Statistical Sampling:

PAST, PRESENT AND FUTURE
ORETICAL AND PRACTICAL

Kowalewski / Tye, editors

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Statistical Sampling: Past, Present and Future Theoretical and Practical

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Foreword

The symposium on Statistical Sampling was presented in Philadelphia on 2 April 1990. ASTM Committee E-11 on Quality and Statistics sponsored the symposium. Milton J. Kowalewski, U N C Geotech, served as chairman of the symposium and co-editor of the resulting publication. Josh B. Tye, Sverdrup Technology, also served as co-editor.

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Overview

The First Symposium of ASTM Technical Committee E-11 on Quality and Statistics was a resounding success. Over 40 paid registrants were in Philadelphia, Pennsylvania on April 2, 1990 at ASTM headquarters. The symposium was opened by the chairman, myself, with remarks on Dr. Joseph M. Juran, a 1912 immigrant from Gurahumora, Romania. Highlights of my remarks follow:

Dr. Juran was closely associated with Harold F. Dodge, a 1920's employee of Bell Laboratories, who is the focus of our symposium. Dr. Juran's employer, Western Electric Company urged Bell Telephone Laboratories to apply statistical tools to control the quality of manufactured products. Together they included newly invented Shewhart Control Charts, sampling theory, and a demerits plan for evaluating outgoing quality.

In the late 1920's, the Joint Bell-Western Electric Committee on inspection, statistics, and economy met every few months and most fruitfully developed sampling tables. Woven into this development was the identification and terminology of sampling risks, single, double, and continuous sampling plans, the AOQL (average outgoing quality limit) concept, and the process average concept (an early version of the process capability concept).

Derivatives of these developments emerged as published sampling tables: Military Standard 105, the Dodge-Romig Tables, and many others. The Joint Committee had hardly any significant impact on the U.S. economy as a whole until the second world war when the U.S. armed forces needed sampling inspection plans.

Dr. Juran was instrumental in the pioneering of statistical sampling. Dr. Harold F. Dodge was also a great pioneer in the field. Dr. Juran, who spoke at the 44th American Quality Congress in San Francisco in May of 1990, offers these friendly words, "When I am gone, let no one weep for me. I have led a wonderful life." The chairman of this symposium hopes that all of us are able to make this statement as our lives unfold.

In memory of Dr. Harold F. Dodge, this symposium is dedicated. Dr. Dodge's graduate students and doctoral candidates gladly accepted an invitation to present their doctoral works under Dr. Dodge at this symposium. Leading the students was Dr. Edward G. Schilling of the Rochester Institute of Technology who gave an overview of "Statistical Sampling: Past, Present, and Future."

Dr. Schilling referred to sampling by attributes and the Shewhart "P" control chart letter. His historical development was exceedingly informative. The inequalities presented were interesting. His description of the type A and B sampling plan operating characteristic curves was clear. The distinction he made between probability distributions was very helpful to both the novice and experienced statistician. Reference to Dr. Edward Deming's work reinforced the original type A and B concepts presented. Labeling of types A and B as police function and feedback system, respectively, was very enlightening to the symposium participants. His final zero defects control chart presented a great baseline for participant perspectives to work from.

Dr. Robert F. Perry of McDonnell Aircraft presented a high energy talk spiced with humor. He continually made reference to the immoveable rigor of his mentor. He asked for questions during his presentation and provided meaningful feedback to the participants. He was candidly honest about the American philosophy of not desiring to reject lots. In fact, he stated that, "Industry will sample a lot until it is acceptable." Dr. Perry exhibited many figures as examples of his thesis. He shared other of his thesis ideas and brought us up-to-date on his philosophy of skip-lot sampling. The U.S.D.A. and ANSI/ASQC Standard S1 examples he provided were very helpful and complex.

