NOT MEASUREMENT SENSITIVE

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DEPARTMENT OF DEFENSE HANDBOOK

COMPANION DOCUMENT TO MIL-STD-1916

This handbook is for guidance only. Do not cite this document as a requirement.

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FOREWORD

1. This handbook is approved for use by all Departments and Agencies of the Department of Defense. This document provides guidance on the use of MIL-STD-1916 to defense contractors and other commercial organizations supplying goods and services to the U.S. Government. The most significant difference between MIL-STD-1916 and previous product acceptance Military Standards is its emphasis on process-oriented improvement efforts. MIL-STD-1916 promotes the use of alternate methods of acceptance to sampling, and specifically endorses the implementation and use of a statistical process control (SPC) program. In compliance with DoD procurement quality strategy, MIL-STD-1916 emphasizes prevention. Furthermore, MIL-STD-1916 allows freedom on the part of suppliers to develop, plan, and implement their own quality system in so far as it is prevention-oriented and founded on the principles of continuous improvement of process and product quality. The standard also provides a series of zero-based sampling plans that can be used for product acceptance.

2. This handbook is for guidance only. This handbook cannot be cited as a requirement; if it is, the contractor does not have to comply.

3. Continuous quality improvement is a basic concept currently embedded in the DoD/Defense Industries Quality Excellence Program. The DoD has stated that Military and Federal Specifications that prescribe fixed levels of nonconformances, such as Acceptable Quality Levels (AQLs) and Lot Tolerance Percent Defectives (LTPDs), inhibit quality improvements and effective competition based on excellence, and should be eliminated. While Military and Federal Specifications may continue to utilize sampling techniques, DoD procurement activities have been instructed not to include prescribed AQLs, LTPDs, or other requirements for allowable levels of nonconformances.

4. The discontinued use of specifications incorporating AQLs and LTPDs, and contractual reference to standards based on them, left a serious void in the procurement quality assessment. The avoidance of language in procurement documents and standards which could be construed as allowing any nonconformances, led to the adoption of plans with acceptance numbers (c) of zero. In response to this mandate to not specify fixed levels of nonconformances in procurement, MIL-STD-1916 was developed by a committee comprised of volunteer members from education, government, and industry. This standard can be used in lieu of MIL-STD-105, MIL-STD-414, MIL-STD-1235, ANSI/ASQC Z1.4, and ANSI/ASQC Z1.9.

5. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be useful in improving this document should be addressed to: Commander, U.S. Army Armament Research, Development and Engineering Center, ATTN: AMSTA-AR-EDE-S, Picatinny Arsenal, NJ 07806-5000, by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

CONTENTS

Section 1: SCOPE

1.1 Purpose. The purpose of this handbook is to:

a. Provide guidance on using MIL-STD-1916 to improve industrial practices through statistical process control and other continuous improvement techniques.

b. Furnish an understanding of how the sampling inspection plans work and how they can be replaced by alternate acceptance methods.

1.2 Applicability. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply. Please note that in MIL-STD-1916 and this Handbook the following word pairs are used synonymously:

a. contractor, supplier
b. subcontractor, vendor
c. customer, government

Section 2: APPLICABLE DOCUMENTS

2.1 General. The documents listed below are not necessarily all of the documents referenced herein, but are the ones that are needed in order to fully understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto.

STANDARDS

DEPARTMENT OF DEFENSE

MIL-STD-1916	-	DoD PREFERRED METHODS FOR ACCEPTANCE OF PRODUCT

(Unless otherwise indicated, copies of the above specifications, standards, and handbooks are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.3 Non-Government publications. The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the latest DoDISS, and supplement thereto.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

ISO 9000 SERIES - QUALITY MANAGEMENT AND QUALITY ASSURANCE STANDARDS

(Copies of international standards, catalogs, and handbooks (ISO and IEC), as well as all foreign standards from ISO member body countries (DIN, JISC, BSI, AFNOR, etc.) are available in the U.S. from ANSI, 11 West 42nd Street, New York, NY 10036.)

AMERICAN NATIONAL STANDARDS INSTITUTE/AMERICAN SOCIETY FOR QUALITY

ANSI/ASQC 9000 SERIES - QUALITY MANAGEMENT AND QUALITY ASSURANCE STANDARDS

(Application for copies should be addressed to Quality Press, 611 East Wisconsin Avenue, P.O. Box 3005, Milwaukee, WI 53201-3005)

2.4 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

Section 3: DEFINITIONS, ACRONYMS and SYMBOLS

3.1 Definitions. The following definitions supplement those found in MIL-STD-1916:

a. Alpha risk (α). This is also known as the producer's risk. When referring to lot acceptance sampling, it is the probability that an acceptable lot will be rejected. When applied to control charts, the alpha risk is the probability that an out-of-control signal will be observed when the process is actually in control.

b. ANOVA (Analysis of Variance). A technique that subdivides the total variation of a set of data into meaningful component parts associated with specific sources of variation for the purpose of testing some hypothesis on the parameters of the model or estimating variance components. The technique, in conjunction with the F ratio, is used to provide a test of significance for the effects of these sources of variation and/or to obtain estimates of the variances attributable to these sources. The basic assumptions are that the effects due to all the sources of variation are additive and that the experimental errors are independently and normally distributed with zero mean and have equal variances throughout all subdivisions of data.

c. Benchmarking. A continuous, systematic process for evaluating the products, services, and work processes of organizations that are recognized as representing best practices for the purpose of organizational improvement.

d. Beta risk (β). This is also known as the consumer's risk. When referring to lot acceptance sampling, it is the probability that a lot of rejectable quality will be accepted. When applied to control charts, the beta risk is the probability that an out-of–control condition will not be observed when it actually exists.

e. Bonus Tolerance (also known as "Increase in Positional Tolerance"). Where the actual size of a feature is at maximum material condition (MMC), the geometric tolerance is zero. Where the actual size of the feature has departed from MMC, an increase in the geometric tolerance is allowed (bonus tolerance) equal to the amount of such departure. The total permissible variation is maximum at least material condition (LMC).

Bonus tolerancing is applied on an MMC, LMC, or 'regardless of feature size" (RFS) basis. The bonus tolerance, datum, and symbols are contained within feature control frames. This tolerance is in addition to the feature tolerance and permits the feature location and form to vary from true (theoretically exact) position. Basically, while maintaining the specified size limits of the feature, the center, axis or feature surface may not exceed the boundary established by the bonus tolerance. This may produce a distribution that is not centered on nominal and/or skewed.

A detailed explanation is available in ASME Y14.5M, Dimensioning and Tolerancing.

f. Cause and Effect Diagram. A method which graphically illustrates the factors (Causes) that impacts on a quality characteristic or contributes to some problem (the Effect). The causes are categorized under general headings that relate to the effect. Commonly used headings are; "Materials, Methods, People, Machines, Measurement and Environment". This technique is used to aid in determining and ranking the severity or impact of the causes on the effect.

g. Central tendency. Central tendency is the tendency of a set of measurement data to cluster or to center about certain numerical values.

h. Check Sheets. A check sheet is a data collection sheet where categories or ranges of possible measurements are printed on the sheets. The data collector records tally, or tick, marks across from the appropriate category or measurement. It allows the user to systematically record and compile data from historical sources, or observations as they happen, so that patterns and trends can be clearly detected and shown.

i. Chi-square test (goodness of fit test). This is a statistical test that provides confidence levels and intervals to describe whether or not the data truly approximates a particular distribution such as the normal distribution.

j. Common Cause. Factors that contribute to variation and are inherent to the process. When a process is in statistical control, the only variation existing comes from common causes. Common cause variation can only be reduced by management action on system components, e.g., improving equipment capability, better training, etc. (Also called chance cause).

k. Continuous process improvement. This is a goal of quality driven organizations, namely, to continually improve and optimize their processes.

l. Cycle variation. This is the variation from piece to piece with no time element involved. The pieces could have been made in any time order.

m. Histogram. A Histogram is plot of frequency distribution in the form of a bar chart whose bases are equal to the cell interval and whose areas are proportional to the frequencies. It is used to summarize data from a process that has been collected over a period of time, and graphically presents its frequency distribution.

n. Key characteristic. The feature of a material, part, or process whose variation has a significant influence on product fit, performance, service life, or manufacturability.

o. Normality. This is the tendency of variables data to pattern itself in a bell shaped curve. Many processes innately behave in this manner. Some processes, however, do not produce output whose measurements can be characterized by the normal distribution. Therefore, before performing operations that depend on assumptions of normality, it is wise to test those assumptions.

p. Normal probability paper. Paper that is scaled to show graphically how close a variables data distribution approximates a normal distribution is called normal probability paper.

q. Pareto Analysis. A Pareto Analysis is used to graphically focus efforts on the problems that offer the greatest potential for improvement by showing their relative frequency, cost, or other metric in a descending bar graph. It is based on the proven Pareto principle: approximately 20% of the sources cause approximately 80% of any problem.

r. Poka-Yoke. Poka Yoke is Japanese for “mistake proofing”. These devices are used either to prevent the special causes that result in defects, or to inexpensively inspect each item that is produced to determine whether it is acceptable or defective. A Poka Yoke device is any mechanism that either prevents a mistake from being made or makes the mistake obvious.

s. Positional variation. This is the within piece variation. (e.g., measuring the paint thickness on the fender of a truck.)

t. Quality system. This is a documented procedure, written by the supplier explaining just how the organization will control quality in its processes and/or production of product.

u. Rational subgroup. These are subgroups that are rationally or logically selected to only include common cause variability.

v. Run/Trend Charts. A run (or trend) chart is a line graph of the data, with time units represented on the x-axis, and the data values on the y-axis. This type of chart is used to show visual signals in the 'behavior' of the process data with time; it is not a control chart *per se* and typically does not include any form of limits.

w. Scatter Diagram. A scatter diagram is an X-Y plot of paired data from two variables. It is used to examine the strength of the relationship between a variable plotted on the horizontal axis, and a second variable plotted on the vertical axis. A scatter diagram provides visual information that should be used in conjunction with investigations such as correlation analyses.

x. Shapes of distributions. These are the patterns formed by data when placed on a histogram.

y. Shapiro-Wilk Test. The Shapiro-Wilk Test is a quantitative test for normality. It is designed for sample sizes less than or equal to 2000 and it computes the Shapiro-Wilk statistic (W). The statistic measures the strength of linear relationship between the set of data and the expected Normal distribution.

z. Short run SPC. Short run SPC is a method for using control charts when a small number of items are manufactured; too few to use traditional control charts.

aa. Skewness. This is an indication of asymmetry of the data distribution. If skewed, a distribution is skewed to the right or left. If skewed to the right, the distribution has a long "tail" to the right, and if skewed to the left, the distribution has a long "tail" to the left.

bb. Special Cause. A factor that contributes to variation and that is feasible to detect and identify. Examples are operator error or a faulty set-up.

cc. Stratified Sampling. The process of selecting units deliberately from various locations within a lot or batch or from various phases or periods of a process to obtain a sample. An attempt is made with stratified sampling to select known homogeneous areas within a lot that is not homogeneous: Random samples are then taken from these various locations, usually proportional in number to the size of the strata. If the strata are known, stratified random sampling will reduce the sampling variability.

dd. Taguchi loss function. A formula that assigns a monetary value to the loss to society incurred due to a quality characteristic deviating from its optimum (target) value.

ee. Temporal variation. This is the measured piece to piece variation of a characteristic over time.

ff. Transformations. A mathematical process that changes data into a desired distribution (e.g., a normal distribution).

gg. Type I Error. The incorrect decision that a process is unacceptable when, in fact, perfect information would reveal that it is located within the zone of acceptable processes. (Ex. The decision to reject a lot of material which, in reality, does not contain enough nonconformities to be classified as unacceptable).

hh. Type II Error. The incorrect decision that a process is acceptable when, in fact, perfect information would reveal that it is located within the zone of rejectable processes. (Ex. The decision to accept a lot of material which, in reality, contains enough nonconformities to be classified as unacceptable).

ii. ZBA. Zero Based Acceptance (ZBA) plans are sampling plans in which the acceptance number is zero for any sample taken. They are also referred to as C=0 and Accept on Zero (AoZ) sampling plans.

3.2 Acronyms used in this handbook. The following acronyms supplement those found in MIL-STD-1916:

a. ADPA - American Defense Preparedness Association, now the National Defense Industrial Association (NDIA)
b. AFI - Average Fraction Inspected
c. AIAG - Automotive Industry Action Group
d. ANOVA - Analysis of Variance
e. AOQ - Average Outgoing Quality
f. AOQL - Average Outgoing Quality Limit
g. AoZ - Accept on Zero
h. ASQC - American Society for Quality Control – changed to American Society for Quality (ASQ) in 1997
i. DOE - Design of Experiments
j. ICC - Intraclass Correlation Coefficient
k. LSL or L - Lower Specification Limit
l. LTPD - Lot Tolerance Percent Defective
m. NCSL - National Conference of Standards Laboratories
n. OC curves - Operating Characteristics Curves
o. PDCA - Plan/Do/Check/Act
p. ppm - parts per million
q. QFD - Quality Function Deployment
r. QPC - Quality Planning & Control
s. QPD - Quality Policy Deployment
t. RPN - Risk Priority Number
u. TQM - Total Quality Management
w. USL or U - Upper Specification Limit

x. ZBA - Zero Based Acceptance

3.3 Symbols. The following symbols are used in either MIL-STD-1916 or in this Handbook:

a. a - attribute
b. c - number of nonconformities
c. f - frequency, Table IV, MIL-STD-1916
d. F - value, Table III, MIL-STD-1916
e. i - clearance number, Table IV, MIL-STD-1916
f. k - value, Table III, MIL-STD-1916
g. m - moving
h. n - sample size
i. N - lot size or normal sampling
j. np - number of nonconforming units
k. p - fraction nonconforming
l. Q - quality index
m. R - range or reduced sampling
n. s - sample standard deviation
o. T - tightened sampling
p. u - number of nonconformities per unit
q. v - variable
r. X or x - individual value
s. Σ - sum of
t. $\sqrt{}$ - square root
u. $\geq$ - greater than or equal to
v. $\leq$ - less than or equal to
w. $\wedge$ - estimated
x. $-$ - average (e.g., $\bar{x}$ = average of the x values)

PART A: PREFERRED METHODOLOGY OF ACCEPTANCE

Section 4: QUALITY SYSTEM

4.1 Prevention vs. detection. Historically the quality system has become proficient at detecting, sorting, and segregating nonconformities. These activities incur costs in addition to the costs of rework, repair, scrap, and warranty services. It is now widely recognized that these practices must change. Prevention is the most economic approach. Problems that are prevented never have to be solved. Detection is the most costly approach.

Statistical Process Control (SPC) is a statistical method which works as an excellent prevention technique. SPC can benefit engineering, administration, clerical, finance, marketing, sales, production control, purchasing, and maintenance, as well as production.

4.2 Prevention-based quality system. Most organizations provide a product or service intended to satisfy a user's needs or requirements. Such requirements are often incorporated in some type of specification. However, meeting technical specifications alone may not guarantee that a customer's requirements will be consistently met. This has led to the development of quality system standards and guidelines that complement relevant product or services requirements given in the technical specifications.

The ISO 9000 series of standards (and their U.S. equivalents, the ANSI/ASQC Q9000 standards) specify a set of requirements aimed primarily at achieving customer satisfaction through the establishment of a documented quality system. The intent is to prevent nonconformities at all stages from design to servicing (see paragraph 5.1.2 of MIL-STD-1916). With the international affiliation of the standards, organizations in all parts of the world can be assured that a supplier complying with the appropriate ISO 9000 standard has the framework for an acceptable quality system.

A basic quality management system should adhere to the elements described in the ANSI/ASQC Q9000 Series of Standards. The ANSI/ASQC Q9000 standards provide a template after which organizations can model their quality systems. Using ANSI/ASQC Q9000 will not in itself assure quality products. However, it will assure that if the organization is using its quality system appropriately, it has in place the necessary mechanisms for corrective and preventive action.

4.3 Providing process focus of quality system. Each business activity may be looked upon as a process. Filing documents, repairing the roof, and designing a missile are examples of different business processes. Simple or complicated, processes have three things in common: (1) inputs of material, information and labor, (2) defined steps or actions to perform the work, and (3) an output or end product. Thinking of everything as a process with these three factors helps to focus on the common aspects of processes. This also assists greatly in simplifying the process improvement activities. The goal is to determine the correct set of conditions that will always produce conforming product with the least amount of variability. Variability reduction results in a

more consistent product, a more predictable system, and lowers cost along with many other benefits. The Taguchi loss function illustrates the costs incurred when a process deviates from the target value.

4.3.1 Design of experiments. Design of Experiments (DOE) is a planned strategy to systematically test combinations of variable elements of a process and analyze the results. The elements of the process to be adjusted are called ‘factors”; the different settings of those factors for the purposes of the experiment are called “levels.” Carefully designed and analyzed experiments can delineate significant factors from those that are less important, and can reveal interaction between factors. DOE aids in establishing an optimum solution based on economics or minimizing variability. DOE is a more efficient experimental strategy than varying one factor at a time while keeping the others constant.[1,2,3]

4.3.2 Tools for design.

4.3.2.1 Quality Function Deployment. A strategic view starts with quality as a part of the overall business plan. This plan identifies how customer requirements and desires are translated into the design of quality products and production processes. Quality Function Deployment (QFD) is a disciplined methodology which begins with customer needs and then translates them into lower and lower levels in the design tree. The end result of QFD is the identification of the specific manufacturing process parameters needed to ensure the customer requirements are met. QFD consists of at least four phases called product planning, part design, process design, and production planning, culminating in a process that assures customer needs are met by a quality product that can be produced with minimum variability and cost over the long term. QFD also defines how complementary techniques such as Failure Mode and Effects Analysis (FMEA), Design of Experiments (DOE), and Quality Planning and Control (QPC) can be used to ensure a quality product is designed and manufactured. It is a disciplined approach to strategically improving market share. In essence, QFD is a methodology for translating customer requirements into quality design and manufacturing requirements. It is a systematic approach for tracking customer needs throughout the quality product-realization process.[4]

4.3.2.2 Failure Mode and Effects Analysis. FMEA is a systematic, analytical approach to properly plan for defect prevention and mistake-proofing. It is a technique for identifying and focusing on those areas in the design and manufacturing process for the prevention, reduction, and elimination of non-conformances in the product or production. During this team-oriented process, each potential defect or failure mode in a system is analyzed to determine the severity of the failure effects, with the purpose of eliminating them. Thus, FMEA is a defect prevention tool that can formalize product reliability planning prior to design or production, and a direct method for identifying process points for installing SPC. The FMEA procedure is to identify all potential failure modes, followed by a determination of the potential severity of each failure mode and the generation of a rating. This is followed by the identification of the occurrence ranking of each failure mode, and an additional ranking is identified for the detection method used for determining the failure model. Finally, an overall ranking for each failure mode is developed from the multiplication of the severity, occurrence, and detection method factors resulting in the Risk

Priority Number (RPN). The failure modes are then ranked by RPN, prioritized, and corrective action taken to eliminate or mitigate them.[5,6]

4.3.3 State of operator control. It is highly desirable that production operators should make decisions on conformance. They are already in the mainstream of the product flow and are most familiar with the nature of the product characteristics. To require others to make measurements and judge conformance adds costs and delays and reduces the sense of responsibility of the operators.

When work is organized in a way that enables a person to have full mastery over the attainment of planned results, that person is said to be in a state of self-control.[7] Self-control is a universal concept, applicable to the General Manager responsible for running an organization division, as well as the machinist running a lathe.

To achieve a state of self-control, the operator must be provided with:

a. Knowledge of how the process is supposed to be operating.
b. Knowledge of how the process is actually operating.
c. Means of regulating the process in the event the goals are not being met. These means must always include the authority and the ability to regulate and improve the process.

If all the parameters have been met, the person is said to be in a state of self-control and can properly be held responsible for any deficiencies in performance. If any of the parameters have not been met, the person is not in a state of self-control and cannot be held responsible for deficiencies.

Section 5: STATISTICAL PROCESS CONTROL

5.1 General.

5.1.1 Why SPC?

a. SPC is a powerful tool to monitor processes, diagnose process problems, and prioritize efforts at quality improvement.

b. SPC can be used as a tool to improve quality by reducing variation in products and processes.

c. Processes that are in statistical control and capable can consistently turn out products which meet, or exceed, all customer requirements and expectations.

d. Application of SPC can result in decreased reject rates, lower inspection costs, and greater consistency of manufactured product.

e. SPC enables operator identification of process problems observed and corrective actions taken.

f. Employment of SPC promotes involvement of operators in quality and control of their processes.

5.1.2 Service and administrative SPC. SPC for service and administrative processes refers to the application of statistical techniques to improve performance. Statistical analysis methods are just as effective in an office environment as they are on the factory floor.

5.1.3 Customer requirements. “Customer” in this document includes both internal and external customers.

a. There should be a clear understanding of the customer's needs and how SPC can help to satisfy them.

b. The supplier should identify those processes that control the variability of the identified key characteristics.

c. Suppliers should meet with the customers and ask:

(1) What would cause those products to be more valuable or easier to use/assemble/fit/etc.? (Form/Fit/Function) How could subassemblies be improved?

(2) Where can dimensions or other product characteristics be improved, with respect to either nominal size or amount of variation being encountered?

(3) Have field failures occurred? If so, has the root cause been identified?[8]

d. From the information received from the customer, the supplier should identify what requirements are not being met or where the customer's expectations are not being satisfied.

5.2 Planning for SPC.[47]

5.2.1 Approach. Knowledge of statistical procedures alone is not sufficient to ensure improvements in product quality and process productivity. A structured approach for implementing SPC is needed. Organizational team structures, such as self-managed work teams, cross-functional teams, and project teams will facilitate and enhance the use of SPC with its many internal and external benefits.

Because each supplier's situation is unique, actual implementation will require a detailed strategy based on the organization's management philosophy, organizational structure and culture, production facilities, past experience, existing Quality System, and availability of resources.[9] The planning and documenting of an SPC System should combine the contract requirements for SPC, if applicable, with appropriate in-house initiatives toward continuous improvement.

The use of SPC software should be considered. Considerations for the use of SPC software are contained in Appendix A.

5.2.2. Preliminary planning. The following factors contribute significantly to effective SPC implementation:

5.2.2.1. Senior management. Senior management should understand the fundamental concepts of SPC, recognize the importance of their involvement in the SPC implementation process and be committed to its success. Management should also clearly communicate its intentions and expectations to the entire organization; one effective way is through the creation of a mission statement.

5.2.2.2 Quality system. Existing efforts should establish the importance of a quality-conscious work force and an integrated process-and results-oriented Quality System.

5.2.2.3 Steering committee. A Steering Committee may be important to guide the SPC efforts. Since effective implementation planning demands consistent senior management leadership and involvement, the committee should be headed by a local authority and include members from each affected function. The committee may also eventually include a facilitator and members of the work force.

5.2.2.4 SPC facilitator. An SPC facilitator should be trained and empowered to coordinate, advocate, and reinforce the activities involved in SPC implementation.

5.2.2.5 SPC policy. An SPC policy should be developed which sets the priorities of process control and quality improvement. This policy should be created by the Steering Committee and endorsed by the chief executive and top managers.

5.2.2.6 Goals. Specific goals should be developed in support of the policy. These goals should clearly define the scope of SPC applications, state improvement targets, and provide metrics to help evaluate progress.

5.2.2.7 Milestones. A reasonable implementation schedule should be developed which lists all SPC-related activities. This will help track progress and select milestones/goals for the various stages in planning, training, resource allocation, and implementation.

5.2.2.8 SPC plan. A written SPC implementation plan (SPC Plan) should be developed which does the following:

a. Outlines the activities required to involve all levels and functions in the SPC effort;

b. Incorporates general and specific (detailed) process information; includes rationale for identifying critical processes, especially any that influence key characteristics;

c. Identifies what/how/when/by whom the process is being measured/charted;

d. Plans for and commits the resources necessary to support the SPC implementation, including personnel time, training, tools, techniques, materials, and technology.

The plan should contain written procedures for reacting to out-of-control and out-of-specification conditions. Both short-term (immediate actions) and long-term (elimination/prevention) measures should be addressed. Procedures should specifically define what decisions (with regard to the product and process) are appropriate and allowable under such conditions, and who is authorized to make those decisions. Procedures should also address how special and common causes of variation are handled. Anyone with SPC responsibility or involvement (including audit functions) should be trained in the performance of these procedures. The SPC Plan should provide for root cause analysis and permanent corrective action.

Raw materials, subcontracted materials and services play a critical role in assuring finished product quality. The supplier should provide for the early involvement of vendors (subcontractors) in the SPC planning and implementation process. The supplier should also provide for the appropriate review of vendor SPC plans and offer to assist vendors in establishing an SPC program, including training, if necessary.

5.2.2.9 SPC verification. The verification of effective internal and vendor SPC programs has its basis in an effective SPC audit program.

Once an effective SPC plan has been established, it is recognized that the full implementation of the events defined in the plan may take a long time. Therefore, at various times during this implementation and practice of SPC, the SPC program should be reviewed for compliance.

Some of the more important aspects of SPC practices to be evaluated during an audit will be:

a. Management participation and support of SPC
b. Organization policies, directives or procedures related to SPC
c. Organizational responsibilities related to use of SPC
d. SPC training programs and training materials
e. Vendor/Supplier involvement in SPC programs
f. Manufacturing controls and decision-making criteria related to SPC
g. Computer hardware and software utilized with SPC
h. Automatic gage equipment and recording devices
i. Control chart applications and uses
j. Operator /management responses to out of control conditions
k. Process capability studies
l. Data collection and sampling practices
m. Documentation of identified special causes
n. Production machinery and equipment measured by SPC
o. SPC use in departments or organizations other than manufacturing
p. Comparisons of scrap and rework reports with the control charts

Some or all of these items will be included in each SPC audit. The intent of the audits is to identify the compliance to the SPC program as well as areas for improvement.

5.2.3 Training. Initial SPC training should be provided for all supplier personnel who will be involved in the program to impart knowledge of the philosophy and concepts of SPC. Visiting similar facilities that exemplify the type of commitment required can be beneficial. An overall training strategy should be developed and included in the SPC plan. The strategy should consider and account for the needs of all personnel levels and responsibilities. It should draw from a mixture of resources including trade journals, books, videos, and in-house and outside experts. A training plan should consider:

a. Requirement: Has the individual received prior training? Is it adequate?
b. Training needed: Who receives training, and how much? This is based on responsibilities and level of SPC involvement.
c. Certification: Is certification required?
d. Frequency/availability of refresher training: Periodically (normally annually) assess the capabilities of those previously trained. Provide refresher training if required.
e. Course instructor: Who is the instructor? Is she/he adequately qualified?
f. Course materials: What course/materials are used? Are training books or materials cited in the plan? Are those materials available for operator's reference?

g. Records: Records should be kept of all supplier personnel training and test results. This includes both initial and refresher training.

5.3 Process knowledge.

5.3.1 Flow diagramming. In order to optimize and control a process, and maximize the benefits from SPC implementation, a thorough knowledge of the process is of paramount importance. Therefore, prior to implementing SPC, it is very helpful to systematically diagram (flowchart) the overall process. Often, flow-charting will immediately reveal opportunities to improve or simplify the process by removing redundant operations. Flow diagrams may consider:

a. Work flow
b. Information flow
c. Check, test, inspect, and audit points
d. Corrective action loop
e. Materials flow (transportation route map)—are there any shortcuts?
f. Shelf life, time-critical process steps (heating, cooling, storage, curing, etc.)
g. Areas of environmental impact (to process)

5.3.2 Additional tools and techniques to gain knowledge of the process. Upon completion of flow diagramming, several other problem solving tools and techniques may also be used to analyze, study, control and optimize the processes. These techniques, described in Appendix B, include:

a. Pareto analysis
b. Cause and effect diagram
c. Check sheets
d. Run/Trend charts
e. Histograms
f. Scatter diagrams

Inputs for the above techniques may be data from customers (both external and internal), final inspection, reliability assessments, field observations, benchmarking, vendor or supplier (of raw materials or parts) recommendations, and others. Input from activities affecting the process should also be considered, such as maintenance logs, preventive maintenance schedules, laboratory analyses (both in-process and incoming raw materials), and environmental factors, such as ambient temperatures, humidity, lighting, etc. Such factors may affect not only the operation of the actual process, but may contribute to variations in process inputs as well.

5.3.3 Characterizing variation. There are, in general, three main mechanisms of variation: [10]

a. Positional variation (within a piece)
b. Cyclical variation (between pieces)
c. Temporal variation (over time)

It is important that the relative contribution of these sources is investigated; when establishing SPC control charting, subgroup formulation and sampling procedures are based on this information. The use of multi-vari charts is very beneficial in tracking down the sources of variation. Multi-Vari charts use vertical lines to represent the range of variation of one unit of product. The resulting vertical lines are plotted against the tolerance limits to visually show the amount of variation that is using up the tolerance. By using this chart over a series of units, the variation of the product can be traced to either within piece, piece to piece, or time to time variability. This is useful in the establishment of control charts and actions to take for improvement.

5.3.4 Determining optimum process settings. Statistically designed experiments should be conducted for systematically identifying optimum levels, as well as any interactions that may exist. Experimentation can also help to identify those process parameters that do not need to be rigidly controlled. Using experimental results, parameters can be set to optimum levels. Results can be verified by monitoring product characteristics with SPC.

In order to determine process parameters when unknown, the desired product characteristics and requirements must be known. Then, it should be determined how to "build them in." Designed experiments are effective. Design of Experiments (DOE) is a systematic approach to answer the question, “How do changes in process parameters impact the final product characteristics?” Most processes involve many variables that can be established at a multitude of levels. Designed experiments involve choosing key variables and testing them under different conditions to find the optimum target level for each variable. Once it is understood how the levels and combinations of each variable affect the product characteristics, they can be incorporated into the process.

5.4 What to measure.

5.4.1 Key characteristics to control. The flow diagram may be used as a “road map“ in the selection of the most advantageous, or key, characteristics for SPC application. By following the flow “upstream”, the supplier can identify key characteristics that significantly impact later operations, and therefore, provide the greatest potential cost savings from the prevention of product nonconformities and process instabilities. Analysis of rework, repair and scrap costs may identify key upstream characteristics.

While upstream operations may promise the greatest cost savings, both the customer and the supplier are keenly interested in controlling those key characteristics throughout the entire process that most significantly impact the functionality of the finished product. Therefore, key characteristics may also be dictated by external or internal customers. Analysis of quality cost data on customer returns may define them. Effects on product performance, or interface, could be a source. Requirements to reduce variation may pinpoint the characteristics.

5.4.2 Process variables to control product characteristics. While SPC data usually results from the direct measurement of product characteristics, using SPC to control variable process input and

environmental conditions is often more beneficial. [11,12] Controlling variables in a plating process to control the product plating thickness is an example. This should be done whenever possible as the control of process variables is a real-time system, whereas the control of the characteristic is an after-the-fact system. SPC should be applied to the process variables that have the greatest impact on the product characteristic. Common process variables to consider include:

a. Temperatures
b. Pressures
c. pH
d. Feed rates
e. Powder grain size
f. Chemical composition (of raw materials or ingredients)
g. Cycle or residence times
h. Cutter feeds and speeds
i. Cooling fluid flow or temperature
j. Densities
k. Plating current densities
l. Viscosities, etc.

5.5 Normality.

5.5.1 When and why normality is important. When using $\overline{X}$, R control charts, sample means are plotted and the central limit theorem is very helpful. This theorem says that the sample means tend toward normality as the subgroup size increases, regardless of the population distribution of individual values. Because of this theorem, plotting control charts for means, whose limits are based on the normal curve, is usually not dependent on the assumption of normality. There are times, however, when normality is important. When a control chart for individuals is drawn, the control limits are simply 3 standard deviations (of the individuals) from the process average. Normality is important here because if the individual values are not normally distributed, the percent of the population expected outside the control limits, due to chance, is not the same as for an $\overline{X}$ chart.

Normality is also important when a capability/performance study is being run and a conventional index, such as C_p or C_{pk}, is used. These indices assume normality and can give misleading results if the distribution of individuals is not normal.

Non-normal distributions are any distributions other than the normal distribution. It should be understood that a non-normal distribution may or may not be characteristic of the process. It is possible for a process to be in statistical control and have a non-normal distribution.

5.5.2 Tests for normality. Methods of testing for normality include:

a. Chi-square test (goodness-of-fit test)

b. Normal Probability Paper
c. Calculation of skewness
d. Shapiro-Wilk test

It is recommended that the first three tests be used when reasonably large amounts of data are available. [7,13] The Shapiro-Wilk test is recommended for small data sets. [14]

5.5.3 Transformations/Curve-fitting. Many SPC software packages are now available with statistical tools that will determine if a distribution is normal or not. These packages provide the most expeditious way to evaluate distributions. In the event the distribution is non-normal, additional tools provide for a transformation of data or a determination of the best fitting distribution to the data. Once a suitable transformation is made, or a determination has been made as to the actual distribution type, a valid calculation of a process capability can be made, and valid control limits for an individual X chart can be plotted.

Some types of transformations that may be used are: [7,15]

a. Log-normal
b. Square root
c. Arcsin

5.6 Control charting. The control chart has been utilized to enhance process control and process improvement capabilities since its introduction in the late 1920's by W.A. Shewhart. It has become the cornerstone of the time proven methods and practices of SPC. [13,16,17,18,19]

5.6.1 The basic control chart and its use. The control chart is a method to detect the presence of special causes of variation. The actual identification and elimination of special causes are tasks for production and engineering personnel. The chart shows when trouble exists, not what the trouble is. Knowing the time trouble occurred often helps in the diagnosis; i.e., identification of the trouble. In addition, the control chart often gives a warning of impending difficulty. Steps can be taken to investigate the situation and prevent the actual occurrence of trouble. [19,20,21,22,23]

5.6.2 Types of control charts. There are two major types of control charts:

a. Variable control charts which use measured values of a characteristic. (See Table A).
b. Attributes control charts which use discrete data, such as “conforming” and “nonconforming”. (See Table B).

5.6.2.1 Variable charts. Variable charts are concerned with three characteristics:

a. The central tendency (location) of the data.
b. The variability or dispersion or spread of the data.
c. The shape of the distribution of the data.

TABLE A. Sample size rules for variable control charts.

Control Chart Type	Sample Size (n)
Average & Range ($\overline{X}$, R)	10 or fewer, usually 2 to 5
Average & Standard Deviation ($\overline{X}$, s)	10 or greater
Moving Average & Moving Range (m$\overline{X}$, mR)	10 or fewer, usually 2 to 5
Individuals & Moving Range (X, mR)	1

The X-bar, mX-bar, and X charts indicate where the process is centered for the specific characteristic being controlled. The R, s, and mR charts describe the dispersion of the process. The two types of charts (central tendency and dispersion) are used together to monitor the stability of the process.

5.6.2.2 Attributes charts. Attribute control charts may be applied to quality characteristics that can be observed only as attributes, or those that are actually recorded as attributes even though they might have been measured as variables. Attributes charts are concerned with:

a. The central tendency (location) of the data
b. The variability or dispersion or spread of the data

TABLE B. Sample size rules for attribute control charts.

Control Chart Type	Sample Size
Fraction nonconforming (p)	50 or greater, Variable sample size
Number nonconforming (np)	50 or greater, Constant sample size
Number of nonconformities (c)	Constant inspection unit
Number of nonconformities per unit (u)	Variable inspection unit

5.6.3 Rational subgroups.[47] The control chart is a technique to distinguish between common cause and special cause variability. The control limits are based upon within-subgroup variability. This suggests that subgroups need to be rationally or logically selected to only include common cause variability. The differences between subgroups will then be due to special causes.

In most instances, a small group of consecutively produced products or consecutive measurements of a characteristic is likely to be a rational subgroup because a special cause is less likely to occur in this short duration of time. This short-term variation is assumed to be due to common causes.

An Example

A production process consists of three parallel machines. Each machine has four stations, called A, B, C, and D. Every hour, a twelve-part sample is collected, and one reading is taken, at each of four stations, on all three machines. The following Table C shows an example of the data from one hourly sample.

TABLE C. Example of multiple sources of variation.

	STATION			
MACHINE	A	B	C	D
Machine 1	10	11	10	12
Machine 2	12	9	9	8
Machine 3	11	13	10	10

Similar situations occur with multi-cavity molds, multi-head filling machines or any other situation where multiple lanes of products are produced.

In this case there are three sources of variation. Machine-to-machine variation is captured by the differences in the rows, station-to-station variation is captured by the differences in columns and hour-to-hour (temporal) variation is captured by the differences between the twelve-part samples taken every hour.

There are several ways to define subgroups in this case.

a. If each row is defined as a subgroup, then a separate control chart could be developed for each machine. The within subgroup variance will include station-to-station variability. Hour-to-hour variation will appear between subgroups and machine-to-machine differences will be obtained by comparing different control charts.

b. If each column is defined as a subgroup, then there could be four separate control charts, one for each station. Machine-to-machine variability is captured within the subgroup and hour-to-hour variation appears between subgroups. Station-to-station differences can be obtained by comparing the different control charts.

c. If the subgroup is defined as the combined output of all machines, there is a single control chart. Assuming mixing, the within subgroup variability includes both the machine to machine and the station to station variability. The hour to hour variation appears between subgroups.

Which method of subgrouping is rational? The answer depends upon the relative magnitude of the variability due to the different sources of variation and the specific questions the control chart is intended to answer.

Rational subgroups should be defined by first understanding the causes of variation and their relative contribution to the total variability. Only common causes of variation should be included within a subgroup in order to ensure that when the control chart produces an out of control signal, it is in fact due to special causes.

5.6.4 Rationale for subgroup size. The following points should be considered in selecting the subgroup size.

a. The alpha risk remains constant as the subgroup size changes but the beta risk decreases as the subgroup size increases.

b. For ($\overline{X}$ and R) and ($\overline{X}$ and S) charts, subgroup sizes of four or five are usually satisfactory. Smaller subgroup sizes may be used if the cost of sampling and testing is high (e.g., destructive testing). Smaller subgroups may also be used if the process is highly capable, namely, the process variability is very small such that the chance of producing out of specification product is very low. The converse is also true. For sample sizes of four or five, the $\overline{X}$ chart will look reasonably normal regardless of the shape of the original distribution (for most distributions).

c. For individual X and moving range charts the subgroup size is one.

d. For np and p charts, the subgroup sizes should generally be at least fifty. For both p and np charts the subgroup size should be large enough so that the process is not considered to be out of control upon finding one nonconforming unit. One recommendation for np and p charts is that the minimum subgroup size satisfy

$$n\bar{p} > 3$$

where n is the sample size. [24]

e. For the c chart, the subgroup size can be any number provided it is constant. For the u chart, the subgroup size can be any convenient number. For both c and u charts, the subgroup size should be large enough so that the process in not considered to be out of control upon finding one nonconformity.

5.6.5 Rationale for sampling frequency. Selecting the appropriate sampling frequency (i.e., the interval between subgroups) is as important a decision as selecting the subgroup size. Sampling frequency may be expressed in terms of time or as a proportion of units produced, such as one subgroup after every 200 units produced. Sampling frequency influences the speed with which process changes are detected and also affects the cost of sampling. The following factors should be considered:

a. Rapidity of process changes. The smaller the interval between inherent process changes, the smaller the interval between subgroups.

b. Relative variability of the process. If the process variability is very small and the chance of producing an out of specification product is negligible, then such a process may be monitored infrequently. This is so particularly if the cost of sampling and testing is high.

c. Initial data collection. At first, it may be desirable to sample frequently to arrive at conclusions quickly. After sufficient process knowledge is gained, it may be advisable to reduce the frequency of sampling.

d. Potential non-conforming product. How much product a supplier can afford to produce, between the beginning of a change in process average and the detection of that change should influence the sampling interval. This relates to factors such as production rates, and inspection and rework costs.

5.6.6 SPC for short run production. Because current SPC methods require 20-25 subgroups of data (typically 2-5 items per subgroup) to be collected before calculating control limits, many suppliers have difficulty in applying traditional SPC methods. A production run may not produce enough data to generate meaningful control limits.

Several SPC concepts that work well with very short production runs (some with a lot size of only one piece) allow every organization to take advantage of the power of SPC methods, even when lot sizes are small. Different part numbers may be monitored on the same chart. Multiple process streams or characteristics can be plotted together on one chart, minimizing paperwork for the operator and maximizing process understanding. Short Run charts work with either variable or attribute type data. If the process parameters selected demonstrate statistical control, and these can be directly correlated with the key product characteristics, including inspection results data, this may suffice. Under the "process-focus" concept from Paragraph 4.3, if the inputs and defined steps or actions are held in statistical control, the assumption is that the output of the process will also be in control. This assumption must be periodically verified. [11,12]

5.6.6.1 Control charts for short run production - variables data.

a. The Nominal $\overline{X}$ and R Chart is often used in short run situations to monitor the behavior of a process running different part numbers and still retain the ability to assess statistical control. This is done by coding the actual measured readings in a subgroup as variations from a common reference point, in this case the nominal print specification for the part number being run. This nominal value becomes the zero point on the $\overline{X}$ control chart scale.

b. The Target $\overline{X}$ and R Chart is often used when the process should not be centered at the nominal print specification. For example, if it is desirable to run the process average at some value other than the nominal value, or if the specifications are unilateral (either a minimum or maximum only). If either case happens, use the historical process average of a part number as the target X-double bar value (in place of the nominal) and measure the variation of future pieces from this target. Since this target value is used, this control chart is called the Target $\overline{X}$ and R Chart.

c. The Short Run $\overline{X}$ and R Chart can be used when the $\overline{R}$'s for different part numbers are significantly different. [24,25,26,27]

d. The individual X and Moving Range Chart (IX & MR) can be used when only one piece is to be measured. This chart allows operators to use the power of SPC to improve quality and maintain uniformity of these processes. This chart has special definitions, symbols and formulas.

e. The Moving Average and Moving Range Chart has tighter control limits and is more sensitive to shifts in the process than control charts for individuals.

5.6.6.2 Control charts for short run production - attribute data.

The traditional SPC charts for attribute data suffer from the same problems as do the traditional variable data charts in that they are designed to monitor only one part number per chart. However, by using the proper data transformation, different part numbers can be plotted on the same short run attribute chart by standardizing the data. [25]

5.6.7 Control chart auditing.

a. A party independent of the production process being audited should regularly, preferably once each shift, inspect SPC charts for each operation where SPC is used for Final Acceptance

b. The inspection should be accomplished with the use of a checklist. A sample checklist is shown in APPENDIX G.

5.7 Assess stability, capability, and performance.

5.7.1 Stability.

5.7.1.1 Introduction. A process is said to be operating in a stable manner (that is, in statistical control) when all special causes have been eliminated from the production process to the extent that substantially all the points plotted on the control chart(s) remain within control limits and exhibit no unusual trends or patterns. The only sources of variation remaining in a stable process are from common causes.

5.7.1.2 Criteria (interpretation). Interpreting control charts involves determining when special causes are present and diagnosing the reasons for them so that they can be removed, or if beneficial, incorporated into the process. Examples of the latter include downward shifts or trends on R charts and attribute charts when caused by process improvement.

The following is one commonly used set of criteria [7,13] that indicates a process is not behaving in a stable manner (i.e., out-of- control) or that the subgroups are not rational. When one of these criteria is signaled, it means that the plotted results are unexpected and that special causes of variation are present. These special causes, when identified, should be noted on the charts. Not all criteria have to be used in all cases. Other criteria may also be used.

