STATISTICAL QUALITY CONTROL STUDIES AND FINDINGS RELATIVE TO HIGHWAY CONSTRUCTION: AN ANNOTATED BIBLIOGRAPHY

By

J. G. Darroch
Assistant Research Statistician

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Application of Statistical Quality Control Principles
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1. INTRODUCTION

This is the report for 1967-1968 of what was set up to be a continuing project on statistical quality control but which has not been renewed for 1968-1969. Of the five study objectives, two, Quality Control Research in the Highway Field, and Applications to Highway Construction, have been accomplished and are summarized in this report.

In order to set the current interest in statistical quality control (SQC), relative to highway construction, in historical perspective, a brief history of early developments in SQC is presented.

For the individual who does not wish to spend time perusing the annotated bibliography, a digest of the pertinent activities with respect to highway construction has been prepared. This digest has not been tied to the bibliography by citing the individual references because of time and readability considerations.

A brief section expressing some thoughts on the management of SQC function has been included. The highway industry, meaning states and contractors, stands to benefit from a careful examination of how SQC has been incorporated in the managerial structure over a wide range of companies, where it has become a vital part of the organization.

The annotated bibliography is, of course, the principal component of this report. The introductory section to the bibliography outlines the nature of it, the coverage attempted, the organization of the bibliography and other detail. This should be read prior to delving into the bibliography itself.

It is believed that some formal organization is desirable to add coherence to the effort presently being expended. In view of the in-

formation contained in the historical section, it is here recommended that serious consideration be given to affiliation with the American Society for Quality Control. This is a viable organization which has an aggressive educational program and so could be extremely helpful in putting together a suitable training program. It also supports publications which are highly regarded as disseminators of statistical quality control information.

2. A BRIEF HISTORY OF SQC

The production of a quality product has been the concern of industry since the industrial revolution. During the Middle Ages the medieval guilds insisted on a long period of apprenticeship and demonstrated ability before allowing use of such titles as master craftsman. Thus quality control has long been a concern of industry itself, of governmental agencies in a regulatory capacity, and of professional societies.

Statistical quality control, as distinct from quality control, is of much more recent origin. The first application of statistical quality control was made by Dr. Walter Shewhart of the Bell Telephone Laboratories during the 1920's. In 1924 he prepared a memorandum which included a sketch of a modern "control chart." In 1931 he published the first book devoted to statistical quality control. His pioneering work was expanded by his associates (also with Bell Telephone), H. F. Dodge and H. G. Romig, to encompass sampling inspection; and their Sampling Inspection Tables are now well known throughout industry.

This new methodology was promoted during the 1930's by the American Society for Testing Materials, the American Standards Association and the American Society for Mechanical Engineers. Production engineers, however, preferred to concentrate on improving technical methods to the point of removing virtually all quality variations, and, at the same time, there were few industrial personnel skilled in the requisite statistical methods. The net result then, for this decade, was that only a very few American industries seriously exploited the techniques

of statistical quality control.

World War II had a powerful impact upon the acceptance of statistical quality control in the United States. General Lester E. Simon is cited as one of those who recognized its power and aggressively promoted its use. The War Department, convinced of its utility, took the lead in promoting intensive short courses in statistical quality control; these were first of 10 days duration but were soon condensed to 8 days. In the interval 1943 to 1945 over 800 organizations from 35 states sent personnel to the 33 short courses sponsored by the Office of Production Research and Development, of the War Production Board. This educational effort stimulated its application to a great variety of industrial products; since that time this impetus has been sustained with the net result that the areas of application have continued to diversify.

A natural next step was an organization of people with like interests to actively promote the dissemination of statistical quality control information. To this end the Society of Quality Control Engineers in Buffalo, jointly sponsored by the University of Buffalo, started the publication of Industrial Quality Control in 1944. The American Society for Quality Control was formed in 1946 and assumed the publication of "Industrial Quality Control" at that time. This organization now has sections in all parts of the United States and in Japan and has a total membership of about 22,000 at the time of this writing.