Dr. Joseph R. Troxell of Lasalle University described suspension systems for today's manufacturing environment. In light of the importance of continual improvement needed in America in the 1990's, his presentation was most timely and applicable. His use of simple statistical methodology, as also purported by Victor E. Kane in his new book, "Defect Prevention," in manufacturing is mandatory, and Dr. Troxell's suspension system for stop-line techniques fulfills the need.

Dr. H. Alan Lasater of Tennessee Associates International, Incorporated provided a lively description right after lunch on "The Robustness of a Class of Continuous Sampling Plans" under certain types of process models. His integration of wit into the opening and delegation of questions to Dr. Troxell was enjoyable. His absurd hypothesis was uniquely presented. The development of his work was very easy to understand. The practicality of the number of pieces produced where stability occurs was revealing.

Dr. Larry Romboski of the California University of Pennsylvania described his "Quick Switching Systems" of acceptance sampling. He opened with revelations about the simplicity of Dr. Dodge's suppositions. Dr. Romboski presented the four basic points in his outline succinctly. The points described were easy to follow. The synergy of his graphical family of curves was as catchy as his sampling plans. The explanation of the table made good sense. The QSS (quick switching system) plans discussed were concrete examples for participant use. Dr. Romboski's analogy to shopping with his wife was vivid.

Dr. Ken Stevens was the only student of Harold F. Dodge that could not be contacted to present his thesis work.

The symposium departed from Dodge's students to three other speakers invited to present the results of their work in the statistical sampling discipline.

Dr. Charles H. Proctor of the North Carolina State University presented a paper on "Sampling Terms of Reference" and advice on calling a statistician where needed. Dr. Proctor's presentation was very well outlined for ease of understanding. He described the basic concept of the frame and its variations. In addition, the practical application of his examples were a relaxing departure, for novice participants, from the rigorous theoretical detail presented in some of the earlier sessions.

Josh B. Tye of Sverdrup Technology, Incorporated answered one of the questions posed to a panel of Dodge students at mid-day. He described practical sampling plans with low consumer's risk for lots in excess of 100,000 and at levels of acceptable quality in the parts per million (PPM) range. He opened with two unwritten laws of sampling that are observed by statisticians and quality professionals often. His visuals were simple and of high clarity. Josh's illustration of minor differences in sampling plans, in portions of the operating characteristic (OC) curve at large sample sizes and PPM defectives, was revealing.

The final speaker of the day challenged our attention span and concentration. Dr. Richard A. Bilonick of the Consolidation Coal Company described Gy's particulate material sampling theory. His identification of issues related to the guidance provided by standards bodies and the standardization of unscientific methods was helpful and revealing. Gy's correlation of theoretical idea and practical data is novel and refreshing. The visuals exhibited were very complete and realistic. It was interesting to note that those who sample and classify particulates can be biasing samples even though they religiously follow approved standard methods. This is a challenge to ASTM to update our existing methods to incorporate and recognize theories such as Gy's.

In conclusion, the symposium would not have been possible without the tireless efforts of our forerunners and friends. I thank posthumously, Dr. Harold F. Dodge, for his insights and the courage to explore a new frontier and our recently deceased friend and mentor, Dick Freund, for the vision and persistence of ASTM Committee E-11's birth of this first of many Quality and Statistics Symposiums.

I thank the ASTM staff for the superbly coordinated and provided guidance, advertising, facilities, and reception. In addition, I thank Kathy Greene and Barbara Stafford for their persistence in printing this special technical publication (STP) in record time.

Most importantly, I thank all of you who participated in this historical event and purchased this STP.

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Edward G. Schilling

ACCEPTANCE SAMPLING - PAST, PRESENT, AND FUTURE

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ABSTRACT: Acceptance sampling procedures can be used as part of the quality system to achieve better quality at lower cost, increased productivity, and improved control. This paper presents an overview of the past, present, and future use of modern acceptance sampling plans, schemes, and systems in applications involving unique lots or a steady flow of product from the producer. Sampling procedures must continually be made to match existing conditions in terms of quality history and sampling results. In this way they can be used with process control in an evolutionary manner to supplement each other in a continuing approach to quality improvement and elimination of massive inspection programs.