Test 1. A point outside the control limits

Test 2. Nine points in a row on one side of the centerline

Test 3. Six points in a row steadily increasing or decreasing

Test 4. Fourteen points in a row alternating up and down

Test 5. Two out of three successive points in Zone A (area between +2 and +3, or –2 and –3 standard deviations) or beyond, on the same half of the chart

Test 6. Four out of five successive points in Zone B (area between +1 and +2, or –1 and –2 standard deviations) or beyond, on the same half of the chart

Test 7. Fifteen points in a row in Zone C (area between the centerline and the +1, or the centerline and –1 standard deviations), above and below the centerline

Test 8. Eight points in a row with none in Zone C (above and below the centerline) Note: for attribute charts (p, np, c, u) only tests 1,3, and 4 should be applied.

5.7.1.3 Verification. A stable process can be verified by drawing the data points on a control chart and examining its statistical behavior. If the chart does not manifest any of the criteria in paragraph 5.7.1.2, the process is stable and thus in a state of statistical control. Many processes, because of a large amount of common cause variation, have wide control chart limits and are not very sensitive to the presence of special causes. Improvement comes from continuous study of variation, identifying the common causes, and acting to reduce the effect of these common causes.

5.7.2 Capability. In MIL-STD-1916, as in other standards in the past, C_p and C_{pk} were both called Capability indices. More recent practitioners have labeled C_p as a capability index (which answers the question, “Is the process capable of meeting the specification?”) and C_{pk} as a performance index (which answers the question, “Is the process actually meeting the specifications?”). This handbook follows the latter usage.

5.7.2.1 Introduction. Process capability is determined by the variation that comes from common causes. Capability refers to what can be predicted from a stable process. The capability index of a process compares the process variation to the specification limits. The capability index alone does not indicate whether the process is actually meeting the specification limits or not. A capability value should only be calculated from data that is in statistical control and from a known distribution.

Capability indices can be broadly grouped into two categories: short-term and long-term. Short-term capability studies are based on measurements collected from one operating run. If no special causes are found on the control charts, the short-term capability can then be calculated using the control chart data. This type of study is often used to validate the initial parts produced from a

process for customer submission. Another use, sometimes called a machine capability study, is to validate that a new or modified process actually performs within the engineering parameters.

When a process has been found to be stable and capable of meeting requirements in the short-term, a long-term capability study can then be made. [28] This involves a collection of measurements over a longer period of time. The data should be collected in a way to include all expected sources of variation. Many of these sources of variation may not have been observed in the short-term study. The data must truly represent the entire process. One use for this study is to describe the ability of the process to satisfy customer requirements over long periods of time with many possible sources of variation included - i.e., to quantify process performance.

5.7.2.2 Process capability index = C_p = (USL-LSL)/(6 sigma). This index of capability requires two specification limits and assumes a normal distribution of individuals. The calculation of this index does not require the process to be centered between the specification limits but it does reveal the potential capability of the process as if it were centered. A C_p calculation should be accompanied by a C_{pk}. (See paragraph. 5.7.3.2.) [29]

5.7.2.3 Capability of non-normal distributions. In the strict sense of a capability study, the shape of the distribution is not as important as how it compares to the engineering specification. However, when expressing process capability as a numeric value, like C_p or C_{pk}, it should be understood that these values are dependent on the normal distribution for their interpretation.

If after using the methods of paragraph 5.5.2 (Tests for Normality), it is found that the distribution does not approximate a normal distribution, there are alternative methods which will lead to a valid process capability evaluation. These methods should only be used after an investigation of the special sources (causes) of variation has been conducted and documented:

Visual inspection of a Histogram
Transformation of data (e.g., log transformation, Johnson transformation, etc.)
Determination of whether any part of the non-normal distribution, that includes 99.7% of the distribution, has a width less than the quantity (USL-LSL). If the distribution has no such section, it is not capable.

5.7.2.4 Capability for one-sided specifications. C_p has meaning only for two-sided specifications. Potential capability, however, could be spoken of if there exists a target value and one specification limit. For example, if C_{pt} is calculated as C_{pt} = |spec limit - Target|/(3 sigma), this would yield the potential capability if the process is considered to be centered on the target value.

5.7.2.5 Verification. The C_p values should be verified as often as is necessary. If the Cp values are equal to or less than one and one-half (1½) times the minimum acceptable values, i.e., 2.0 for majors, 1.5 for minors, etc., the C_p's should be verified on at least a monthly basis. If the C_p's are greater than one and one-half times the minimum values, significant changes can be determined by visual examination of the dispersion chart. In these cases verification by calculation should be performed at least every six months.

5.7.3 Performance.

5.7.3.1 Introduction. The performance index determines how well the process is actually performing relative to the specification limits. [18,29]

5.7.3.2 Index. One common performance index for a normal distribution is C_{pk} = the minimum of (process average – lower spec limit)/(3 sigma) and (upper spec limit – process average)/(3 sigma).

C_p and C_{pk} should be used together. If a process has a good C_p and a poor C_{pk}, it may only require a shift in the process average. If both are poor, then the process variability must be reduced.

Another performance index sometimes used is P_{pk} where, P_{pk} = the minimum of (process average – lower spec limit)/(3 sigma of all values) and (upper spec limit – process average)/(3 sigma of all values). "All values" means all of the individual values sampled. For example, these individual values can come from all of the subgroup individual values from a control chart or from a broad sampling of an overall population. The latter should be used with caution since the process that produced the parts may not have been in statistical control.

5.7.3.3 Performance for non-normal data distributions.

Method 1. The parameters of the distribution which best fits the data are estimated first. Then a check for goodness of fit is made. If fit is not rejected, the area under the curve in the region outside of the spec limits is estimated. The percent nonconforming or, alternatively, the parts per million (ppm), is the estimate of performance of the process.

Method 2. The data is transformed into a normal distribution (see paragraph 5.5.3). The resulting numbers will then be normally distributed and the performance can be calculated using the C_{pk} formula above.

Method 3. If enough attribute data has been collected, an estimate of the performance can be calculated by simply dividing the number of items out of spec by the number of items inspected. For example, if 3000 units have been inspected in order to plot 750 means of size four on an xbar chart, and 30 of those units are observed to have been out of spec, then an estimate of the performance is that the process is 30/3000 or 1% defective. Similarly, if a p-chart has been plotted and after 10,000 total individual units have been inspected, 250 are classified as defective, then the process average is 250/10000 = pbar = .025 = 2.5% and this is an estimate of the process performance.

5.7.3.4 Verification. C_{pk} values should be verified as often as is necessary. If the C_{pk} values are equal to or less than one and one-half (1½) times the minimum acceptable values, i.e., 2.0 for majors, 1.5 for minors, etc. (see paragraph 5.9.1), the C_{pk}'s should be verified on at least a monthly basis. If the C_{pk}'s are greater than one and one-half times the minimum values, significant

changes can be determined by visual examination of the charts. In these cases verification by calculation should be performed at least every six months.

5.7.3.5 Economic positioning of process. Sometimes targeting the process in the middle of the specification limits is not practical. Process owners must often make decisions to target their process where an optimum economic condition is achieved. This decision is sometimes based on the unique characteristics of the process, tooling, requirements, etc. In some situations, geometrical dimensioning and tolerancing may have been applied to a feature. In the case of a hole diameter for a bolt hole pattern, if the process is capable, it is logical to drill the hole to a diameter that approaches the upper specification limit. This allows the process owner to benefit from the bonus tolerance, consistently achieve the proper hole alignment of the two parts and still have a capable process.

A statement that covers the rationale for making this kind of economic positioning decision should be included in the organization's general SPC plan. This will assist in supporting seemingly low C_{pk} values.

5.7.3.6 Continuous improvement prioritization. The goal of an organization should be to continually improve and optimize its processes. This is accomplished through the use of continuous improvement tools and using SPC as a means to monitor the process. Part of the knowledge of the continuous improvement process is knowing when sufficient capability has been achieved to warrant focusing the organization's resources on other opportunities for improvement. A statement that covers the rationale for making this kind of decision should be included in the organization's general SPC plan.

5.7.4 Other measures. Other indices used in describing capability/performance include C_{pm}, CPU, CPL, C_r, and more. [30,31] In general, both the producer and the consumer should agree on the "operational definitions" and usage of such indices. It is important to understand the strengths and shortcomings of an index before its use, especially in contractual situations.

5.8 Gaging and measurement. It is very important to have valid measurement studies to ensure that the data and measurements collected are accurate and precise. There are a number of methods used to determine validation of the measuring system. Some of the commonly used techniques are:

a. The original Gage R&R study used by the Automotive Industry [32]
b. The Modified Gage R&R Study in the AIAG Manual [33]
c. Measurement Study using Analysis of Variance (ANOVA)
d. The use of the Intraclass Correlation Coefficient (ICC) and Discrimination Ratio [34]

The supplier should state the method to be used and the acceptable limits of variation of the measurement system.

Measurement standards deteriorate in accuracy and precision during use. Maintaining the required amount of accuracy requires a continuing system of calibration control. Examples of calibration programs can be found in ANSI/NCSL Z540-1 [35] and ISO 10012. [36]

5.9 Final acceptance by SPC.

5.9.1 Requirements for acceptance. Prior to utilization of SPC for Final Acceptance of a characteristic, the controlling process(es) should have demonstrated statistical control and a minimum C_{pk} (or equivalent) of 1.00 for minor, 1.33 for major, and 2.00 for critical characteristics. The process(es) should be in control for a period long enough to assure that all the causes of variation have been represented and special causes of variation, (i.e., the environment, different machines, different operators, etc.), have been eliminated. The plan submitted by the supplier (see paragraph 4.1.2.b of MIL-STD-1916) should provide for periodic verification of process stability and capability.

5.9.2 Actions for acceptance by SPC.

a. A parallel run of SPC and Final Inspection should be performed to validate the SPC data. These results should be submitted to the customer for review.

b. The SPC data being collected should be audited in accordance with a formalized audit plan.

c. Only properly trained personnel should construct and interpret control charts.

d. If a significant lapse in production occurs, a capability study should be performed before continuing Final Acceptance with SPC. The process C_{pk} should be the values in paragraph 5.9.1 as a minimum.

e. Provisions should be made for response to, and documentation of, out-of-control conditions.

5.9.3 Customer report generation. A myriad number of SPC activities can be tracked to develop internal metrics and generate customer reports. Internal metrics are typically calculated and published on a monthly basis. This data is then accumulated into a customer report and submitted per the contract. Typically, this is on a quarterly basis. [8,37,38]

Examples of customer reports are as follows:

- Total number or percent of processes utilizing SPC broken out by variable and attribute.
- Total number or percent of processes evaluated/flowcharted for use of SPC.
- Total number or percent of processes having process capabilities (C_p) and process performance (C_{pk}) indices broken out as follows:

< 1.33
≥ 1.33 but < 2.00
≥ 2.00

- Percent of vendors with approved SPC plans.
- Percent of employees trained in SPC techniques, broken out by job function.
- Number of characteristics submitted and approved where SPC was utilized for product acceptance in lieu of sampling inspection.

5.9.4 Submission to the customer. Figures 1, 2, and 3 describe the steps to be followed in submitting an alternate methods of acceptance plan.

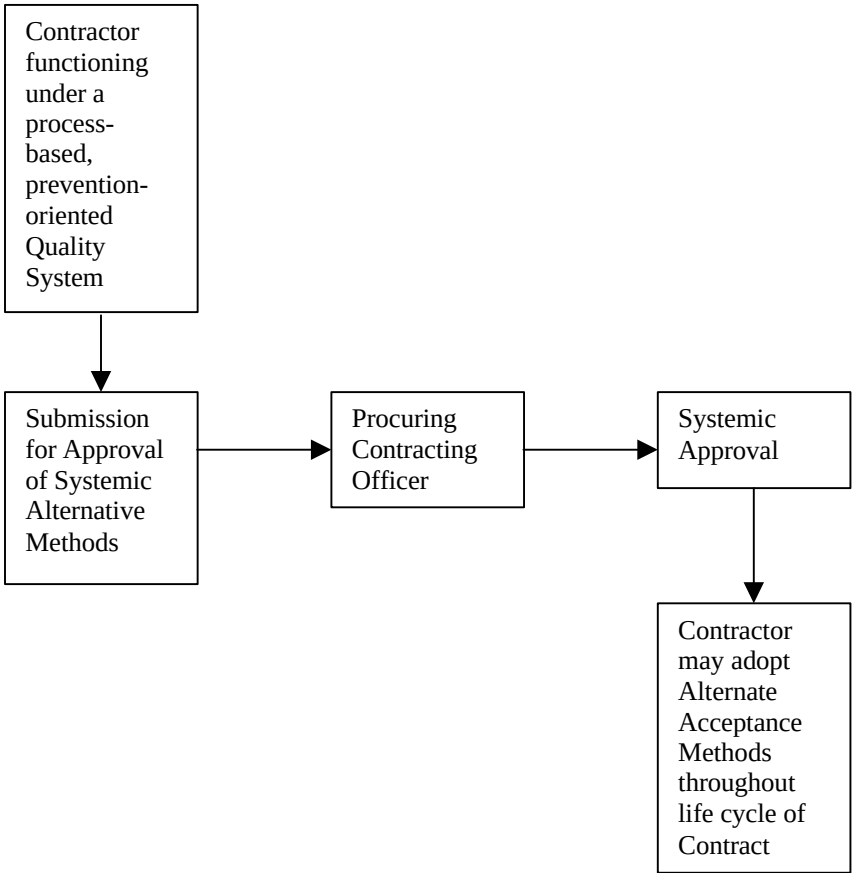

FIGURE 1. Submission for systemic approval before contract award

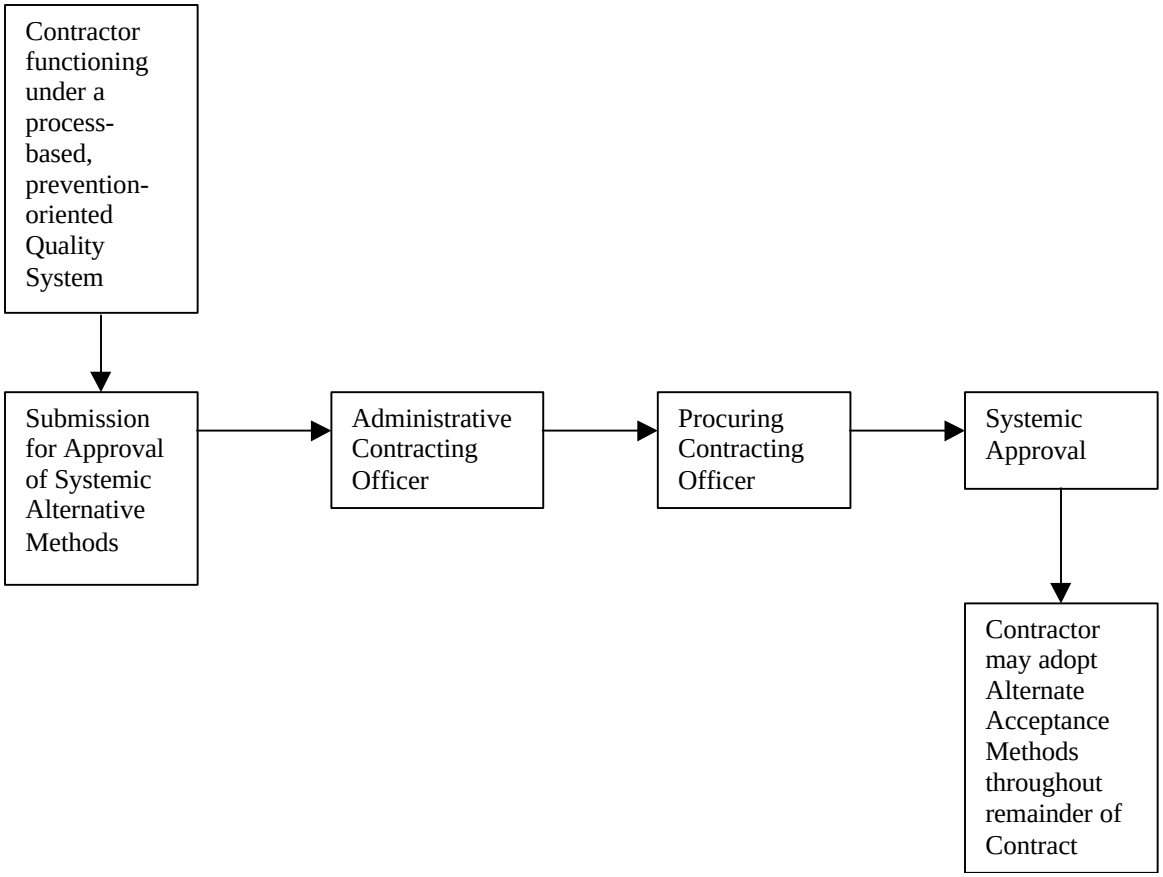

FIGURE 2. Submission for systemic approval after contract award

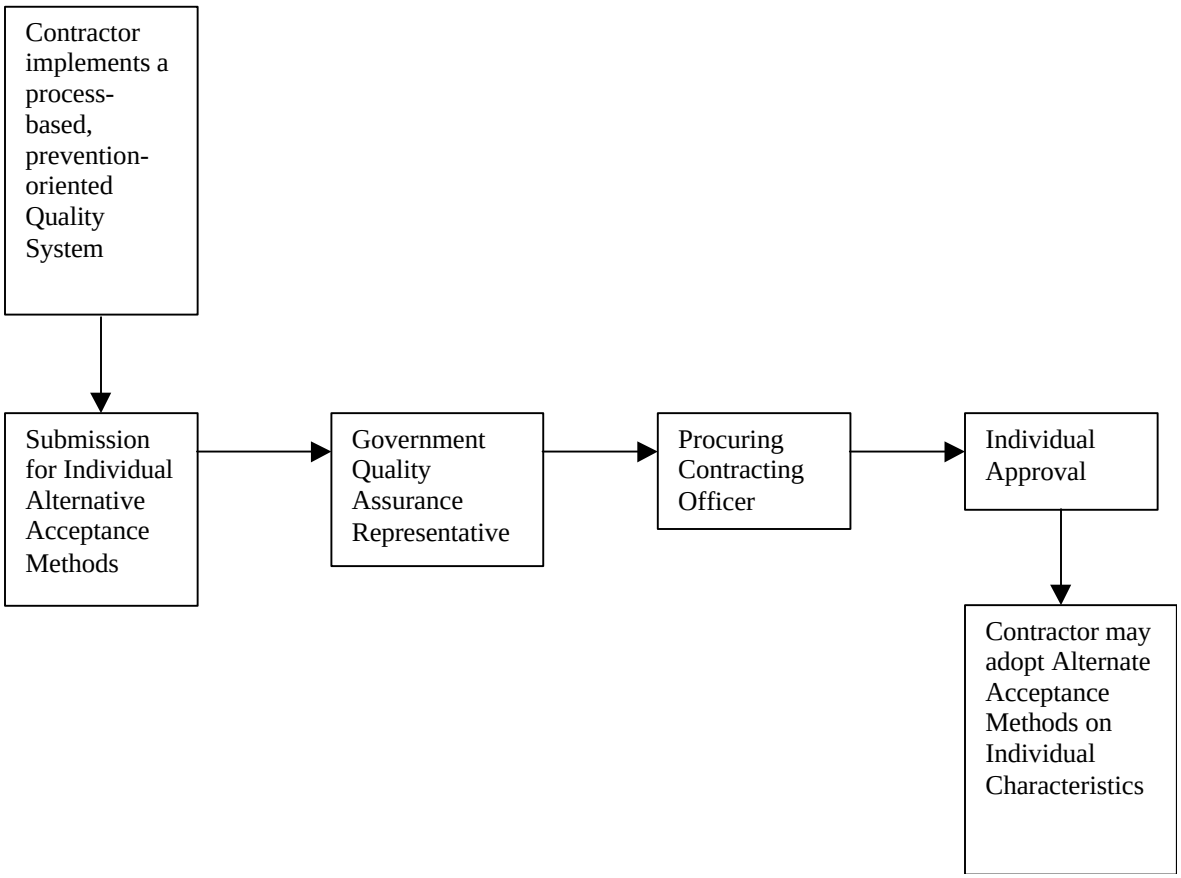

FIGURE 3. Submission for individual approval at any time during contract

Section 6: ACCEPTANCE BY OTHER METHODS (NEITHER SPC NOR MIL-STD-1916 SAMPLING TABLES)

6.1 General. Although MIL-STD-1916 focuses on statistical process control and acceptance by the AoZ Tables when SPC is not possible, it is recognized that other product acceptance methodologies are also viable. Examples of these other acceptance techniques include Poka-Yoke, calibrated fixtures as a media of inspection, 100% automated inspection, tool control, etc. Any supplier-proposed acceptance plan must demonstrate that it provides customer protection that is equal to or greater than the acceptance provisions of the standard. Effectiveness of the plan should also be periodically demonstrated and verified by the supplier. The acceptability of the supplier-proposed plan is dependent upon the existence of a quality system, the demonstration of its process focus, and the availability of objective evidence of the effectiveness of the proposed plan. (See paragraph 4.1.2 of MIL-STD-1916.)

6.1.1 Poka-Yoke or mistake-proofing. Poka-Yoke is a Japanese term that generally translated means “mistake-proofing” or “fail-safing”. Poka-Yoke is an approach that uses techniques or devices that prevent production errors or prevents movement of product with errors to the next step in the production process. [5,9] Even if an error occurs, Poka-Yoke will prevent nonconformances or halt the process. The types of Poka-Yoke devices are:

a. Source inspection to avoid errors at their source – before they cause nonconformities. An example is an additional locator pin to prevent misalignment of the workpiece.

b. 100% inspection for nonconformities using an inexpensive sensing device such as a limit switch.

c. Immediate action to stop operations when an error is detected, such as an interlocked circuit that automatically shuts down the machine.

If Poka-Yoke is used as an alternate means of acceptance, it must be periodically audited to assure its continued effectiveness. [39]

6.1.2 Calibrated fixtures as a media of inspection. Production Tooling Used as Media of Inspection. When production jigs, fixtures, tooling masters, templates, patterns and such other devices are used as media of inspection, they shall be proved for accuracy prior to release for use. These devices shall be proved again for accuracy at intervals formally established in a manner to cause their timely adjustment, replacement or repair prior to becoming inaccurate.

Sometimes contractors elect to use production tooling for inspection and gaging. In such cases, they should take special precautions to assure accuracy. This involves both proof of accuracy before release for use as well as checking at regular, formally established intervals thereafter to prevent inaccuracy. Some equipment used for special manufacturing operations contains

automatic gaging controls which are considered a part of a contractor's product quality control system.

6.1.3 100% automated inspection. This system must be verified as to the accuracy of the inspection and its fail-safe feature.

PART B: SAMPLING INSPECTION TABLES

Section 7: GENERAL

7.1 Why c=0? The question of why the Table II plans of MIL-STD-1916 all have an accept number (c) of zero is often asked. The accept-on-zero (AoZ) plans in this standard were formulated with a clear understanding of the following points: a), observance of zero nonconformances in a sample does not imply that the population is perfect; b), expectation of no nonconformances in an entire population of product can be unreasonable; and c), AoZ plans may not be as discriminating as non-zero-plans. It is nevertheless desirable to use sampling plans that accept on zero nonconformances for the reasons given below.

a. Customers generally do not like to give the perception that some small level of percent nonconforming product is acceptable or even tolerable. Whether intended or not, when a sampling plan of, for example, n=100, accept-on-one is used, how could a supplier not get the impression that the customer would be perfectly satisfied, if not elated, to receive product that is, say, 1% nonconforming?

b. If the user really expects product whose quality level is nearly perfect (say, for example, 0 to 20 ppm nonconforming), then allowing one or two nonconformances in a sample of n=50 or n=100 would be inconsistent with the user's wishes. It would seem to contradict the claim that the population is of a low ppm nonconforming level.

c. Use of non-zero-one plans of themselves do not foster a desire on the supplier's part to continuously improve. If the supplier knows that a certain percent nonconforming is acceptable, there is little incentive to continuously improve.

It should be understood that if AoZ plans are used as a "stand-alone act", one could expect that the only possible way higher quality levels would be attained would be because of the supplier's fear of excessive lot rejection. The big picture is that process controls are what is needed to stabilize, monitor, and improve processes. Process controls are then accompanied by AoZ plans, if necessary, to verify or "spot check" that the process controls are indeed working. AoZ plans are also needed when the process controls are not yet in place or have not yet reached a mature level. The intent of MIL-STD-1916 and this Handbook is that process control is of primary importance; AoZ plans are secondary.

7.2 Background of tables. The purpose of the tables is to provide an alternative acceptance method to the preferred method of acceptance by SPC. As such, the (acceptance by) table method ought not to be construed as a preferred method. See Appendix E for further information.

7.3 Risk equivalents/OC curves. Tables were developed showing, for each plan: 95%, 50%, and 10% points on OC curves; AOQL (at p% incoming); AFI (at p=0%). OC curves, AFI curves, and AOQ curves are also provided in this handbook (See Appendix D). [7,19,21]

Section 8: PLANNING FOR SAMPLING

8.1 Classification of characteristics. There are three traditional classifications of characteristics used in inspection and test: Critical, Major, and Minor. These are defined in MIL-STD-1916.

8.2 How to select verification levels. For Critical Characteristics - VL VII should always be used. This inspection is a verification of the automated screening or fail-safe manufacturing operation implemented in accordance with paragraph 4.4 of MIL-STD-1916. Majors should typically use VL levels between III and VI. Minors should typically use VL levels between I and III. The more important the characteristic is, the higher the VL. Lower VL's may also be considered where relatively small sample sizes are necessary and large sampling risks can or must be tolerated as, for example, when inspection costs are high. If no VL is specified, then VL IV for majors and VL II for minors should be used.

8.3 Sampling of group characteristics vs. individual characteristics.

8.3.1 Table II attribute plans and Table III variable plans. If several characteristics of a product have the same verification level (VL), one sample can be taken and used for the acceptance or non-acceptance of the entire group of characteristics.

8.3.2 Table IV continuous plans. If several characteristics of a product have the same VL, the entire group of characteristics can be inspected on each unit whether that unit is on sampling or screening. Agreement then has to be reached ahead of time regarding what action to take upon finding a nonconformity . For example, while under the sampling mode a nonconformity is found for characteristic #3 of 7 characteristics. Either all 7 characteristics can be screened, or screen only characteristic #3 while keeping the rest on a sampling basis. This decision, made beforehand, involves many factors such as cost, time, record keeping, etc. . The disadvantage of having some characteristics on screening while others are on sampling, is the increase in record keeping and possible confusion as to the status of each characteristic at any point in time. This is especially true if different characteristics are at different points with regard to clearing the "i" number.

8.4 Limitations of use. Customers may impose limitations/ modifications of MIL-STD-1916 via the contract or specification. The specification may say, for example, that the supplier shall use only plans from Table III (variables) and not have the option of using Table II or IV plans. For that matter, the specification may, in certain instances, state that only acceptance by tables will be used.

If modifications are made to the sampling tables (e.g., using code letters other than those specified by Table I of MIL-STD-1916), this will change the levels of protection depicted by the curves of Appendix D for a particular lot size.

Section 9: USE OF THE SAMPLING TABLES

9.1 Assumptions/prerequisites for each table.

9.1.1 Table II - Attributes sampling plans.

9.1.1.1 Random Sample. The use of this table requires a random sample or a stratified random sample.

9.1.1.2 Stratification. While the formation of lots must comply with the general homogeneity requirements of paragraph 4.2.2 of MIL-STD-1916, in practice, lot formation is often a subjective decision. As confidence in a process increases, and if allowed by the contract, suppliers may decide to increase the lot size by including product from multiple qualified sources (multiple raw material lots or multiple machines, tools or operators, etc.) in the same lot. When lots include product from multiple sources (strata), and stratified sampling is used, the sample from each source (stratum) should be randomly selected. If the lot is comprised of strata, there are three options:

a. Take one random sample and pass/fail the lot on the basis of that one random sample.

b. Take a stratified sample where the sample size for each stratum is in the same proportion to the total sample size as the size of the stratum is to the total lot size. The entire lot is passed or failed based upon the results of the total sample.

c. Take a stratified sample where each stratum is treated as a separate lot. A sample size is picked for each stratum using Tables II and III of MIL-STD-1916 and each stratum passes or fails its sampling plan individually.

9.1.2 Table III - Variables sampling plans.

9.1.2.1 Random sample. The use of this table requires a random sample or a stratified random sample.

9.1.2.2 Stratification. If it is known that the various strata are statistically significantly different, then the lot is not homogeneous, and the procedure of MIL-STD-1916 should not be applied as if it were one lot. Each stratum must be treated as if it were a separate lot.

9.1.2.3 Normal distribution. The data must be normally distributed or transformable into a normal distribution. If the data is transformable into a normal distribution, the transformation of the data and of the specification limits must be done before table III is used.

9.1.3 Table IV - Continuous sampling plans.

a. The product being made and inspected must be a moving product.

b. Ample space, equipment and personnel must exist at or near the site of inspection to permit rapid 100% inspection when required.

c. The process must be producing, or be capable of producing, material whose quality is stable - i.e., all units of product are made according to the same drawings and specifications under stable conditions of production. This requirement is termed homogeneity. It is usually satisfied when the production process is not altered by innovation, significant changes in materials, strikes, non-routine retooling, or interruptions other than those due to the end of the shift, day or week.

9.2 Switching rules - logic and background.

a. The rules for switching only apply to the three sampling categories in the standard - normal, tightened, and reduced. If the criteria are met, sampling can go from normal to reduced or tightened, reduced back to normal, or tightened back to normal. Sampling cannot go from one reduced level to another or from one tightened level to another. (See Figures 4 and 5).

b. Unless otherwise specified in the contract, the normal stage of inspection is used at the start of inspection. For continuous plans inspection starts at normal screening.

c. Continuous sampling switching while in continuous sampling is based on the rules for switching during lot or batch sampling. If a nonconformance is found any time during sampling, screening is initiated. If two nonconformances are found within $5xn_a$ (N), regardless of whether the $5xn_a$(N) units are from screening or sampling, tightened inspection is invoked.

d. Continuous examples. All of the cases below make use of Table D below. Note that n_a(N) and n_a(T) come from Table II - Attributes Sampling Plans (MIL-STD-1916).

CASE 1. VL IV, Code letter D, normal screening. 815 consecutive good units have just been found. Go to normal sampling (1/34).

CASE 2. VL IV, Code letter D, normal - on screening for the first time. If two nonconformances are found within 800 units of product, switching is made to tightened screening (i.e., i = 1714).

CASE 3. VL IV, Code letter D, normal - just came to screening from sampling because a nonconformance was found on sampling. If a second nonconformance is found within the next $5xn_a$(N) units (i.e., 5x160 = 800 units) on screening, a switch is made to tightened screening.

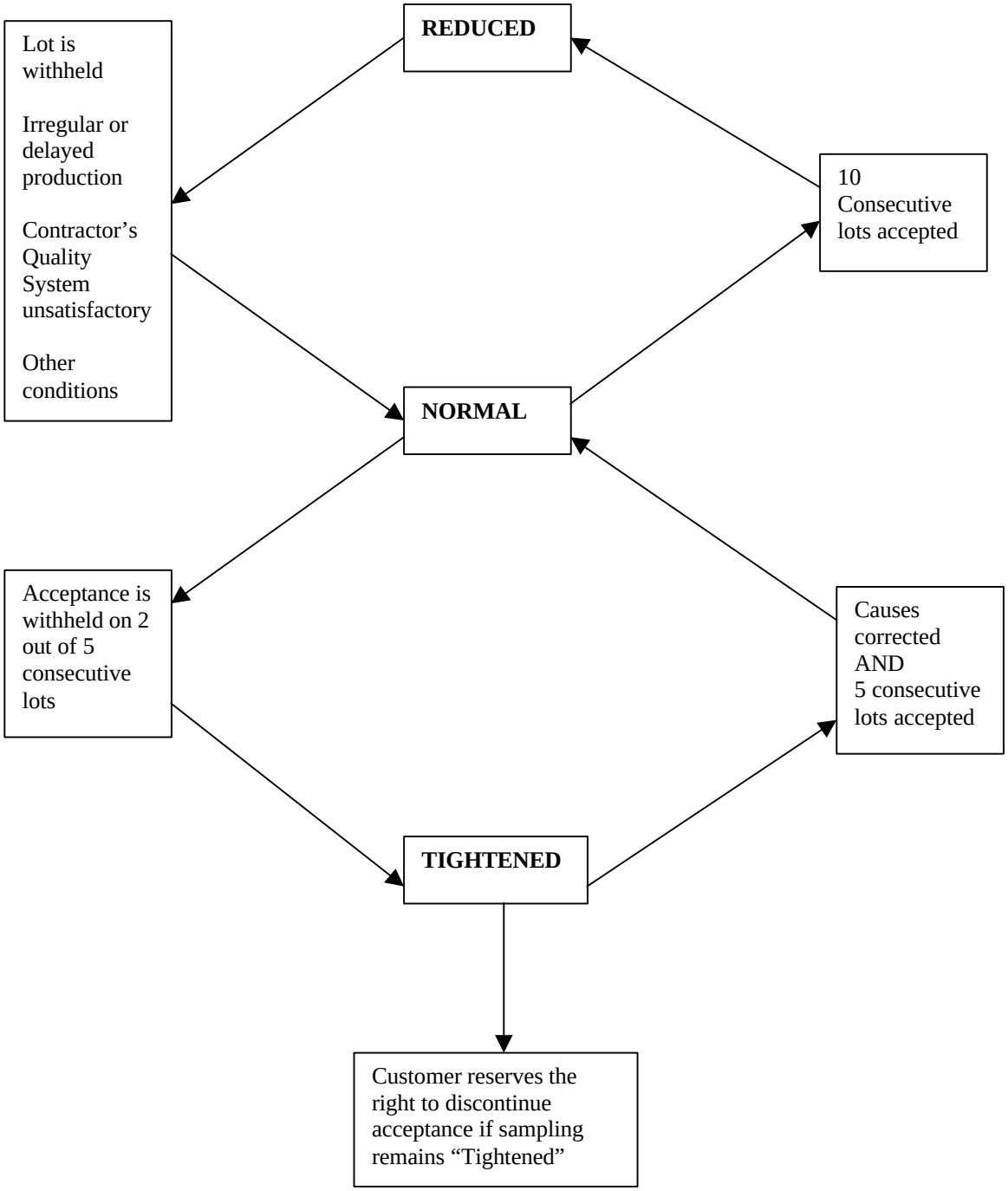

FIGURE 4. Switching rules for lot or batch sampling.

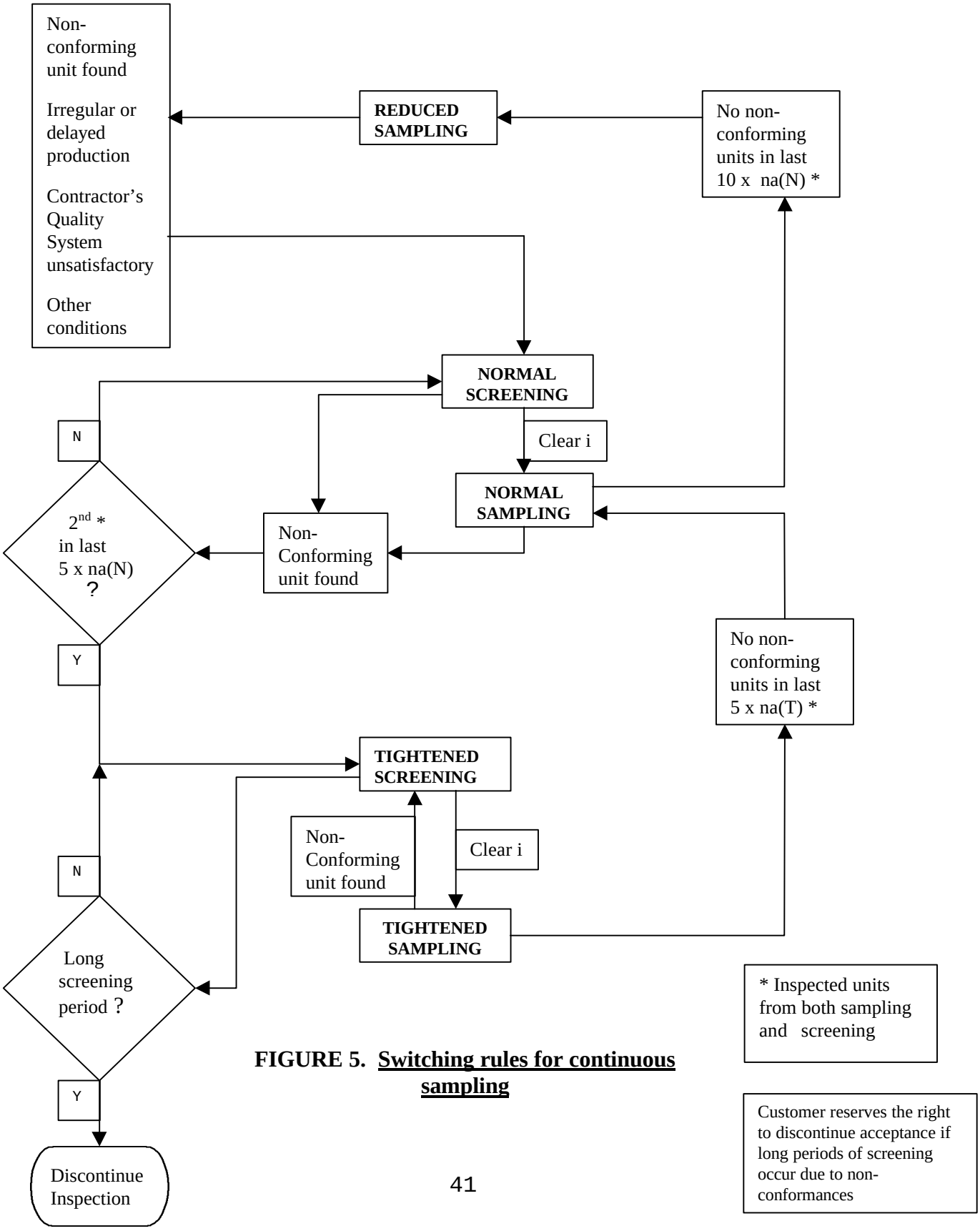

FIGURE 5. Switching rules for continuous sampling

While on tightened screening, if the i number of 1714 is cleared, then the switch is made to tightened sampling (1/24).

TABLE D. Values for CASES 1-7.

	Verification Levels								
	T	VII	VI	V	IV	III	II	I	R
I	16827	8411	3957	1714	815	368	155	73	NA
F	2/17	1/12	1/17	1/24	1/34	1/48	1/68	1/96	1/136
n_a (N)	6144	2560	1024	384	160	64	24	10	4
$5xn_a$(N)	30720	12800	5120	1920	800	320	120	50	20
$10xn_a$(N)	61440	25600	10240	3840	1600	640	240	100	40

CASE 4. VL IV, code letter D is in effect and a nonconformance is found while doing the 1/34 sampling. A screen of 815 parts is required before sampling can be resumed. If, during the screen, a second nonconformance is discovered before the 800th (5x180) part, tightened inspection must be invoked. This means that the screening number becomes 1714 instead of 815. This new screen number starts with the first good part found after the last nonconformance. Switching back to normal sampling is allowed when 1920 (5x384) good parts have been screened. The 1714 parts screened, to allow resumption of sampling inspection, count as part of the 1920. The remaining 206 parts required to switch back to normal inspection would come from the 1/24 sampling inspection, i.e., 206 samples from 4944 parts.

CASE 5. VL IV, Code letter D, normal sampling (1/34). 1600 consecutive good units have just been found (815 while on screening + 785 good units found from 26,690 units produced during sampling). A switch is made to reduced sampling (f=1/48).

CASE 6. VL IV, Code letter D, presently on reduced sampling (f=1/48). A nonconforming unit is found. A switch is made to normal screening (i = 815).

CASE 7. VL III, Code letter D, presently on normal screening (i = 368). After the first nonconforming unit had been found (either on sampling or on screening), a second nonconformance is found within $5xn_a$(N) units (i.e., within 320 production units of the first nonconformance). Tightened screening is then entered (i = 815). While on tightened screening, 800 consecutive good units are found, thereby qualifying the process to go back to normal sampling. But in this case, the i number must be cleared first. In other words, it is only allowed to go back to normal sampling from a tightened screening status if the tightened i number has been cleared and $5xn_a$(T) consecutive good units have been found.

9.3 Disposition of lot/batch where customer acceptance is withheld.

a. The decision on what to do with a quantity of goods when the inspection results or the objective evidence fails to meet the acceptance criteria can be a complex process. The most frequent outcome, however, is simple: the customer refuses to take the goods and refuses to make payment and the supplier either scraps the goods or tries to sell them to another customer, usually at reduced prices.

b. This outcome may not be reasonable for either party in some circumstances. Some examples are: the customer may absolutely need the product and has no other sources that can provide the goods in a timely, economical manner; the supplier may have no other customers for the product and the economic loss from scrapping the goods is too high; the objective evidence may show a deviation from the acceptance criteria small enough to make the product useful to the customer.

c. In these situations, there may be negotiations between the customer and the supplier that extend outside of the initial scope of the contract, and the scope of MIL-STD-1916. The following paragraph (9.3d), lists examples of the types of events/considerations that can occur in the negotiations. They are provided for information, but with a strong caution: the customer's contractual obligations stop when a lot/batch fails the acceptance criteria, and all subsequent actions are, in essence, modifications to the contract.

d. Acceptance/rejection of the lot with known nonconformance(s): Disposition actions can depend on the frequency, nature, and severity of the nonconformance and the degree of fitness for use of the nonconforming unit. Customers often delegate their decision authority to their representatives on minor characteristics, and merely monitor that decision process for adequacy. In military contracts, this is reflected in sections that define the "Materiel Review Board" process. For major and critical characteristics, the customer will rarely permit its representatives to make disposition decisions. A proposed modification to the contract may then take the form of a "Request for Waiver", if submitted by the supplier, and approved by the customer. Disposition actions could include, but are not limited to:

(1) Outright rejection of the lot: the nonconformance exists throughout the lot and there is no feasible means available to screen the lot or for rework or repair of the nonconformance, the entire lot may be scrapped.

(2) "Use as is": the degree or frequency of nonconformance is deemed not to impact product utility sufficiently to make it unusable to the customer. Note that when this decision is made routinely, it is likely that the requirement is too tight, and should be reviewed.

(3) "Repair/Rework": corrective actions on nonconforming units. Generally, the customer wants a voice in the rework or repair procedures to assure that product quality is not degraded in any way.

(4) Full, partial, or zero screening of the lot/batch:

The screening requirement of MIL-STD-1916 can also be an area of negotiation.

The customer may decide to disallow the supplier's screening and re-presentation of the entire lot/batch if the supplier's screening process is considered suspect by the customer.

The customer may decide to allow the supplier to screen and re-present the entire lot/batch only for the characteristic(s) for which acceptance was withheld.

Alternatively, the customer may allow the supplier to screen and re-present only sub-sets of the lot/batch for the characteristic(s) for which acceptance was withheld. These sub-sets might be isolated nonconforming quantities that have come from identifiable sources. The remainder of the lot/batch could either be accepted outright, or it could be accepted based on the outcome of further sampling.