Interestingly enough, in 1932 statistical quality control was introduced to British industry by Dr. Shewhart, and it gained rapid

acceptance there during the 1930's when American industry was still dragging its collective feet. By 1937 it was being widely applied in the coal and coke, textile, glass, building materials and chemical industries. In 1945 the Royal Statistical Society formed an Industrial Applications Sections which functions much like the American Society for Quality Control in the United States. In 1952 the journal "Applied Statistics" was started under the sponsorship of the Royal Statistical Society, aimed at the dissemination of statistical applications in industry.

From the United States and Great Britain the methods and philosophies of statistical quality control have spread to other parts of the world. It might be noted here that the emergence of Japan as a producer of high quality goods in electronics, optics, etc. has been, in no small part, due to their adoption and intensive application of statistical quality control methodologies.

Other significant steps in the communication and promotional aspects of SQC was the joint sponsorship of the journal Technometrics by the American Statistical Association and the American Society for Quality Control; this journal was started in 1959. Technometrics is now considered to be the leading journal of statistics in the physical and engineering sciences. The publication of Industrial Quality Control was suspended in December, 1967. It is being replaced by two journals under ASQC sponsorship. The first, Quality Progress, began monthly publication in January, 1968, and its function is to inform the ASQC membership about Society affairs, and to convey news and material of interest to managerial, engineering and production people. The second,

Journal of Quality Technology, will be published four times a year beginning in January, 1969. It will serve as "the outlet for articles on methods, applications and the technological aspects of related disciplines," to quote Darlene C. Schmidt (Quality Progress 1(10): 46-48, 1968).

The American Society for Quality Control presently is organized into eight subject matter divisions. These are Administrative Applications, Aircraft and Missile, Automotive, Chemical, Electronics, Food and Allied Industries, Reliability and Textile and Needle Trades. Undoubtedly more will be added as the necessity arises.

This historical review, while in no sense complete, should be sufficient to point out that statistical quality control is a well established arm of the manufacturing industries. It is new to the highway construction industry true enough, but ideas for applications in this new area might well be stimulated by an acquaintance with what has already taken place in, seemingly, non-related industries.

3. A SYNOPSIS OF REPORTED HIGHWAY ACTIVITIES RELEVANT TO SQC

The fact that, in the final product (in this case a unit of highway) there exists acknowledged variation, has emerged into the full light of day. This facing up to the facts has taken place in many other industries over the past 40 years (See SQC History Section). The general concensus seems to be that the team assembled for the AASHO Road Test in Ottawa, Illinois, and which team included at least one experienced statistician, Dr. Paul Irick, did a great deal to bring about this confrontation. The team supervised the collection and statistical summarization of a very large volume of construction test data; which, when the specifications and the data were brought together, clearly indicated that there were some striking inconsistencies. The reader should not deduce from this that any criticism of past or present construction is implied or intended, it is not. The hard facts are that specifications have traditionally been written without proper cognizance of the variability of the process producing the sample or test observations.

The basis for statistical quality control (SQC) in this or any other industry depends upon a thorough knowledge of the sources of variation affecting the product being subjected to control. The product has an inherent variability which is dependent upon the underlying process, e.g., a natural material like limestone might be expected to have a much higher level of variability than portland cement, which is the end product of a manufacturing process, albeit the fact that it is produced from a mix of natural materials. Sampling the material is a second source of variation which cannot be completely eliminated although it certainly

can be reduced by careful selection of the sampling method. Testing procedures, once the sample has been obtained, are in turn subject to variation due to such things as operator, weighing, measuring and instrument errors.

The highway construction industry is now engaged in examining the variability picture for the spectrum of materials and processes from which a highway is constructed. For clarity the activities will be treated under methodology, base materials, concrete, asphaltic concrete and miscellaneous topics.