KEYWORDS: Acceptance Sampling, Process Control, Inspection, Quality System, and Sampling

INTRODUCTION

Statistical methods play a vital part in standardization. Standardization, of course, in itself implies existing variation in methodology and approach. Similarly, variation in the materials and processes with which we deal often makes the statistical approach to standards development a necessity. For example, measures are utilized such as the process capability index, which quantify the relationship between specifications and inherent process or product variation. This requires measurement of variability. Statistical sampling provides a means for making estimates of product or process performance in the presence of variation, and for devising strategies for dealing with them in the face of the uncertainty which arises when variation is present.

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TYPES OF SAMPLING

Sampling is often performed for purposes of estimation. In this case, population parameters are unknown and must be determined from a sample. This is quite often the case in bulk sampling of materials when estimates of the properties of a lot or shipment must be obtained.

Another use of sampling is in acceptance sampling which is concerned, not with estimation, but with a means for decision making about a given lot. The decision may be in terms of the immediate lot only, in the case of a "one-shot" determination, or it may be in terms of the process which generated the present lot in the case of a stream of lots from the supplier. The former is called Type A sampling, that is, the decision is made for this lot only. The latter is called Type B sampling, that is, the decision is made in context of the process which generated this immediate lot. In the case of a flow of lots, as is often encountered in-process, or with a "captive" or long-term supplier, the process approach to acceptance sampling provides economies in sampling, insights as to the nature of the supply, and a broad range of strategies which may be used to improve the quality forthcoming from the supplier.

Examples of acceptance sampling strategies, taken from the work of H.F. Dodge and his students, which are process oriented include the following:

- Continuous sampling of product from a steady stream or a finite sequence of units [1]
- Skip-lot procedures to allow for not checking some lots of a steady steam when quality is good [2]
- Quick switching procedures to reduce sample size when quality is good and to increase sample size with evidence of deterioration [3]
- Mixed plans to combine the advantages of measurement and attribute sampling plans [4]
- Cumulative results plans which provide decision rules for cumulated small samples [5]
- Chain sampling which combines the sample results from two or more of a sequence of lots for better discrimination [6]

Proper implementation of such plans involves recognition of the potential for quality improvement that can be attained by working with a supplier (internal or external) in the utilization of the process control techniques necessary to assure acceptance of product against a process oriented (Type B) sampling plan. Such an approach involves not only the sampling plan, but various political, psychological and economic means to assure that quality improves to, and beyond, prescribed levels. In this way, acceptance sampling plans can be used, with process control, as a means for continual quality improvement.

WHY SAMPLE

H. F. Dodge and H. G. Romig [7] have pointed out that, to determine how much inspection is required, "The answer must always be arrived at in terms of economy, for only the least amount of inspection which will accomplish the purpose can be justified." Clearly, the choice is between 100 percent inspection, no inspection at all, or something in between, i.e. sampling. The ability of computerized automatic inspection devices to perform 100 percent inspection at extreme speed is well recognized; however, such equipment is not without cost in terms of design, manufacture, and maintenance. Dependence upon 100 percent inspection is usually costly and is somewhat dangerous in the sense of complacency and decreased incentive for product and process improvement. It has been pointed out that:

> There are two standard procedures that, though often good in themselves, can serve to postpone careful analysis of the production process:
>
> 1. On-line inspection stations (100% screening). These can become a way of life.
> 2. On-line acceptance sampling plans which prevent excessively defective lots from proceeding on down the production line, but have no feedback procedure included.
>
> These procedures become bad when they allow or encourage carelessness in production. It gets easy for production to shrug off responsibility for quality and criticize inspection for letting bad quality proceed. [8]