When screening is expensive, or the test is detrimental to the product in some way, or if the objective evidence or process trends show minimal deviation from the norm, the customer may be willing to consider waiving this requirement. The modification to the contract then may take the form of a "Request for Waiver" by the supplier, prior to a decision being made regarding screening. Disposition of such product should then be based upon review by competent authority, generally the contracting officer. Of course, the screening requirement could also be waived and the product accepted via specification provisions/contractual agreements.

(5) The sample size, the lot acceptance criteria, and any other requirement of the sampling tables of MIL-STD-1916 may also be waived or amended by a contract modification when necessary to meet customer needs. Statistical data, if available, should be considered in making decisions concerning modification of the sampling requirements.

e. Usually the customer will require consideration from the supplier for acceptance of a lot that has not passed the acceptance criteria. In fact, the Federal Acquisition Regulation mandates it for military contracts. The consideration is generally financial, however, it can take other forms of "value". In summary, MIL-STD-1916 covers the process steps up to Product Acceptance. It uses the phrase "Acceptance Withheld" rather than "Rejected" because that point often represents the start of a totally separate process, whereby the customer and the supplier negotiate changes to the basic contractual agreement they have, which was to exchange dollars for a quantity of totally conforming units.

9.4 Examples of use of tables. The Appendix of MIL-STD-1916 and Appendix F of this handbook contain examples of the use of the sampling tables I, II, III, and IV. Continuous examples are also found in paragraph 9.2.d of this handbook.

9.5 Variables sampling – two-sided specification limits with different VL's. When there are two specification limits, and it is found necessary to assign different VL's to them, acceptance by Table III (whether sampling is on normal, tightened, or reduced) is as follows:

a. L and U are defined as the lower spec limit and the upper spec limit respectively. When L and U have different VL's, determine the sample size required by each and select the larger of the two sample sizes.

b. Apply the three-fold acceptability criteria, paragraph 5.2.2.2.3 of MIL-STD-1916:

(1) No nonconforming units (in sample).

(2) Compute the fractions (xbar-L)/s and (U-xbar)/s. Determine the k-values associated with the VL's of L and U respectively. Each fraction must be greater than or equal to the associated k value. Note: xbar and s are both calculated from the larger of the two sample sizes.

(3) Compute the fraction s/(U-L). Determine the F value associated with each of the two VL's. The fraction s/(U-L) must not exceed the larger F value.

9.6 Auditing of MIL-STD-1916 sampling decisions and actions. Both suppliers and customers may choose to audit supplier sampling decisions and corrective actions for compliance to the requirements found in paragraphs 4.2.3 through 4.5 of MIL-STD-1916, and all requirements of applicable sampling tables.

Section 10: NOTES

10.1 Intended use. This document is intended for use by both government and contractor personnel who are using MIL-STD-1916. This handbook provides background and clarifications to the Standard and guidance on how to use the Standard.

10.2 References. References are sometimes cited in the text of this handbook. Where this occurs, it should not be inferred that the reference cited is necessarily the best or the only reference on the matter.

10.3 Subject term (keyword listing).

Acceptance
Attributes
Capability
Continuous
Control
Normality
Performance
Process
Quality assurance
Sampling
Statistical
Variables
Verification

APPENDIX A

SPC SOFTWARE CONSIDERATIONS

A.1 SCOPE. This appendix provides some factors that should be considered in the acquisition of SPC software.

A.2 PURPOSE OF SPC SOFTWARE.

A.2.1 Software and management objectives. SPC Software should support the objectives management establishes for the quality and production systems.

A.2.2 Assessing effectiveness. No matter what SPC software a organization uses, the key to assessing its effectiveness is objective evidence that the software supports the organization's management system.

A.2.3 Convenience. SPC software is used for convenience factors, speed, and accuracy.

A.2.4 Successful usage. The key to successful SPC software usage is real time data gathering, analysis, and action. Ultimately, reliance should be placed upon the people and systems which drive quality.

A.3 SOFTWARE EVALUATION.

A.3.1 End user. Who will be using it?

A.3.2 End use. How will it be used?

a. Data entry/input

b. Plotting, charting, analysis

c. Recalculating limits

d. Response to process condition

e. Summary reports

f. Overall system (SPC) monitoring/maintenance

A.4 SUGGESTED MINIMUM FEATURES. An excellent reference is the annual software issue of “Quality Progress” magazine. [40]

APPENDIX A

A.4.1 Control charts. As a minimum, the SPC software should be able to produce these control charts:

a. Variable charts, such as: X-bar and R, X-bar and S, X and moving R

b. Attribute charts, such as: u, c, p, np

A.4.2 Out-of-control conditions. As a minimum, the SPC software should automatically detect out-of-control conditions using common conventions or rules.

A.4.3 Variable size subgroups. The SPC software should have subgroup sizes which are user configurable.

A.4.4 Control limits. Control limits should be calculated using accepted statistical methods and centerline values should be clearly displayed. The user should specify when (and if) to recalculate the limits.

A.4.5 Subgroups used. User should define what subgroups to use and when to perform calculations.

A.4.6 Out-of control conditions. The software should require that Out-of-control conditions be acknowledged by someone.

A.4.7 Histogram. Software should generate histograms using individual data.

A.4.8 Process capability. During a capability study, the system should warn the user if the process is not stable or not normally distributed.

APPENDIX B

SELECTED PROCESS IMPROVEMENT TOOLS

B.1 Scope. This appendix lists some tools that are useful for process improvement.

B.2 Brainstorming. Brainstorming is a group technique for generating a "shopping list" of ideas about a specific process, problem, or topic. Before starting, everyone in the group should understand the importance of postponing judgment on any given idea until after the brainstorming session is completed. Ideas may be given in either a structured or unstructured setting. [5,6]

B.3 Cause and effect diagram. The "Fishbone", Ishikawa, or Cause and Effect Diagram was developed to represent the relationship between some "effect" and all the possible "causes" influencing it. The effect or problem is stated on the right side of the chart and the major influences or "causes" are listed to the left. [5,7,41]

B.4 Check sheets. Check sheets are simply an easy to understand form used to answer the question, "Are certain events happening and, if so, how often?" It starts the process of translating "options" into "facts". [5]

B.5 Flow charts. A flow chart is a diagram representation of the steps of a process, and can be a useful tool for examining how various steps in a process are related to each other. Flow charting uses easily recognizable symbols to represent the type of processing performed. Flowcharts can aid in: (1) Process simplification, (2) Work flow optimization, (3) Identification of data collection points. [5,7,19]

B.6 Force Field Analysis. [5] Force Field Analysis is the technique used to help identify and visualize the relationships of the significant driving and restraining forces that are trying to influence the “status quo”. Driving forces move a situation towards desired change while restraining forces block that movement. When there is no change, the opposing forces are equal, or the restraining forces are too strong to allow movement, or in many cases the desired change(s) will not occur. Force Field Analysis helps make change happen because:

a. It forces people to think together about all the facets of the desired change; therefore, creative thinking is encouraged.

b. It encourages people to come to a consensus about relative priorities.

c. It provides a starting point for action.

B.7 Histogram. A Histogram displays the distribution of measurement data, e.g., temperature, dimensions, etc. This is critical since all repeated events will produce results that vary over time. A histogram reveals the amount of variation and distribution within a process. [5,7,9]

APPENDIX B

B.8 Hoshin Planning Techniques. [5,6] A recent series of planning and improvement tools, sometimes referred to as Hoshin planning techniques are being used by some quality practitioners; the techniques include:

a. Affinity Chart
b. Interrelationship Diagram (or “Digraph” [6])
c. Tree Diagram
d. Matrix Diagram
e. Matrix Data Analysis
f. Process Decision Program Chart
g. Arrow Diagram.

B.9 Nominal Group Technique. [5,6] Nominal Group Technique is a structured method that a group uses to prioritize items in a list. This method uses the priorities of each group member to discover the overall priorities of the group. Nominal Group Technique assists in:

a. Prioritizing a list of ideas.
b. Making decisions using inputs from all participants.

B.10 Pareto chart. A Pareto Chart is a special form of vertical bar graph that helps prioritize problem solving efforts. Doing a Pareto Chart based upon either Check Sheets or other forms of data collection helps direct attention and efforts to the truly important problems. Generally, more will be gained by working on the tallest bar than tackling the smaller. A pareto chart helps demonstrate that 80/20 rule, that is 80% of the problems are caused by only 20% of the possible number of items that cause problems. A pareto chart separates the so called "Vital Few" from the "Useful Many". [5,19]

B.11 Plan-Do-Check-Act (PDCA) Cycle. (Also known as the Shewhart Cycle, Plan-Do-Study-Act Cycle). The Plan stage consists of studying the current situation, gathering data, and planning for improvement. In the Do stage, the plan is implemented on a trial basis. The Check stage is designed to determine if the trial plan is working correctly and if further problems or opportunities are found. The last stage, Act, is the implementation of the final plan to ensure that the improvements will be standardized and practiced continuously. This leads back to the Plan stage for further diagnosis and improvement. [5,42]

B.12 Run/trend charts. Run/Trend Charts are employed to visually represent data. They are also used to monitor a process to see if the process is changing over time. Run charts are the simplest tool to construct and use. Points are plotted on the chart in the order in which they become available. It is common to chart the results of a process such as machine downtime, yield, scrap, typographical errors, or productivity as they vary over time. NOTE: These are not control charts and should not be analyzed as such. [5,9,19]

APPENDIX B

B.13 Scatter diagram. A scatter diagram is used to study the possible relationship between one variable and another. The scatter diagram is used to test for possible correlation. It cannot prove that one variable causes changes to another, but it does make clear whether a relationship exists and the strength of that relationship. A scatter diagram is set up whereby the horizontal axis (x-axis) represents the measurement values of one variable, and the vertical axis (y-axis) represents the measurements of the second variable. [5,6,7]

B.14 Stratification. Stratification is a technique that rearranges data in different groupings or strata. It is very often useful in analyzing data to find continuous improvement. Stratification also helps analyze cases in which data actually masks the real facts. This often occurs when recorded data is obtained from many sources but is treated as if it came from one source.

ENDNOTE: The Quality Sciences comprise a dynamic field, in which the tools and methods themselves undergo continual improvement. Practitioners are encouraged to follow this evolution. Quality Journals, [43, 44, 45, and others] and increasingly, the Internet,[46,48,49,50,51,52] are excellent sources of information.

APPENDIX C

REFERENCES

C.1 Scope. This appendix provides a list of references that give further information on the topics mentioned in this handbook.

C.2 List of References.

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APPENDIX D

OC CURVES & ASSOCIATED TABLES

D.1 Scope. This appendix provides OC curves (probability of acceptance), AFI curves, AOQ curves, and associated tables for all the sampling plans specified in MIL-STD-1916.

FIGURE D-1. OC Curves for Attributes Plans VL T.

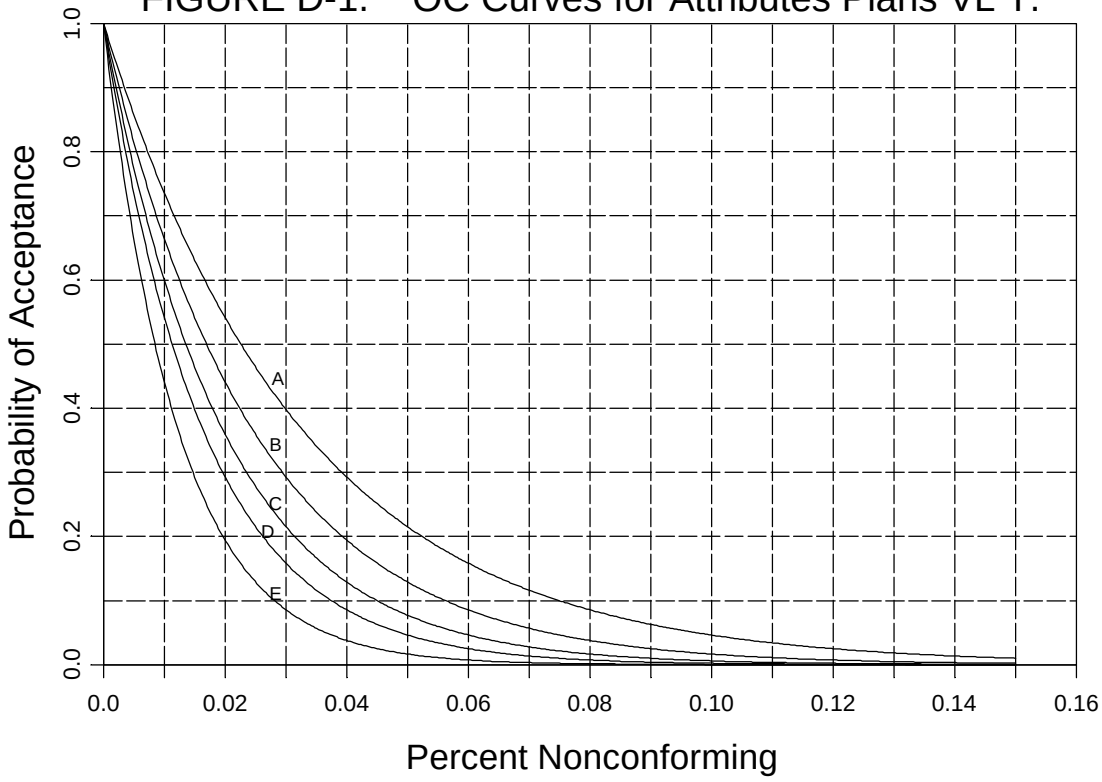
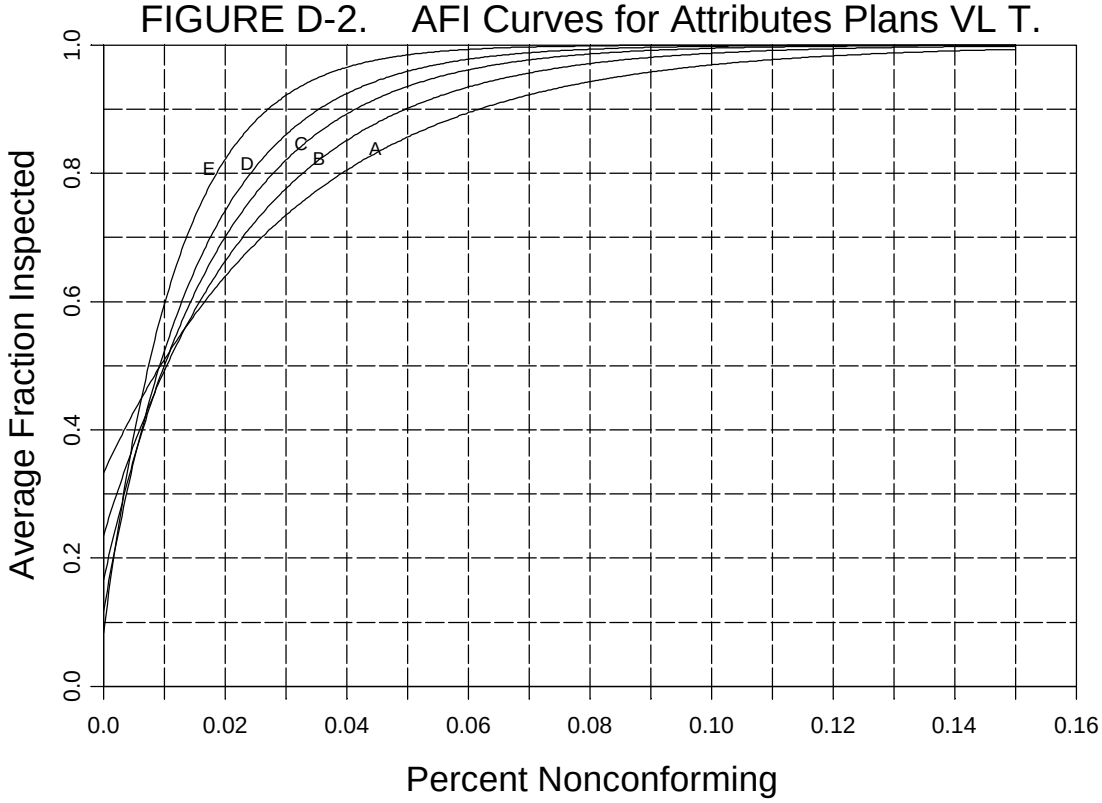


FIGURE D-2. AFI Curves for Attributes Plans VL T.



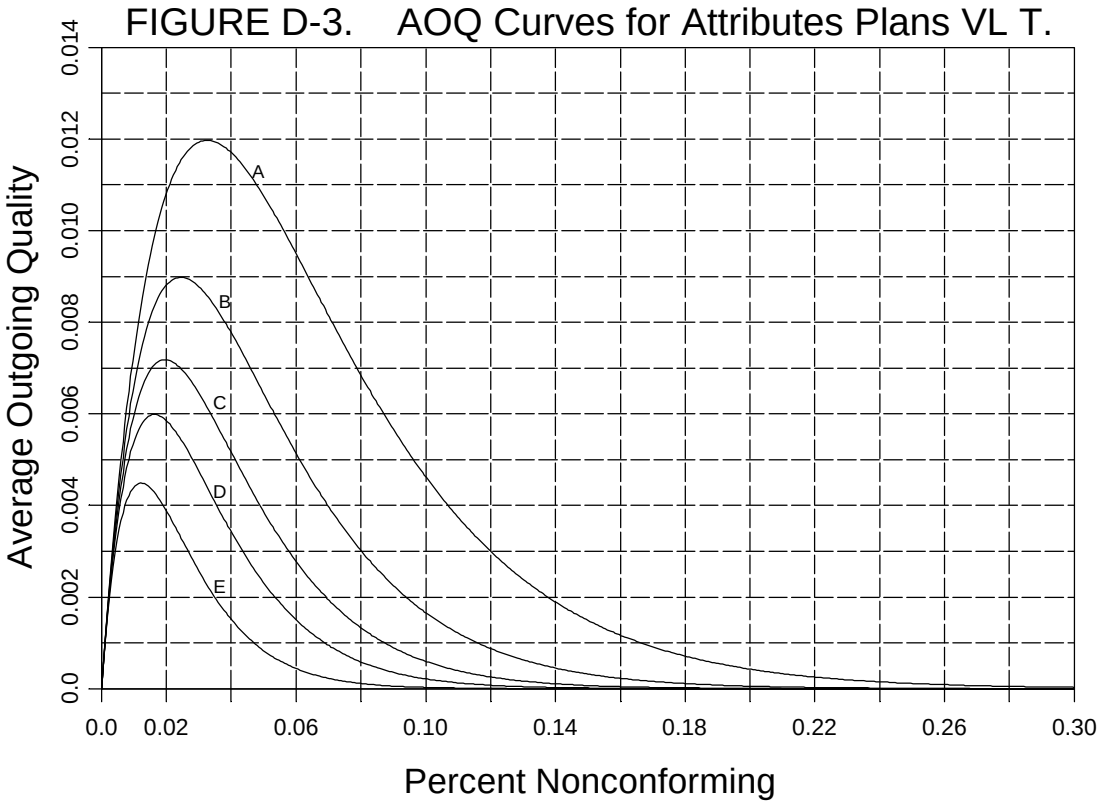


TABLE D-I. AoZ Sampling Plans VL T.

Code Letter	Sample Size	Acceptance Number
A	3072	0
B	4096	0
C	5120	0
D	6144	0
E	8192	0

FIGURE D-4. OC Curves for Variables Plans VL T.

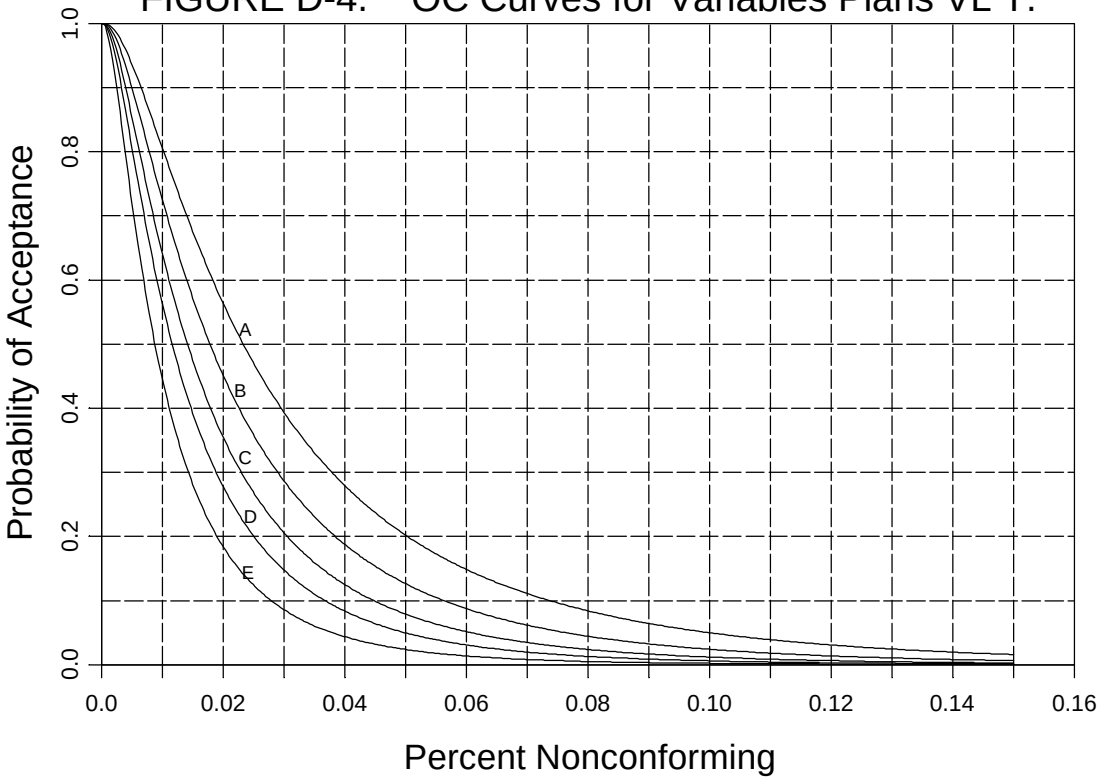


FIGURE D-5. AFI Curves for Variables Plans VL T.

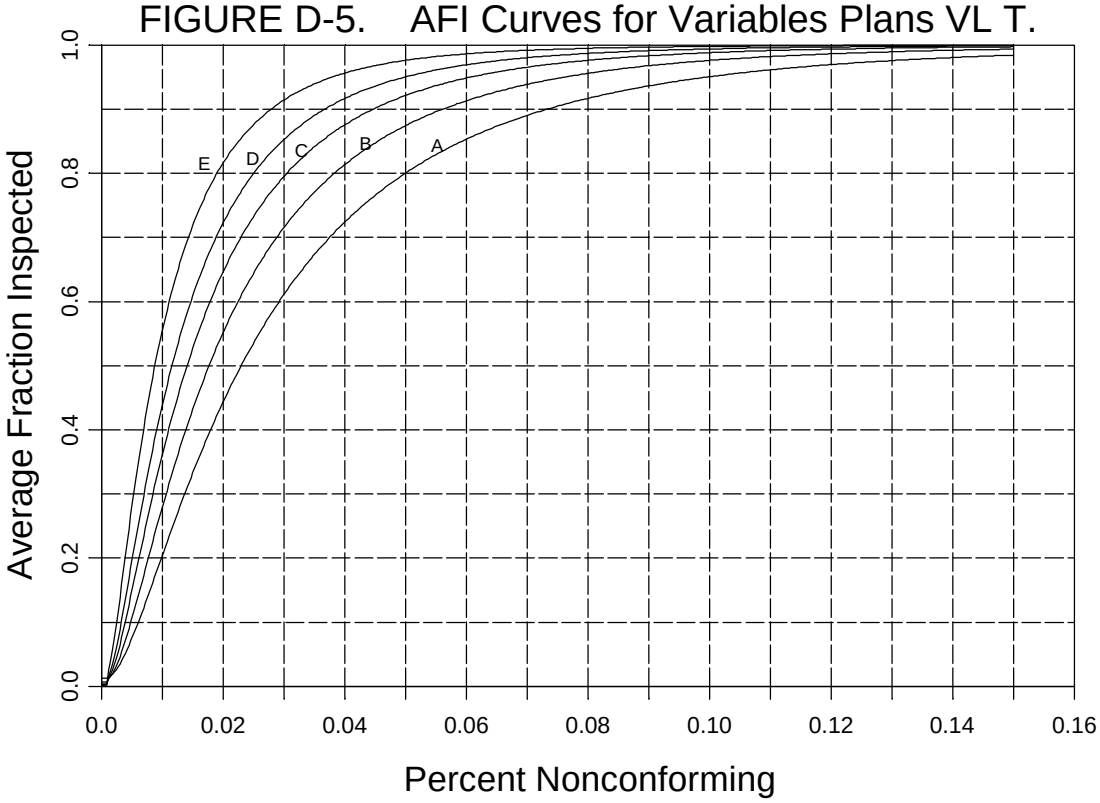


FIGURE D-6. AOQ Curves for Variables Plans VL T.

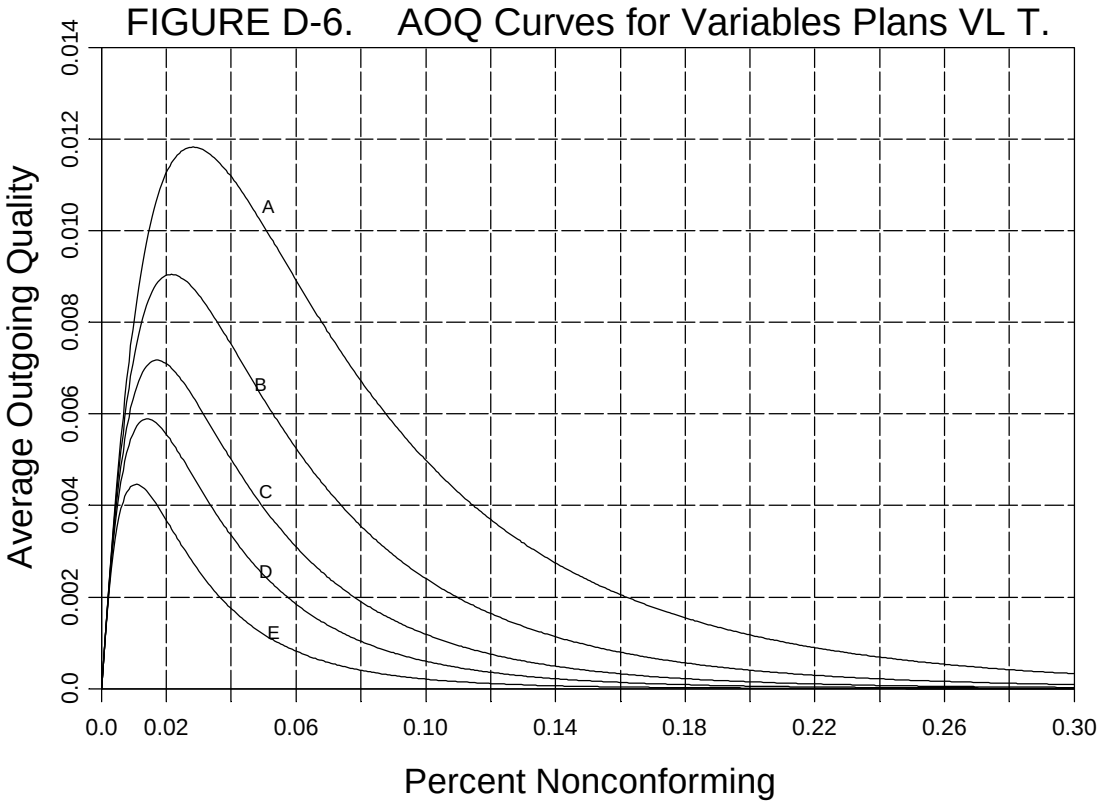


TABLE D-II. Variables Sampling Plans VL T.

Code Letter	Sample Size	Acceptability Constant
A	113	3.51
B	122	3.58
C	129	3.64
D	136	3.69
E	145	3.76

FIGURE D-7. OC Curves for Continuous Plans VL T.

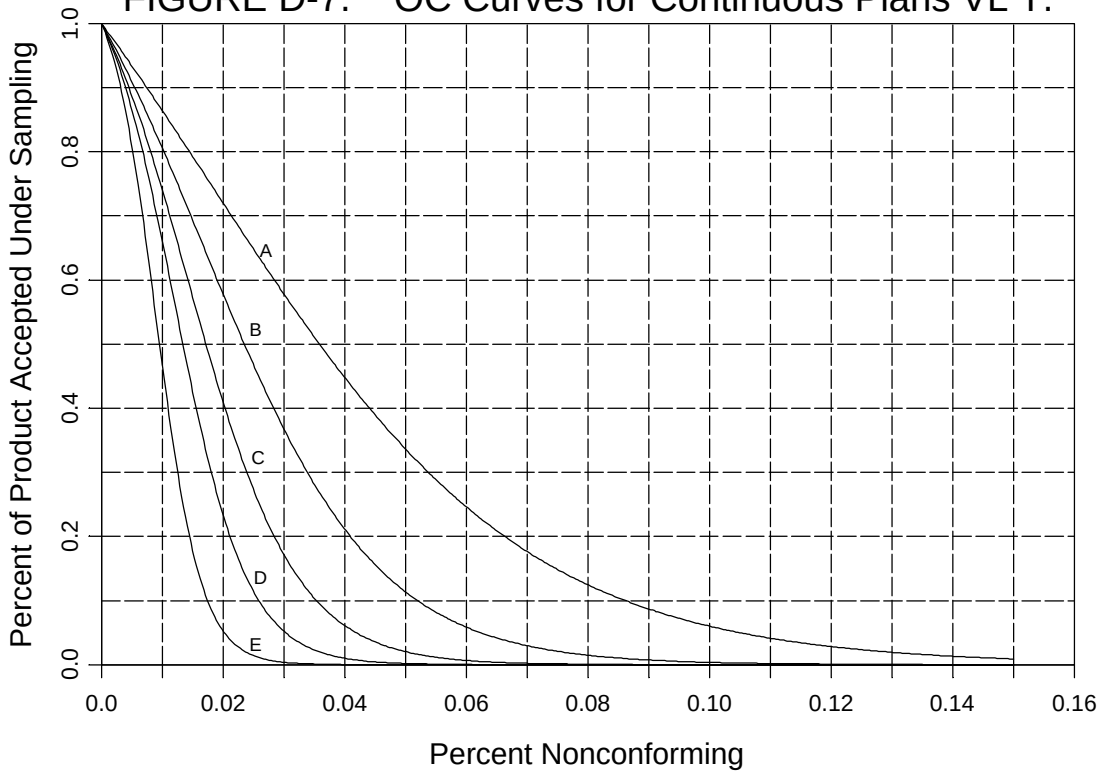


FIGURE D-8. AFI Curves for Continuous Plans VL T.

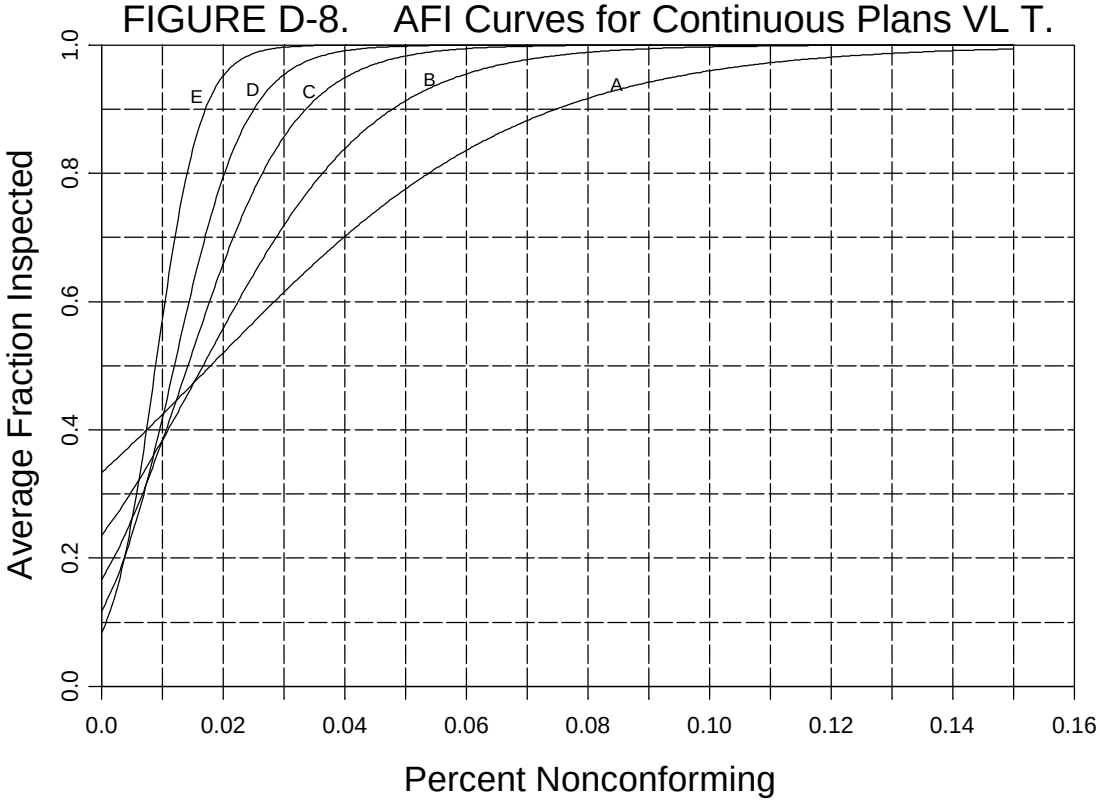


FIGURE D-9. AOQ Curves for Continuous Plans VL T.

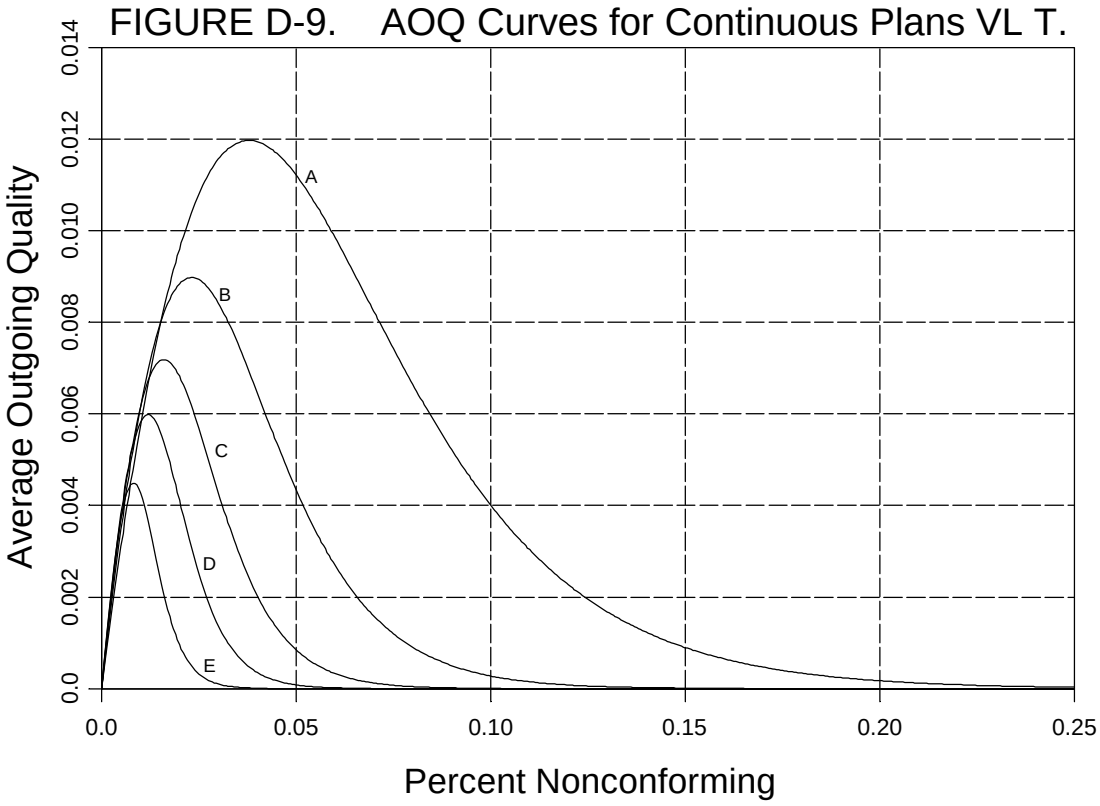


TABLE D-III. Continuous Sampling Plans VL T.

Code Letter	Clearance Number	Sampling Frequency
A	3867	1/3
B	7061	4/17
C	11337	1/6
D	16827	2/17
E	26912	1/12

FIGURE D-10. OC Curves for Attributes Plans VL VII.

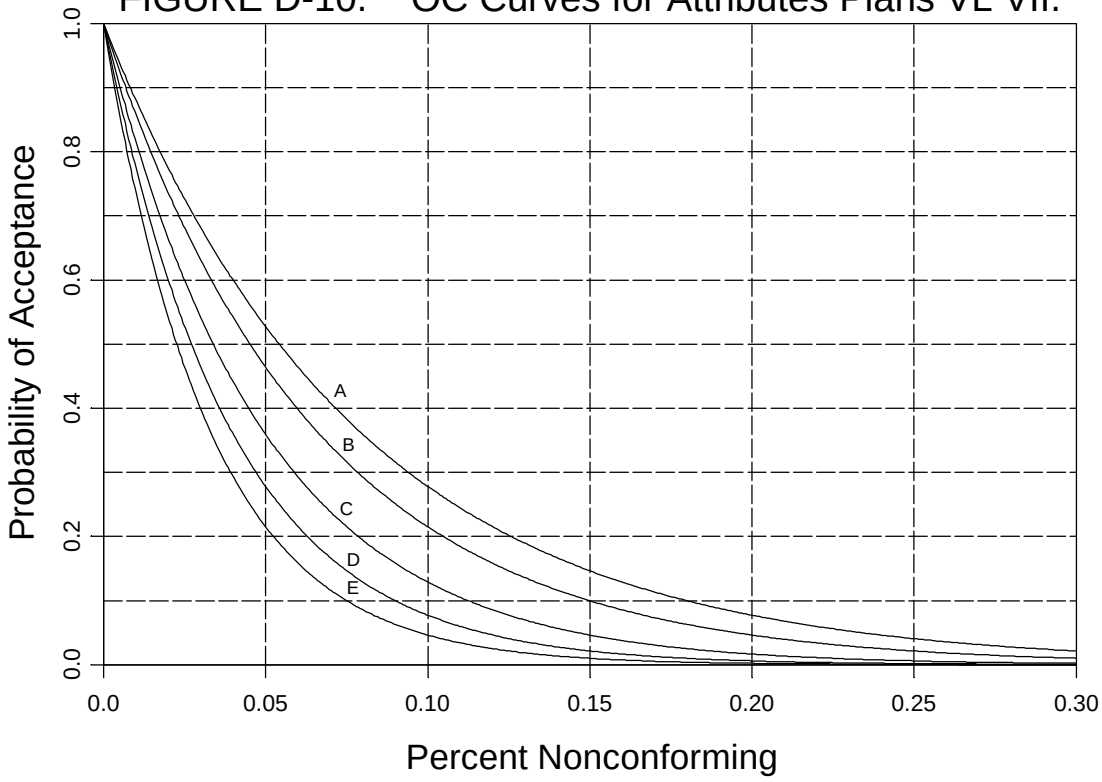


FIGURE D-11. AFI Curves for Attributes Plans VL VII.

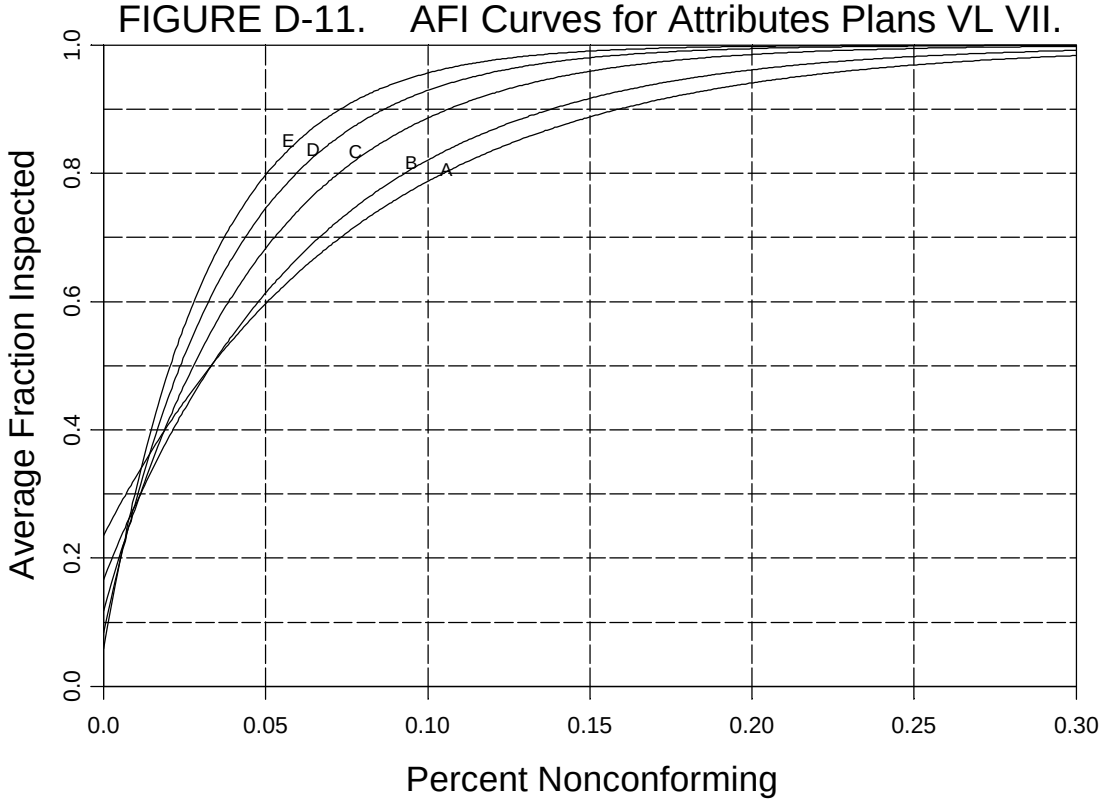


FIGURE D-12. AOQ Curves for Attributes Plans VL VII.