In methodology the one technique that is referred to most frequently is the case of portable nuclear devices for non-destructively estimating the density and moisture of a compacted layer. Some investigations have been carried out using similar devices for estimating asphalt content and for estimating density of a hot mix after a roller pass. With these it is possible to obtain an estimate within a matter of minutes, this is in contrast to the destructive and time consuming standard balloon test which requires an excavation, a volume estimate, removal of the material to the laboratory for moisture determination and, finally, provides a density estimate. The consensus from a number of states and foreign countries is that there is good agreement with standard tests, and no very compelling reasons why the nuclear devices cannot be used as a routine sampling tool. A gyratory compactor has been developed which can be used to replace the more variable hand-compacted samples in a preliminary appraisal of material properties. Improved methods for hand sampling or automatic sampling of aggregates have reduced the

sampling variation.

Some investigators have been stimulated to search for, or make use of known, more fundamental tests to replace empirical ones. Various tests for the quality of aggregate materials, such as the freeze-thaw test, a test for fine aggregates, are being examined. The quality of asphalt is dependent in part on its viscosity, which can be measured at several temperatures and is useful in forcasting its aging characteristics; this is a much more revealing test than is penetration. Estimation of bitumen content using optical density equipment after solvent extraction has been investigated. An acoustical test for asphalt content has possibilities. The standard 28 day test for concrete strength adds to the data file but does not offer much scope for timely action to be taken in the event of unacceptable product. There appears to be some promising methods under development for accelerated tests which will produce strength estimates at the end of 48 hours, and which display a reasonably high degree of correlation with the standard 28 day test.

The construction of a highway starts with a subbase or base, usually constructed from materials found in situ. Economics usually argue against shipping base materials over long distances, and this frequently would be the case if done, since many geographical regions are virtually devoid of aggregate deposits or workable rock formations at or near the surface. The use of lime or cement to stabilize original soil materials has been practiced for a long time; a recent study suggests that use of a mixing plant of some sort will result in a less variable product in terms of uniformity of compaction, this is brought about by a more uniform mixing or blending of the stabilizing material throughout

the native material.

SQC procedures have been applied to compaction control by the use of at least two approaches. In Virginia several highway contracts have been written whereby, after laboratory estimates of the degree of compaction possible, the contractor uses his equipment to produce a control section on representative base material, and an acceptable density level is established by department personnel using nuclear gauging. Thus the contractor has a good estimate of the compactive effort required, and the department is able to ascertain the mean compaction level and its variability based on a realistic (not small) number of samples. California has made use of nuclear gauging to perform acceptance sampling of completed compacted sections, using a pass-fail approach; e.g., a certain proportion of the samples must exhibit a degree of compaction at or above that specified in the contract before the section is accepted.

Washington is constructing a uniformity index for each job based on a review of the test data. Such could be useful in an appraisal of contractor qualifications. On this same vein, Louisiana has examined the compaction variability within contracts and found rather clear-cut evidence of differences in variability between contractors.

Concrete as a surface course is used extensively. This has focussed attention on methods of achieving closer control of quality. California has found that properties of plastic cement and of the aggregates are indicative of final quality. Texas has investigated the use of chemical admixes. In Washington it was found that the mixing time offers a measure of control since it is related to the final strength.

The weight of partially compacted concrete apparently gives a measure of workability. Careful proportioning results in a more predictable level of concrete quality. The ready-mix industry has found that considerable uniformity of product can be assured through careful attention to batch weighing of ingredients, using automatic equipment, blending of the dry materials and then careful timing of the wet mixing period. In the ready-mix operation unsatisfactory loss can arise due to over-mixing while getting to, or waiting at, the job site. Thus careful estimates of required revolutions per minute enroute and of expected waiting times could reduce these loses. SQC has been applied to these and other related problems in Australia, Germany, the United Kingdom, Canada, and in the United States, with considerable success.

The precast and prestress concrete industry could utilize SQC to improve its product. Such details as proper fit at time of assembly, quality of surface finish, more detailed drawings of forming detail, have been indicated as areas needing attention.