Resort to no inspection is a real alternative and is in fact the objective of acceptance sampling; however, without supporting quality history and without confidence of a sufficient state of statistical control, the economy of such a procedure may carry with it considerable risk. Sampling properly ranges between these two extremes and provides a vehicle for movement between them, as sufficient information on the state of control is generated, to allow intelligent reduction of inspection effort. As Walter Shewhart has indicated:

> . . . there are two reasons why it is often necessary to resort to sampling in order to determine whether or not quality meets the specification-(a) it is often uneconomical to give 100 percent inspection, particularly where defective parts would be weeded out in final assembly or at the time of installation, and (b) it is often not feasible to give 100 percent inspection because of the destructive nature of the method of verification of the quality, as, for example, in testing the tensile strength of materials and the blowing current of fuses. [9]

It is evident that, if we knew the extent of conformance to specifications, the decision on the disposition of the lot would be evident and no sample inspection would be necessary. This is the case for a process shown to be in statistical control. The lot would be 100 percent inspected or passed without inspection. Sampling is for use when we do not know the fraction nonconforming in the product or process being investigated as is the case when the process is not in statistical control. This is, unfortunately, prevalent without the hard work to attain control substantiated by extensive quality history. There is little control of quality in the application of a sampling plan to an individual lot of product. But, when used with a process orientation in an effort to encourage continual improvement, the plan becomes a means of: protection for the consumer, protection for the producer, accumulation of quality history, and feedback for process control.

ACCEPTANCE SAMPLING - PAST

The development of the statistical science of acceptance sampling can be traced back to the formation of the Inspection Engineering Department of Western Electric's Bell Telephone Laboratories in 1924. The department was comprised of H. F. Dodge, R. B. Miller, E. G. D. Paterson, D. A. Quarles, and W. A. Shewhart. Later, H. G. Romig, P. S. Olmstead, and M.N. Torrey became members of the group. It was directed initially by R. L. Jones with G. D. Edwards becoming its second and long-term director. Applications to shop operations were at the Western Electric Hawthorne plant in Chicago.

Out of this group and its lineage came the following early developments:

- 1924. The first control chart
- 1925-26. Terminology of acceptance sampling (consumer's risk, producer's risk, probability of acceptance, OC curves, lot tolerance percent defective, average total inspection, double sampling, Type A and Type B risks); LTPD sampling tables
- 1927. AOQL sampling tables
- 1928. Demerit rating system

The 1930 's saw applications of acceptance sampling within Western Electric and elsewhere. A Joint Committee for the Development of Statistical Applications in Development and Manufacturing was formed in 1930 by The American Society for Testing and Materials, The American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Statistical Association, and the American Mathematical Society; with W. A. Shewhart as chairman. By the mid-1930's Egon Pearson had developed British Standards Institution Standard Number 600, "Application of Statistical Methods to Industrial Standardization and Quality Control," which helped to incite interest in England.

The early 1940's saw publication of the Dodge-Romig "Sampling Inspection Tables", which provided plans based on fixed consumer risk (LTPD protection) and also plans for rectification (AOQL protection) which guaranteed stated protection after 100 percent inspection of rejected lots.

With World War II, quality control, and particularly acceptance sampling, came of age. This included the development of sampling tables by the Army's Office of the Ordnance, using a sampling system based on a designated acceptable quality level (AQL). The development of the system was largely due to G. D. Edwards, H. F. Dodge, and G. R. Gause, with the assistance of H. G. Romig and M. N. Torrey. This work later developed into the Army Service Forces (ASF) tables of 1944 which were process oriented. AQL plays a role analogous to $\bar{p}$ on an attribute control chart.

In this period, H. F. Dodge developed an acceptance sampling plan which would perform rectification inspection on a continuous sequence of product, guaranteeing the consumer protection in terms of the maximum average quality the consumer would receive (AOQL protection). Also, A. Wald put forward his new theory of sequential sampling as a member of the Statistical Research Group, Columbia University, which later published applications of Wald's work. This group was responsible for some outstanding contributions during the War. Their output consisted of advancements in variables and attributes sampling in addition to sequential analysis.