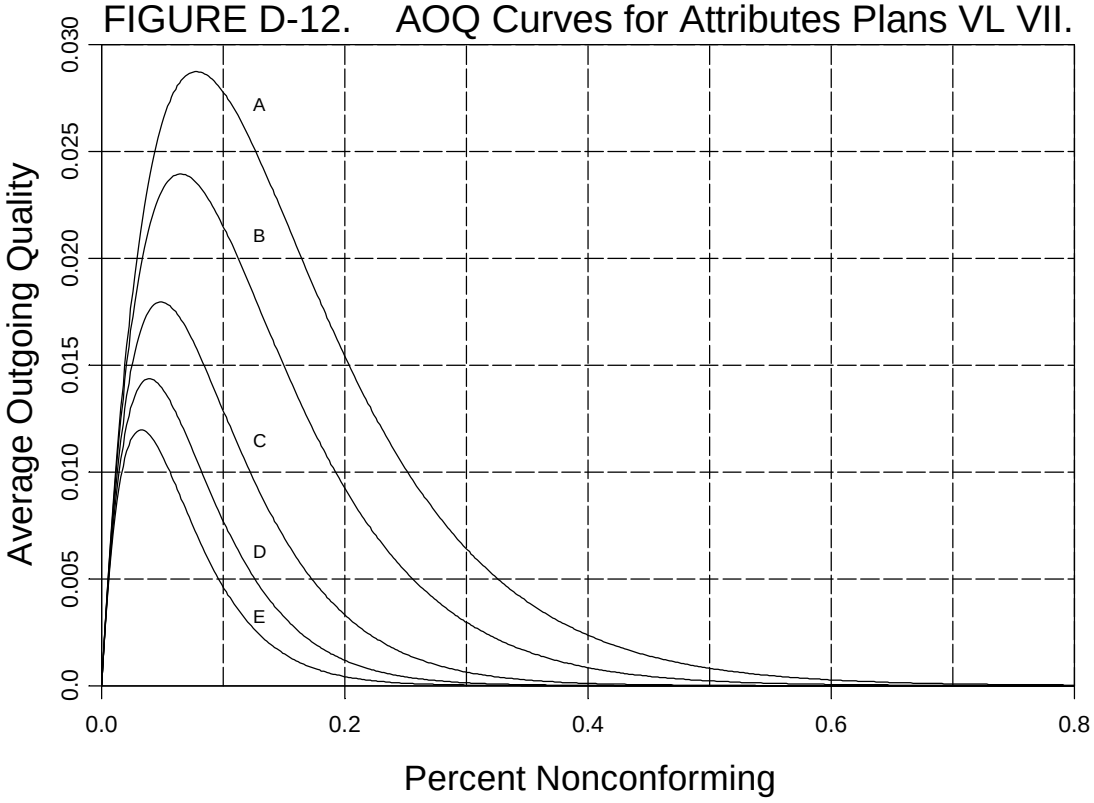


TABLE D-IV. AoZ Sampling Plans VL VII.

Code Letter	Sample Size	Acceptance Number
A	1280	0
B	1536	0
C	2048	0
D	2560	0
E	3072	0

FIGURE D-13. OC Curves for Variables Plans VL VII.

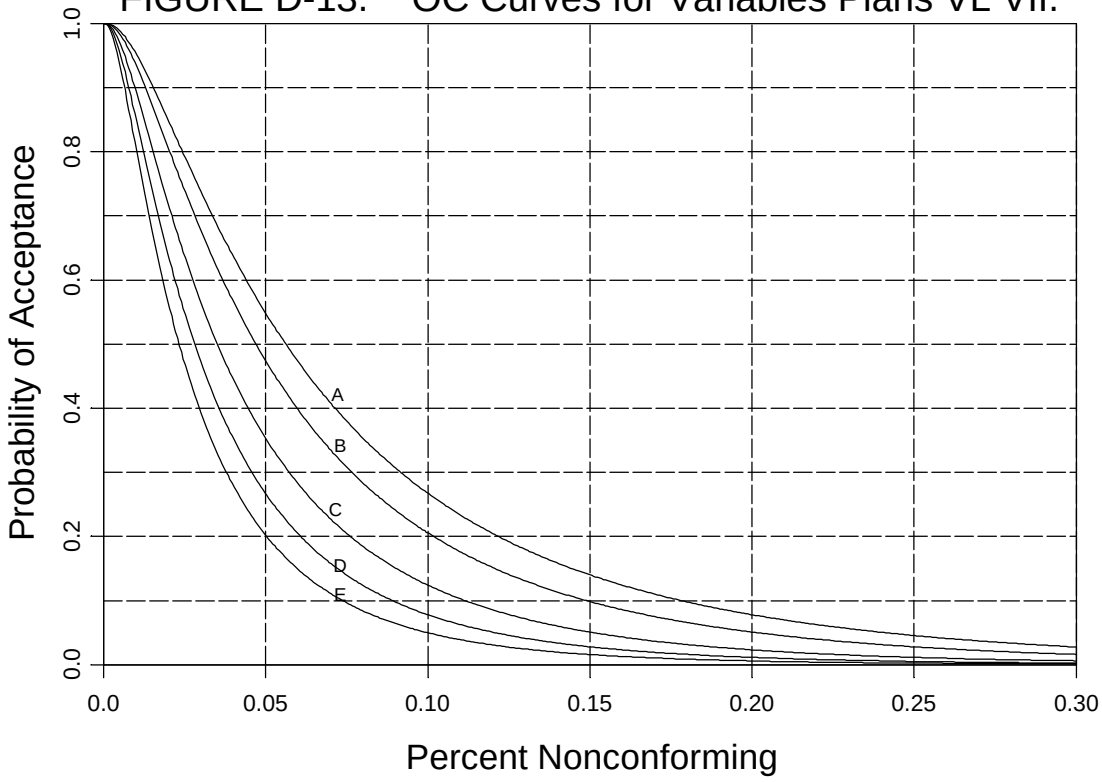


FIGURE D-14. AFI Curves for Variables Plans VL VII.

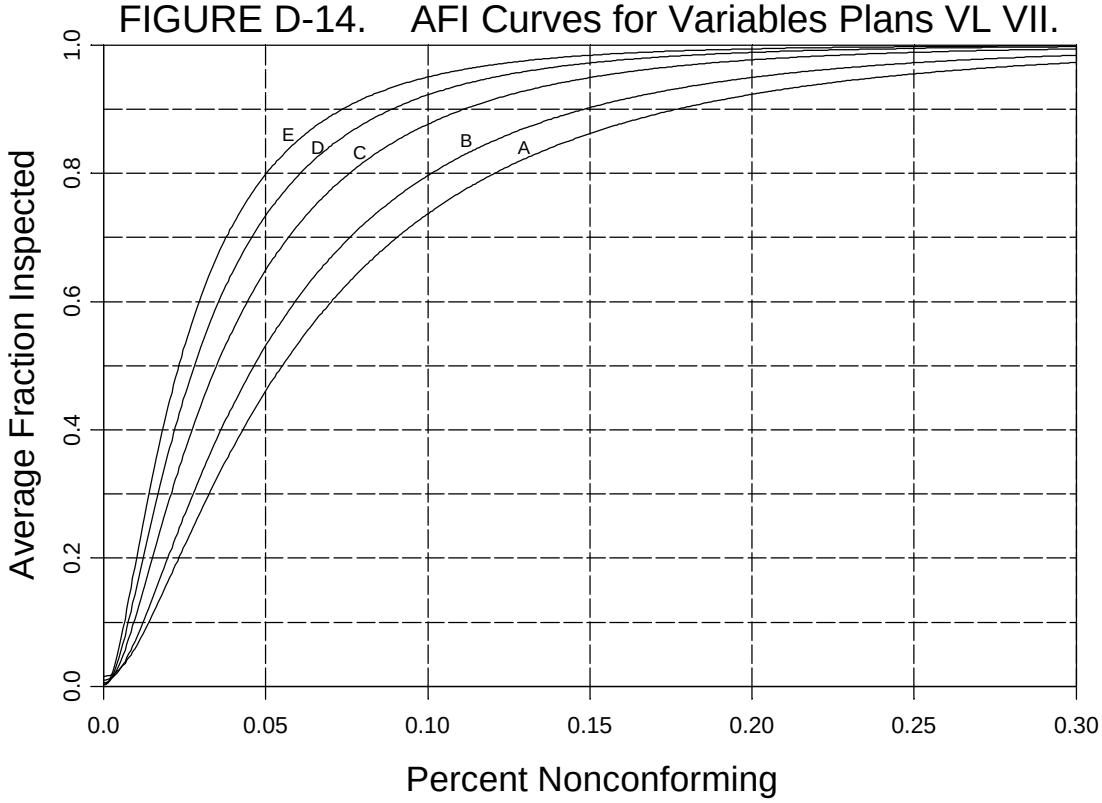


FIGURE D-15. AOQ Curves for Variables Plans VL VII.

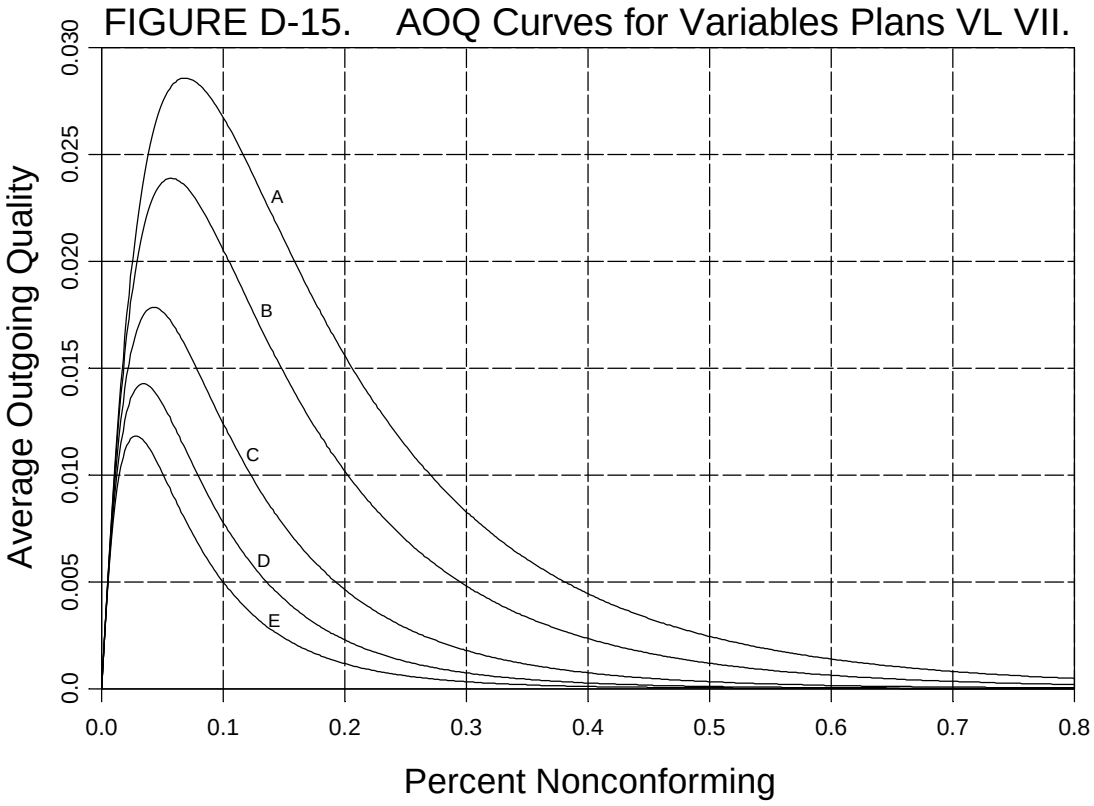


TABLE D-V. Variables Sampling Plans VL VII.

Code Letter	Sample Size	Acceptability Constant
A	87	3.27
B	92	3.32
C	100	3.40
D	107	3.46
E	113	3.51

FIGURE D-16. OC Curves for Continuous Plans VL VII.

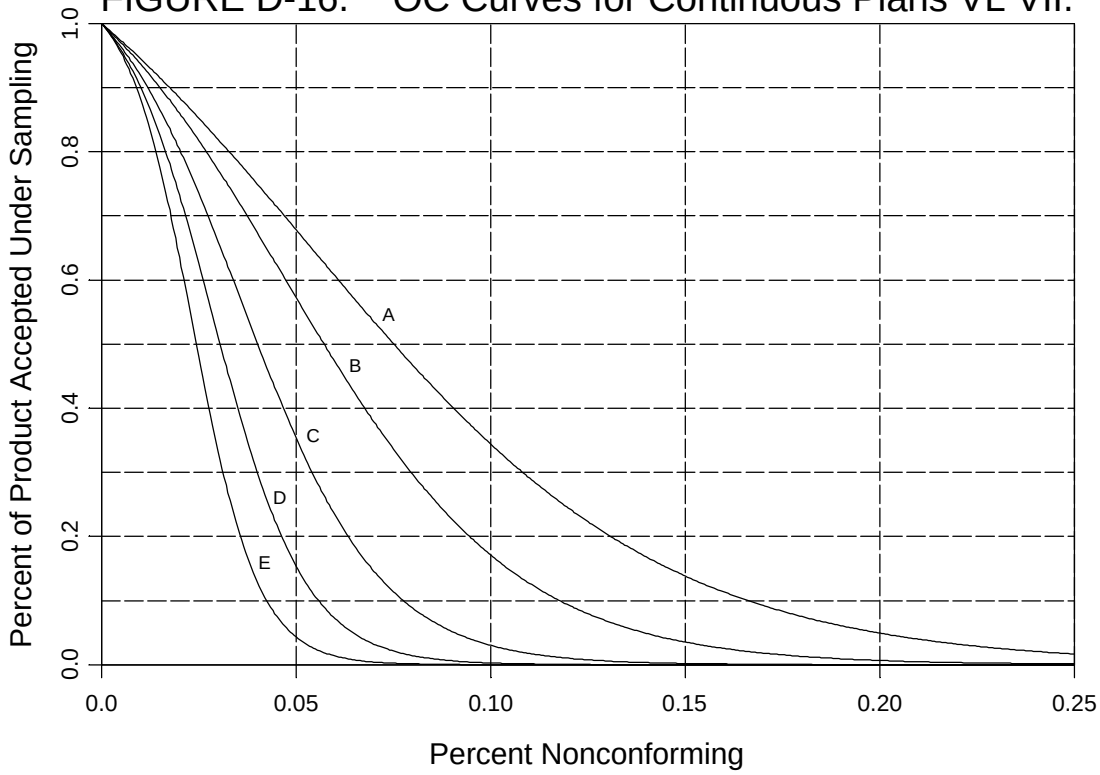


FIGURE D-17. AFI Curves for Continuous Plans VL VII.

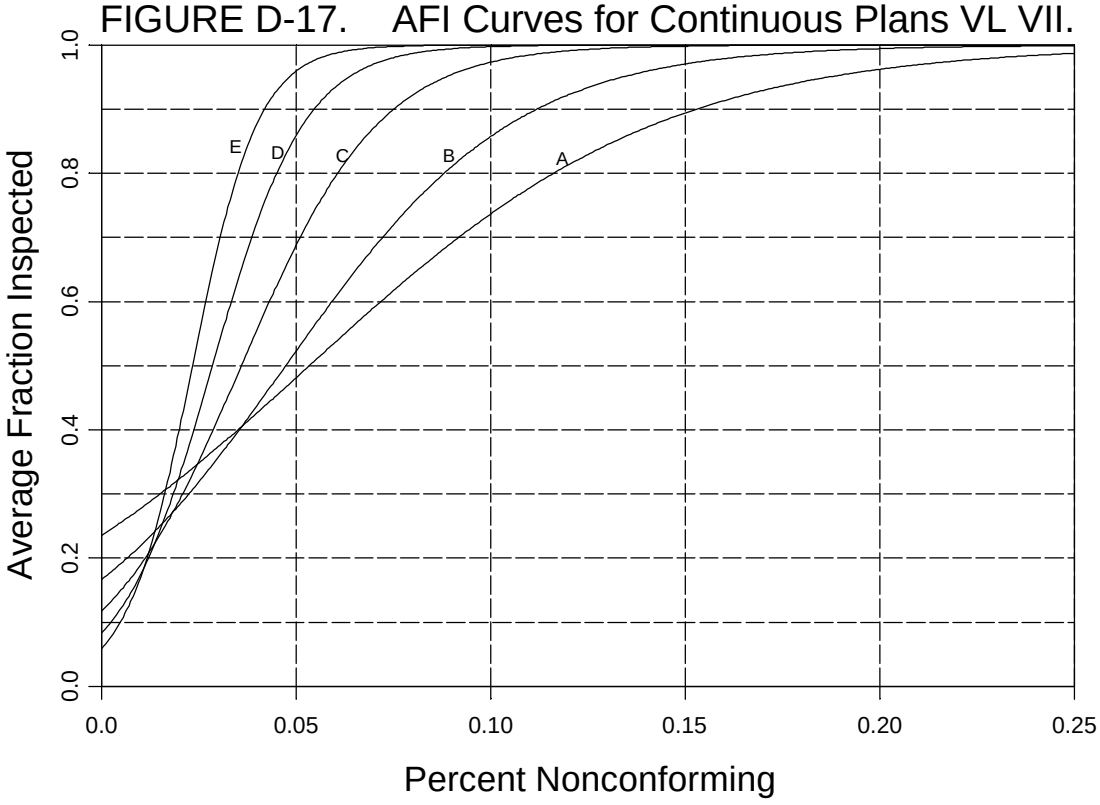


FIGURE D-18. AOQ Curves for Continuous Plans VL VII.

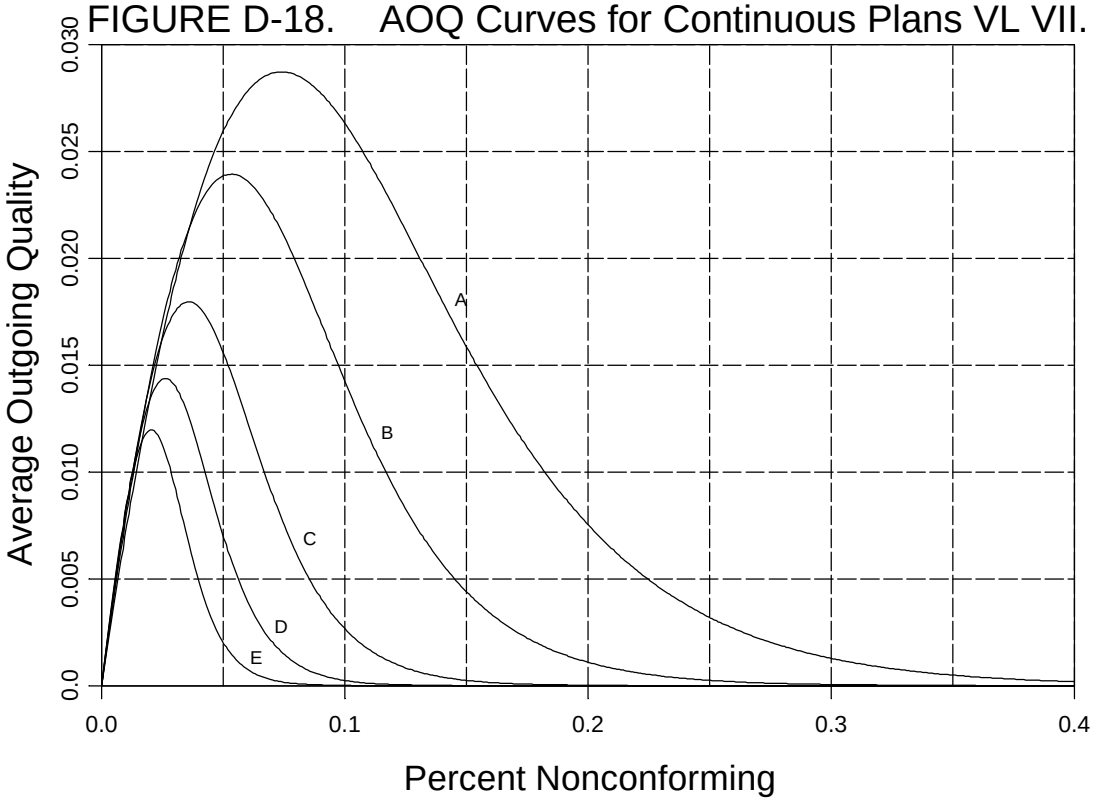


TABLE VI. Continuous Sampling Plans VL VII.

Code Letter	Clearance Number	Sampling Frequency
A	2207	4/17
B	3402	1/6
C	5609	2/17
D	8411	1/12
E	11868	1/17

FIGURE D-19. OC Curves for Attributes Plans VL VI.

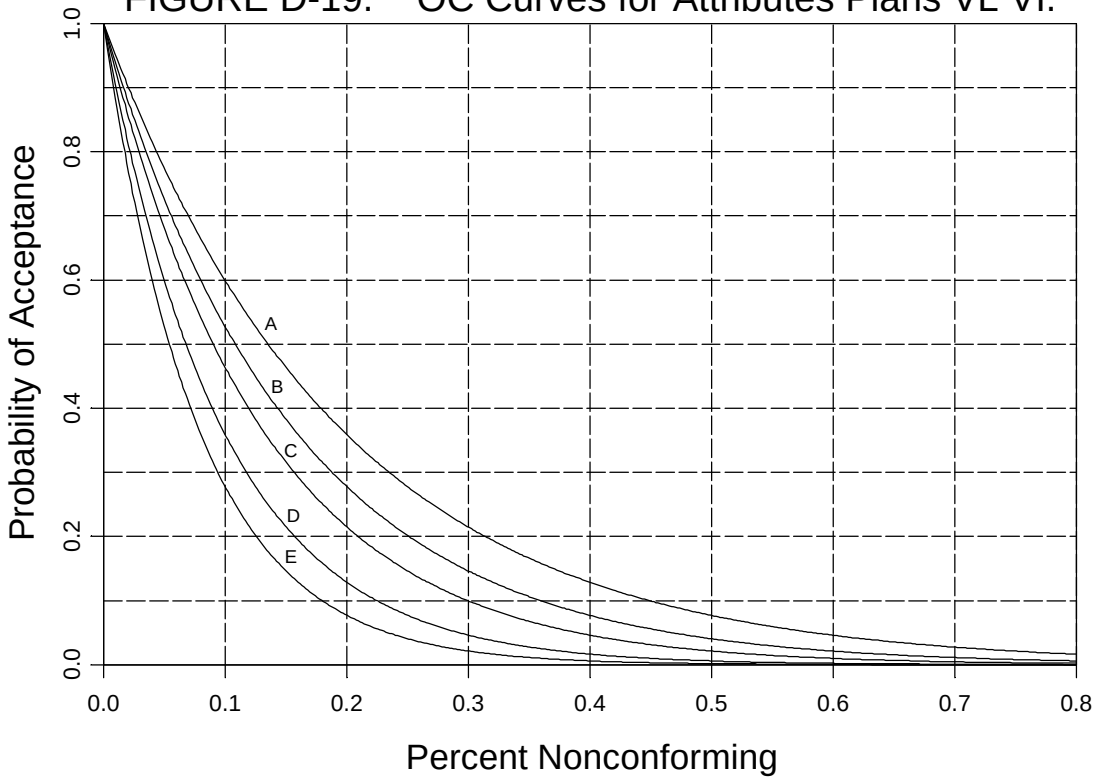


FIGURE D-20. AFI Curves for Attributes Plans VL VI.

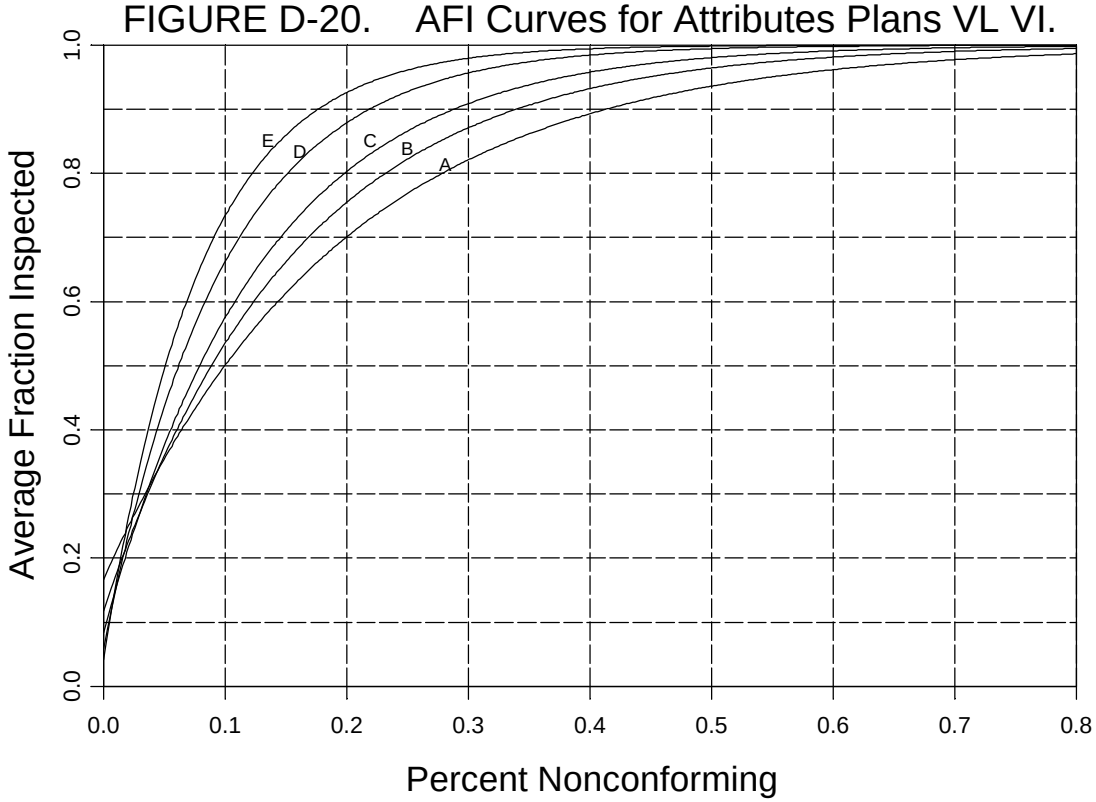


FIGURE D-21. AOQ Curves for Attributes Plans VL VI.

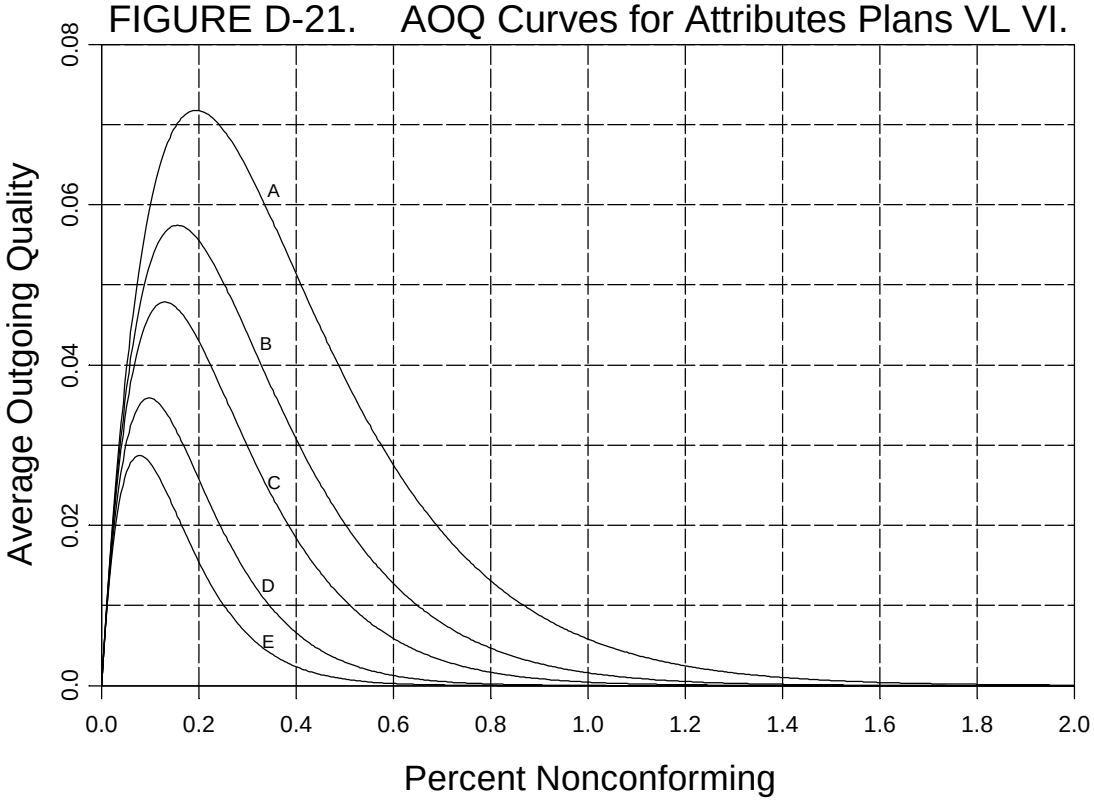


TABLE D-VII. AoZ Sampling Plans VL VI.

Code Letter	Sample Size	Acceptance Number
A	512	0
B	640	0
C	768	0
D	1024	0
E	1280	0

FIGURE D-22. OC Curves for Variables Plans VL VI.

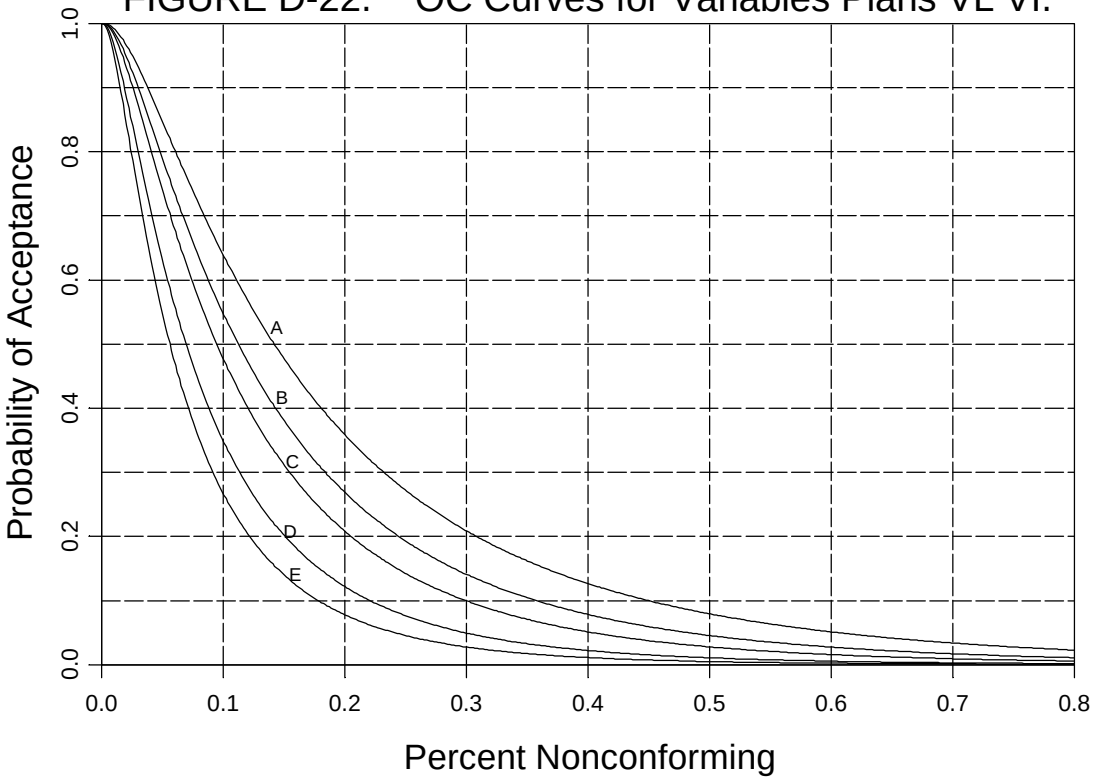


FIGURE D-23. AFI Curves for Variables Plans VL VI.

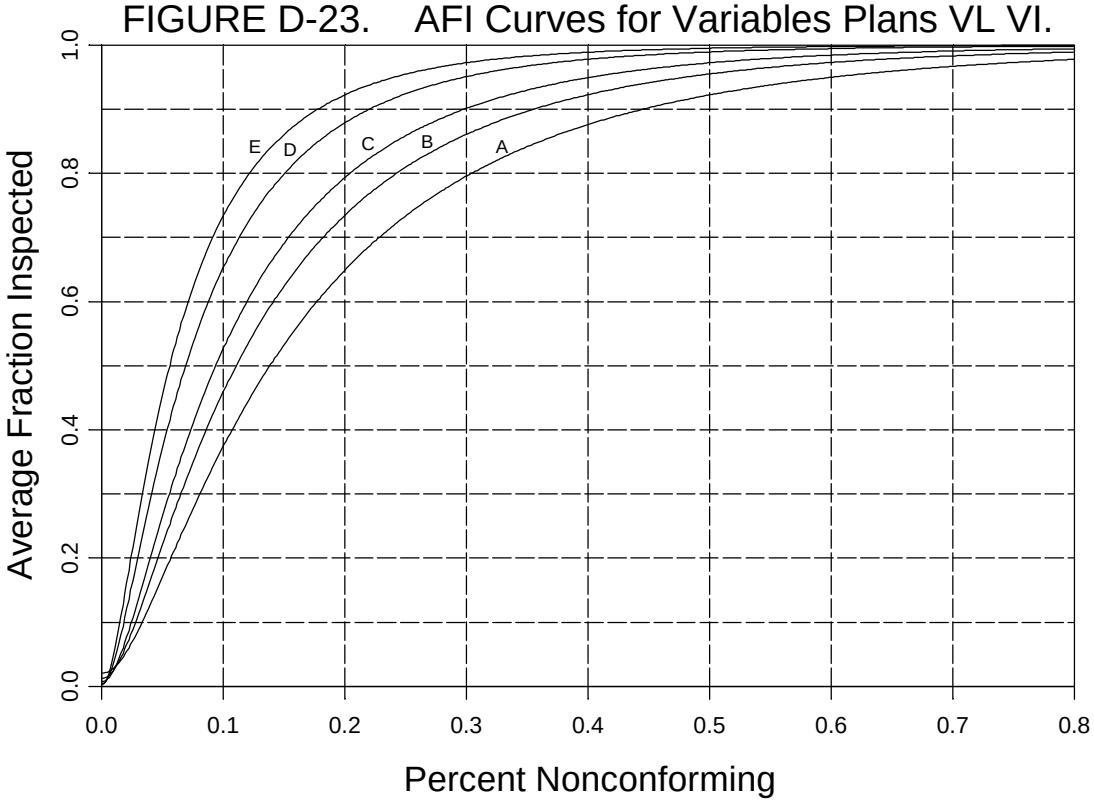


FIGURE D-24. AOQ Curves for Variables Plans VL VI.

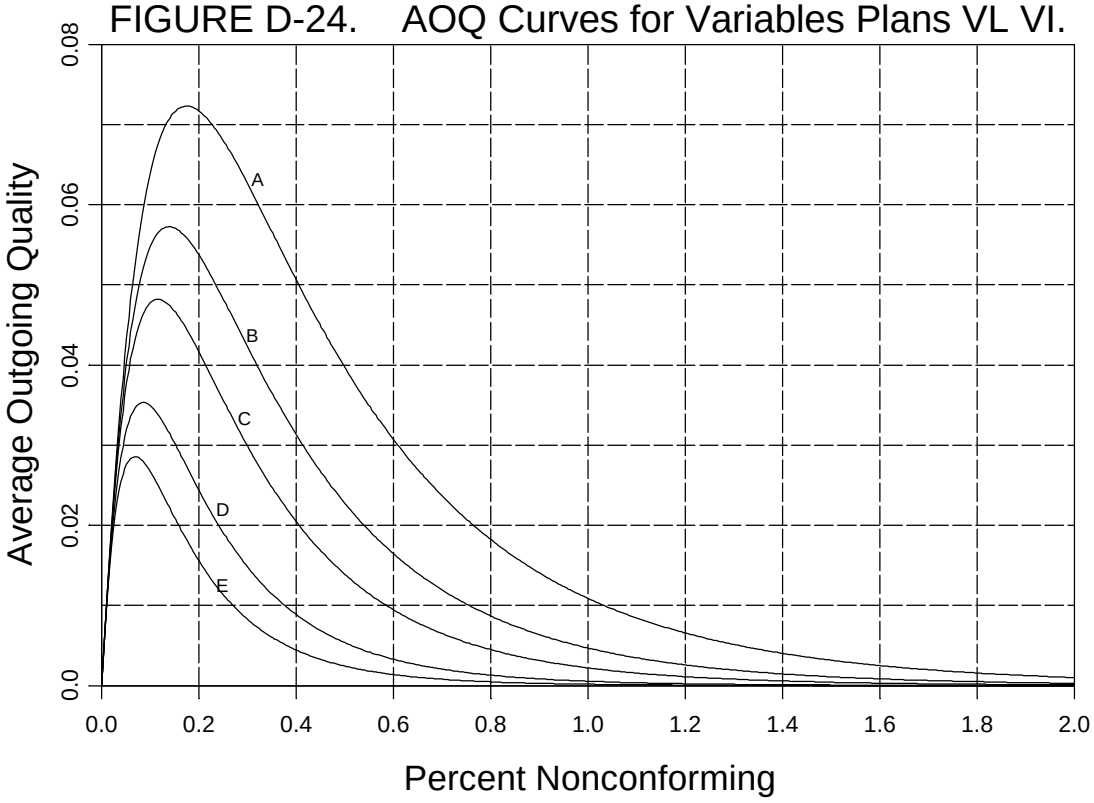


TABLE D-VIII. Variables Sampling Plans VL VI.

Code Letter	Sample Size	Acceptability Constant
A	64	3.00
B	69	3.07
C	74	3.12
D	81	3.21
E	87	3.27

FIGURE D-25. OC Curves for Continuous Plans VL VI.

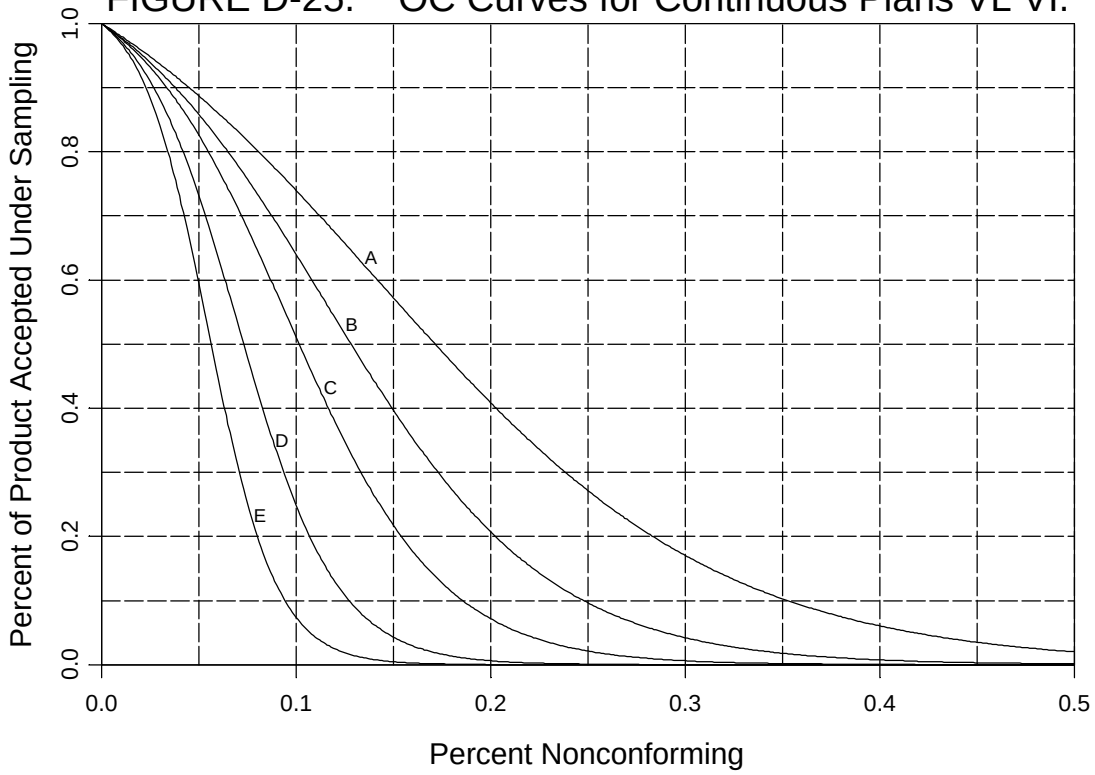


FIGURE D-26. AFI Curves for Continuous Plans VL VI.

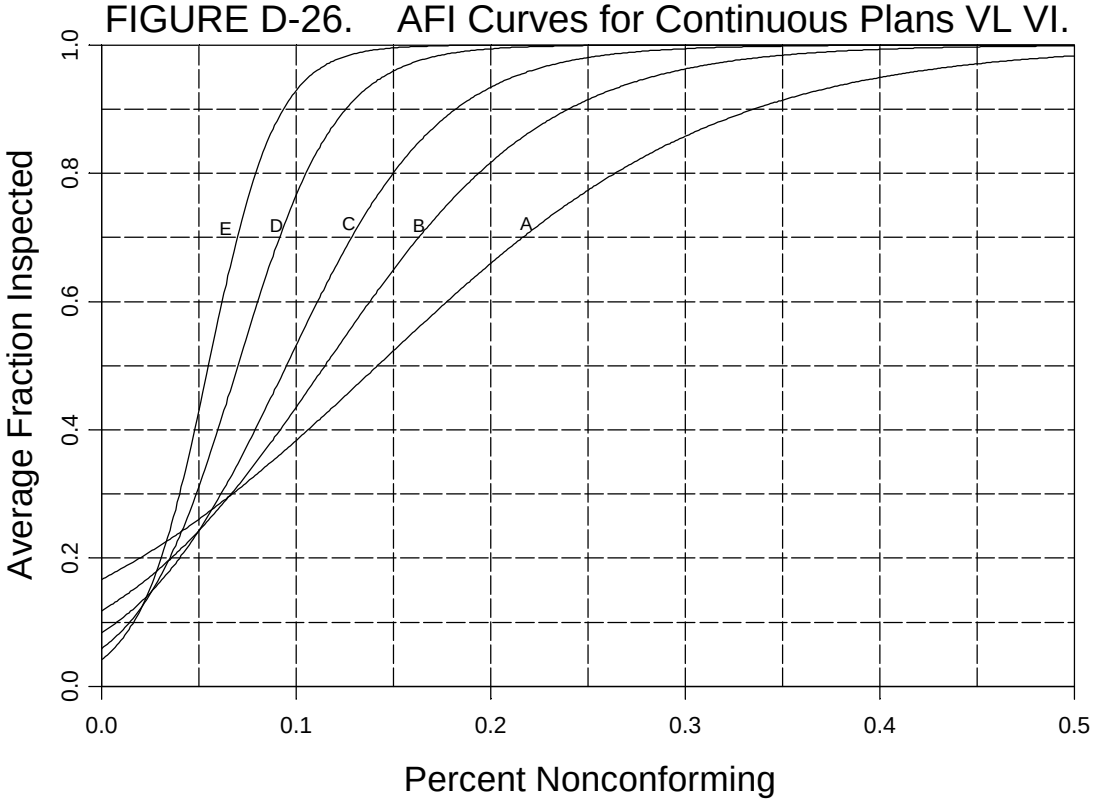


FIGURE D-27. AOQ Curves for Continuous Plans VL VI.