In the production of asphaltic concrete, South Carolina has found the SQC approach, perhaps better called "process control" in this instance, to controlling the outgoing quality of a hot mix plant to be very promising. It gives a clear-cut operational procedure and avoids the arbitrary shut-downs that arise when a state inspector finds a sample out of the specified limits, as under the more usual mode of operation. Several contracts have been completed under the plan and contractors are enthusiastic. Other studies have led to improved thickness control although the matter of smoothness of the finished surface could be improved. Several large-

scale studies have been conducted to obtain estimates of the various statistical parameters, and their variances, associated with the product. These are expected to be used as the basis for SQC plans. Louisiana, the United Kingdom, Canada, Belgium, among others, are either using or promoting the use of SQC procedures.

The steel used in bridges is usually produced under a stringent SQC program and the supplier can provide the purchaser with copies of his quality control records. A quality control approach to satisfactory control of the fabrication process, particularly the acceptance of welds, is heavily dependent upon proper qualification of the individual welder. Some United Kingdom and United States experiences have been recorded.

The preceding paragraphs represent an attempt to indicate the scope of activity aimed at exercising a demonstrated (in other industries) method of controlling variation in the highway construction industry, namely statistical quality control. To see that this is not an isolated view the reader is referred to an article published almost two years ago.[1]

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[1]States and Contractors Prepare for Statistical Quality Control in Highway Construction. Engineering News-Record January 12, 1967; pp. 28-32.

4. ORGANIZING FOR THE SQC FUNCTION

This topic may seem presumptive on two counts. The first in that it tacitly assumes that SQC will become a reality in highway construction. Secondly it may seem to imply criticism of the present organization of highway departments.

The future of SQC as a means of coping with variation has been convincingly demonstrated in many other industries. The completed and current studies in highway construction and the, so far, isolated instances of actual application of SQC procedures clearly demonstrate that, first there is variation in every facet of the construction process, and, second that probability based means of dealing with it can be devised. There is also the pressure currently being exerted by the Bureau of Public Roads for the general adoption of the probability based techniques of SQC as a means of ensuring a specified level of quality in construction, which can be uniformly applied nationwide.

The problem a state highway department (or other similar political units) must face squarely is that of uniform application of the approved SQC procedures to all construction projects throughout the state. The same contractor may have construction projects concurrently active in several highway districts and his quality costs to the state will be least if this uniformity is achieved. The present, sometimes nearly autonomous, structure of highway districts as exists in many states might make for difficulty in achieving this desired degree of uniformity.

Generally it appears that, from an examination of effective organizatio in other industries, it is highly desirable that SQC be represented in top

management, that is, in the state highway engineer's office. Such a unit would serve to keep the state highway engineer informed as to the current status of quality achievement in all districts, and also serve as a basis for coordination and communication between states and/or other governmental agencies. It should be charged with organizing and carrying out an effective and continuing statewide training program--no small task in itself when one considers the number of personnel that have to be reached. It should serve as the clearing house for new techniques and applications in SQC; whether from the published literature, similar units in other states or enterprising and inventive personnel within the state highway department, to name only a few of the possible sources. This same unit should provide liason with the contractors so that the state speaks with one voice on SQC matters, such as explaining the acceptance procedures to be applied when bids are being sought, encouraging the contractors themselves to become active participants in SQC. The many industries now using SQC encourage, even insist that, their suppliers set up their own SQC programs. This might be a way of getting the state out of the position of testing, monitoring the contractor's operation, and finally accepting the resultant product as is frequently the case at present.

The highway districts would need to have qualified SQC personnel assigned to their units for operational purposes, but with their technical responsibility being to the central unit. This may seem opposed to present management practices but would appear to be necessary to ensure the requisite uniformity of application.

Any state seriously considering managerial changes to accommodate this new function would be well advised to seek advice from industries located within its boundaries, or near by, who are presently applying SQC. Also in almost every state in the U.S. there are one or more local chapters of the American Society for Quality Control, whose members represent the managerial as well as the technical side of the SQC function. The chapters or individual chapter members represent a reservoir of SQC competence that is readily approachable and eminently practical.

5. ANNOTATED BIBLIOGRAPHY

The collection contained in this bibliography has been brought together from a variety of sources. An initial collection was obtained from an information retrieval run using the facilities of the Highway Research Information Service, via a request placed through the Texas Highway Department. A direct literature search supplemented this, together with gleanings from a miscellaneous collection of reports and reference lists which was available. The files of the journal "Industrial Quality Control" yielded a wealth of related material.

