation is unknown but may be estimated by the average range method of subsamples [Ref. 5].

The following sections, describing the different types of inspection procedures, are taken from Mathematical and Statistical Principles Underlying Military Standard 414 [Ref. 9].

A. VARIABILITY KNOWN

The variability known method assumes the population mean μ is unknown and the standard deviation σ is a known constant. The sample estimates of the lot fraction defective are then functions of the sample mean

$$\overline{X} = \sum_{i=1}^{n} x_i/n .$$

The Form 1 procedure with a single specification limit involves estimating

$(U-\mu)/\sigma$ by $(U-\overline{X})/\sigma$ or $(\mu-L)/\sigma$ by $(\overline{X}-L)/\sigma,$

depending on whether an upper or lower specification limit
is given. This estimate is then compared with an accepta-
bility constant k obtained from Table D-1, page 91, of MIL
STD 414. If the estimate is greater than or equal to k, the
lot is accepted, otherwise the lot is rejected.

In the Form 2 procedure with a single specification limit,
the estimates for the percent defective p_U' and p_L' are func-
tions of $p_U(\overline{X})$ and $p_L(\overline{X})$ dependent upon the specification
limit given. These estimates are tabled as functions of
the quality index

$$Q_U = \sqrt{n/(n-1)}\,(U-\overline{X})/\sigma \quad \text{or} \quad Q_L = \sqrt{n(n-1)}\,(\overline{X}-L)/\sigma$$

in Table D-5, page 103, of MIL-STD 414. The lot percent
defective estimates $p_U(\overline{X})$ and $p_L(\overline{X})$ are compared with an
acceptability constant M, and the lot is accepted if the
estimate is less than or equal to M, otherwise it is rejected.
The M values for this procedure are given in Table D-3,
page 99, of MIL STD 414.

When double specification limits are given, the Form 2
procedure is used and p' is estimated by $p(\overline{X})$ where

$$p(\overline{X}) = p_U(\overline{X}) + p_L(\overline{X}) \ .$$

The lot is accepted when the total percent defective esti-
mate $p(\overline{X})$ is less than or equal to M.

B. VARIABILITY UNKNOWN--STANDARD DEVIATION

If both population parameters are unknown, then the standard deviation may be estimated by

$$s = \sqrt{\sum_{i=1}^{n} (x_i - \overline{X})/(n-1)} \quad .$$

The Form 1 procedure, with a single specification limit given, involves estimating

$$(U-\mu)/\sigma \quad \text{by} \quad (U-\overline{X})/s \quad \text{and} \quad (\mu-L)/\sigma \quad \text{by} \quad (\overline{X}-L)/s \ ,$$

depending on the specification limit given. This estimate is compared with the acceptability constant k found in Table B-1, page 39, of MIL STD 414, and the lot is accepted when the estimate is greater than or equal to the constant k.

When a single specification limit is given and Form 2 is used, the estimates of p_U' and p_L' are $p_U(\overline{X},s)$ and $p_L(\overline{X},s)$ respectively. These estimates are tabled as functions of the quality index

$$Q_U = (U-\overline{X})/s \quad \text{and} \quad Q_L = (\overline{X}-L)/s$$

in Table B-5, pages 47-51, of MIL STD 414. The acceptability constant M is obtained from Table B-3, page 45, of MIL STD 414. When the estimate is less than or equal to the constant M, the lot is accepted.

19

When double specification limits are given, the Form 2 procedure is used. The estimate of p' is $p(\overline{X},s)$ where

$$p(\overline{X},s) \;=\; p_U(\overline{X},s) + p_L(\overline{X},s) \; .$$

Again the estimates are functions of the quality index as in the Form 2 single specification limit procedure. The sum of the individual estimates $p(\overline{X},s)$ is compared with the acceptability constant M and the lot is accepted when the estimate is less than or equal to M.