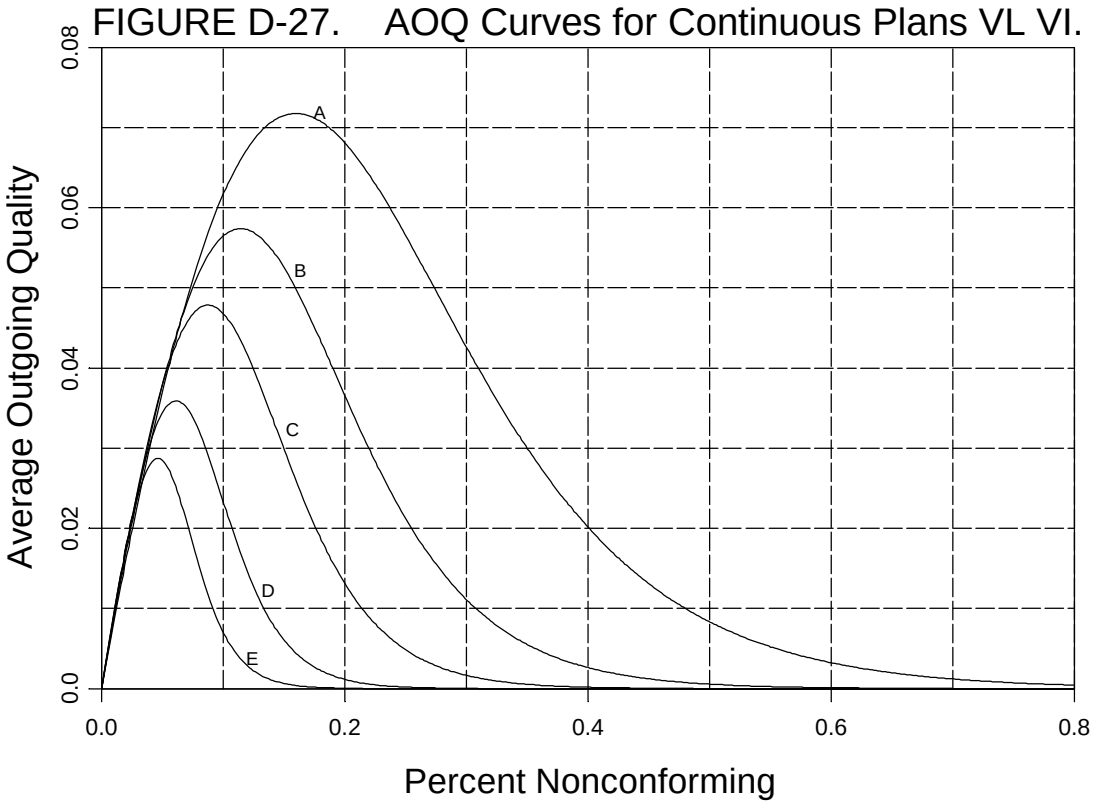


TABLE D-IX. Continuous Sampling Plans VL VI.

Code Letter	Clearance Number	Sampling Frequency
A	1134	1/6
B	1754	2/17
C	2524	1/12
D	3957	1/17
E	5709	1/24

FIGURE D-28. OC Curves for Attributes Plans VL V.

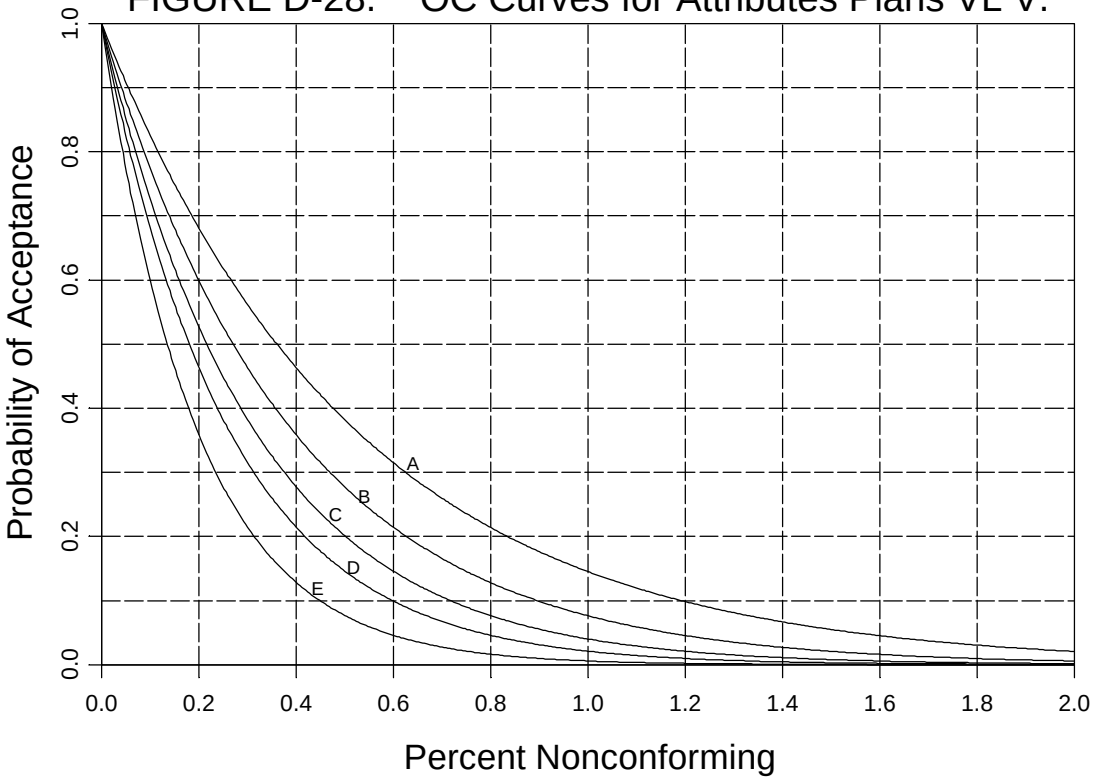


FIGURE D-29. AFI Curves for Attributes Plans VL V.

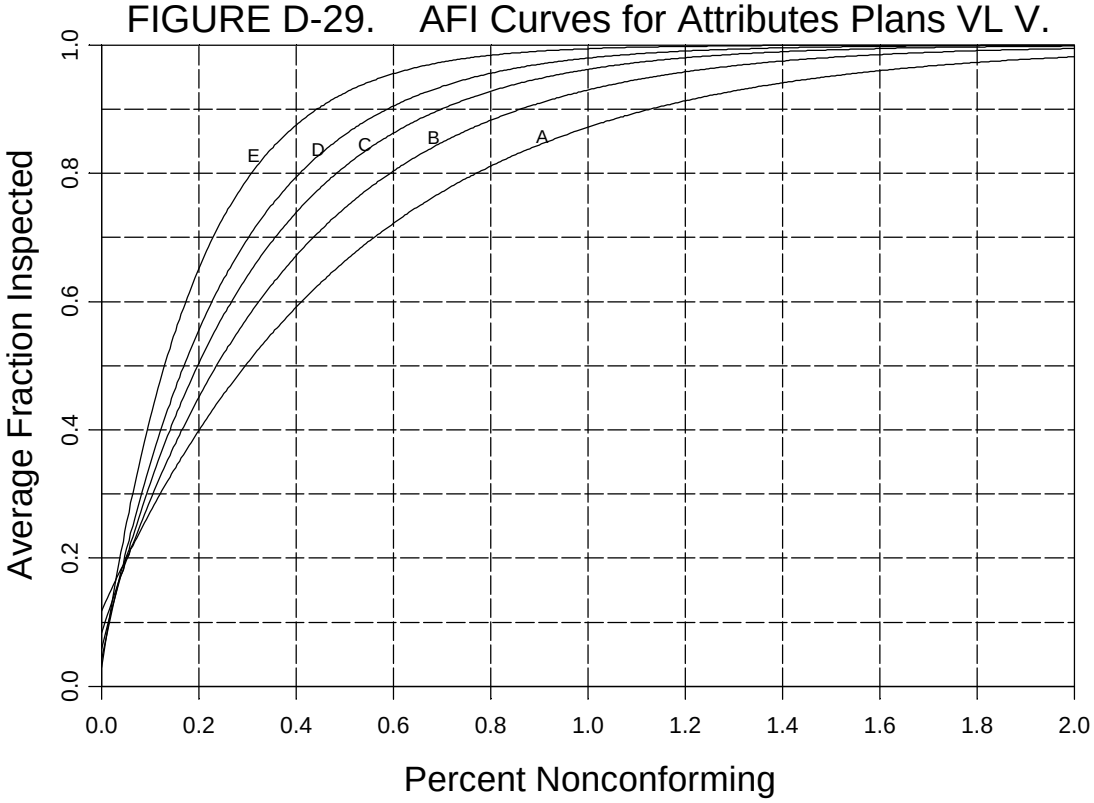


FIGURE D-30. AOQ Curves for Attributes Plans VL V.

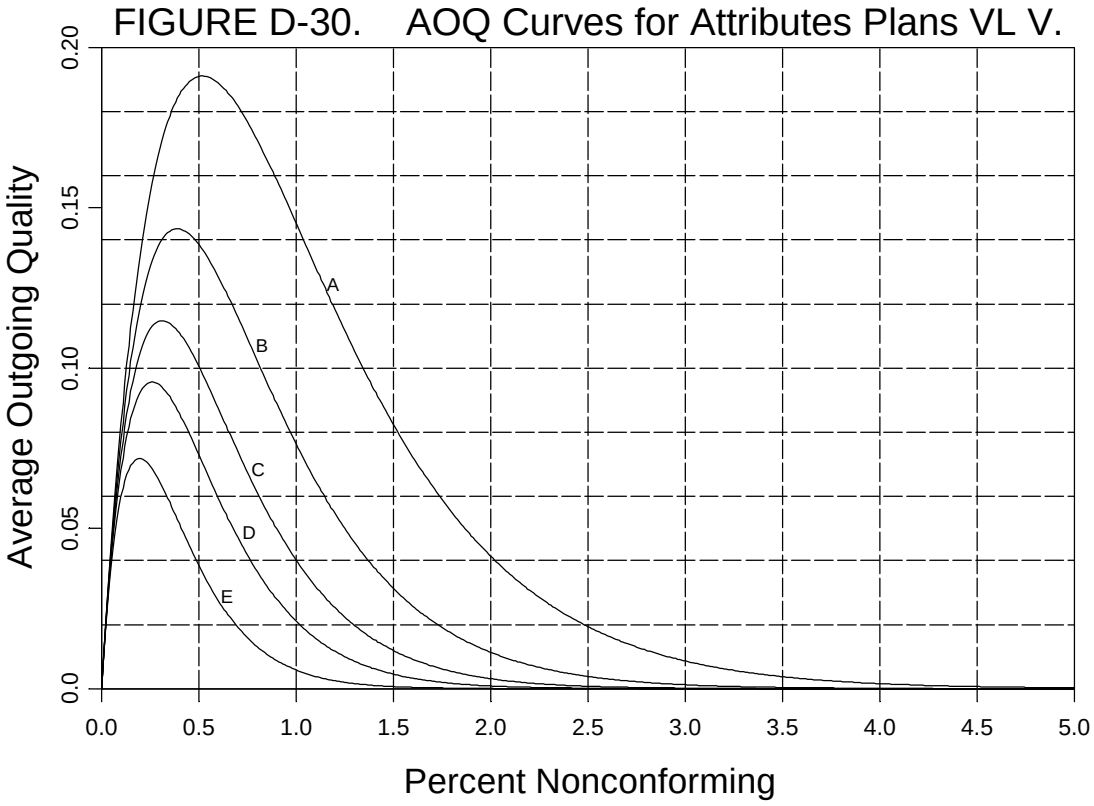


TABLE D-X. AoZ Sampling Plans VL V.

Code Letter	Sample Size	Acceptance Number
A	192	0
B	256	0
C	320	0
D	384	0
E	512	0

FIGURE D-31. OC Curves for Variables Plans VL V.

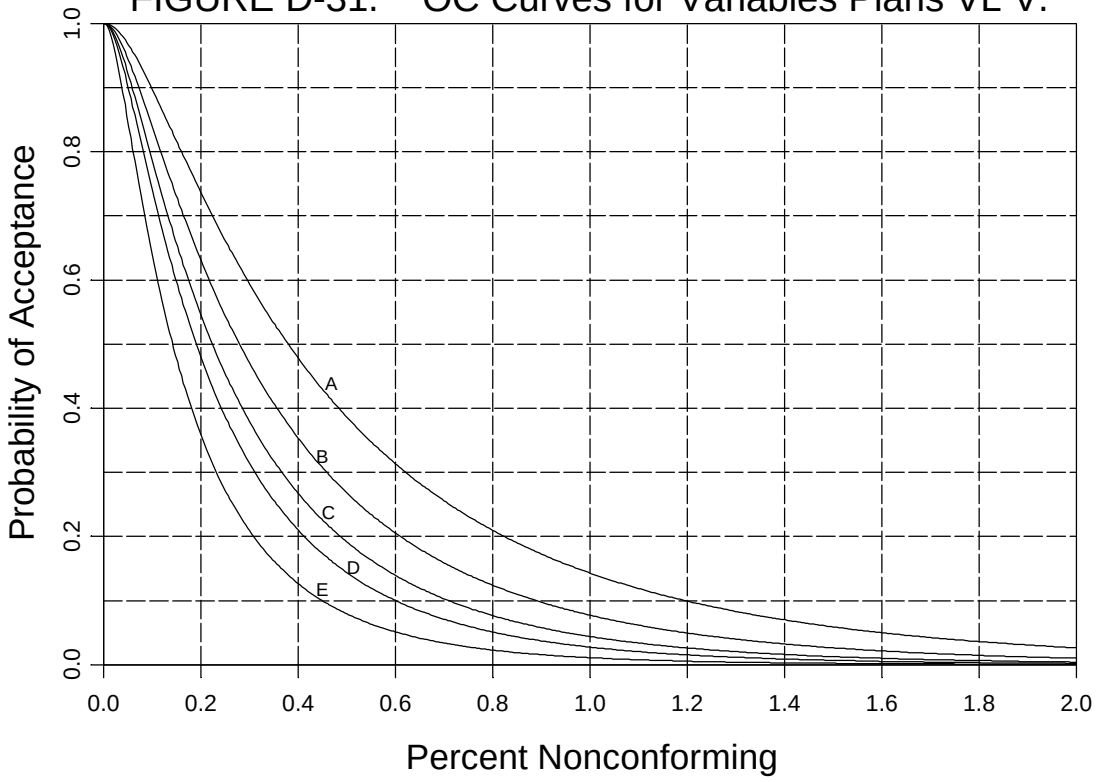


FIGURE D-32. AFI Curves for Variables Plans VL V.

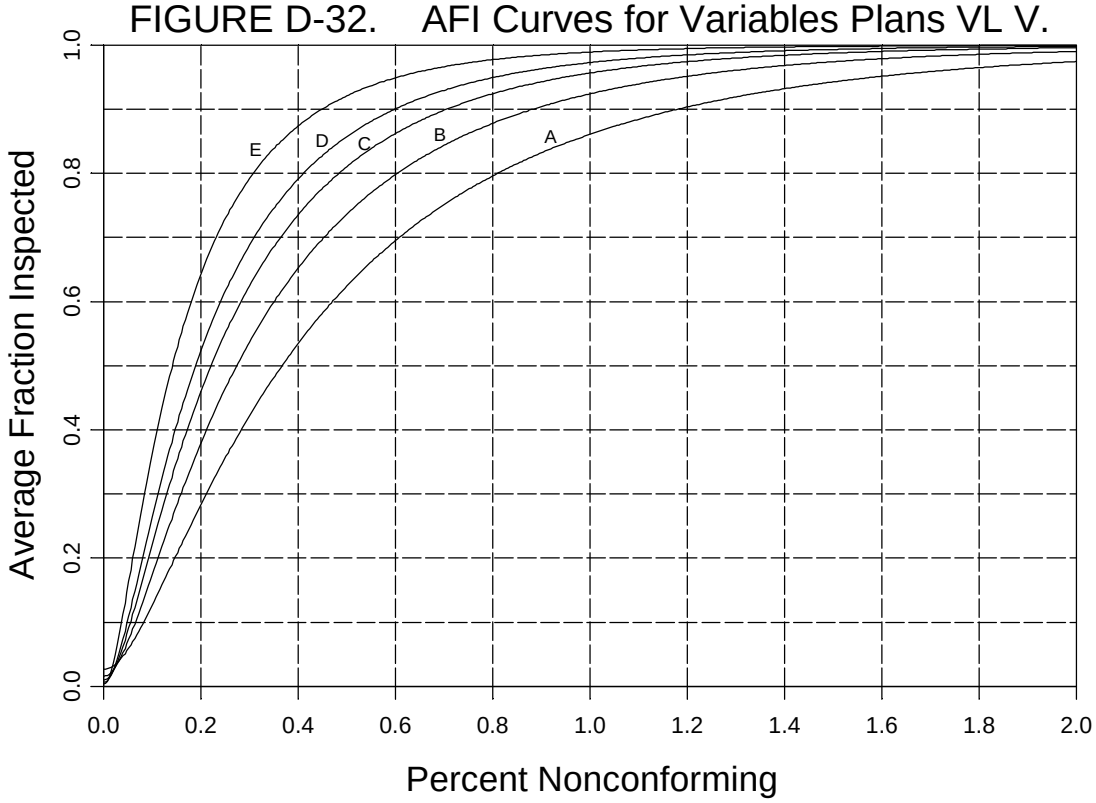


FIGURE D-33. AOQ Curves for Variables Plans VL V.

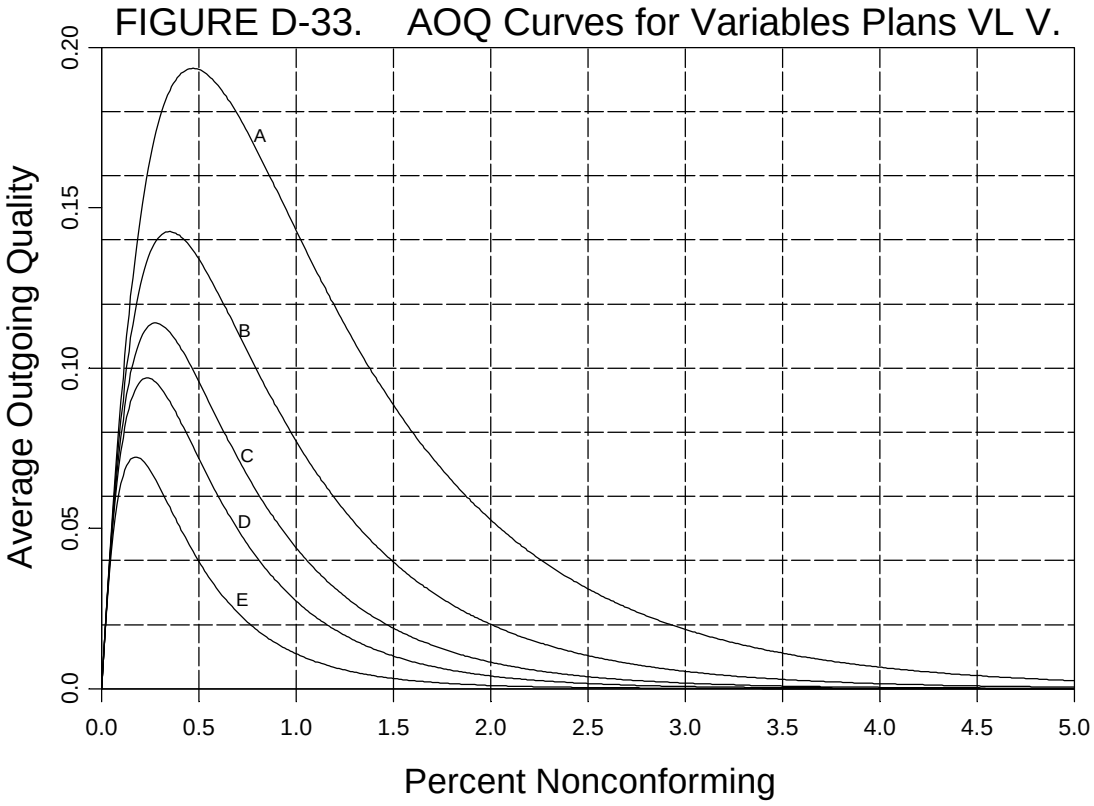


TABLE D-XI. Variables Sampling Plans VL V.

Code Letter	Sample Size	Acceptability Constant
A	44	2.69
B	49	2.79
C	54	2.86
D	58	2.91
E	64	3.00

FIGURE D-34. OC Curves for Continuous Plans VL V.

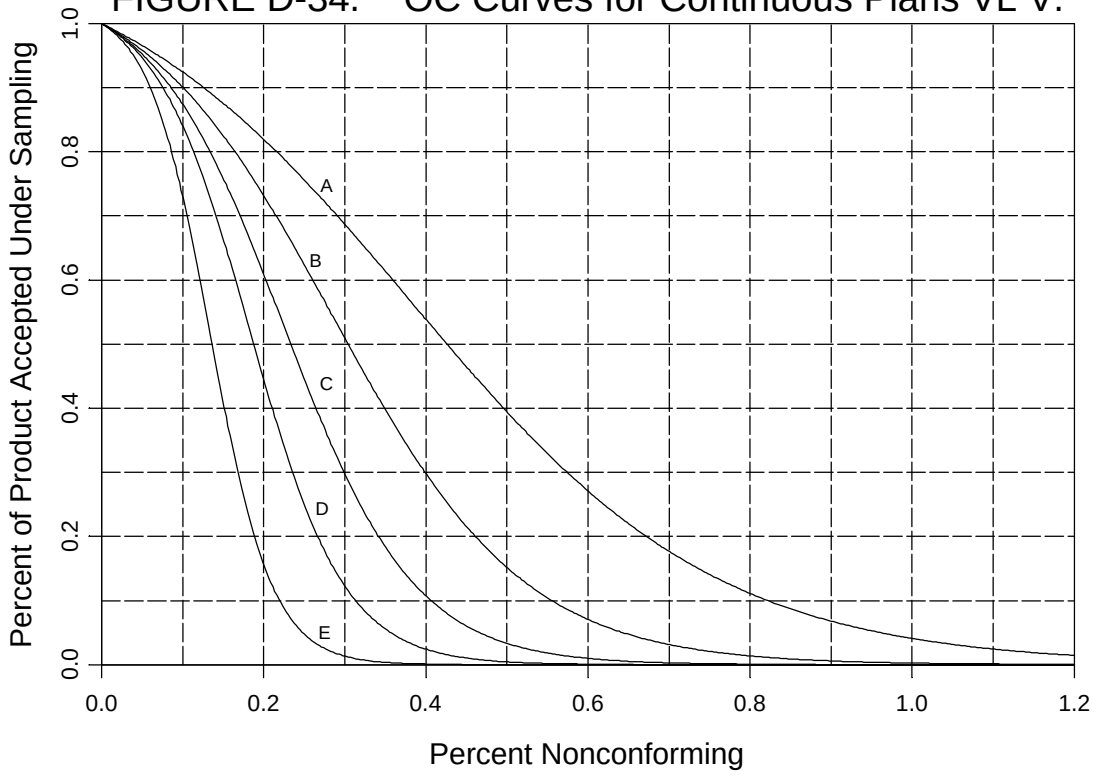


FIGURE D-35. AFI Curves for Continuous Plans VL V.

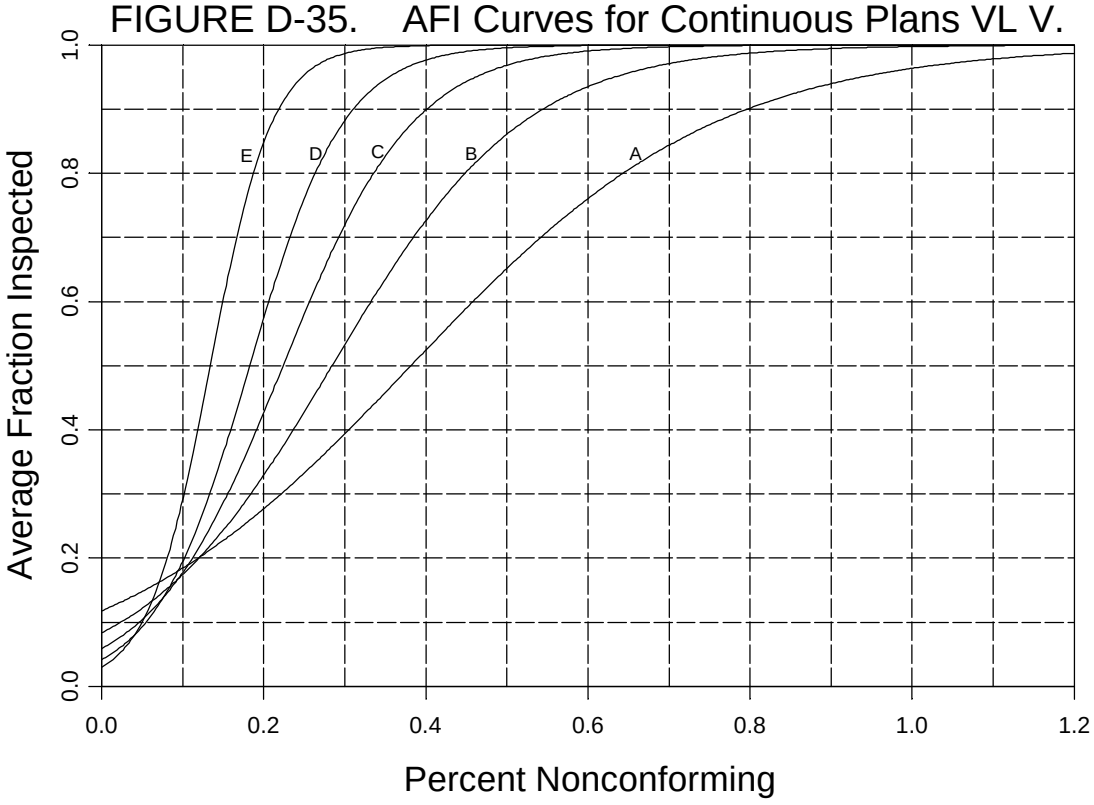


FIGURE D-36. AOQ Curves for Continuous Plans VL V.

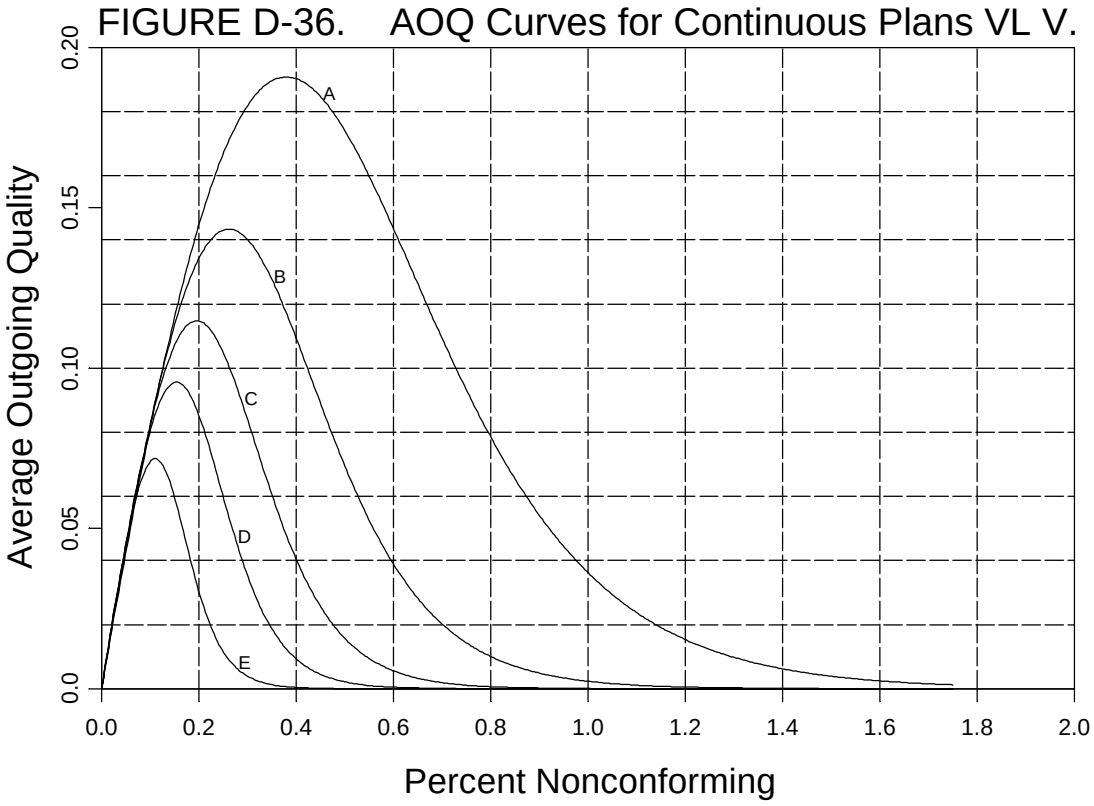


TABLE D-XII. Continuous Sampling Plans VL V.

Code Letter	Clearance Number	Sampling Frequency
A	527	2/17
B	842	1/12
C	1237	1/17
D	1714	1/24
E	2605	1/34

FIGURE D-37. OC Curves for Attributes Plans VL IV.

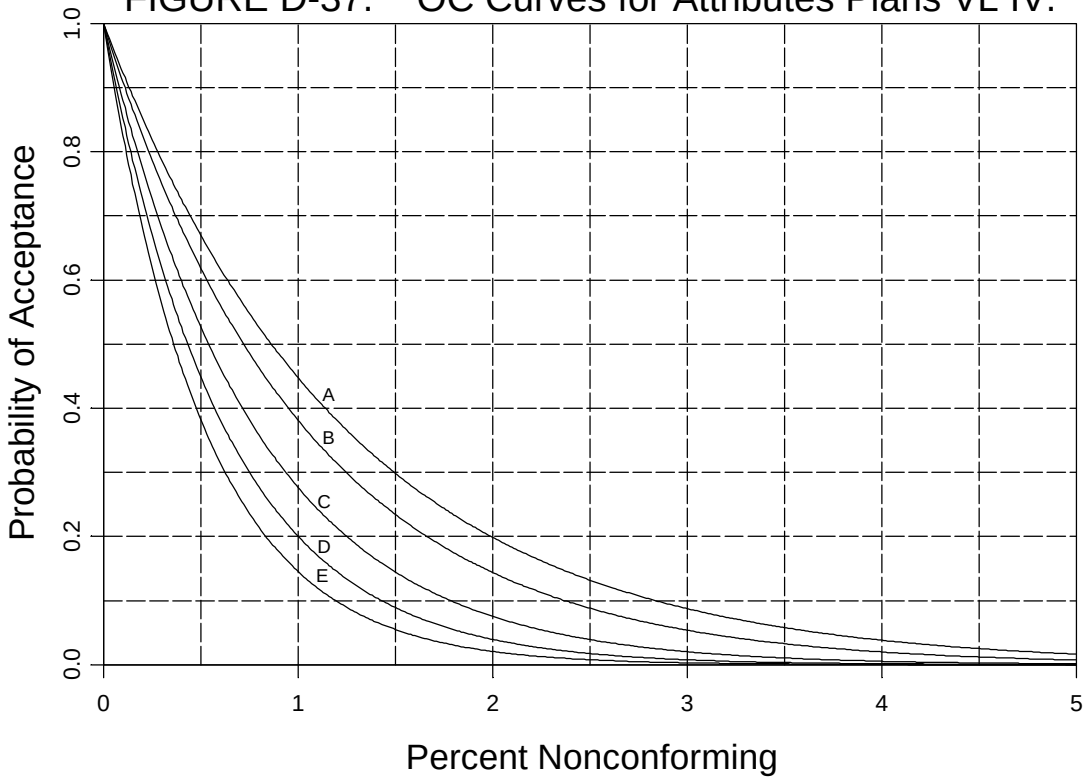


FIGURE D-38. AFI Curves for Attributes Plans VL IV.

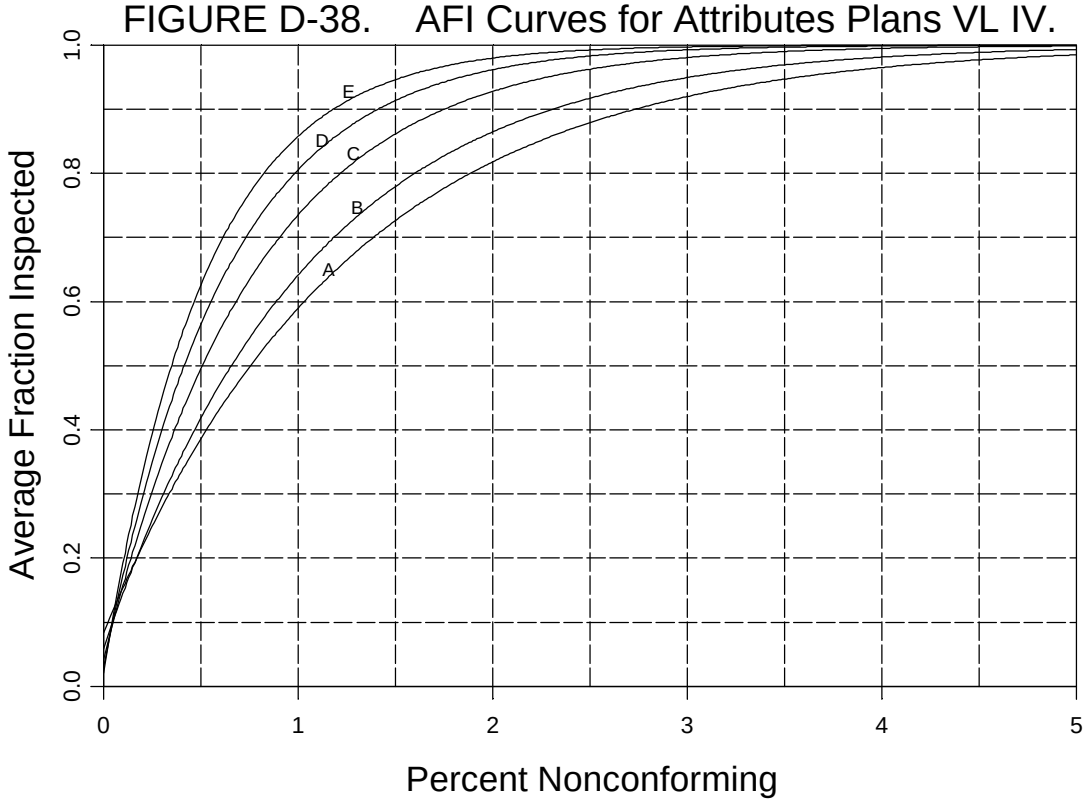


FIGURE D-39. AOQ Curves for Attributes Plans VL IV.

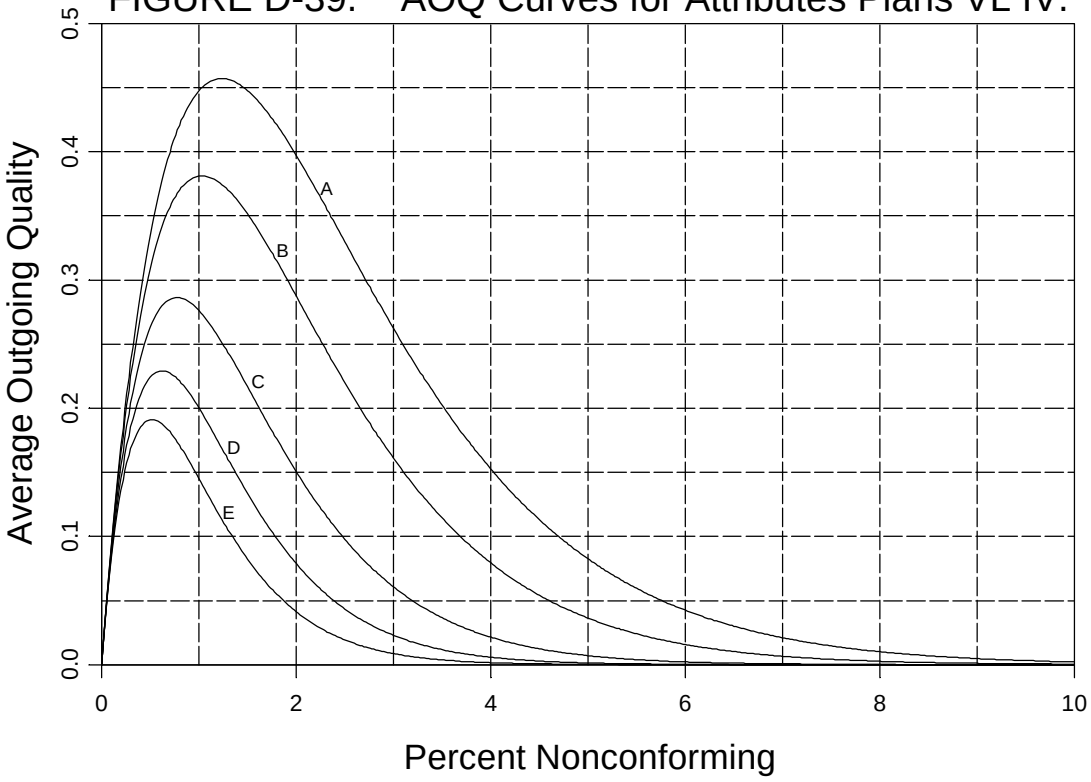


TABLE D-XIII. AoZ Sampling Plans VL IV.

Code Letter	Sample Size	Acceptance Number
A	80	0
B	96	0
C	128	0
D	160	0
E	192	0

FIGURE D-40. OC Curves for Variables Plans VL IV.

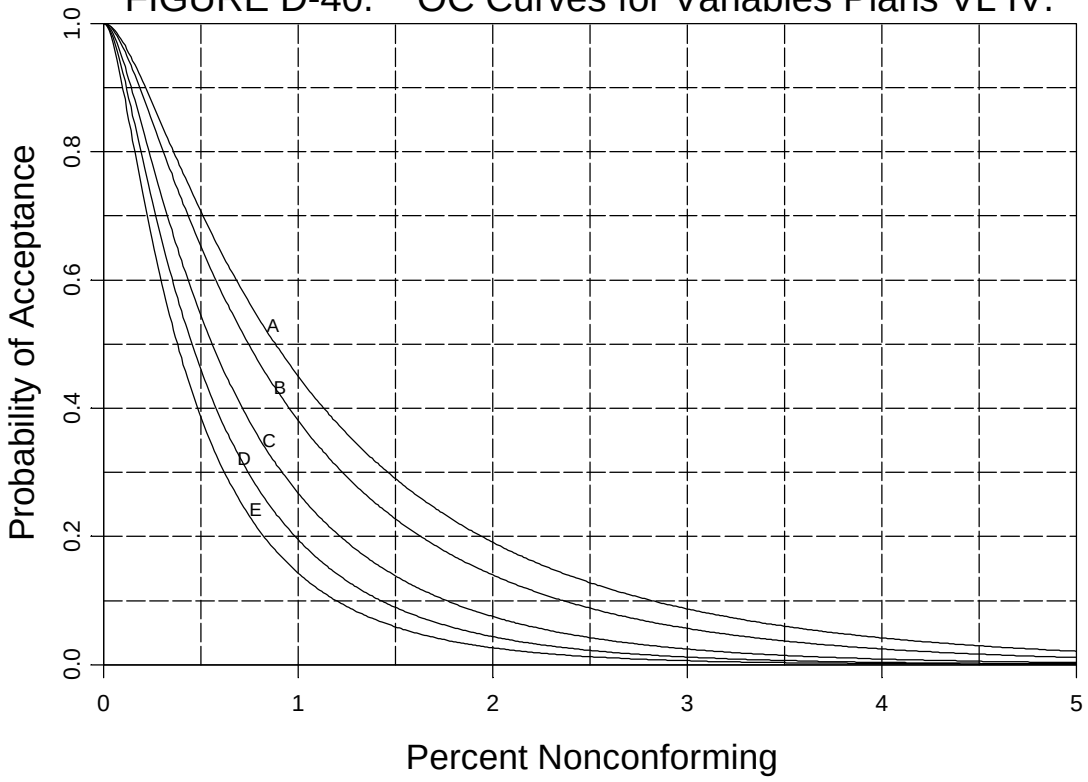


FIGURE D-41. AFI Curves for Variables Plans VL IV.

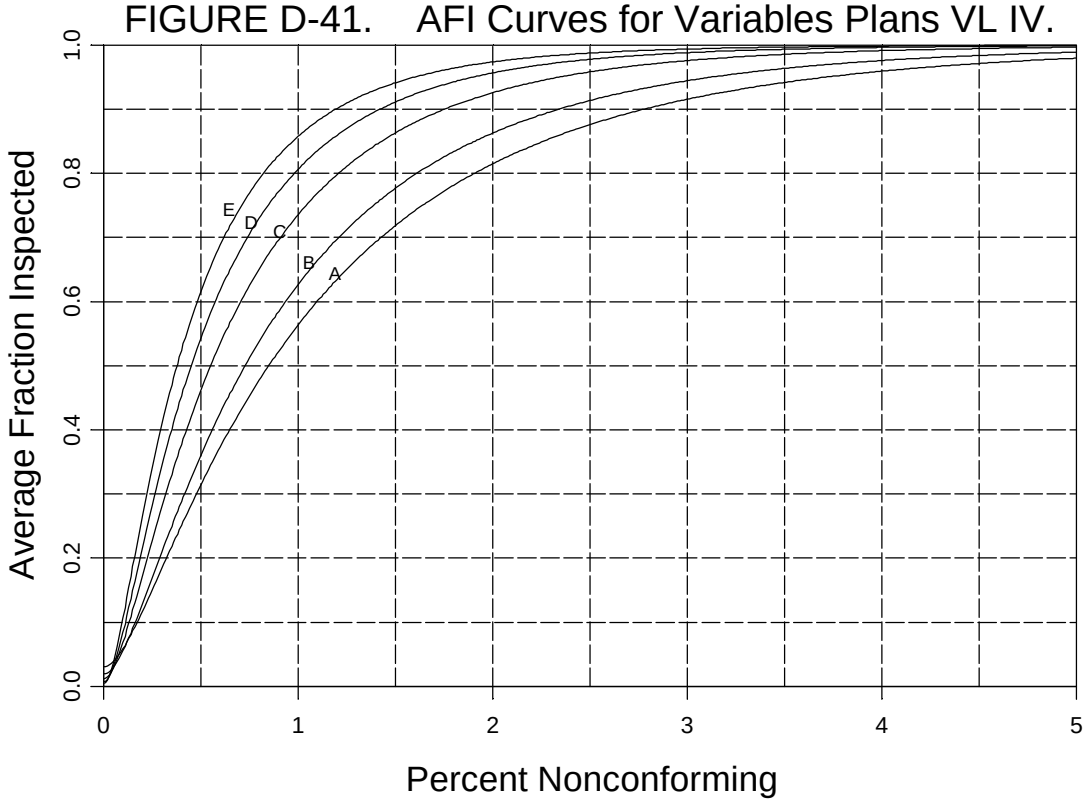


FIGURE D-42. AOQ Curves for Variables Plans VL IV.