They were active in theoretical developments in process quality control, design of experiments, and other areas of industrial and applied statistics as well. Out of the work of the Statistical Research Group came a manual on sampling inspection prepared for the U. S. Navy, Office of Procurement and Material. Like the Army Ordnance Tables, it was a sampling system also based on specification of an acceptable quality level (AQL). In 1949 the manual became the basis for the Defense Department's nonmandatory Joint Army-Navy Standard JAN-105; however, a committee of military quality control specialists had to be formed to reach a compromise between JAN-105 and the ASF tables. This resulted in MIL-STD-105A issued in 1950, and subsequently revised as 105B, 105C, 105D,and 105E. MIL-STD-105A-C used control charts as an integral part of the process oriented procedures. MIL-STD-105D and E use control chart principles without actually plotting the charts.

Work in the area of acceptance sampling did not end with World War II. More detailed accounts of the history and development of acceptance sampling will be found in Dodge [10] who was responsible for much of the research over the period including continuous plans, chain sampling plans, cumulative results plans, mixed plans, quick switching procedures, and the like. Other developments included multi-level plans, deferred sentencing plans, and a host of corresponding military and civilian standards on acceptance sampling. Many of these plans are listed in Table I together with their purpose and the nature of the sequence of lots (supply) to which they are applied [11, p569].

ACCEPTANCE SAMPLING -PRESENT

Typical of current quality concerns, the military has been placing emphasis on Total Quality Management in recent years. This has given rise to MIL-STD-105E, which reflects a broader system concern for quality, while using the same tables as the previous version. The private sector is similarly placing greater emphasis on the quality system, while moving in-process implementation out of the hands of inspectors and on to the operators. This facilitates feed back of the information generated by the acceptance sampling system. Similarly vendor quality programs modify the extent and nature of incoming inspection. When used properly, acceptance sampling is an integral part of the quality information system, with results fed back to appropriate parts of the organization. Plans are withdrawn as process control becomes effective and are reinstituted when processes are out of control. The emphasis of acceptance sampling becomes one of support of doing it right the first time rather than sorting poor quality after the fact.

Acceptance sampling procedures are necessarily defensive measures, instituted as protective devices against the threat of deterioration in quality. As such, they should be set up with the aim of discontinuance in favor of process control procedures as soon as possible.

Process quality control is that aspect of the quality system concerned with monitoring and improving the production process by analysis of trends and signals of quality problems or opportunities for the enhancement of quality. Its methods include various types of control charts, experiment designs, response surface methodologies, evolutionary operations, and other procedures including those of acceptance sampling. These methods are an essential adjunct for effective acceptance control since:

TABLE 1

SAMPLING PURPOSE AND PROCEDURES [11]

PURPOSE	SUPPLY	ATTRIBUTES	VARIABLES
Simple guarantee of producer's and consumer's quality levels at stated risks	Unique lot	Two point plan (Type A)	Two point plan (Type B)
	Series of lots	Dodge-Romig LTPD Two point plan (Type B)	Two point plan (Type B)
Maintain level of submitted quality at AQL or better	Series of lots	MIL-STD-105E QSS Plan	MIL-STD-414 No Calc Plan
Rectification guaranteeing AOQL to consumers	Series of lots	Dodge-Romig AOQL Anscomb Plan	Romig Variables Plans
	Flow of individual units	CSP-1, 2, 3 Multi-Level Plan MIL-STD-1235A	Use measurements as go-no go
	Flow of sequence of production	Wald-Wolfowitz Girschik	Use measurements as go-no go
Reduced inspection after good history	Series of lots	Skip-Lot Chain Deferred Sentencing	Lot Plot Mixed Narrow Limit Gauging
Check inspection	Series of lots	Demerit Rating	Acceptance Control Chart
Compilance to mandatory standards	Unique lot	Lot Sensitive Plan	Mixed Variables - Attributes with c = 0
	Series of lots	TNT Plan	Simon Grand Lot Plan
Reliability sampling	Unique lot	Two point plan (Type B)	H-108 TR 7
	Series of lots	LTPD Plan QSS System CRC Plan	TR 7 using MIL-STD-105E switching rules
Check accuracy of inspection	Series of lots	H-109	Use measurements as go-no go