C. VARIABILITY UNKNOWN--AVERAGE RANGE METHOD

Another method of estimating the standard deviation is the average range of subsamples. A sample of size n may be randomly divided into m subgroups of size g (in MIL-STD 414 g is equal to 5). The range of each subgroup, R_i, is obtained and the arithmetic mean of the subgroup ranges

$$\overline{R} \;=\; \sum_{i=1}^{m} R_i/m \; ,$$

is computed. This value of $\overline{R}$ is then used to estimate

$$(U-\mu)/\sigma \quad \text{by} \quad (U-\overline{X})/\overline{R} \quad \text{or} \quad (\mu-L)/\sigma \quad \text{by} \quad (\overline{X}-L)/\overline{R} \; ,$$

in the Form 1 procedure. The estimate is compared with the acceptability constant k obtained from Table C-1, page 65,

of MIL STD 414. If the estimate is greater than or equal to k, the lot is accepted.

In the Form 2 procedure, the statistic $\overline{R}/d_2^*$ is used in the estimate. Table C-3, page 71, of MIL STD 414 gives the value of d_2^* (labeled c in the table) for the statistic with n-1 degrees of freedom. In this procedure, p_U' and p_L' are estimated by $p_U(\overline{X},\overline{R})$ and $p_L(\overline{X},\overline{R})$ respectively. These estimates are tabled as functions of

$$Q_U = (U-\overline{X})c/\overline{R} \quad \text{or} \quad Q_L = (\overline{X}-L)c/\overline{R} \, ,$$

and are found in Table C-5, pages 73-77, of MIL STD 414. These estimates are compared with the acceptability constant M from Table C-3, page 71, of MIL STD 414, and the lot is accepted when the estimate is less than or equal to M.

When double specification limits are given, the estimate of p' is the sum of the two different limit estimates, $p_U(\overline{X},\overline{R})$ and $p_L(\overline{X},\overline{R})$. If this sum, $p(\overline{X},\overline{R})$, is less than or equal to the constant M, the lot is accepted.

In the next chapter, the elimination of the Form 1 procedure and an ordering of preference for the three different methods of sampling inspections for MIL-STD 414 are discussed.

III. FORMAT CHANGE

The two basic procedures used by MIL STD 414 for determining acceptance or rejection of a lot are called Form 1 and Form 2. These two procedures were discussed in Chapter II. Also discussed were the three different methods of sampling plans that may be used with each procedure, depending upon the knowledge of the variance of the normal random variable, giving a total of six different sampling plans to choose from. There are no guidelines in the standard as to which sampling procedure or method is preferred for use. This ambiguity may be eliminated by deleting one of the procedures and creating a hierarchy for the variance methods to be used.

A. FORM 2 VS. FORM 1

In the Form 2 procedure of MIL STD 414, the quality index

$$Q_L = (\bar{X}-L)/\sigma(\sqrt{n/(n-1)})$$

(for lower specification limit given and standard deviation known), yields the minimum-variance unbiased estimate of the fraction defective p' [Ref. 1]. The estimate of the lot fraction defective, $p(\bar{X})$, is compared with an acceptability constant M (the values of M used in the standard are verified in Reference 9], and the lot is accepted when $p(\bar{X})$ is

less than or equal to M. Both the estimate and M may be
expressed as either fraction defective or percent defective,
both of which are useful descriptors of the lot quality.

In the Form 1 procedure, the acceptability constant M
is transformed into a critical value k (the values of k used
in MIL STD 414 are verified in Reference 9). The relationship
between M and k is

$$M = 1 - F(k\sqrt{n/(n-1)}) \quad \text{or} \quad k = -z_m\sqrt{(n-1)/n}((\overline{X}-L)/\sigma) \ ,$$

where $F(z)$ is the normal cumulative distribution function
[Ref. 1]. The sample estimate $(\overline{X}-L)/\sigma$ is compared with k
and the lot rejected if the estimate is less than k. Although
this procedure requires *fewer computations and table lookup*,
neither k nor the estimator can be described as a fraction
defective. The units of measurement of the lot quality are
meaningless to the person who is not familiar with statistics.