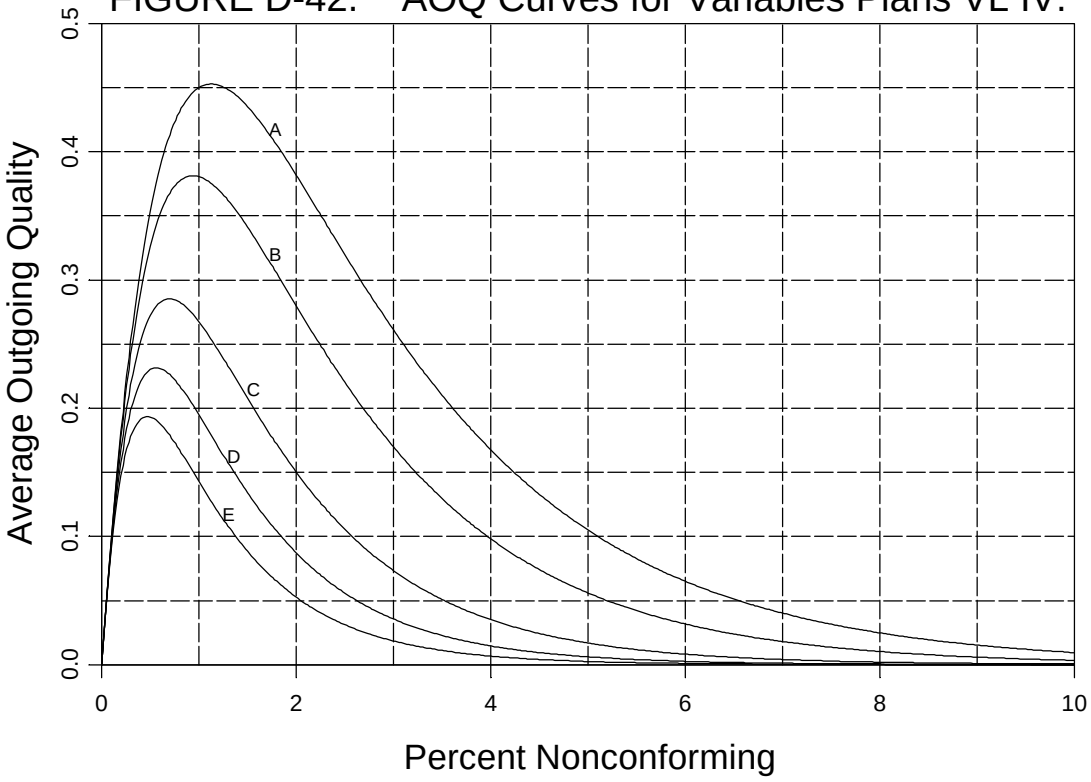


TABLE D-XIV. Variables Sampling Plans VL IV.

Code Letter	Sample Size	Acceptability Constant
A	29	2.40
B	32	2.46
C	37	2.56
D	41	2.63
E	44	2.69

FIGURE D-43. OC Curves for Continuous Plans VL IV.

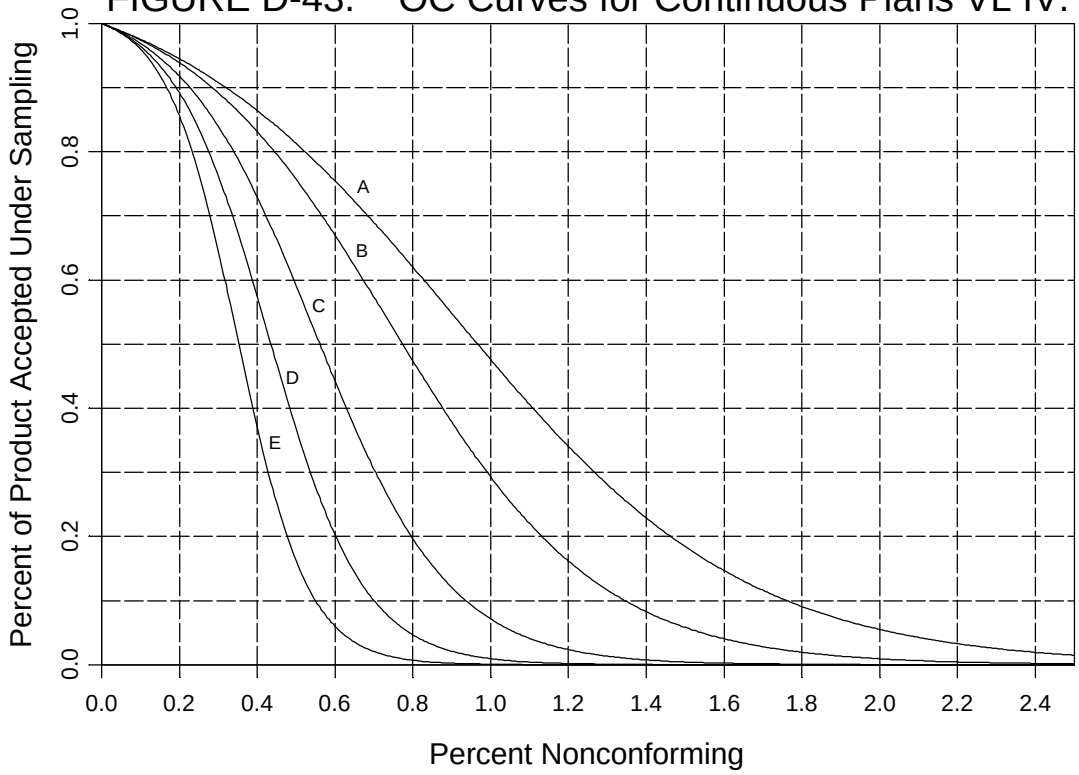


FIGURE D-44. AFI Curves for Continuous Plans VL IV.

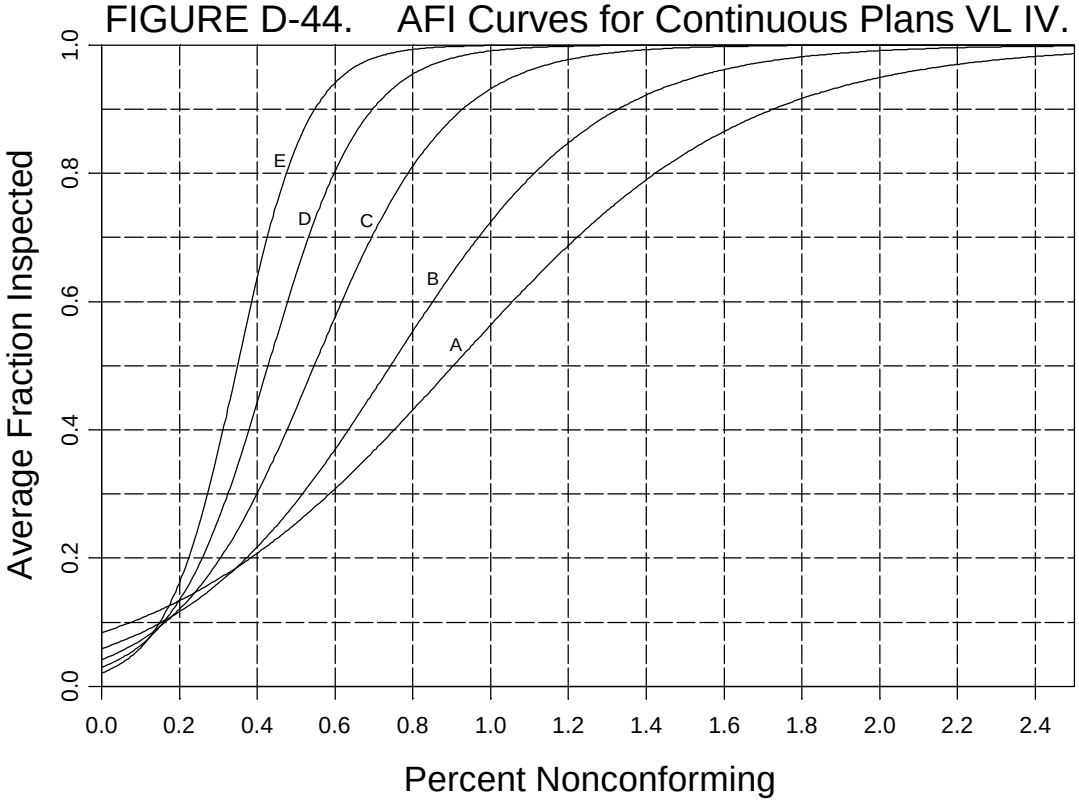


FIGURE D-45. AOQ Curves for Continuous Plans VL IV.

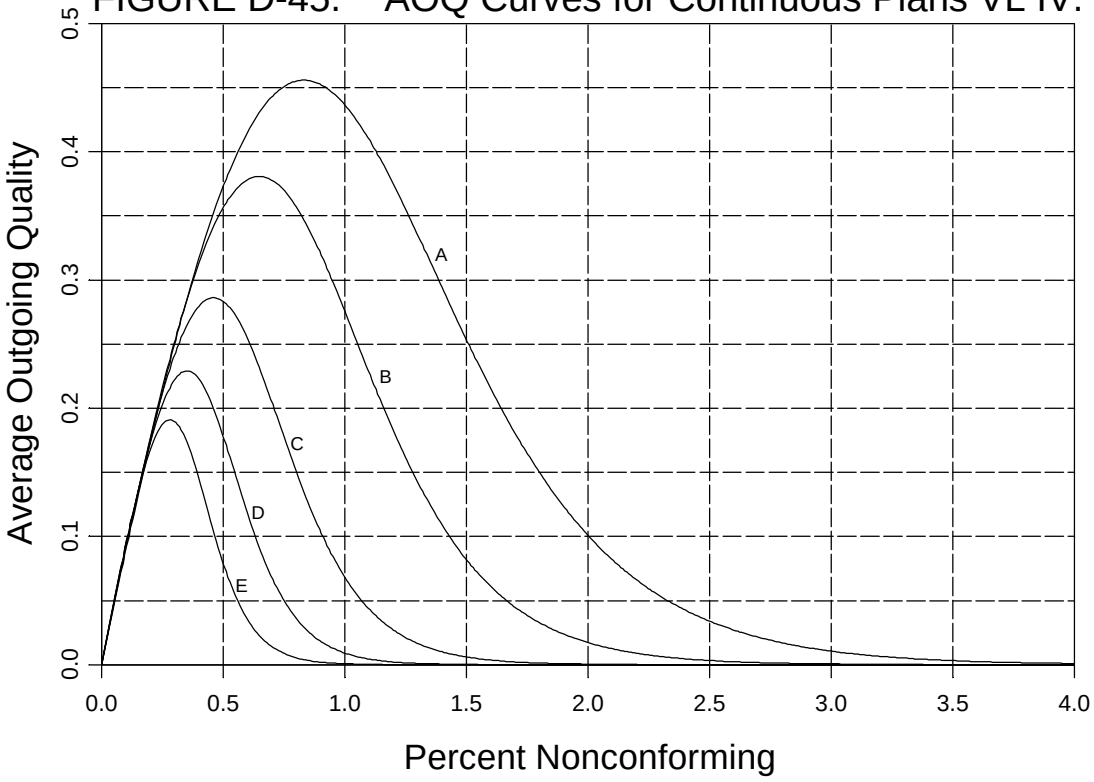


TABLE D-XV. Continuous Sampling Plans VL IV.

Code Letter	Clearance Number	Sampling Frequency
A	264	1/12
B	372	1/17
C	572	1/24
D	815	1/34
E	1101	1/48

FIGURE D-46. OC Curves for Attributes Plans VL III.

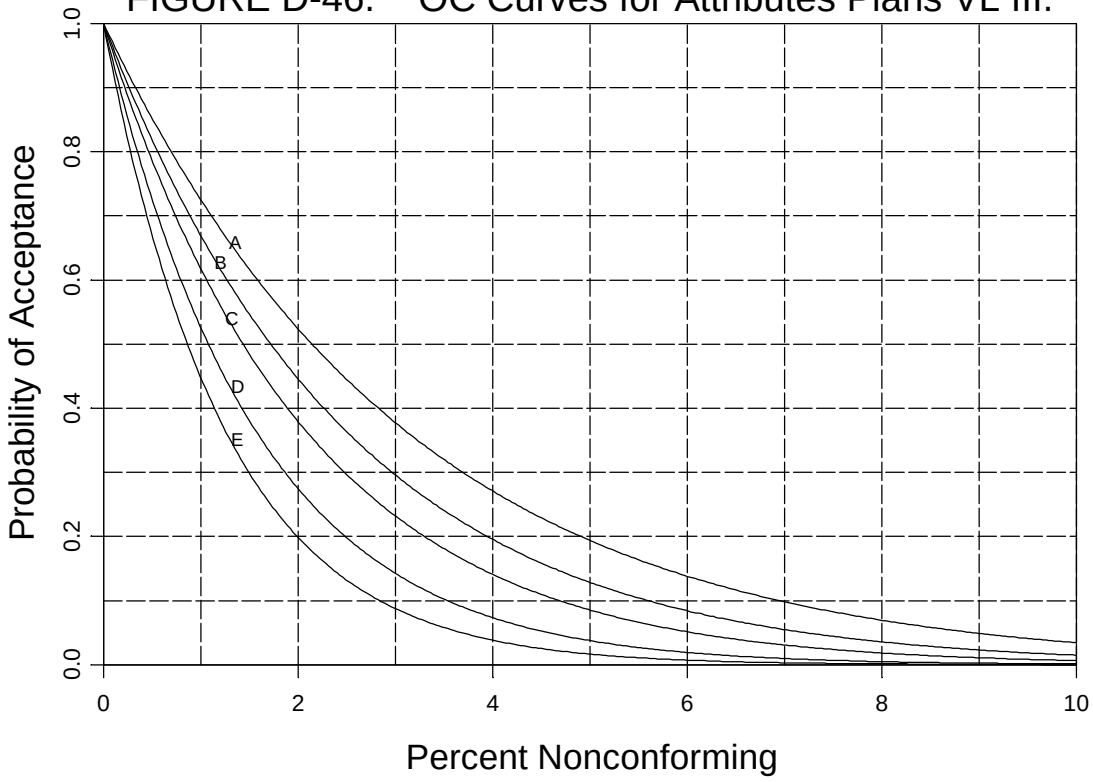


FIGURE D-47. AFI Curves for Attributes Plans VL III.

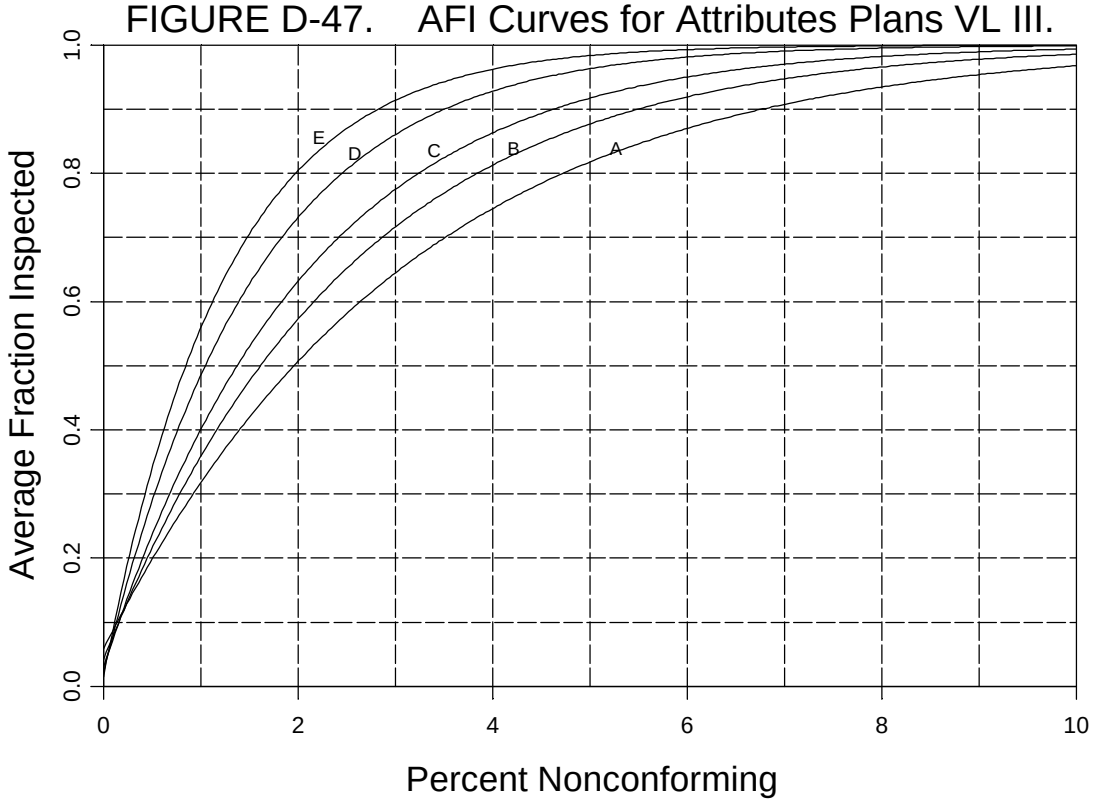


FIGURE D-48. AOQ Curves for Attributes Plans VL III.

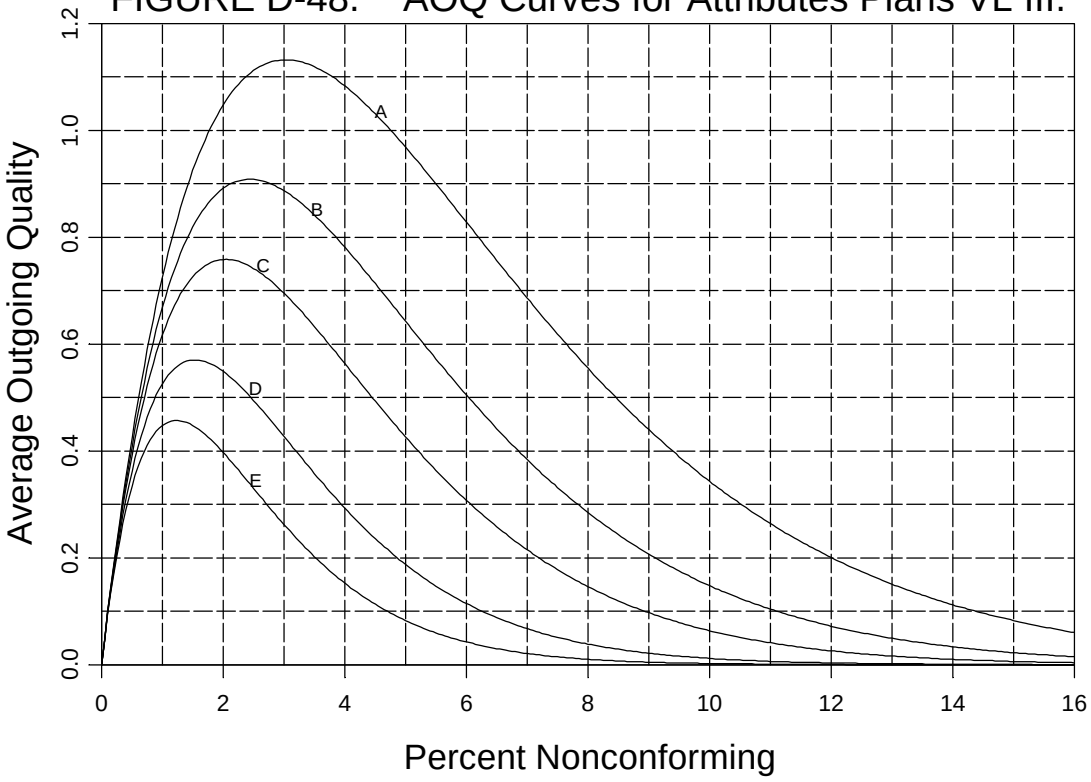


TABLE D-XVI. AoZ Sampling Plans VL III.

Code Letter	Sample Size	Acceptance Number
A	32	0
B	40	0
C	48	0
D	64	0
E	80	0

FIGURE D-49. OC Curves for Variables Plans VL III.

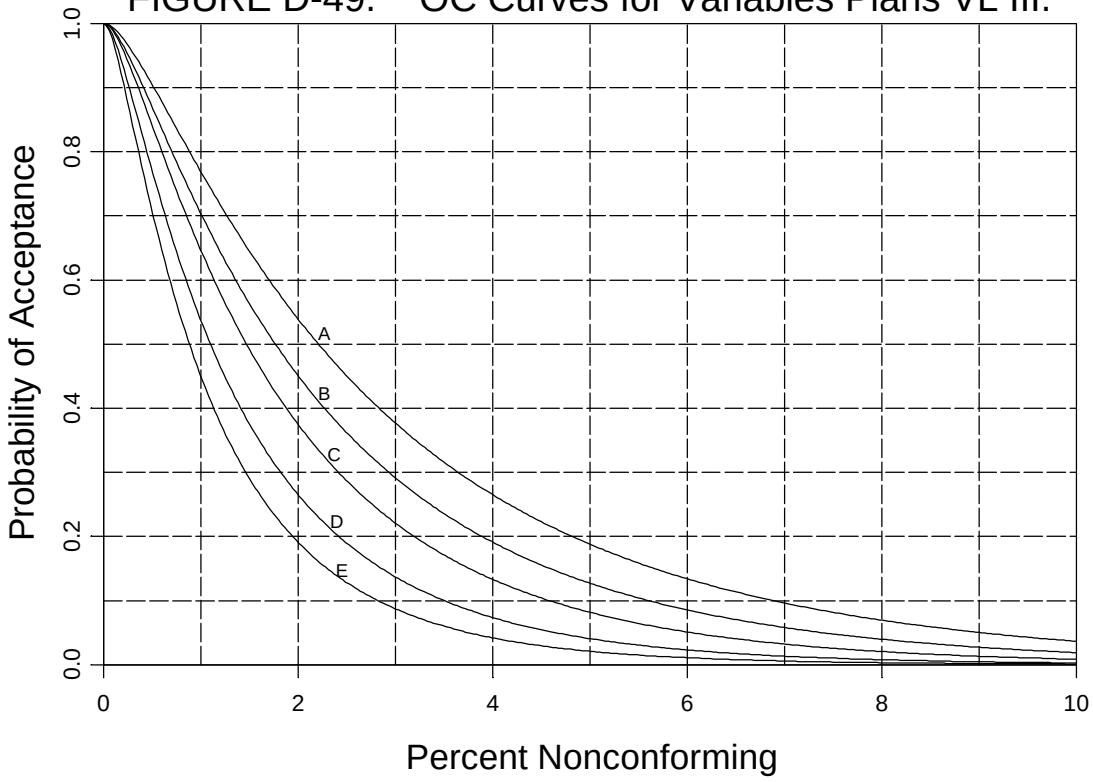


FIGURE D-50. AFI Curves for Variables Plans VL III.

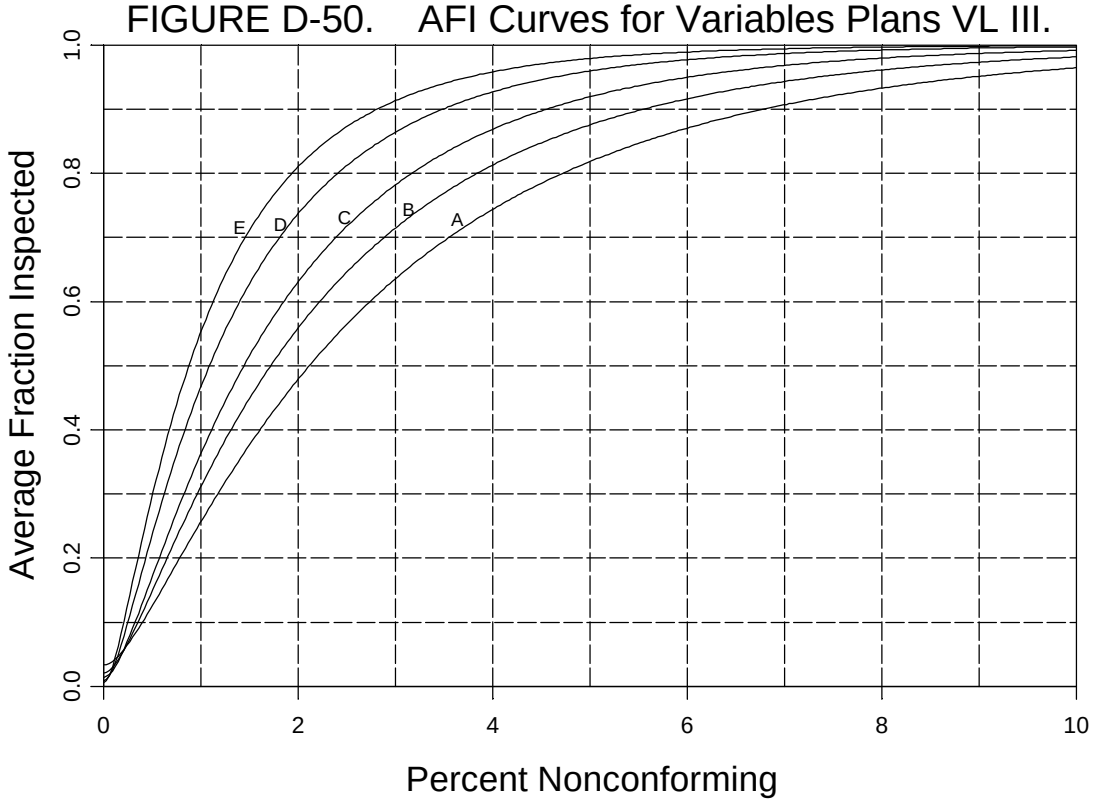


FIGURE D-51. AOQ Curves for Variables Plans VL III.

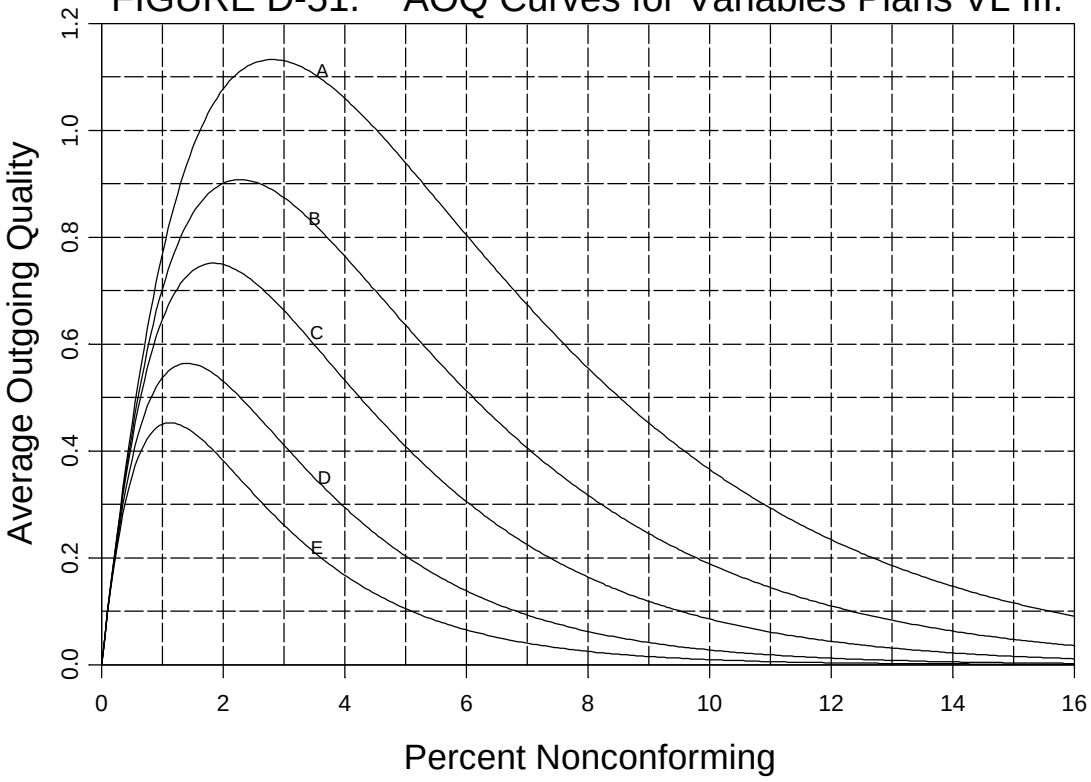


TABLE D-XVII. Variables Sampling Plans VL III.

Code Letter	Sample Size	Acceptability Constant
A	18	2.05
B	20	2.14
C	23	2.21
D	26	2.32
E	29	2.40

FIGURE D-52. OC Curves for Continuous Plans VL III.

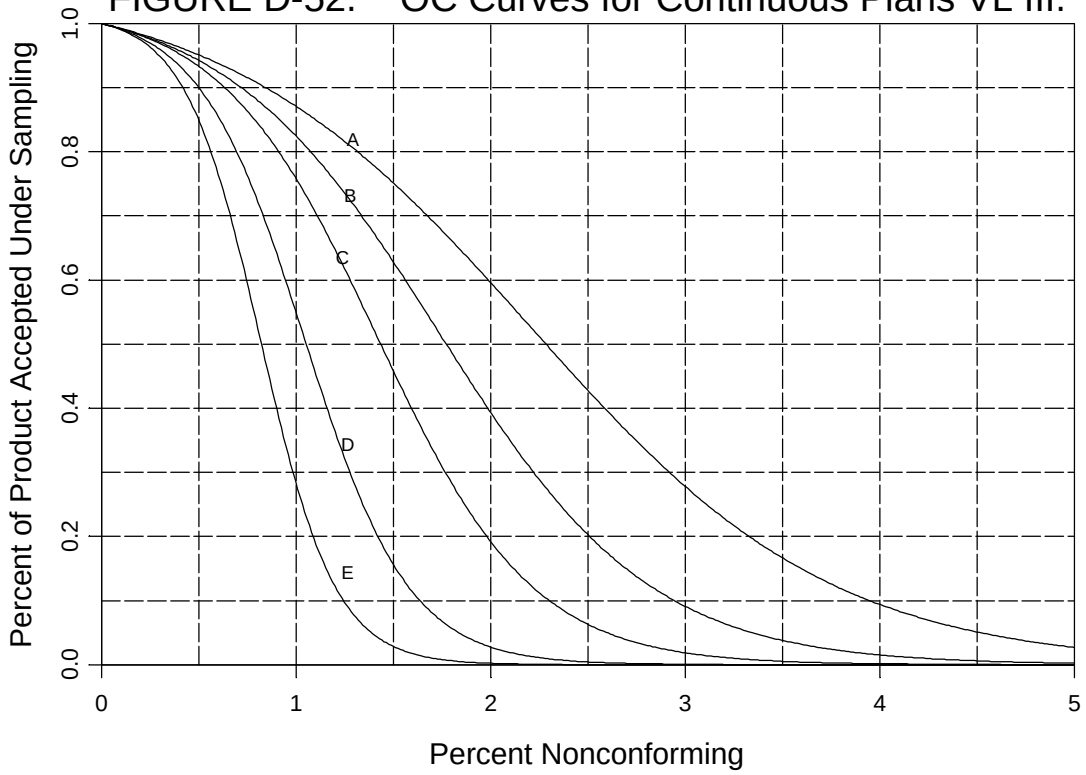


FIGURE D-53. AFI Curves for Continuous Plans VL III.

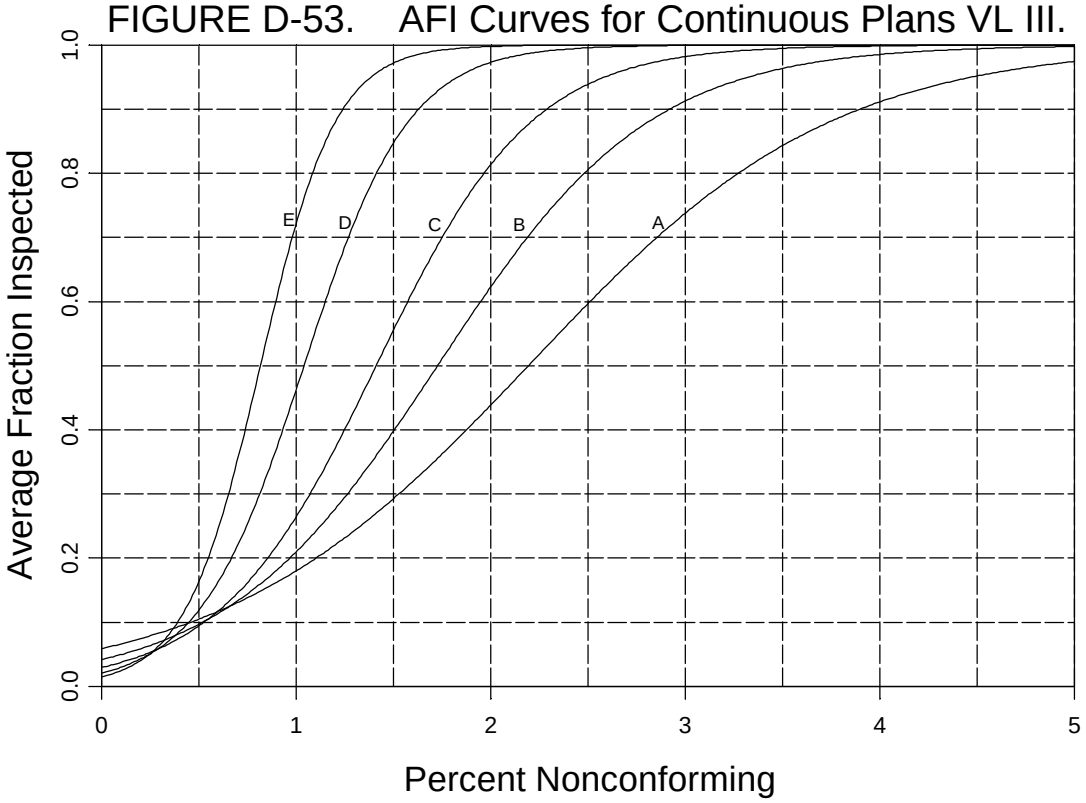


FIGURE D-54. AOQ Curves for Continuous Plans VL III.

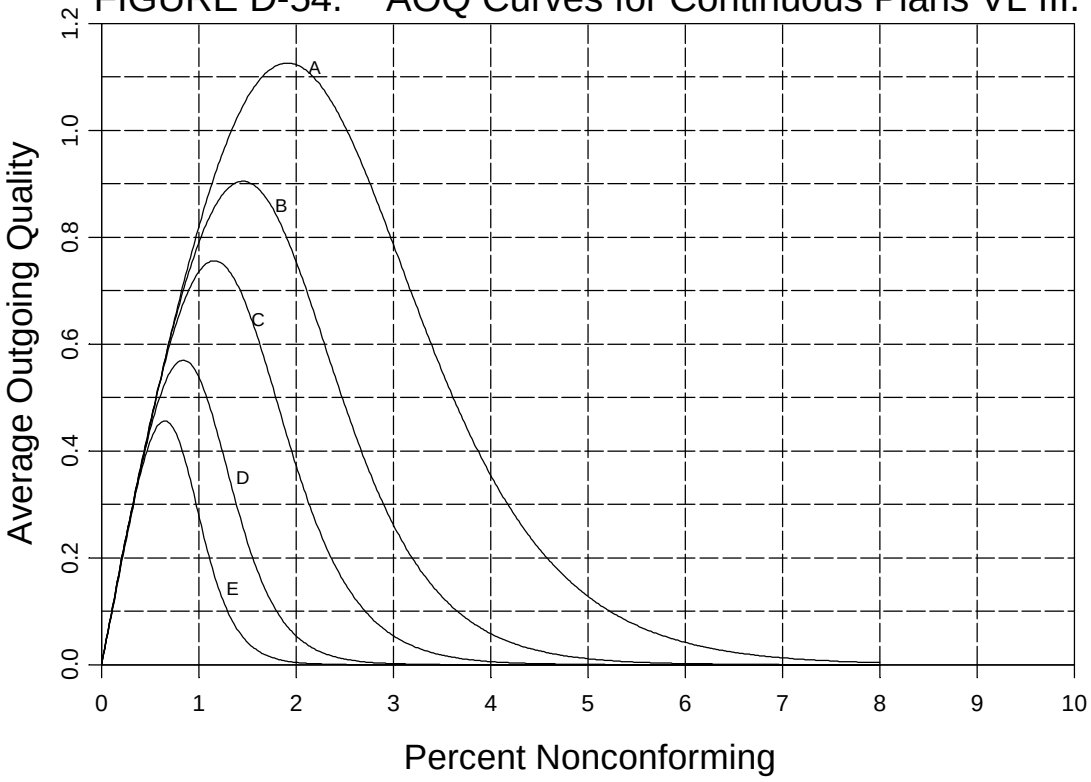


TABLE D-XVIII. Continuous Sampling Plans VL III.

Code Letter	Clearance Number	Sampling Frequency
A	125	1/17
B	180	1/24
C	246	1/34
D	368	1/48
E	513	1/68

FIGURE D-55. OC Curves for Attributes Plans VL II.

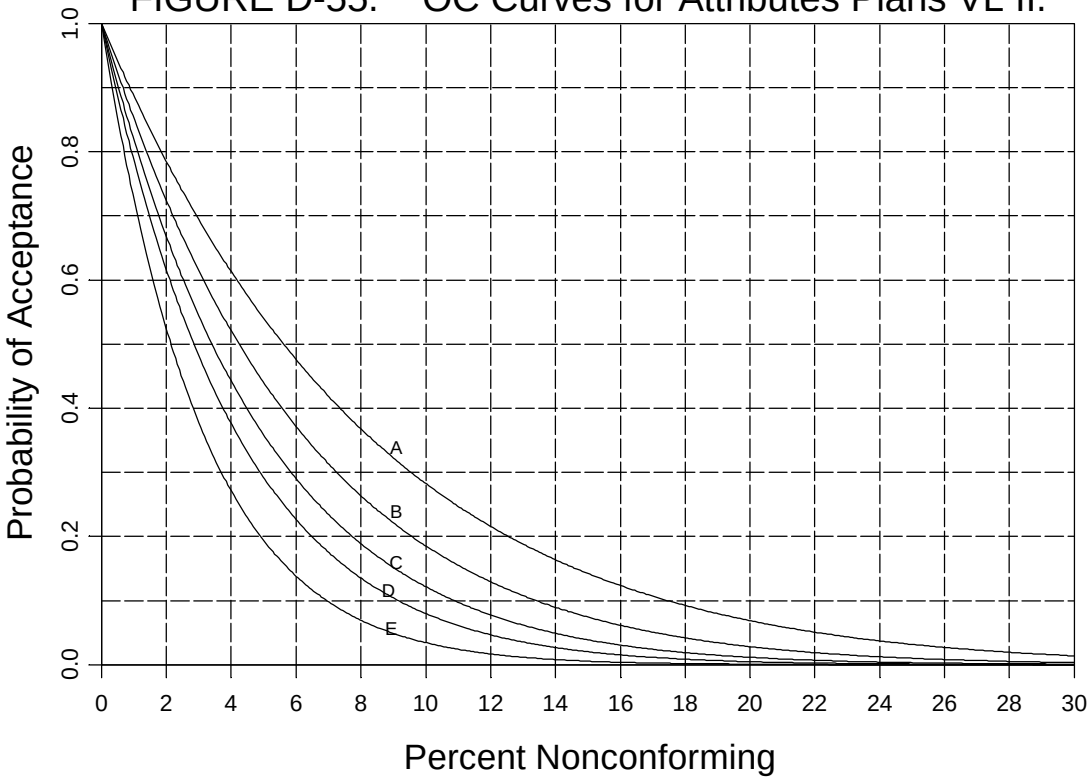


FIGURE D-56. AFI Curves for Attributes Plans VL II.

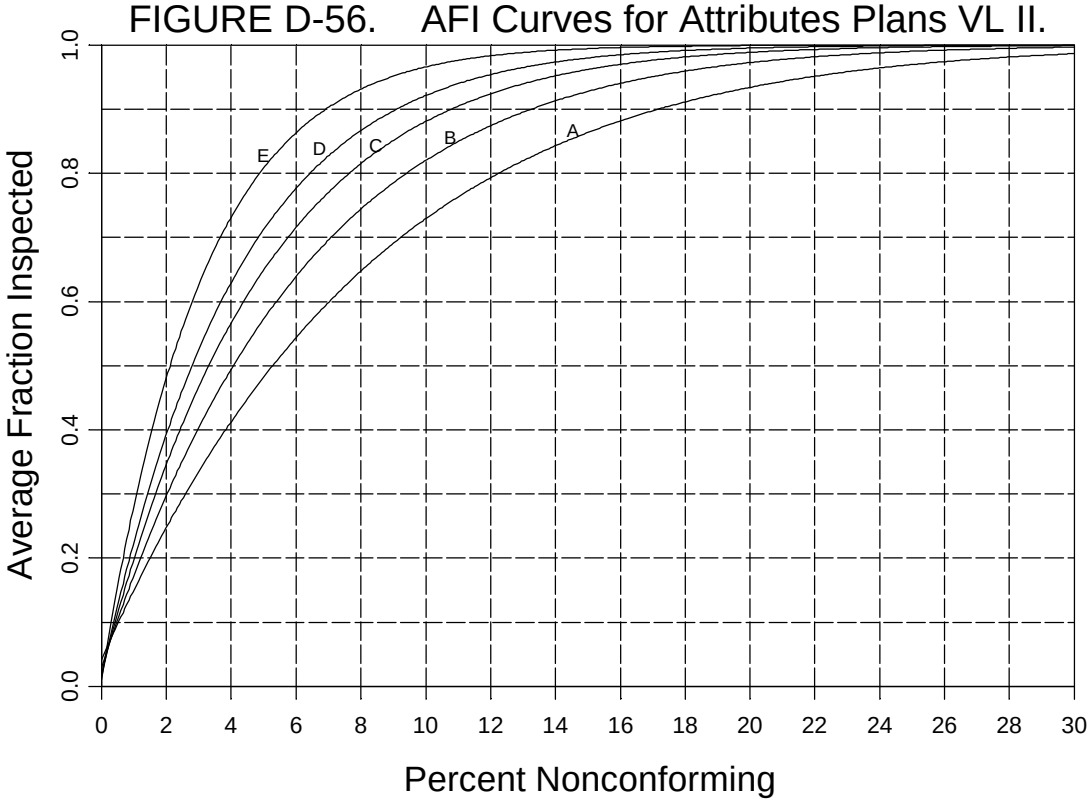


FIGURE D-57. AOQ Curves for Attributes Plans VL II.

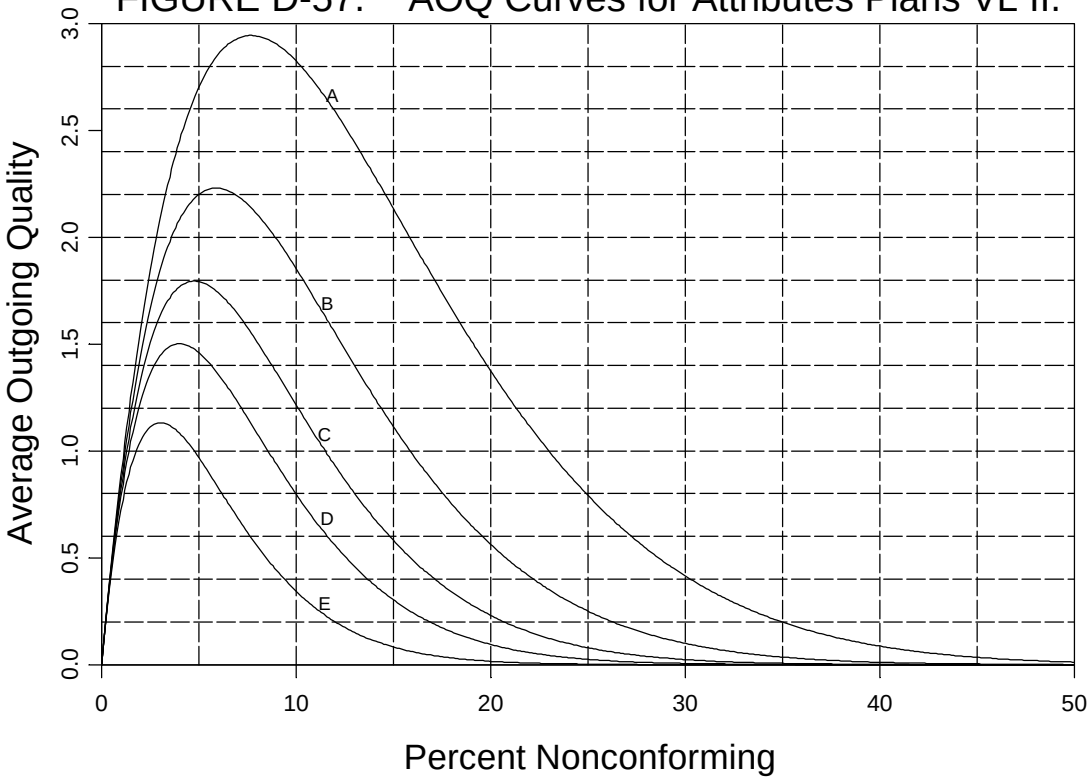


TABLE D-XIX. AoZ Sampling Plans VL II.