1. Quality levels for selecting an appropriate sampling procedure should be determined from control chart analysis to ascertain what minimum quality levels the producer can reasonably and economically guarantee and what maximum levels can be tolerated by the consumer's process or will fulfill the consumer's wants and needs.
2. Acceptance sampling procedures should be set up to "self-destruct" after a reasonable period in favor of process controls on the quality characteristic in question. Simultaneous use of product quality control and process quality control should eventually lead to improvement in quality levels to the point that regular application of acceptance sampling is no longer needed.

Similarly, acceptance sampling procedures supplement process control in its implementation and operation since:

1. Acceptance sampling provides essential information for properly starting up process control while 30 or more samples are being taken to start a control chart
2. Acceptance sampling provides a means of product control for product manufactured during the period in which statistical control is being achieved. That is, while the process is out of control and during which process control is impotent as a product control device.
3. Acceptance sampling is essential during periods of lack of control throughout the life cycle of the product..
4. Acceptance sampling provides a basis for the spot checking and auditing of the process after control charts are removed.

Thus, both process control and acceptance sampling are intimately related and each is supportive of the other so that together they interact in support of the quality system.

ACCEPTANCE SAMPLING - FUTURE

Much research and development remains to be done in acceptance sampling. Older plans such as MIL-STD-105E need to be completely reworked to better address the needs of system oriented total quality management. Plans should be constructed which complement the systems approach to vendor quality. New plans need to be devised which better utilize the information from the extensive process control systems that are being put in place. At this same time, process control systems need to take serious account of the consequences of lack of control as impacting the product and of incorporating appropriate acceptance sampling procedures to protect against poor product being produced while such a condition exists. It is difficult to troubleshoot a line with process control procedures when it is shut down. It is difficult to find assignable causes without process control. Acceptance sampling procedures allow the line to be run while out of control by providing protection against shipping defective product. A good quality system utilizes both acceptance sampling and process control in a harmonious, and economically beneficial relationship.

The challenge for the future is the research, development, and implementation necessary to achieve a mutually symbiotic and supportive relationship between process control and acceptance sampling that will heighten the inherent economic and administrative advantages of both.

CONCLUSION

Proper use of acceptance sampling involves "a continuing strategy of selection, application, and modification of acceptance sampling procedures to a changing inspection environment." [11] It provides the means to work with vendors or suppliers in the development of process control procedures while at the same time providing the consumer with protection against poor quality.

In a progressive atmosphere, new products, process and product modifications, as well as manufacturing difficulties can lead to periods of lack of control and increased nonconforming material. Levels of noncomformances are usually in such stituations, high enough (greater than 0.5 percent) to assure acceptance sampling is effective. This is when acceptance control can prevent the problem from spreading to the consumer. The resulting lot rejections can be strong medicine. But, no one should take medicine when they are not ill. Acceptance control procedures should be designed to self-destruct when they are no longer needed, to be supplemented by check inspections, control charts, or other methods in a system which allows more stringent acceptance sampling procedures to be reinstituted when a need again becomes apparent.

As H. F. Dodge [12] has pointed out:

> Using inspection results as a basis for action on the product at hand for deciding whether to accept or reject individual articles or lots of product as they come along is, of course, an immediate chore that we always have with us. However, inspection results also provide a basis for action on the production process for the benefit of future product, for deciding whether the process should be left alone or action taken to find and eliminate disturbing causes.

This is the true nature of acceptance sampling, the active use of sampling plans as a vehicle for process improvement.