When double specification limits are given, MIL STD 414
uses only the Form 2 procedure to estimate lot quality.
This procedure is more comprehensive and provides the optimum
statistical efficiency for estimating the percent defective.
The Form 1 procedure must be modified if used when double
specification limits are given [Ref. 1].

MIL STD 414 was established as an alternative to the
attributes standard, MIL STD 105D. The attributes standard
expresses the estimates in terms of fraction defective or

23

percent defective. For compatibility of the two standards, it would be reasonable to express the estimates of the lot quality obtained by using MIL STD 414 in the same units of measurement as the attributes standard. It is recommended that MIL STD 414 be changed to allow only one procedure, Form 2, for sampling inspections. This would not only ease the decision process, but would also allow a better understanding of the results obtained from the inspection.

B. PREFERENCE OF VARIABILITY METHODS

When a variables sampling plan is to be implemented, the variance of the random variable may or may not be known. When the variance is unknown, two methods of estimating the standard deviation of the process measurements are the sample standard deviation method or the average range of subsamples method. Both of these methods were discussed in Chapter II.

The variables standard was to be an alternative to the attributes standard that would reduce sampling costs by reducing the sample size required for inspection to obtain a given quality assurance. The three methods of sampling by variability use different sample sizes in order to maintain the same operating characteristic curve. The smallest sample size is obtained when the variance known method is used, and the largest sample size is needed when the average range method is used. There is no statistical advantage to

using the average range method, only a greater ease in administration is possible [Ref. 1].

When using the average range method to estimate the standard deviation of a random variable, the optimum sub-group size is m = 7, 8, or 9. This is obtained by selecting the combination with the highest degrees of freedom for equal values of the subgroup size m multiplied by g, the number of subgroups [Ref. 1]. For ease in table construction and sample size computation, MIL STD 414 is structured so that m = 5 in all cases [Ref. 9], which does not always given an optimal estimate of the standard deviation.

The average range method was established to make the computations easier, but it also increases the sample size in order to maintain the same operating characteristic (OC) curve [Ref. 1]. With the advent of hand-held calculators and computers, the average range is no longer much easier to compute than the standard deviation [Ref. 10], and thus it is recommended that the average range method be deleted from the standard and the standard deviation method be used when-ever the variability of the lot is unknown.

C. REVISED FORM OF MIL STD 414

In conclusion, it is recommended that a revised version of MIL-STD 414 contain only those sampling plans associated with the present Form 2 procedure, and that the process variance shall be used whenever known. If the variance is unknown, the standard deviation should be estimated using

the unbiased estimator s. The variables standard, revised
in this manner, would be an acceptable alternative to the
attributes standard that expresses inspection results in the
same units of measurement, is cost-effective, and the num-
bers obtained during the inspection would have meaning to
both the producer and the consumer.

In the following chapter various ways to bring the presen-
tation of the variables standard closer to that of the
attributes standard are discussed. This will allow better
comparison of individual sampling plans from each standard.

IV. PARALLELING MIL STD 414 AND MIL STD 105D

It is very difficult to compare MIL STD 414 with MIL STD 105D to ascertain which standard will be more cost effective yet provide nearly equal risk of acceptability on a given lot. The present operating characteristic (OC) curves of the two standards cannot be matched in order to compare the sample sizes necessary for the individual inspection levels. Duncan [Ref. 1], states, "Sampling plans of different types can generally be designed so that for practical purposes they have roughly the same OC curves. The risk involved in sampling is thus not a point of difference in the comparison of various types of plans. Meaningful comparisons are only made between plans that have roughly the same OC curve." An attempt has been made by the American Society for Quality Control to achieve this closeness between its attributes standard, ANSI/ASQC Z1.4, which corresponds directly with MIL STD 105D [Ref. 8], and its variables standard ANSI/ASQC Z1.9. The following recommendations for the revision of MIL STD 414 closely follow ANSI/ASQC Z1.9.