For the purpose of annotation a summary or abstract was used; many abstracts were available in the files of the Highway Research Abstracts; some publications require that the author(s) prepare an abstract. For those cases where nothing was available an abstract was prepared by the author of this report, for all such cases the resultant abstracts are identified by the initials: JGD. Since relevant literature citations are an indication of the thoroughness of an investigation, the annotation concludes with the number of citations given in the original publication, wherever this information was available.

The annotated collection is listed under four appendix headings as follows:

(1) Statistical Quality Control Studies and Applications in all Areas of Highway Construction.

(2) Listing of Current Research Projects Relative to Statistical Quality Control in Highway Construction.

(3) Management of the Quality Control Function.

(4) Some Techniques in Application of Quality Control to Business and Industry.

Section (1) requires no further comment, since it is obviously pertinent to the project objectives.

Section (2) arose as a result of the HRIS information run and serves to display the near world-wide interest in statistical quality control which has developed among governmental agencies and within the construction industry itself. The projects were sorted into domestic (United States) and foreign; within the domestic they are listed in alphabetical order by states, within the foreign they are listed in alphabetical order by country and chronologically within country, with the exception of Canada. For Canada the projects were listed alphabetically by province and chronologically within province. The original computer reports have been edited into a standard format giving project title; agency performing the investigation, and for the United States projects, a state project number and a Bureau of Public Roads project number, one or both as appropriate; personnel directing the investigation (where given); period in calendar years apparently covered by the investigation (this information was often fragmentary and/or incomplete); objective(s) of the investigation; and listing of reports issued up to the time the project was placed in the information file. Other information, such as funding, was eliminated since the records were quite incomplete. No attempt was made to augment the HRIS run so this is, at best, only a partial collection.

The attention in Section (3) is focussed on how industry has approached the problems of effective management of the quality control

function. Since the manufacturing industries have, in some cases, twenty or more years of experience it would be well to examine how they have incorporated this activity into their management structure. This is done with the expectation that, in the very near future, there will be a rather general movement towards the adoption of statistical quality control procedures by the highway construction industry. This shift will undoubtedly require management changes to ensure that uniform procedures are applied to all construction contracts.

Major attention by interested personnel is presently focussed on Section (1), the statistical quality control applications to highway construction. The purpose of Section (4) is to proffer a sampling of statistical quality control applications in such areas as office management, personnel and other imaginative applications which may prove equally rewarding. State highway departments are generally large enough to offer many opportunities for such applications.

Each section, except Section (2), has been organized in the following manner. The bibliography is arranged in alphabetical order by author so long as an author or investigator is indicated. For those cases where this information is not available they are ordered alphabetically by title key words and are so assembled at the end of the section.

APPENDIX 1

STATISTICAL QUALITY CONTROL STUDIES AND APPLICATIONS IN ALL AREAS OF HIGHWAY CONSTRUCTION

1. Abdun-Nur, Edward A.
Product Control and Incentives
Jour. of the Const. Div., Proc. ASCE 92 (CO3): 25-40. 1966
(Digest from Trans. ASCE 132: 537-538. 1967.)

Much criticism has been directed toward the subject of quality control on construction projects. Actually control has always existed, and was exercised by a cooperative day to day meeting of minds between the engineer representing the owner at the construction site, and the contractor. A lot of it was a matter of judgement, but it worked - witness the large number of projects that have been built and have served their purpose well over the years.

The accelerated pace of construction and the mechanization and sophistication of operations in the last few years, has made such leisurely daily contact assessment of quality impractical; hence, much has to be relegated to inspectors and foremen. This has brought about the need for a means to measure the control of quality more objectively.

Manufacturing industrial operations had to face this problem years ago and, fortunately for the construction industry, they have over the years developed workable approaches to this problem. Because today construction is nothing but an outdoor manufacturing industrial operation, the basic principles developed by industry can be modified and applied to quality control in construction.