Code Letter	Sample Size	Acceptance Number
A	12	0
B	16	0
C	20	0
D	24	0
E	32	0

FIGURE D-58. OC Curves for Variables Plans VL II.

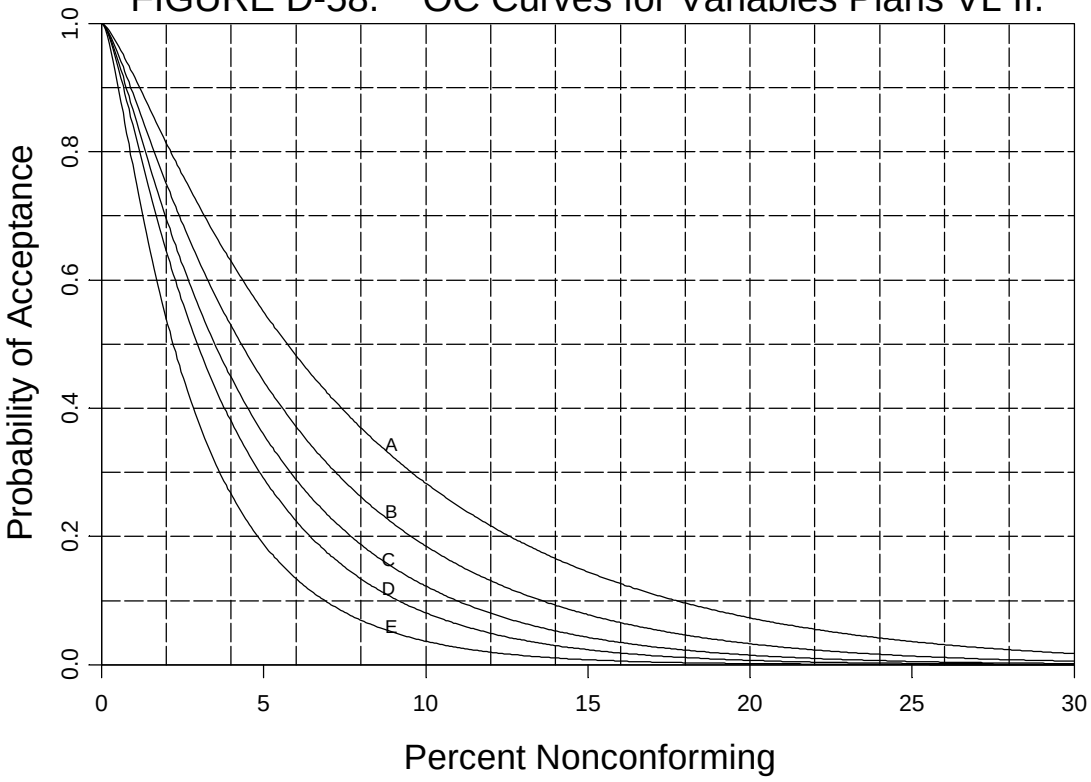


FIGURE D-59. AFI Curves for Variables Plans VL II.

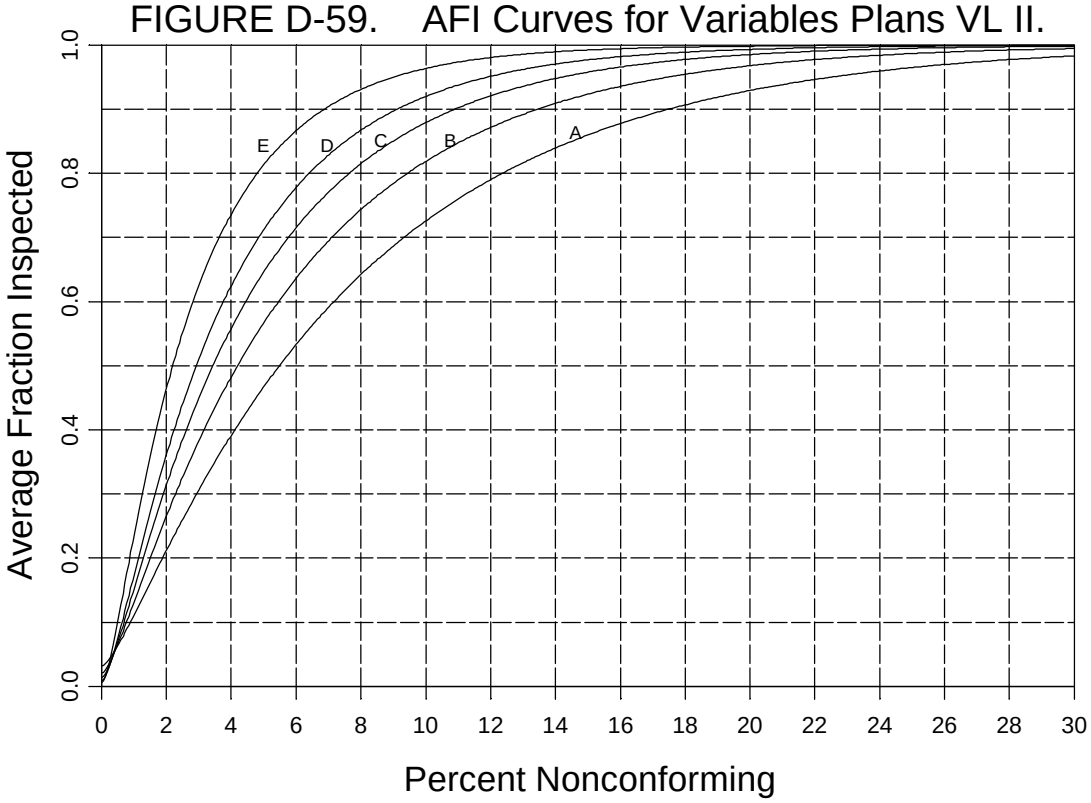


FIGURE D-60. AOQ Curves for Variables Plans VL II.

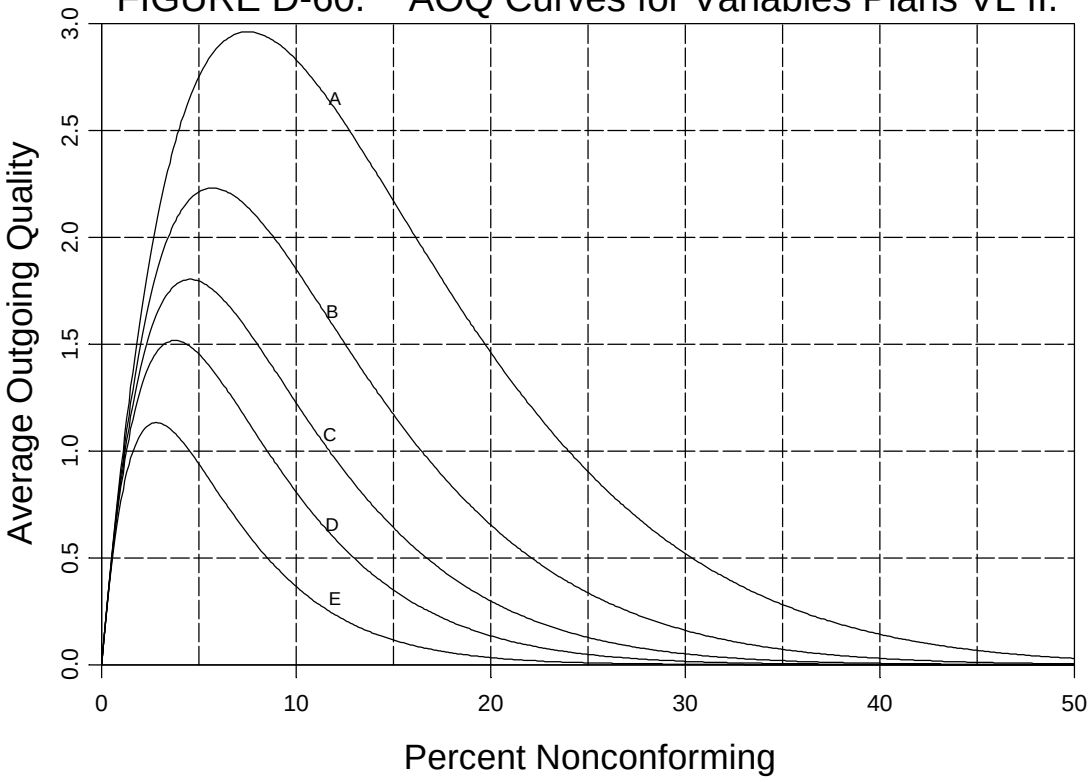


TABLE D-XX. Variables Sampling Plans VL II.

Code Letter	Sample Size	Acceptability Constant
A	9	1.64
B	11	1.77
C	13	1.86
D	15	1.93
E	18	2.05

FIGURE D-61. OC Curves for Continuous Plans VL II.

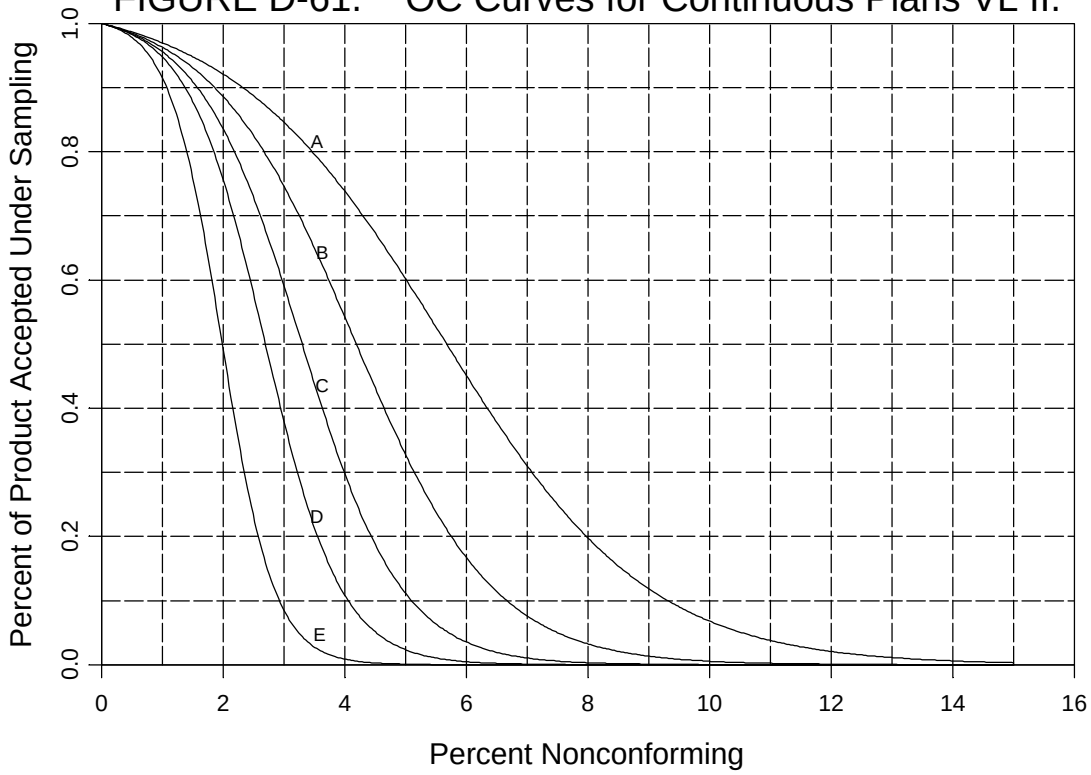


FIGURE D-62. AFI Curves for Continuous Plans VL II.

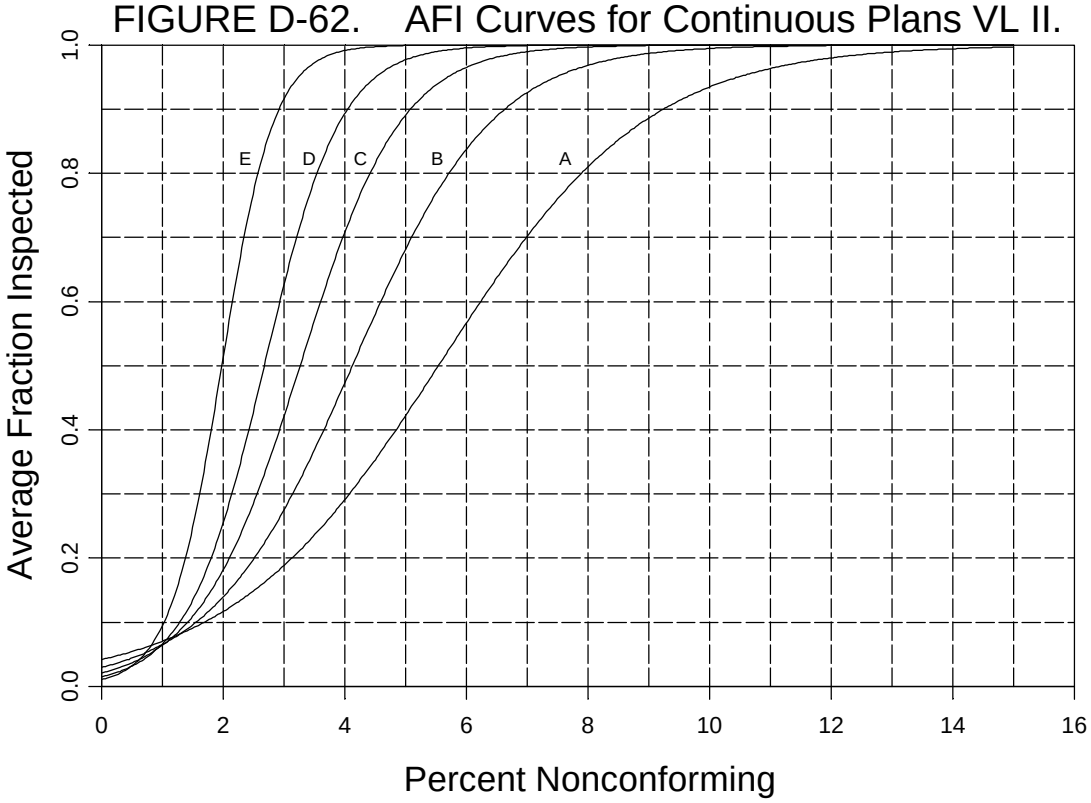


FIGURE D-63. AOQ Curves for Continuous Plans VL II.

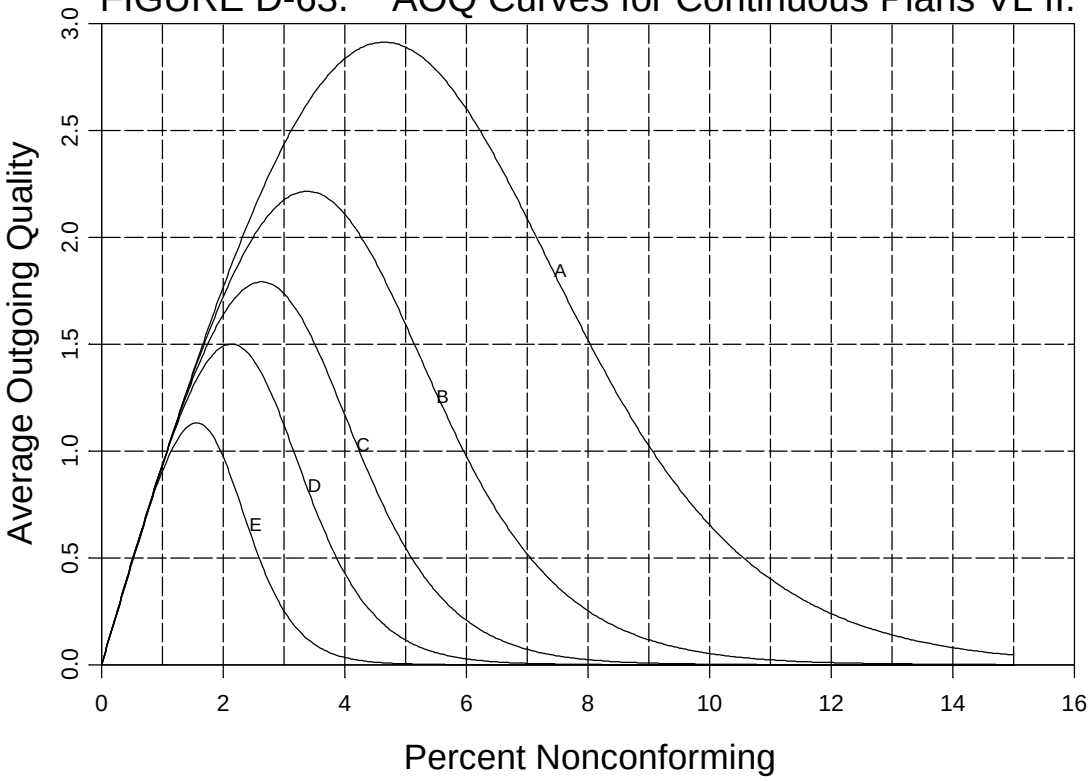


TABLE D-XXI. Continuous Sampling Plans VL II.

Code Letter	Clearance Number	Sampling Frequency
A	55	1/24
B	83	1/34
C	116	1/48
D	155	1/68
E	228	1/96

FIGURE D-64. OC Curves for Attributes Plans VL I.

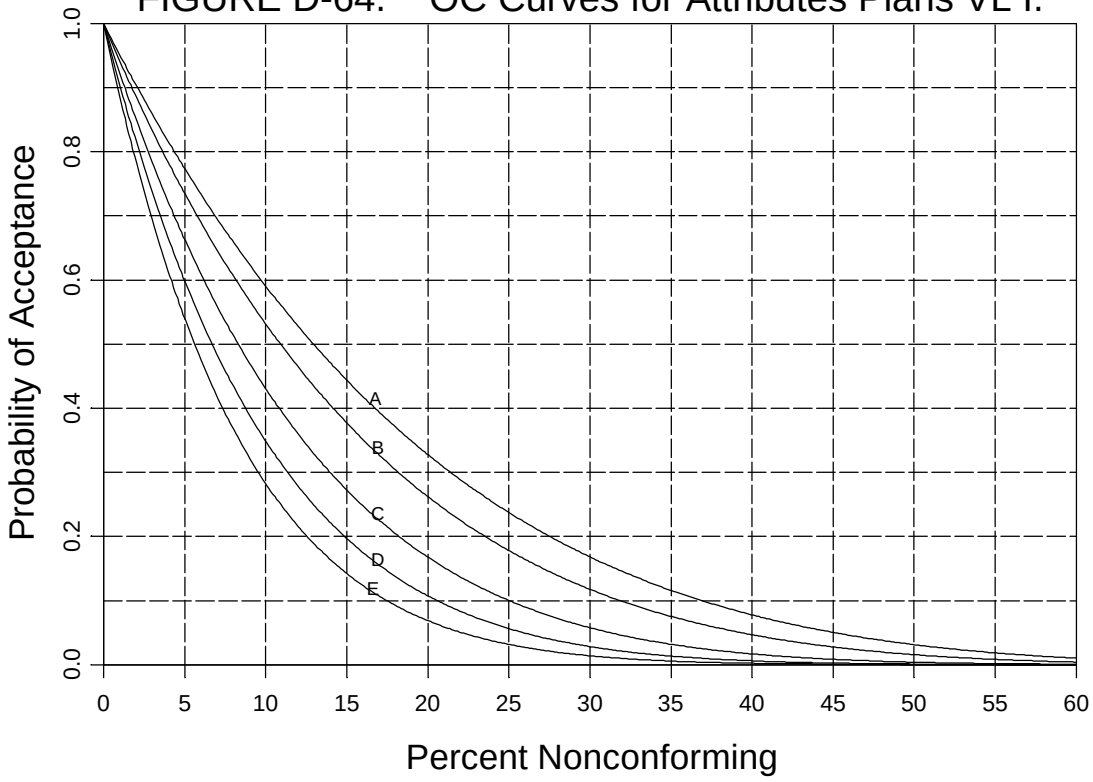


FIGURE D-65. AFI Curves for Attributes Plans VL I.

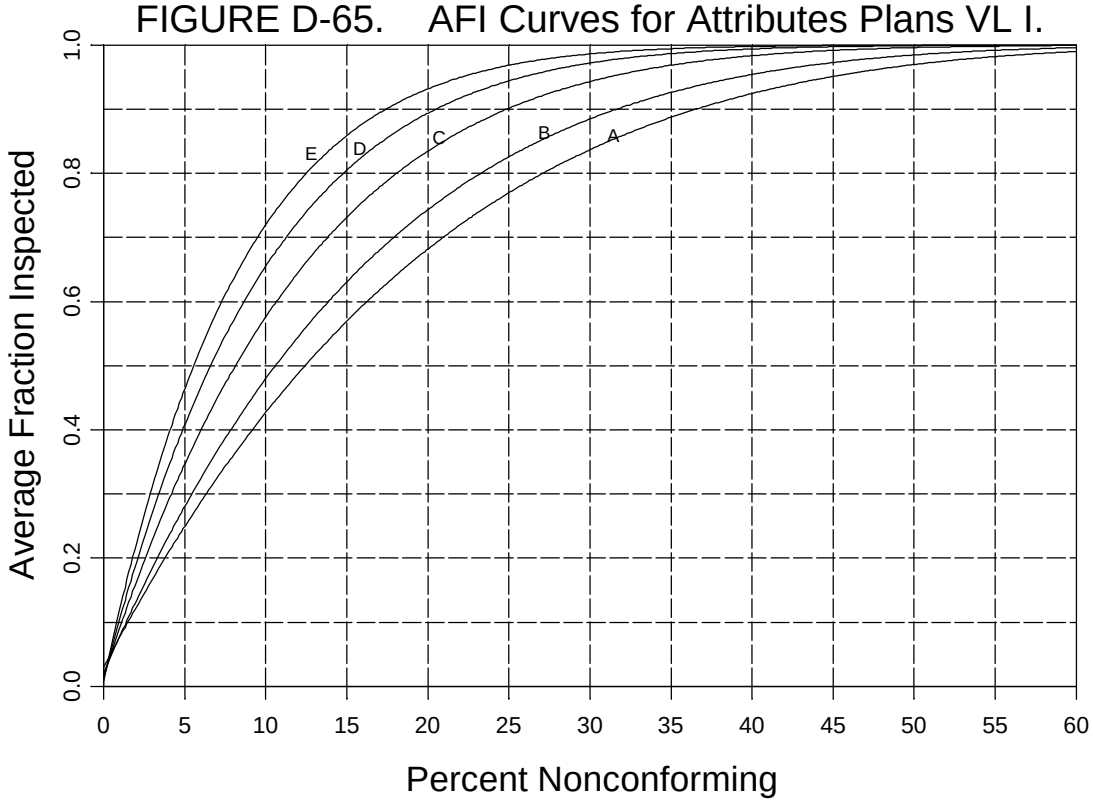


FIGURE D-66. AOQ Curves for Attributes Plans VL I.

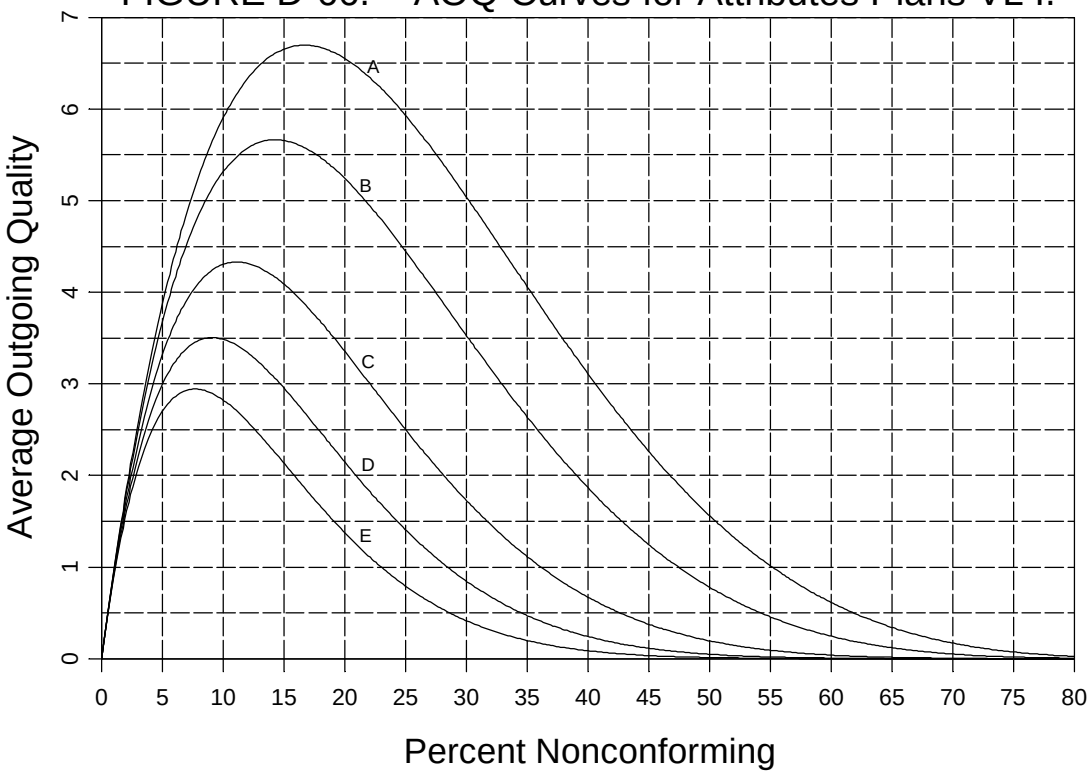


TABLE D-XXII. AoZ Sampling Plans VL I.

Code Letter	Sample Size	Acceptance Number
A	5	0
B	6	0
C	8	0
D	10	0
E	12	0

FIGURE D-67. OC Curves for Variables Plans VL I.

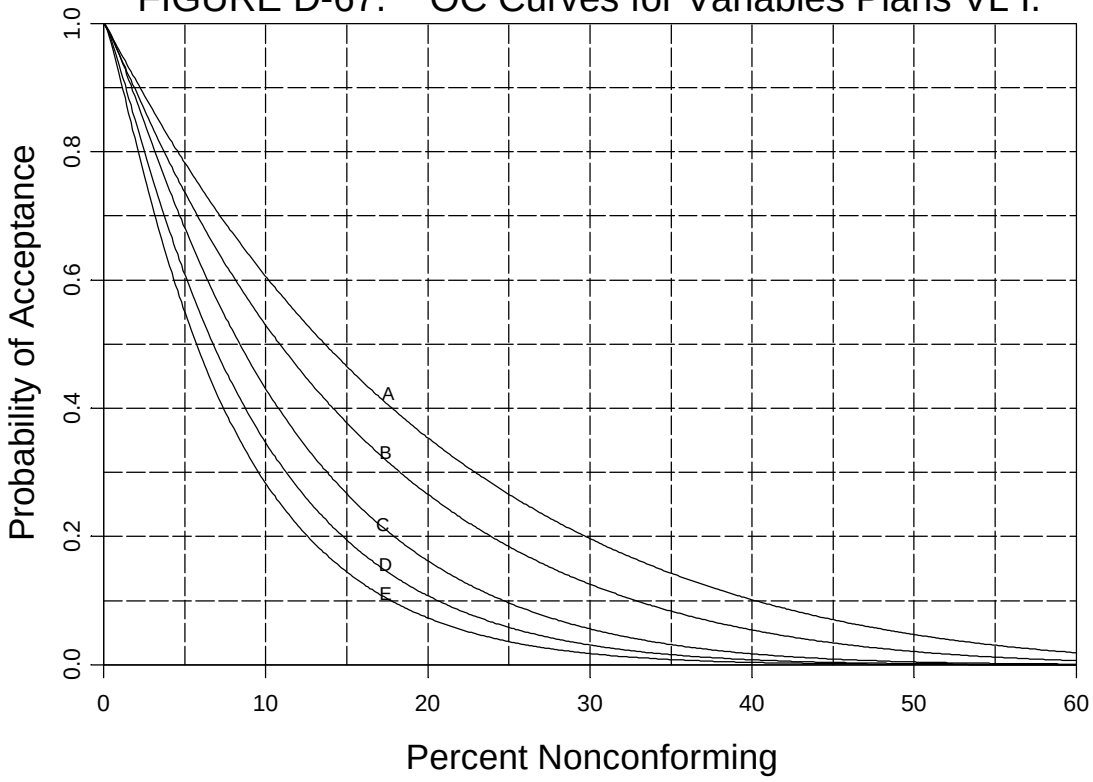


FIGURE D-68. AFI Curves for Variables Plans VL I.

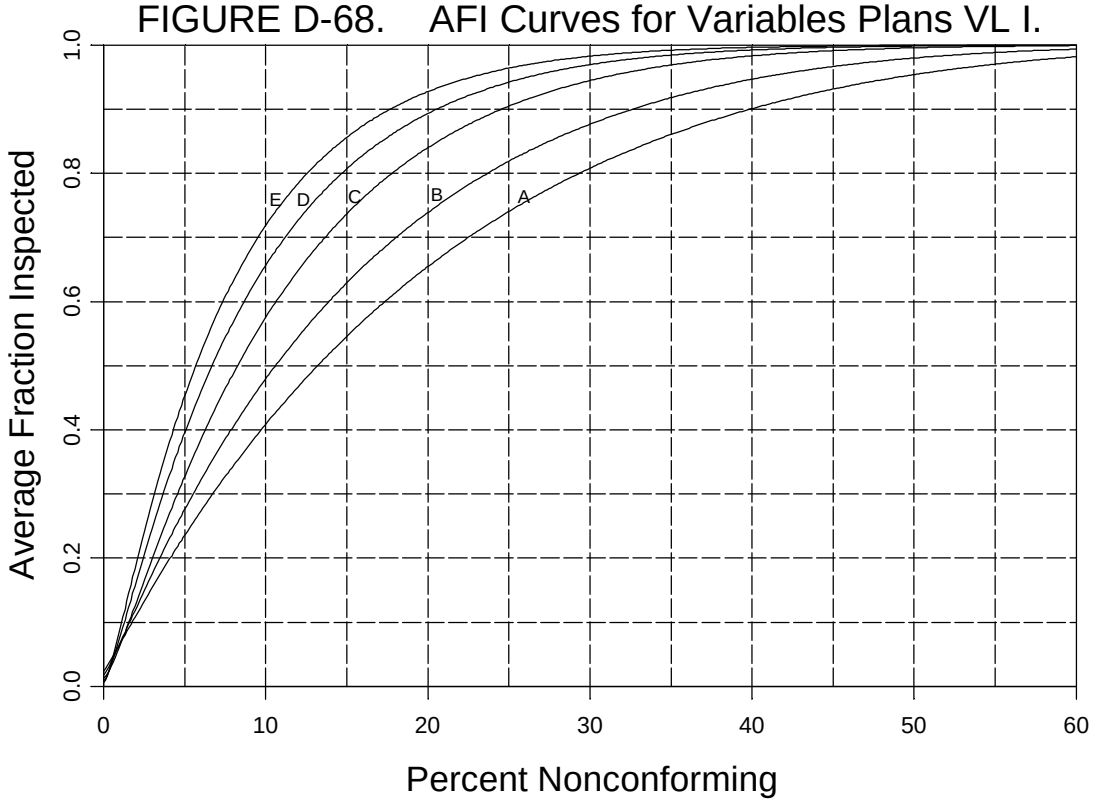


FIGURE D-69. AOQ Curves for Variables Plans VL I.

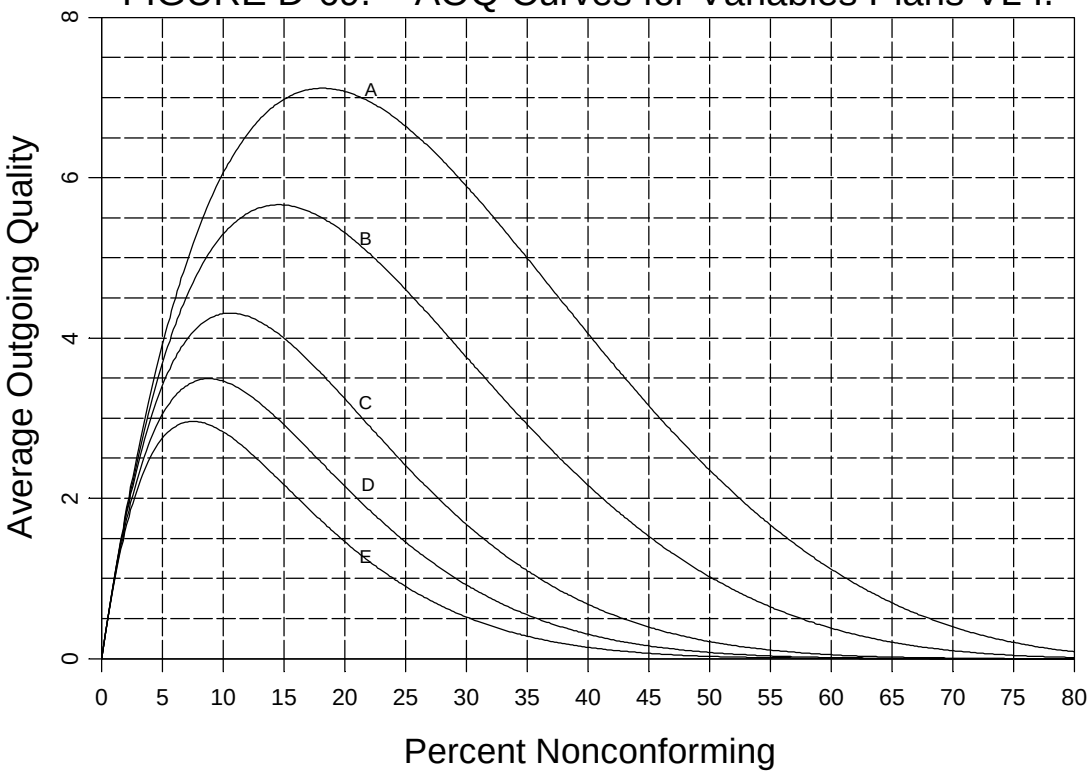


TABLE D-XXIII. Variables Sampling Plans VL I.

Code Letter	Sample Size	Acceptability Constant
A	4	1.21
B	5	1.33
C	7	1.45
D	8	1.56
E	9	1.64

FIGURE D-70. OC Curves for Continuous Plans VL I.

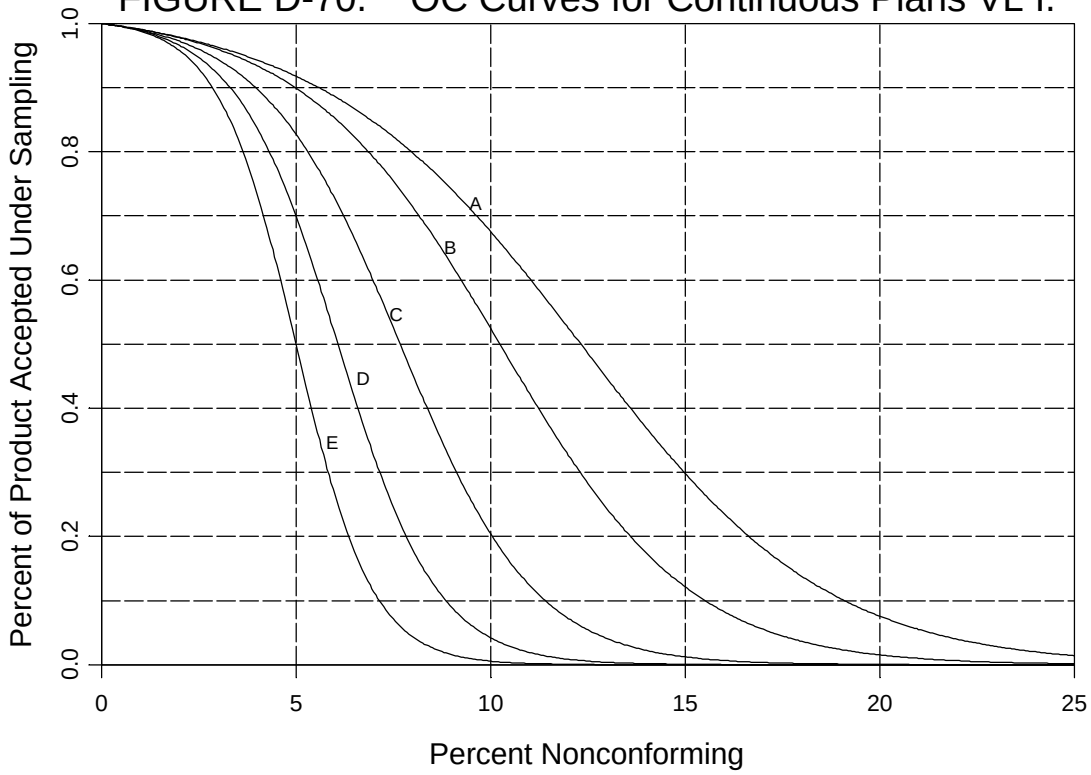


FIGURE D-71. AFI Curves for Continuous Plans VL I.

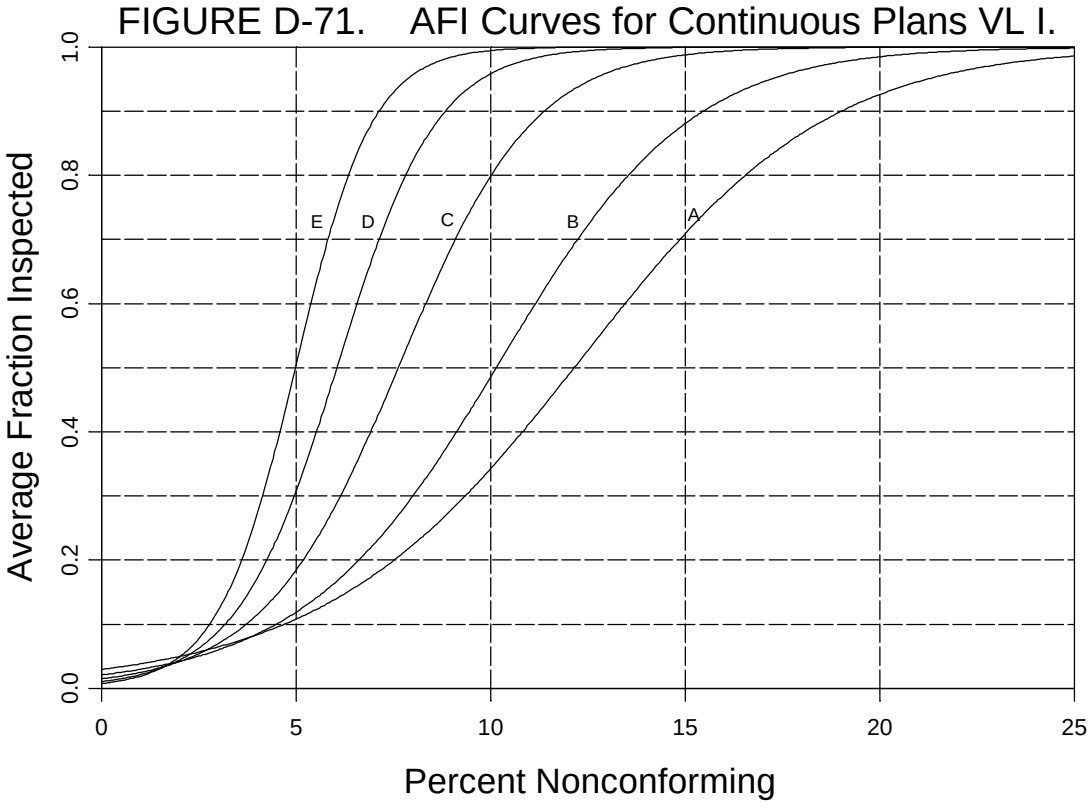


FIGURE D-72. AOQ Curves for Continuous Plans VL I.

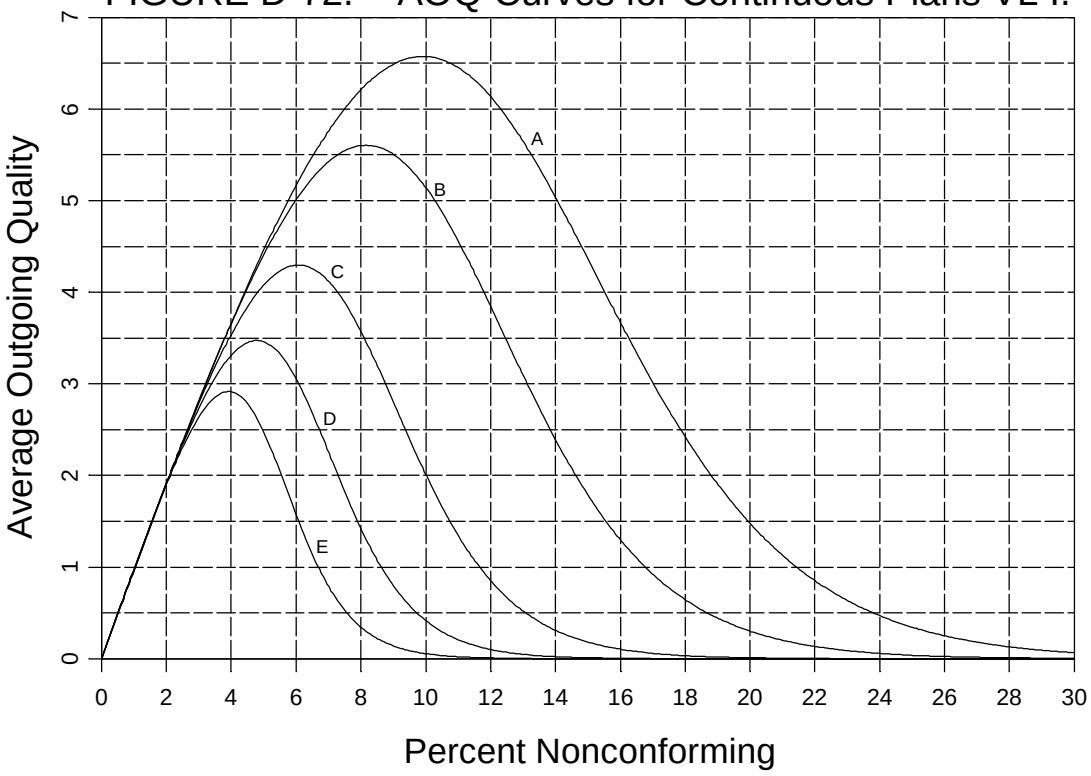


TABLE D-XXIV. Continuous Sampling Plans VL I.

Code Letter	Clearance Number	Sampling Frequency
A	27	1/34
B	36	1/48
C	53	1/68
D	73	1/96
E	96	1/136

Figure D-73. OC Curves for Attribute Plans VL R.