A. INSPECTION LEVELS

The inspection level determines the relationship between the lot size and the sample size. The level to be used for any particular requirement will be determined by the responsible authority [Ref. 2].

27

The inspection levels, lot size divisions and associated sample size code letters of MIL STD 414 are shown in Table I. The inspection level to be used for normal inspections is Level IV, unless otherwise specified [Ref. 3].

TABLE I

Sample Size Code Letters: Inspection
Levels, MIL STD 414

Lot Size		Inspection Levels				
		I	II	III	IV	V
3 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	40	B	B	B	D	F
41 to	65	B	B	C	E	G
66 to	110	B	B	D	F	H
111 to	180	B	C	E	G	I
181 to	300	B	D	F	H	J
301 to	500	C	E	G	I	K
501 to	800	D	F	H	J	L
801 to	1,300	E	G	I	K	L
1,301 to	3,200	F	H	J	L	M
3,201 to	8,000	G	I	L	M	N
8,001 to	22,000	H	J	M	N	O
22,001 to	110,000	I	K	N	O	P
110,001 to	550,000	I	K	O	P	Q
550,001 and over		I	K	P	Q	Q

Table II shows the same information for MIL STD 105D. The normal inspection level is Level II. Level I may be used when less discrimination is needed, and Level III may be used when greater discrimination is necessary. The special levels S1, S2, S3, and S4 may be used when relatively small sample sizes are necessary and large sampling risks may be tolerated [Ref. 2].

TABLE II

Sample Size Code Letters: Inspection
Levels, MIL STD 105D

Lot Size			Inspection Levels					
			Special				General	
		S-1	S-2	S-3	S-4	I	II	III
2 to	8	A	A	A	A	A	A	B
9 to	15	A	A	A	A	A	B	C
16 to	25	A	A	B	B	B	C	D
26 to	50	A	B	B	C	C	D	E
51 to	90	B	B	C	C	C	E	F
91 to	150	B	B	C	D	D	F	G
151 to	280	B	C	D	E	E	G	H
281 to	500	B	C	D	E	F	H	J
501 to	1,200	C	C	E	F	G	J	K
1,201 to	3,200	C	D	E	G	H	K	L
3,201 to	10,000	C	D	F	G	J	L	M
10,001 to	35,000	C	D	F	H	K	M	N
35,001 to	150,000	D	E	G	J	L	N	P
150,001 to	500,000	D	E	G	J	M	P	Q
500,001 and over		D	E	H	K	N	Q	R

A comparison of the two tables shows that Levels I, II, III, IV, and V from the variables standard are similar to Levels S3, S4, I, II, and III, respectively, from the attributes standard. A simple relabeling of the levels of inspection of the variables standard to match those of the attributes standard is recommended. With the relabeling of the inspection levels, the general inspection levels would be Levels I, II, and III. Level II would be the normal inspection level to be used unless otherwise specified. Level I may be used when less discrimination is needed, and Level III may be used when greater discrimination is necessary. The special levels, S3 and S4, may be used when relatively small sample sizes are necessary and large sampling risks may be tolerated [Ref. 8].

B. LOT SIZE RANGES

The lot size ranges corresponding to the various inspection levels of the two standards do not match. ANSI/ASQC Z1.9 divides the lot size ranges into groups that closely resemble those of MIL STD 105D. The only difference is the division of the lot size range of 281 to 500 of MIL STD 105D into two groups in the variables standard. The two groups are 281 to 400 and 401 to 500 [Ref. 8]. The only inspection level where this division makes a difference in the sample size code letters is Level II, the normal inspection level. This division allows a closer comparison of the OC curves of the two standards.