Basically, the fundamental principle underlying all industrial quality control is that variability is the law of life - nature abhors identities. And, it has been found over the years that the laws of probability provide a tool that can be used to predict quality levels through proper sampling plans and testing.

From a practical standpoint, the normal probability curve reasonably approximates the pattern of variability in construction materials especially if each test is determined from an average of two or three samples or specimens. For any given material, the degree of control or variability determines the shape of the normal probability curve that represents it.

The lower the average level of quality that is needed to attain compliance the less it costs the producer or contractor.

Here is where the proper approach and wording in a specification can use this phenomenon as an incentive for a producer or contractor to set up good controls of his operation. It then becomes a matter of economy as to how far to carry control. Every refinement is justified as long as the gain is more than the cost; however, it ceases to be

advantageous if the cost becomes higher than the benefit. This is a self regulating matter that permits the degree of control to seek its own economic and advantageous level. When followed, it has been found to create a strong incentive in producers and contractors to set up their own quality control.

Everyone gains by such an approach - the contractor by reducing his costs, the owner by obtaining a structure with lower variability thus lowering maintenance costs. Eventually, some of the extra profit gained by the contractor is passed on to the owner as a result of the competitive bidding process.

Some engineers have tried this approach and found it works nicely, and the contractors have found it advantageous to continue it on subsequent projects. Other engineers do not believe that the laws of probability can be used to predict quality, nor that incentives create powerful motivations for setting up quality control. The latter is an unfortunate situation, because from the experience of industry control through the probability approach results in savings in attaining a given quality level. Such control is here to stay and will become more common, as neither the contractor nor the owner can ignore the ensuing advantages for long, now that these facts have been recognized in the field of construction. Using incentives to spur the use of the probability approach to the control of quality is simply a smart thing to do, in order to reap the benefits as fast as possible.

2. Afferton, Kenneth C.
A Statistical Study of Asphaltic-Concrete
Highway Research Record 184: 13-24. 1967.

A typical New Jersey State Department of Transportation Construction project was selected to establish average values and variability parameters for asphaltic pavement material characteristics, such as asphalt content and gradation, presently used as measures of quality. The effect of variations in material or the material production process, sampling, and field and laboratory testing on the measured variability parameters are discussed. A comparison is made between present field and laboratory testing to determine the possibility of reducing the number of tests normally run on a construction project. The validity of the Department's present sampling and testing processes, and the adequacy of its present asphaltic-concrete specifications are studied.

A FORTRAN computer program was used to perform the analysis.

Findings indicate that for New Jersey, field testing alone cannot as yet supplant laboratory testing as the basis for final judgment on

material compliance. For the asphaltic content determination, it was established that the Department's present sampling and laboratory testing processes are as valid (in uniformity) as those typical of the highway field today. It was found that in general the asphaltic-concrete specifications, for the construction project studied, dealt fairly with the material supplier allowing sufficiently for the natural variabilities encountered. However, a few important exceptions were noted which occurred in the critical areas of the asphaltic-concrete test. In these instances the specifications were found to be overly restrictive for the present capabilities of the production, sampling, and testing processes. (4 citations)

3. Amirikian, A.
Dimensional Tolerances and Quality Control in Welded Steel Construction
Highway Research Record 85: 23-26. 1965.

Recently the American Welding Society issued two regulations for welded construction one for buildings and the other for bridges. A brief discussion is given of the pertinent clauses devised to provide an acceptable quality of workmanship and to specify the limits of dimensional deviation obtained in welded fabrication.

4. Anday, M. C. and C. S. Hughes
Compaction Control of Granular Base Course Materials by Use of Nuclear Devices and a Control Strip Technique
HRA 36(12): 102. December, 1966.

In an attempt to overcome some of the problems encountered in the compaction control of granular base materials through conventional methods, Virginia has recently developed a new approach. A control strip is constructed by the contractor, a density standard is established through nuclear moisture-density testing, and this standard is used as the basis for controlling the compaction of other sections built with like material. The method has proven to be very satisfactory on three projects, and will be used on eight more that are now ready for advertisement.