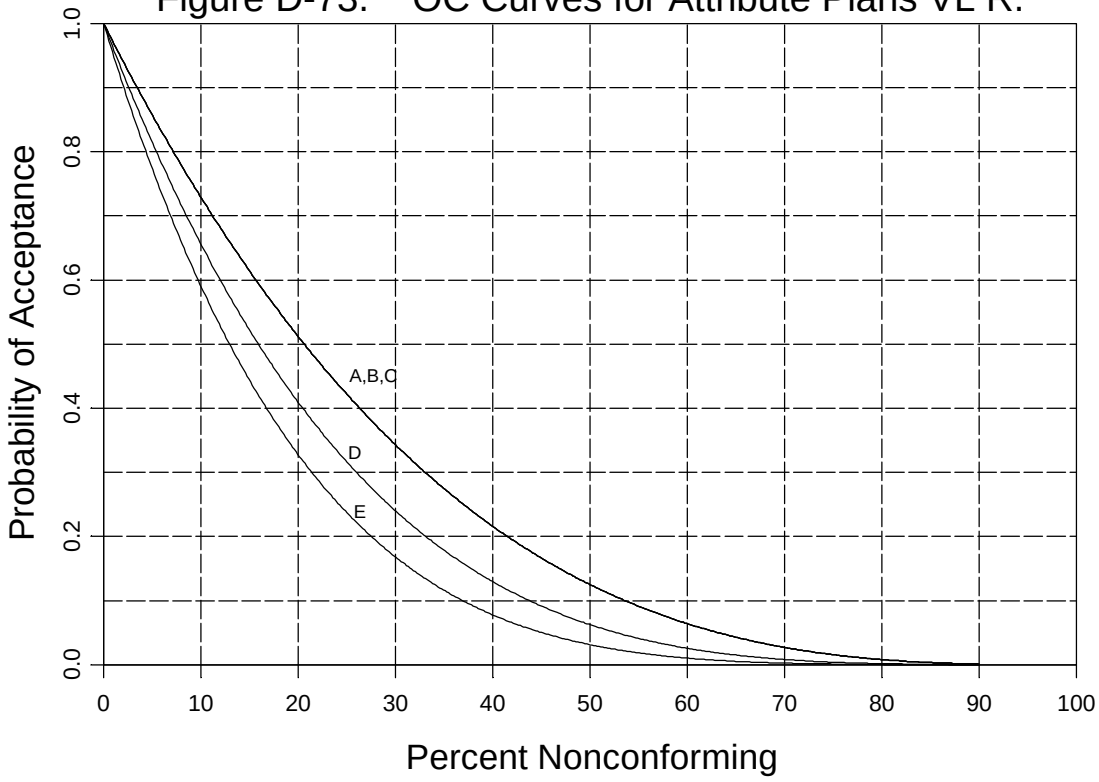


Figure D-74. AFI Curves for Attribute Plans VL R.

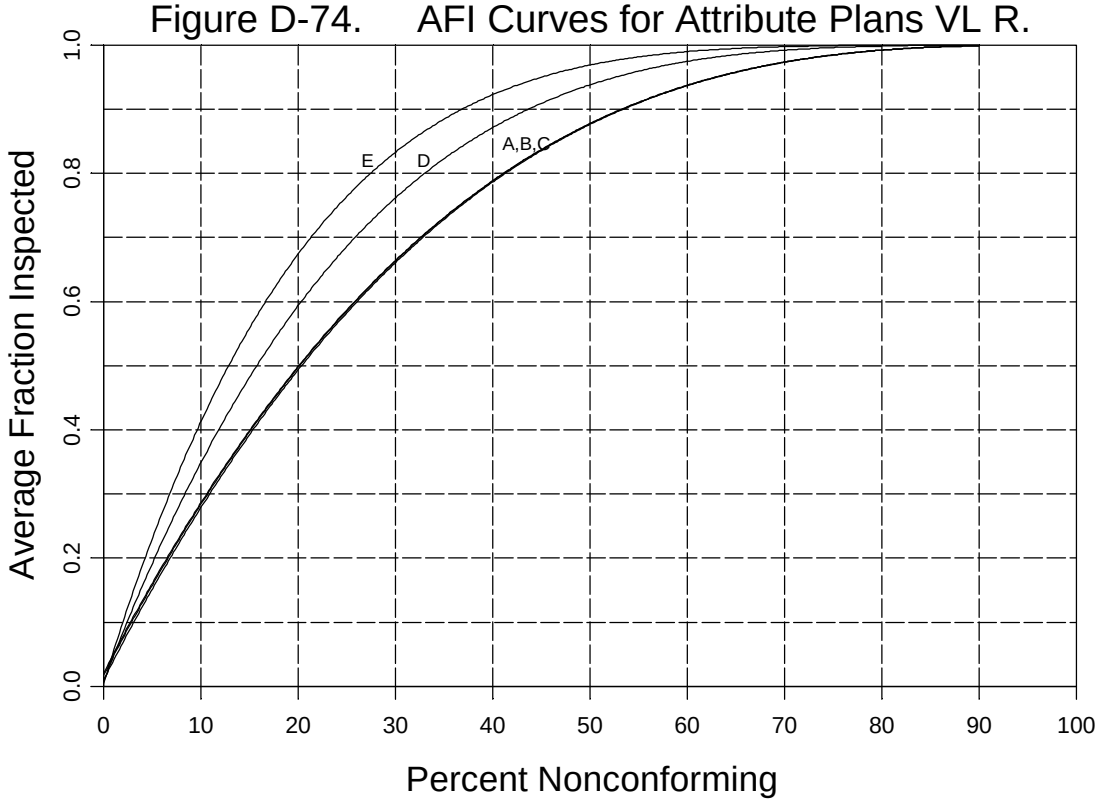


Figure D-75. AOQ Curves for Attribute Plans VL R.

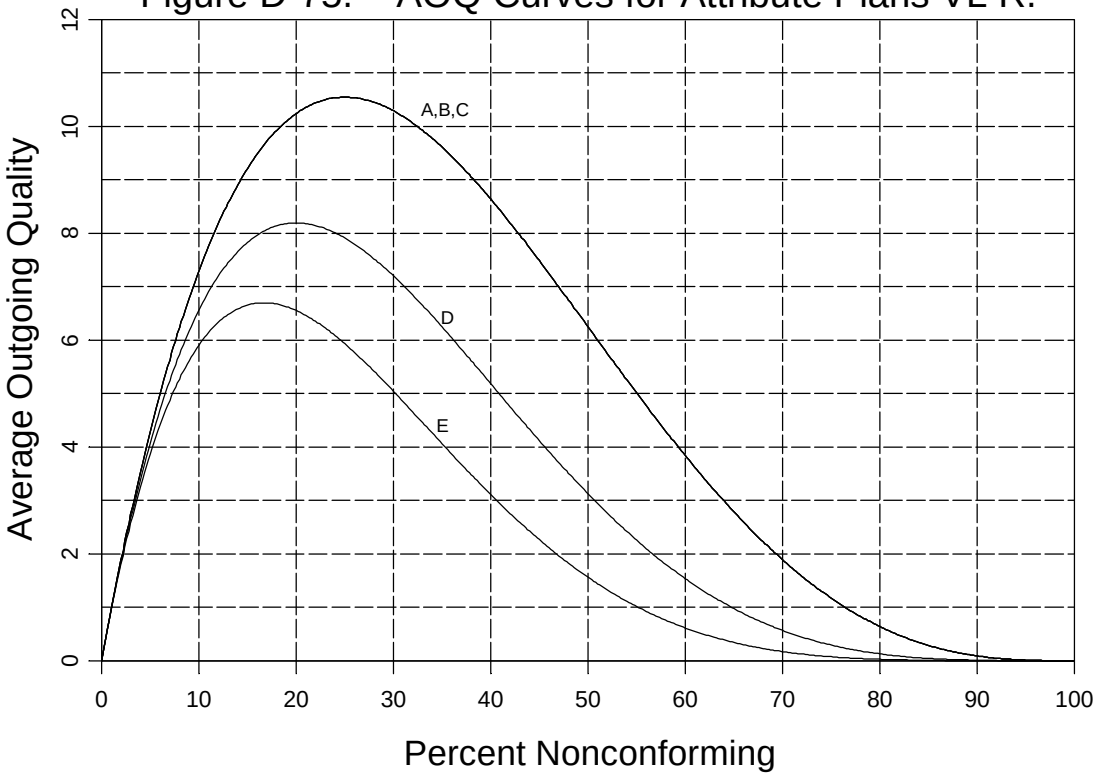


TABLE D-XXV. AoZ Sampling Plans VL R.

Code Letter	Sample Size	Acceptance Number
A	3	0
B	3	0
C	3	0
D	4	0
E	5	0

Figure D-76. OC Curves for Variables Plans VL R.

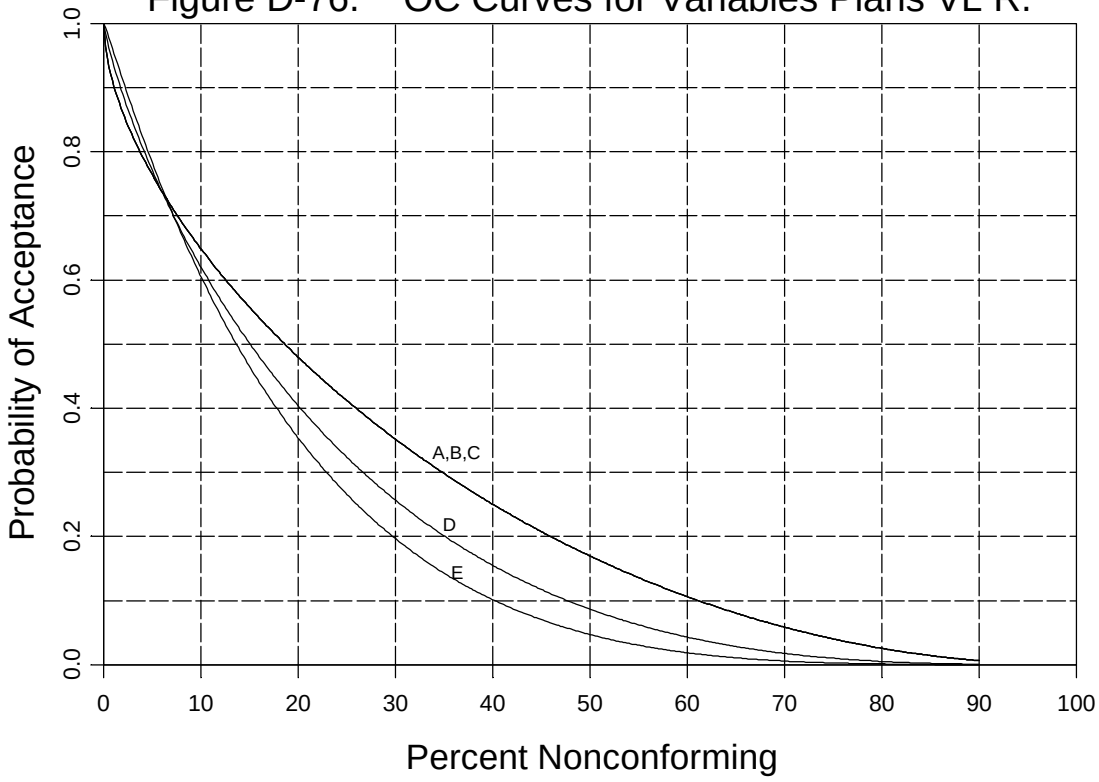


Figure D-77. AFI Curves for Variables Plans VL R.

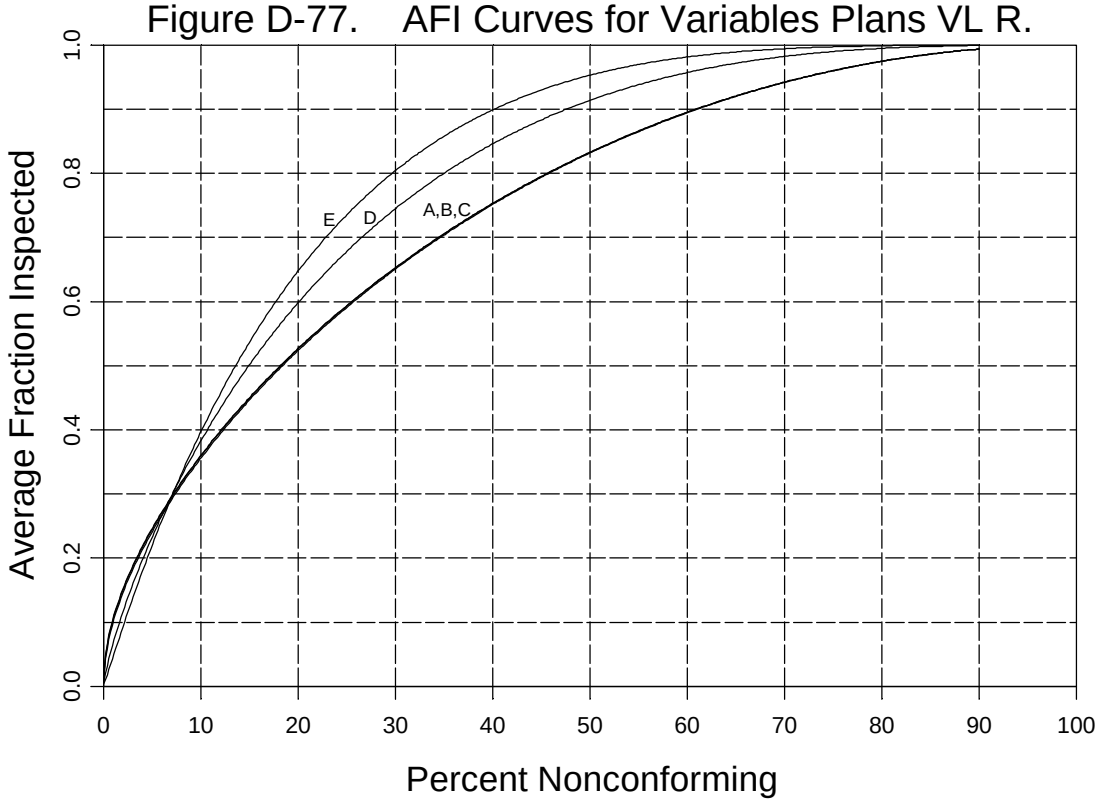


Figure D-78. AOQ Curves for Variables Plans VL R.

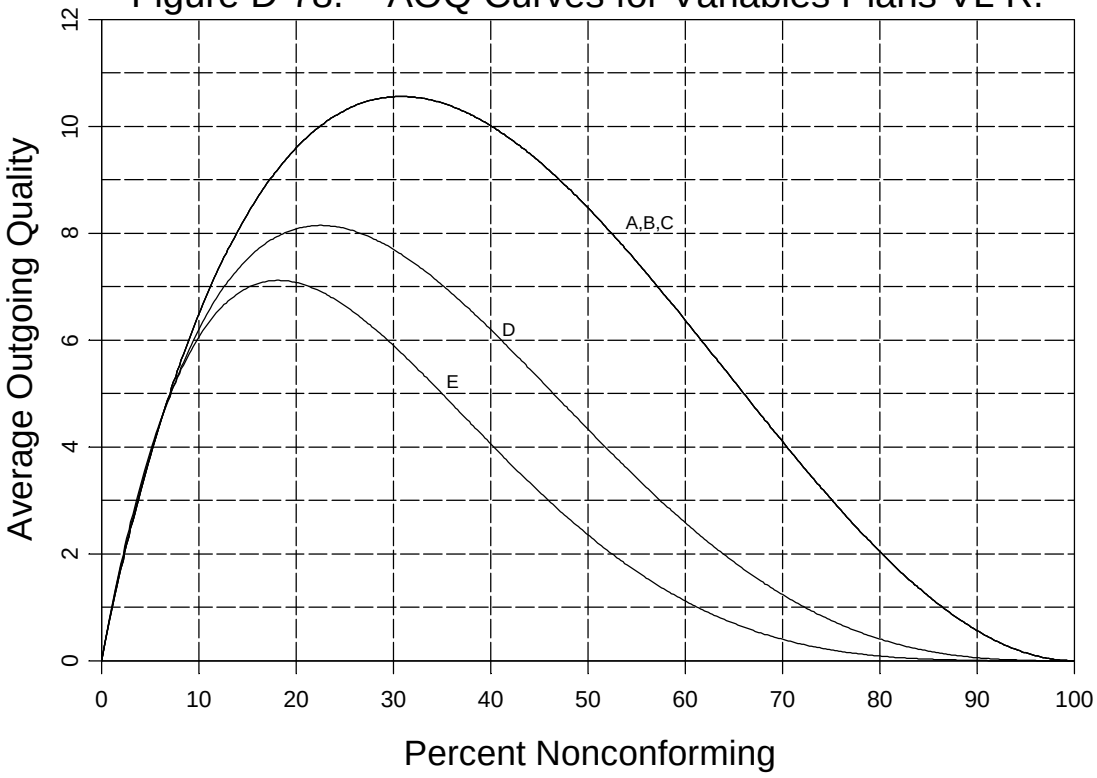


TABLE D-XXVI. Variables Sampling Plans VL R.

Code Letter	Sample Size	Acceptability Constant
A	2	1.20
B	2	1.20
C	2	1.20
D	3	1.20
E	4	1.21

TABLE D-XXVII. Summary of attributes plans.

VL	Code	na	% Nonconforming (p)			aoql	p	lot size	afi at p=0
			Pa=.95	Pa=.50	Pa=.10				
R	A	3	1.6953	20.6300	53.5841	10.5469	25.0000	144	0.02083
R	B	3	1.6953	20.6300	53.5841	10.5469	25.0000	204	0.01471
R	C	3	1.6953	20.6300	53.5841	10.5469	25.0000	288	0.01042
R	D	4	1.2742	15.9103	43.7658	8.1920	20.0000	544	0.00735
R	E	5	1.0206	12.9449	36.9041	6.6980	16.6667	960	0.00521
I	A	5	1.0206	12.9449	36.9041	6.6980	16.6667	170	0.02941
I	B	6	0.8512	10.9101	31.8708	5.6653	14.2857	288	0.02083
I	C	8	0.6391	8.2996	25.0105	4.3305	11.1111	544	0.01471
I	D	10	0.5116	6.6967	20.5671	3.5049	9.0909	960	0.01042
I	E	12	0.4265	5.6126	17.4596	2.9438	7.6923	1632	0.00735
II	A	12	0.4265	5.6126	17.4596	2.9438	7.6923	288	0.04167
II	B	16	0.3201	4.2397	13.4036	2.2299	5.8824	544	0.02941
II	C	20	0.2561	3.4064	10.8749	1.7947	4.7619	960	0.02083
II	D	24	0.2135	2.8468	9.1482	1.5017	4.0000	1632	0.01471
II	E	32	0.1602	2.1428	6.9428	1.1320	3.0303	3072	0.01042
III	A	32	0.1602	2.1428	6.9428	1.1320	3.0303	544	0.05882
III	B	40	0.1281	1.7179	5.5939	0.9084	2.4390	960	0.04167
III	C	48	0.1068	1.4337	4.6838	0.7585	2.0408	1632	0.02941
III	D	64	0.0801	1.0772	3.5338	0.5704	1.5385	3072	0.02083
III	E	80	0.0641	0.8627	2.8372	0.4570	1.2346	5440	0.01471
IV	A	80	0.0641	0.8627	2.8372	0.4570	1.2346	960	0.08333
IV	B	96	0.0534	0.7194	2.3700	0.3812	1.0309	1632	0.05882
IV	C	128	0.0401	0.5401	1.7828	0.2863	0.7752	3072	0.04167
IV	D	160	0.0321	0.4323	1.4288	0.2292	0.6211	5440	0.02941
IV	E	192	0.0267	0.3604	1.1921	0.1911	0.5181	9216	0.02083
V	A	192	0.0267	0.3604	1.1921	0.1911	0.5181	1632	0.11765
V	B	256	0.0200	0.2704	0.8954	0.1434	0.3891	3072	0.08333
V	C	320	0.0160	0.2164	0.7170	0.1148	0.3115	5440	0.05882
V	D	384	0.0134	0.1803	0.5978	0.0957	0.2597	9216	0.04167
V	E	512	0.0100	0.1353	0.4487	0.0718	0.1949	17408	0.02941
VI	A	512	0.0100	0.1353	0.4487	0.0718	0.1949	3072	0.16667
VI	B	640	0.0080	0.1082	0.3591	0.0574	0.1560	5440	0.11765
VI	C	768	0.0067	0.0902	0.2994	0.0479	0.1300	9216	0.08333
VI	D	1024	0.0050	0.0677	0.2246	0.0359	0.0976	17408	0.05882
VI	E	1280	0.0040	0.0541	0.1797	0.0287	0.0781	30720	0.04167
VII	A	1280	0.0040	0.0541	0.1797	0.0287	0.0781	5440	0.23529
VII	B	1536	0.0033	0.0451	0.1498	0.0239	0.0651	9216	0.16667
VII	C	2048	0.0025	0.0338	0.1124	0.0180	0.0488	17408	0.11765
VII	D	2560	0.0020	0.0271	0.0899	0.0144	0.0390	30720	0.08333
VII	E	3072	0.0017	0.0226	0.0749	0.0120	0.0325	52224	0.05882
T	A	3072	0.0017	0.0226	0.0749	0.0120	0.0325	9216	0.33333
T	B	4096	0.0013	0.0169	0.0562	0.0090	0.0244	17408	0.23529
T	C	5120	0.0010	0.0135	0.0450	0.0072	0.0195	30720	0.16667
T	D	6144	0.0008	0.0113	0.0375	0.0060	0.0163	52224	0.11765
T	E	8192	0.0006	0.0085	0.0281	0.0045	0.0122	98304	0.08333

E.g. VL IV code letter B. The plan is to sample n=96 units in normal sampling mode and accept the lot if zero nonconformances are found. If the true percent nonconforming of the lot is .0534%, the probability of lot acceptance will be 0.95. For 0.7194% and 2.37% nonconforming the probabilities of lot acceptance are 0.50 and 0.10 respectively. The AOQL for this plan is 0.3812% nonconforming and it occurs when the production nonconforming rate is 1.0309% . The average fraction inspected when the percent nonconforming is zero is 0.05882 using a lot size of 1632 as a basis for calculation.

TABLE D-XXVIII. Summary of variables plans.

VL	Code	nv	k	% Nonconforming (p)			aoql	p	lot size	afi at p=0
				Pa=.95	Pa=.50	Pa=.10				
R	A	2	1.20	0.3172	18.6282	61.1424	10.5595	30.7936	144	0.01389
R	B	2	1.20	0.3172	18.6282	61.1424	10.5595	30.7936	204	0.00980
R	C	2	1.20	0.3172	18.6282	61.1424	10.5595	30.7936	288	0.00694
R	D	3	1.20	0.7535	15.0639	47.6758	8.1454	22.5102	544	0.00551
R	E	4	1.21	1.1462	13.6508	40.2028	7.1164	18.1775	960	0.00417
I	A	4	1.21	1.1462	13.6508	40.2028	7.1164	18.1775	170	0.02353
I	B	5	1.33	1.0045	10.8607	32.8279	5.6630	14.5592	288	0.01736
I	C	7	1.45	0.9985	8.3962	24.6620	4.3116	10.5889	544	0.01287
I	D	8	1.56	0.7897	6.7639	20.6077	3.4940	8.7958	960	0.00833
I	E	9	1.64	0.6791	5.7235	17.7181	2.9614	7.5172	1632	0.00551
II	A	9	1.64	0.6791	5.7235	17.7181	2.9614	7.5172	288	0.03125
II	B	11	1.77	0.5323	4.3064	13.5654	2.2297	5.6926	544	0.02022
II	C	13	1.86	0.4607	3.4954	10.9598	1.8029	4.5501	960	0.01354
II	D	15	1.93	0.4153	2.9546	9.1532	1.5168	3.7618	1632	0.00919
II	E	18	2.05	0.3221	2.2083	6.8827	1.1326	2.8046	3072	0.00586
III	A	18	2.05	0.3221	2.2083	6.8827	1.1326	2.8046	544	0.03309
III	B	20	2.14	0.2562	1.7655	5.6006	0.9079	2.2763	960	0.02083
III	C	23	2.21	0.2263	1.4687	4.5816	0.7514	1.8448	1632	0.01409
III	D	26	2.32	0.1680	1.0992	3.4988	0.5641	1.4061	3072	0.00846
III	E	29	2.40	0.1372	0.8827	2.8178	0.4528	1.1276	5440	0.00533
IV	A	29	2.40	0.1372	0.8827	2.8178	0.4528	1.1276	960	0.03021
IV	B	32	2.46	0.1194	0.7452	2.3609	0.3813	0.9397	1632	0.01961
IV	C	37	2.56	0.0924	0.5587	1.7621	0.2853	0.6969	3072	0.01204
IV	D	41	2.63	0.0770	0.4542	1.4255	0.2315	0.5612	5440	0.00754
IV	E	44	2.69	0.0646	0.3794	1.1956	0.1935	0.4698	9216	0.00477
V	A	44	2.69	0.0646	0.3794	1.1956	0.1935	0.4698	1632	0.02696
V	B	49	2.79	0.0475	0.2792	0.8892	0.1426	0.3487	3072	0.01595
V	C	54	2.86	0.0389	0.2238	0.7089	0.1141	0.2770	5440	0.00993
V	D	58	2.91	0.0337	0.1905	0.6003	0.0970	0.2337	9216	0.00629
V	E	64	3.00	0.0253	0.1420	0.4497	0.0723	0.1747	17408	0.00368
VI	A	64	3.00	0.0253	0.1420	0.4497	0.0723	0.1747	3072	0.02083
VI	B	69	3.07	0.0201	0.1124	0.3574	0.0573	0.1386	5440	0.01268
VI	C	74	3.12	0.0172	0.0948	0.2994	0.0482	0.1158	9216	0.00803
VI	D	81	3.21	0.0126	0.0695	0.2208	0.0353	0.0853	17408	0.00465
VI	E	87	3.27	0.0103	0.0562	0.1782	0.0286	0.0686	30720	0.00283
VII	A	87	3.27	0.0103	0.0562	0.1782	0.0286	0.0686	5440	0.01599
VII	B	92	3.32	0.0087	0.0470	0.1489	0.0239	0.0573	9216	0.00998
VII	C	100	3.40	0.0065	0.0351	0.1115	0.0178	0.0428	17408	0.00574
VII	D	107	3.46	0.0053	0.0281	0.0890	0.0143	0.0341	30720	0.00348
VII	E	113	3.51	0.0044	0.0233	0.0737	0.0118	0.0282	52224	0.00216
T	A	113	3.51	0.0044	0.0233	0.0737	0.0118	0.0282	9216	0.01226
T	B	122	3.58	0.0034	0.0178	0.0563	0.0090	0.0215	17408	0.00701
T	C	129	3.64	0.0027	0.0141	0.0448	0.0072	0.0171	30720	0.00420
T	D	136	3.69	0.0022	0.0116	0.0367	0.0059	0.0140	52224	0.00260
T	E	145	3.76	0.0017	0.0088	0.0279	0.0045	0.0106	98304	0.00148

E.g. VL IV code letter B. The plan is to sample n=32 units in normal sampling mode and accept the lot if zero nonconformance are found and (xbar-L)/s is ≥ the k value of 2.46 [or when (U-xbar)/s ≥ 2.46]. If the true percent nonconforming of the lot is 0.1194%, the probability of lot acceptance will be 0.95. For 0.7452% and 2.3609% nonconforming the probabilities of lot acceptance are 0.50 and 0.10 respectively. The AOQL for this plan is 0.3813% nonconforming and it occurs when the production nonconforming rate is 0.9397%. The average fraction inspected when the percent nonconforming is zero is 0.01961 using a lot size of 1632 as a basis.

TABLE D-XXIX. Summary of continuous plans.

VL	Code	i	f	aoql	p	afi at p=0
R	A	NA	1/48	NA	NA	0.02083
R	B	NA	1/68	NA	NA	0.01471
R	C	NA	1/96	NA	NA	0.01042
R	D	NA	1/136	NA	NA	0.00735
R	E	NA	1/192	NA	NA	0.00521
I	A	27	1/34	6.5749	9.9115	0.02941
I	B	36	1/48	5.6052	8.1565	0.02083
I	C	53	1/68	4.2977	6.0700	0.01471
I	D	73	1/96	3.4740	4.7784	0.01042
I	E	96	1/136	2.9161	3.9170	0.00735
II	A	55	1/24	2.9126	4.6463	0.04167
II	B	83	1/34	2.2151	3.3792	0.02941
II	C	116	1/48	1.7911	2.6305	0.02083
II	D	155	1/68	1.5000	2.1314	0.01471
II	E	228	1/96	1.1309	1.5626	0.01042
III	A	125	1/17	1.1260	1.9107	0.05882
III	B	180	1/24	0.9047	1.4522	0.04167
III	C	246	1/34	0.7559	1.1577	0.02941
III	D	368	1/48	0.5698	0.8392	0.02083
III	E	513	1/68	0.4566	0.6503	0.01471
IV	A	264	1/12	0.4559	0.8315	0.08333
IV	B	372	1/17	0.3808	0.6479	0.05882
IV	C	572	1/24	0.2861	0.4602	0.04167
IV	D	815	1/34	0.2291	0.3514	0.02941
IV	E	1101	1/48	0.1910	0.2815	0.02083
V	A	527	2/17	0.1908	0.3798	0.11765
V	B	842	1/12	0.1433	0.2618	0.08333
V	C	1237	1/17	0.1148	0.1955	0.05882
V	D	1714	1/24	0.0956	0.1539	0.04167
V	E	2605	1/34	0.0718	0.1101	0.02941
VI	A	1134	1/6	0.0718	0.1598	0.16667
VI	B	1754	2/17	0.0574	0.1144	0.11765
VI	C	2524	1/12	0.0479	0.0874	0.08333
VI	D	3957	1/17	0.0359	0.0612	0.05882
VI	E	5709	1/24	0.0287	0.0462	0.04167
VII	A	2207	4/17	0.0287	0.0740	0.23529
VII	B	3402	1/6	0.0239	0.0533	0.16667
VII	C	5609	2/17	0.0180	0.0358	0.11765
VII	D	8411	1/12	0.0144	0.0263	0.08333
VII	E	11868	1/17	0.0120	0.0204	0.05882
T	A	3867	1/3	0.0120	0.0378	0.33333
T	B	7061	4/17	0.0090	0.0231	0.23529
T	C	11337	1/6	0.0072	0.0160	0.16667
T	D	16827	2/17	0.0060	0.0119	0.11765
T	E	26912	1/12	0.0045	0.0082	0.08333

E.g. VL IV code letter B. The plan is to screen all units produced (normal sampling mode) until 372 consecutive acceptable units are found. When that point is reached, sampling then replaces screening and sampling is done at the rate of one unit inspected for every 17 units produced. The AOQL for this plan is 0.3808% nonconforming and it occurs when the production nonconforming rate is 0.6479%. The average fraction inspected when the percent nonconforming is zero is 0.05882 and the initial screening phase is ignored.

APPENDIX E

BACKGROUND AND RATIONALE OF TABLES

E.1 Scope. This appendix explains the background and rationale of the tables of MIL-STD-1916.

E.2 Tables I-IV. Tables (I-IV) of MIL-STD-1916 were developed with the idea of never permitting a nonconformance in a sample. The tables were designed to have simple switching procedures. Table II was the first table to be developed. Tables II, III, and IV were developed to have virtually the same average outgoing quality limits (AOQL's) in corresponding cells. Compare, for example, the AOQL's for VL IV for code letter C for the attributes (.2863%), variables (.2850%), and continuous (.2860%) plans. In addition, the entire AOQ curves of corresponding cells are also well matched for the attributes and variables plans because their operating characteristic (OC) curves are matched.

E.3 Table I. Table I was developed in order to allow Tables II and IV to have similar average fraction inspected (AFI) curves for percent nonconforming very close to zero. For example, see the AFI curves for VL IV for attributes and for continuous plans for percent nonconforming very close to zero.

E.4 Table II. The number of possible sample sizes, hence the number of plans, and the size of the table were to be kept to a practical minimum. It was decided to make Table II an n by m (rows by columns) table, where n=3, 4, 5, or 6, and m=6, 7, 8, 9, or 10. Included at the extremes are columns for tightened and reduced inspection. A 5 by 9 table was chosen, not because of special virtue of these numbers, but by how such a table could accommodate the progression of sample sizes being considered. These sample sizes are" nice" round numbers.
Examination of Table II reveals that rows 1, 3 and 5 follow roughly MIL-STD-105 sample sizes, except that Table II entries are powers of two, 3 times a power of two, or 5 times a power of two. Rows 2 and 4 constitute "in-between" rows having no MIL-STD-105 counterparts.

E.5 Table III. Table III is derived from Table II by matching the OC curves of its entries. This was accomplished with a computer program that found the Table III plan that simultaneously approximates the corresponding Table II plan at its 95, 90, 70, 50, 30 and 10 probability-of-acceptance points. Thus, Tables II and III match, with respect to OC curves, over the whole range of potential nonconformance rates. For this reason, their AOQ curves are also well matched.

E.6 Table IV. Since the OC curve of a continuous plan has a different interpretation than a Table II or Table III plan, matching OC curves could not be the basis for determining Table IV. Instead, average fraction inspected at 0% nonconforming (AFI0) is utilized. AFI0 of a Table II plan is simply na/nlot, where na is the attribute sample size and nlot is the lot size. At this point, it was found necessary to define a Table I of applicable lot size ranges to be used in all the other tables. Table I provides the basis of matching the Table IV plans to their Table II counterparts.

APPENDIX F

EXAMPLES OF USE OF MIL-STD-1916 SAMPLING TABLES

F.1 Scope. This appendix provides examples of the use of the MIL-STD-1916 sampling tables.

F.2 Examples.

Attributes Inspection Example - Lot Basis

Given: Verification level = IV, Lot Size (N) = 1,500
Attributes inspection

Task: Determine n_a for normal, tightened and reduced inspection.

Step 1. Determine sample size code letter (CL) from Table I based on VL and N:

For VL = IV and N = 1500, CL = B

Step 2: Select appropriate Sampling Plan Table (Table II, III, or IV) for type of inspection:

Table II is applicable for attributes (lot or batch) inspection.

Step 3. Determine sample size(s) from Sampling Plan Table selected in Step 2.

a. n_a for normal inspection is at the intersection of the row indexed by CL and the column indexed by VL:

$n_a = 96$ Normal Inspection

b. n_a for tightened inspection is the number in the table cell immediately to the left of the normal inspection sample size:

$n_a(T) = 256$ Tightened Inspection

c. n_a for reduced inspection is the number in the table cell immediately to the right of the normal inspection sample size:

$n_a(R) = 40$ Reduced Inspection

Attributes Inspection Example - Lot Basis

Given: VL = III, N = 10,000
Attributes inspection

Task: Determine n_a for normal, tightened and reduced inspection.

Step 1. From Table 1, CL = E.

Step 2. Table II is applicable for inspection by attributes (lot basis).

Step 3. a. $n_a = 80$ b. $n_a(T) = 192$ c. $n_a(R) = 32$

Variables Inspection Example - Lot Basis

Given: VL = II, N = 3,000
Variables inspection.

Task: Determine sample sizes (n_v), k and F for normal, tightened and reduced inspection.

Step 1. Determine CL from Table I based on VL and N:

CL = E

Step 2. Select appropriate Sampling Plan Table (Table II, III, IV) based on type of inspection:

Table III is applicable for inspection by variables.

Step 3. Determine samples sizes from top section of Table III:

a. $n_v = 18$ b. $n_v(T) = 29$ c. $n_v(R) = 9$

Step 4. Determine k values from middle section of Table III:

a. $k = 2.05$ b. $k(T) = 2.40$ c. $k(R) = 1.64$

Step 5 (Double-sided specification only). Determine F values from bottom section of Table III:

a. F = 0.222 b. F(T) = 0.193 c. F(R) = 0.271

Variables Inspection Example - Lot Basis

Given: VL = VI, N = 15,000
Variables Inspection, Double-sided specification limit

Task: Determine nv, k and F for normal, tightened and reduced inspection.

Step 1. From Table I, CL = D

Step 2. Table III is applicable for sampling inspection by variables in accordance with MIL-STD-1916.

Step 3. a. $n_V = 81$ b. $n_V(T) = 107$ c. $n_V(R) = 58$

Step 4. a. k = 3.21 b. k(T) = 3.46 c. k(R) = 2.91

Step 5. a. F = 0.148 b. F(T) = 0.138 c. F(R) = 0.162

---

k and F Criteria for Variables Inspection

For variables inspection by lot or batch, the lot or batch under consideration is acceptable if and only if:

a. Sample contains no nonconforming units; i.e., all samples must be within specifications and

b. The applicable k criterion from Table III is met and

c. For two-sided double specifications only, the applicable F criterion from Table III is met.

APPENDIX F

k and F values in Table III are limits on the variability of a process:

a. For a one-sided single specification:

QL = $(\overline{X} - L)/s$ must be ≥ k value from Table III or

QU = $(U - \overline{X})/s$ must be ≥ k value from Table III

b. For a two-sided double specification:

QL and QU must both be ≥ k value from Table III and

$\hat{F} = s/(U - L)$ must be ≤ F value from Table III.

U = upper specification limit L = lower specification limit

s = sample standard deviation $\overline{X}$ = sample mean

MIL-STD-1916 LOT ACCEPTABILITY WORKSHEET
Inspection by Variables

EXAMPLE - DOUBLE SPECIFICATION LIMIT

Item Missile casing diameter (major characteristic)

Specification Requirement: 194.5 ± 14.5 mm

Lot Size: 40 Verification Level (VL): III

Sample Results:

197mm	188mm	184mm	205mm	202mm
199mm	200mm	201mm	204mm	198mm
195mm	197mm	193mm	190mm	180mm
196mm	195mm	195mm		

APPENDIX F

	Value Obtained	Source
1. Determine Upper Specification Limit (U) when applicable: U = nominal value + upper tolerance	209mm	Calculation
2. Determine Lower Specification Limit (L) when applicable: L = nominal value - lower tolerance.	180mm	Calculation
3. Determine sample size code letter (CL) based on lot size and VL.	A	Table I
4. Determine sample size (nv)	18	Table III
5. Determine k value.	2.05	Table III
6. Determine F value (double-specification).	0.222	Table III
7. Calculate sample mean: $\overline{X} = \sum X/n$	195.5	Sample data/Calculation
8. Calculate sample standard deviation (s): $s = \sqrt{\sum (x - \overline{x})^2 / (n-1)}$	6.618	Sample data/Calculation
9. CalculateUpper Quality Index (QU) when an upper specification limit applies: $QU = (U - \overline{X})/s$	2.040	Calculation
10. Calculate Lower Quality Index (QL) when a lower specification limit applies: $QL = (\overline{X} - L)/s$	2.342	Calculation
11. Calculate sample F value ($\hat{F}$) for double specifications only: $\hat{F} = s/(U-L)$	0.228	Calculation
12. Determine lot acceptability:		
Are all samples within specifications?	Yes x	No

Is Qu ≥ k? 2.04 ≥ 2.05? NA_____ Yes_____ No__x___

Is QL ≥ k? 2.34 ≥ 2.05? NA_____ Yes___x__ No_____

If $\hat{F} \leq F$? 0.228 ≤ 0.222? NA_____ Yes_____ No__x___

Is lot acceptable? Yes_____ No__x___

Attributes Inspection Example - Continuous Sampling,
Production Interval Basis

Given: VL = V, Production Interval = 5,000
Attributes Inspection, Continuous Sampling

Tasks: Determine clearance numbers (i), and sampling frequencies (f) for normal, tightened and reduced inspection. Also determine the 5 x n_a(T) value for switching from tightened to normal inspection and the 10 x n_a(N) value for switching from normal inspection to reduced inspection.

Step 1. Determine CL from Table I based on VL specified and the size of the production interval:

CL = C

Step 2. Select the correct Sampling Plan Table (Table II, III, or IV):
Table IV is the correct Sampling Plan Table for attributes inspection, continuous sampling, production interval basis.

Step 3. Determine i values from top section of Table IV based on VL and CL:

a. i = 1237 b. i(T) = 2524

c. i(R) = Not applicable – See Note (2) of Table IV

Step 4. Determine f values from bottom section of Table IV based on VL and CL:

a. f = 1/17 b. f(T) = 1/12 c. f(R) = 1/24

Step 5: Determine 5 x n_a(T) and 10 x n_a(N) values from Table II.

a. 5 x n_a(T) = 5 x 768 = 3,840

b. 10 x n_a(N) = 10 x 320 = 3,200

Attributes Inspection Example - Continuous Sampling,
Production Interval Basis

Given: VL = VII, Production Interval = 30,000
Attributes Inspection, Continuous Sampling

Tasks: Determine i and f values for normal, tightened and reduced inspection. Also determine the 5 x n_a(T) value for switching from tightened to normal inspection and the 10 x n_a(N) value for switching from normal to reduced inspection.

Step 1. From Table 1, CL = D

Step 2. Sampling Plan Table IV is applicable for attributes inspection, continuous sampling, production interval basis.

Step 3. a. i(N) = 8411 b. i(T) = 16,827 c. i(R) = NA

Step 4. a. f(N) = 1/12 b. f(T) = 2/17 c. f(R) = 1/17

Step 5: a. 5 x n_a(T) = 5 x 6144 = 30,720

b. 10 x n_a(N) = 10 x 2560 = 25,600

APPENDIX G.

AN EXAMPLE OF AN SPC AUDIT CHECKLIST

G.1 Scope. This appendix provides an inspection checklist of a Statistical Process Control Chart as an example of an SPC Audit Checklist.

COMPONENT _____ OPERATION _____ CHARACTERISTIC _____

DATE/SHIFT														
The operator has provided date, time and initials.														
Sample size is correct.														
Calculations are performed correctly.														
Data is plotted.														
No columns are skipped.														
Batch changes are recorded.														
Adjustments are made in accordance with SPC Management Plan.														
Reasons for all adjustments are recorded.														
Blade changes and down-times are noted.														
Reasons for out-of control average chart noted.														
Reasons for out-of-control Range chart noted.														
Supervisor has initialed at the end of the previous shift.														
INSPECTOR														

Upon verification of each item, place a check mark in the corresponding block.

NOTE: Notify _____ immediately if any block can not be checked.

CONCLUDING MATERIAL

Custodians:
Army - AR
Navy - OS
Air Force - 05
DLA-DH

Preparing activity:
Army - AR

Review activities:
Army - AT, AV, CR, EA, GL, MI, MR
Navy - AP, AS, CH, EC, NM, NW, SA, SH, YD1
Air Force - 10, 11, 13, 17, 19, 70, 71, 80, 82, 84
DLA - CC

(Project QCIC -0010)

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

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I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER	2. DOCUMENT DATE (YYMMDD)
	MIL-HDBK-1916	990210

3. DOCUMENT TITLE

Companion Document to MIL-STD-1916

4. NATURE OF CHANGE (*Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.*)

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME (*Last, First, Middle Initial*)	b. ORGANIZATION	
c. ADDRESS (*Include Zip Code*)	d. TELEPHONE (*Include Area Code*) (1) Commercial (2) AUTOVON (*if applicable*)	7. DATE SUBMITTED (*YYMMDD*)

8. PREPARING ACTIVITY

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c. ADDRESS (*Include Zip Code*) ATTN: AMSTA-AR-QAW-E, B-12 Picatinny Arsenal, NJ 07806-5000	IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT: Defense Quality and Standardization Office 5203 Leesburg Pike, Suite 1403, Falls Church, VA 22041-3466 Telephone (703) 756-2340 AUTOVON 289-2340	