C. SAMPLE SIZE CODE LETTERS

The next step in paralleling the two standards is the designation of the sample size code letters with respect to the inspection levels and the lot size ranges. Table III shows the recommended sample size code letters along with the inspection levels and lot size ranges. This table may be compared with Table II to show the close correlation between the variables standard, ANSI/ASQC Z1.9, and the attributes standard, MIL STD 105D. The inspection level table of QSTAG 330 uses the same scheme of inspection levels, lot size ranges, and sample size code letters as that of ANSI/ASQC Z1.9.

With this symmetry between the variables standard and the attributes standard, a table can be generated and added to both standards which shows the sample sizes of each for a given sample size code letter and acceptable quality level. Table IV taken from QSTAG 330 shows these sample size comparisons. (The sample sizes listed in the QSTAG table are the same as the sample sizes of ANSI/ASQC Z1.9 and MIL STD 105D respectively.) The standards can now be compared effectively to find which approach for inspection of a given lot might be preferred.

D. OPERATING CHARACTERISTIC CURVES

The above changes to MIL STD 414 do not bring the variables standard directly in parallel with MIL STD 105D, but the OC curves are more closely matched than the original

TABLE III

Sample Size Code Letters: Inspection Levels, ANSI/ASQC Z1.9

Lot Sizes		Special		General		
		S-3	S-4	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

TABLE IV

Sample Size Code Letters: Sample Sizes, QSTAG 330

Code Letter	's' method / 'σ' method												Attribute Sample Size
	Acceptable Quality Level (Percent Defective)												
	All	.10	.15	.25	.40	.65	1.0	1.5	2.5	4.0	6.5	10	
B	3												3
C	4						2	2	2	2	3	3	5
D	5					2	2	2	3	3	3	4	8
E	7			2	2	3	3	3	4	4	5	5	13
F	10		3	3	3	4	4	4	5	5	6	7	20
G	15	4	4	4	5	5	6	6	7	8	9	11	32
H	20	5	5	6	6	7	7	8	9	10	12	14	50
I	25	6	6	7	8	8	9	10	11	13	15	17	—
J	35	8	9	9	10	11	12	14	15	18	20	24	80
K	50	11	12	13	14	16	17	19	22	25	29	33	125
L	75	16	17	19	21	23	25	28	32	36	42	49	200
M	100	22	23	25	27	30	33	36	42	48	55	64	315
N	150	31	34	37	40	44	49	54	61	70	82	95	500
P	200	42	45	49	54	59	65	71	81	93	109	127	800

33

variables standard and the attributes standard. Table V, from ANSI/ASQC Z1.9, and Table VI, from MIL STD 105D, show the 95, 50 and 10th percentiles (probability of accpetance from the OC curves) for lots of submitted quality (in terms of percent defective) for each AQL and sample size at normal inspection level [Ref. 8].

Comparing these two tables, it can be seen that the standards are closely matched with most of the differences in the quality of lots submitted being less than one percentage point for a given probability of acceptance. This matching of the OC curves allows meaningful comparison of plans from the two standards, and enables the use of either plan with nearly the same risk. The OC curves of MIL STD 414 would be the same as those in ANSI/ASQC Z1.9 if the above recommendations for inspection levels, lot size ranges and sample size code letters were adopted.

E. SWITCHING RULES FOR TIGHTENED AND REDUCED INSPECTION

The present switching rules of MIL STD 414 are based primarily on the estimated process average of ten or more lots, and this knowledge of the process average is essential in order to encourage the producer to submit acceptable products [Ref. 10]. It is suggested that the criteria of MIL STD 105D, that involve the individual outcome of consecutive lots, also be used when determining switching from normal, tightened, or reduced inspection.

TABLE V

Z1.9 Percentage Points in Terms of Percent Defective

Probability of Acceptance	Z-1.9—1980 Code Letter	Acceptable Quality Level										
		.10	.15	.25	.40	.65	1.00	1.50	2.50	4.00	6.50	10.00
95.0	B								1.04	1.89	3.52	6.02
50.0									16.68	20.30	25.22	30.97
10.0									49.34	52.83	57.24	62.08
95.0	C						.44	.69	1.32	2.29	4.13	6.85
50.0							9.52	11.28	14.44	17.93	22.89	28.61
10.0							34.88	37.26	41.15	45.05	50.13	55.55
95.0	D					.28	.46	.77	1.38	2.43	4.30	7.11
50.0						6.34	7.82	9.71	12.47	15.97	20.75	26.40
10.0						25.94	28.40	31.24	34.98	39.25	44.55	50.32
95.0	E			.11	.18	.32	.53	.83	1.50	2.65	4.57	7.46
50.0				2.89	3.72	4.83	6.18	7.69	10.28	13.66	18.11	23.53
10.0				14.42	16.33	18.60	21.09	23.58	27.43	31.93	37.28	43.25
95.0	F		.07	.12	.21	.36	.57	.94	1.65	2.83	4.84	7.81
50.0			1.53	2.08	2.79	3.77	4.82	6.33	8.62	11.69	15.91	21.09
10.0			7.95	9.44	11.15	13.23	15.23	17.84	21.40	25.66	30.99	36.98
95.0	G	.06	.09	.15	.25	.45	.68	1.09	1.91	3.09	5.30	8.41
50.0		.90	1.17	1.57	2.20	3.09	3.99	5.32	7.51	10.15	14.27	19.25
10.0		4.31	5.07	6.13	7.58	9.41	11.12	13.38	16.77	20.48	25.76	31.63
95.0	H	.07	.11	.17	.29	.49	.79	1.21	2.07	3.39	5.69	8.88
50.0		.76	1.01	1.38	1.90	2.69	3.66	4.81	6.86	9.51	13.49	18.31
10.0		3.16	3.85	4.73	5.88	7.46	9.23	11.14	14.25	17.94	23.01	28.70
95.0	I	.08	.12	.20	.32	.56	.85	1.28	2.23	3.61	5.98	9.27
50.0		.68	.89	1.28	1.73	2.53	3.39	4.47	6.54	9.12	13.00	17.74
10.0		2.55	3.08	3.99	4.93	6.46	7.97	9.73	12.81	16.34	21.24	26.82
95.0	J	.09	.13	.23	.36	.60	.94	1.40	2.38	3.80	6.21	9.65
50.0		.59	.76	1.10	1.54	2.21	3.05	4.05	5.98	8.41	12.10	16.82
10.0		1.90	2.29	3.02	3.87	5.10	6.50	8.07	10.85	14.11	18.71	24.23
95.0	K	.10	.15	.26	.40	.64	1.02	1.49	2.51	4.04	6.52	10.00
50.0		.19	.65	.98	1.37	1.94	2.76	3.68	5.48	7.90	11.45	16.00
10.0		1.36	1.70	2.35	3.07	4.03	5.33	6.72	9.23	12.39	16.72	21.98
95.0	L	.11	.17	.27	.43	.70	1.06	1.58	2.62	4.18	6.81	10.34
50.0		.40	.56	.82	1.19	1.74	2.43	3.34	5.02	7.29	10.84	15.24
10.0		.97	1.27	1.74	2.37	3.24	4.28	5.58	7.82	10.70	14.94	19.95
95.0	M	.12	.18	.29	.47	.74	1.12	1.66	2.73	4.31	6.97	10.51
50.0		.37	.51	.77	1.12	1.64	2.31	3.18	4.80	7.00	10.45	14.75
10.0		.80	1.05	1.50	2.06	2.86	3.81	5.01	7.11	9.84	13.89	18.73
95.0	N	.13	.19	.31	.48	.77	1.18	1.73	2.82	4.41	7.07	10.80
50.0		.32	.46	.69	1.00	1.48	2.14	2.96	4.49	6.59	9.90	14.28
10.0		.62	.85	1.21	1.68	2.36	3.26	4.34	6.26	8.78	12.58	17.44
95.0	P	.143	.210	.344	.534	.84	1.25	1.86	3.00	4.66	7.40	11.22
50.0		.321	.445	.683	1.000	1.48	2.08	2.96	4.48	6.58	9.88	14.27
10.0		.571	.763	1.116	1.567	2.22	3.02	4.12	5.98	8.45	12.19	16.98

TABLE VI

MIL STD 105D Percentage Points in Terms of Percent Defective

Probability of Acceptance	Z-1.4 Code Letter	.10	.15	.25	.40	.65	1.00	1.50	2.50	4.00	6.50	10.00
95.0										1.70		
50.0	B									20.6		
10.0										53.6		
95.0									1.02			7.63
50.0	C								12.9			31.4
10.0									36.9			58.4
95.0								.64			2.64	11.1
50.0	D							8.30			20.1	32.1
10.0								25.0			40.6	53.9
95.0							.394			2.81	6.63	11.3
50.0	E						5.19			12.6	20.0	27.5
10.0							16.2			26.8	36.0	44.4
95.0						.256			1.80	4.22	7.13	14.0
50.0	F					3.41			8.25	13.1	18.1	27.9
10.0						10.9			18.1	24.5	30.4	41.5
95.0					.161			1.13	2.59	4.39	8.50	13.1
50.0	G				2.14			5.19	8.27	11.4	17.5	23.7
10.0					6.94			11.6	15.8	19.7	27.1	34.1
95.0				.103			.712	1.66	2.77	5.34	8.20	12.9
50.0	H			1.38			3.33	5.31	7.30	11.3	15.2	21.2
10.0				4.50			7.56	10.3	12.9	17.8	22.4	29.1
95.0			.064			.444	1.03	1.73	3.32	5.06	7.91	11.9
50.0	J		.863			2.09	3.33	4.57	7.06	9.55	13.3	18.3
10.0			2.84			4.78	6.52	8.16	11.3	14.2	18.6	24.2
95.0		.0410			.284	.654	1.09	2.09	3.19	4.94	7.40	11.9
50.0	K	.554			1.34	2.14	2.94	4.54	6.14	8.53	11.7	17.3
10.0		1.84			3.11	4.26	5.35	7.42	9.42	12.3	16.1	22.5
95.0				.178	.409	.683	1.31	1.99	3.09	4.62	7.45	
50.0	L			.839	1.34	1.84	2.84	3.84	5.33	7.33	10.8	
10.0				1.95	2.66	3.34	4.64	5.89	7.0	10.1	14.1	
95.0			.112	.259	.433	.829	1.26	1.96	2.94	4.73		
50.0	M		.532	.848	1.17	1.80	2.43	3.39	4.66	6.88		
10.0			1.23	1.69	2.12	2.94	3.74	4.89	6.39	8.95		
95.0		.071	.164	.273	.523	.796	1.23	1.85	2.98			
50.0	N	.336	.535	.734	1.13	1.53	2.13	2.93	4.33			
10.0		.778	1.06	1.34	1.86	2.35	3.08	4.03	5.64			
95.0		.102	.171	.327	.498	.771	1.16	1.86				
50.0	P	.334	.459	.709	.959	1.33	1.83	2.71				
10.0		.665	.835	1.16	1.47	1.93	2.52	3.52				
95.0		.109	.209	.318	.494	.740	1.19					
50.0	Q	.294	.454	.614	.853	1.17	1.73					
10.0		.534	.742	.942	1.23	1.61	2.25					
95.0		.131	.199	.309	.462	.745						
50.0	R	.284	.384	.533	.733	1.08						
10.0		.464	.589	.770	1.01	1.41						

All inspections would use normal inspection, unless otherwise specified, and normal inspection would be continued throughout the course of the inspection except where tightened or reduced inspection is required.

1. Tightened Inspection

In MIL STD 414, tightened inspection is only instituted when the estimated process average computed from the preceding ten lots is greater than the acceptable quality level [Ref. 3]. It is recommended that the criteria from MIL STD 105D, that tightened inspection is instituted whenever two out of five consecutive lots have been rejected on original inspection, be added to the switching rule [Ref. 8].

In the present form of the variables standard, when tightened inspection is in effect, normal inspection should be reinstated when the estimated process average of lots is less than or equal to the AQL [Ref. 3]. This leaves undecided how many lots under tightened inspection must be used in the estimation of the process average. The rule from the attributes standard could be added such that the estimated process average must be less than or equal to the AQL and that five consecutive lots have been accepted on original inspection.

2. Reduced Inspection

MIL STD 414 and MIL STD 105D presently agree on the switching rules for normal to reduced inspection and reduced

to normal inspection. MIL STD 105D uses a total count of defectives that compares with the estimated process average method of the variables standard, and thus no changes are suggested for these switching rules.

3. Discontinuance of Inspection

MIL STD 414 does not have a clause that allows for discontinuance of inspection for material of inferior quality. ANSI/ASQC Z1.9 requires that if, ten consecutive lots remain on tightened inspection, the inspection is to be discontinued pending action to improve the quality of submitted material. MIL STD 105D also uses this requirement and it is a recommended addition to MIL STD 414.

The standard should now be easier to use, and Table IV is helpful in a cost analysis. An example may be taken from MIL STD 414 to compare the two standards. Example B-2, page 38, of MIL STD 414 gives an upper specification limit, a lot size of 40, normal inspection level, and an AQL of 1%. The variance of the lot is unknown. From Table II and Table III, we can see that the sample size code letter is D, the same in both standards. From Table IV we can find the sample size for the variables sampling plan is 5, and the sample size for an attributes sampling plan is 8. Disregarding other factors, we would use the inspection by variables whenever the cost was 8/5 or less than that of inspection by attributes.

The revisions suggested by this thesis are summarized in Chapter V.

V. SUMMARY

We have discussed how MIL STD 414 may be made more
attractive to use by eliminating many of the decisions an
inspector might have to make. The first of these was the
elimination of the Form 1 procedure so that all results from
inspections from the variables sampling plan would now be
expressed in terms of percent defective, a unit of measure-
ment that relates to MIL STD 105D. The range method,
because of its larger sample size and the advent of com-
puters and hand-held calculators, has been recommended for
deletion. The inspector only needs to know whether or
not the lot variance is known to know which sampling method
to use. If the variance is known, he would use the present
Form 2 procedure with variance known, and if the variance
is unknown, it would be estimated by the standard deviation.

MIL STD 414 and MIL STD 105D will have the same inspec-
tion level numbers for general inspection and special inspec-
tions if the suggested revisions are used. The lot size
ranges will be the same, except for one group, as will the
sample size code letters. A lot of a specified size that
is to be inspected at a certain level of inspection will
have the same sample size code letter in both standards,
allowing an easy comparison for a cost analysis.

39

The changes to the switching rules were minor and do not affect the OC curves of the standard. The ambiguity of when to switch from tightened to normal was eliminated.

It is hoped that the suggestions in this thesis will be helpful in the revision of MIL-STD 414. The following summarize the recommendations that have been made in this thesis:

1) delete the Form 1 procedure,

2) delete the average range method,

3) relabel the inspection levels to agree with MIL STD 105D,

4) change the lot size divisions to agree with ANSI/ ASQC Z1.9,

5) change the sample size code letters to agree with ANSI/ASQC Z1.9,

6) combine the switching rules of MIL STD 414 and MIL STD 105D, and

7) add a clause allowing for discontinuance of inspection.

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