5. Anderson, Arthur R.
Construction Tolerances for Concrete in Highway Structures
HRA 33(12): 57. December, 1963.

Construction tolerances for concrete now generally specified or recommended in various design standards are discussed. The need for new tolerance criteria, and a basic approach to tolerancing as a function of design, are proposed, taking into account service requirements, structural integrity, and appearance of concrete construction.

6. Anderson, Arthur R.
Quality Control for Precast Concrete Construction
Civil Engineering - ASCE 36 (3): 56-58. 1966.

Quality control in precast concrete construction requires that each member be cast accurately to fit in its assigned position, and be adequately strong and attractive. Some precast structures have not measured up because of inadequate planning, failure of engineers to definitely assign responsibility, and less-than-needed quality of the finished structure. Precast concrete construction requires carefully detailed ground rules for general contractor, fabricator and erector. Few engineers detail this adequately; consequently what is everyone's business is no one's responsibility. To achieve quality in precasting, workers must have adequate technical support and enthusiastic direction by management.

7. Baker, A. B.
Deflection Beam Measurements in the Copperbelt District of Zambia
Road Research Laboratory (UK) LN (745). 12pp. 1965.

A turn-wheel loaded to 7000 lbs. was used to locate weak sections of road which looked sound. The results showed wide variability and a statistical technique for their analysis is suggested. A method of interpretation, based on a Quality Control System, is given in an appendix and permits location of road sections which are significantly weaker than the average. Further long-term observations of beam deflections and pavement performance will be necessary to provide a correlation between them.

8. Barclay, H. W.
The First National Inventory of Automotive Materials, Parts and Components, Quality Control, Test and Inspection Operations
Automotive Industries 135 (10): 71-86. 1966. Automotive Industries 136 (2): 79-86. 1967.

In 1960, studies were first initiated to correlate the safety standards of the American Standards Association, the American Society for Testing and Materials, and the Society of Automotive Engineers. Continuing questionnaires have been sent. The results of the studies are presented, with a discussion of their significance. The samples include both large and small firms interested in all phases of automobile, tire, component and petroleum products manufactures. Figures are given covering costs and manpower expenditures. A second series of articles show pictures of the testing processes. It is pointed out that cars embody safety design developed by the automotive industry, occasionally in excess of the standards required by governments, both federal or state.

9. Beaton, J. L.
Statistical Specifications. Analysis Phase of Quality Control Study Raises Many Questions
California Highways and Public Works 44 (9-10): 42-45. 1965.

The U. S. Bureau of Public Roads is co-operating with the authorities in California in a regional workshop study of quality control. The purpose of this study is to make a statistical analysis of road material control tests and to develop statistical specifications for control of construction. This report describes the procedures followed in this study and observations made as a result of the statistical surveys and evaluation of statistical specifications.

10. Beaton, John L.
Statistical Quality Control in Highway Construction
Jour. of the Construction Division, ASCE 94 (CO1), Proc. Paper 5708, pp. 1-15. 1968 (HRA 38 (7): 18. 1968).

California's experience in making a statistical study of its quality specifications for highway and bridge construction materials is described. Four years of research on sampling and testing of materials such as compacted embankment, plastic concrete, cement-treated base, structural concrete aggregate, untreated base material and aggregate subbase material are beginning to provide information concerning variations due to sampling, testing, and those inherent in the materials itself. Suggested in place of traditional methods is statistical quality control (SQC). The use of SQC could shift the quality control responsibility to the contractor with the buyer basing his purchase on a statistically sound end-point evaluation. Problems arising in the use of SQC may be met by training in the technology of statistical control, recognition of the fact that there is no need to supply statistical specifications to every construction item, the establishment of new specification limits, and a revision of testing procedures.

11. Beaton, J. L, G. B. Sherman, R. O. Walkins.
A Statistical Analysis of Percent of Cement in Cement Treated Base
California Division Highways Materials and Research Department M&R 631133-7, HPR. April, 1967.

A statistical analysis of the cement content of plant-mixed cement treated base is reported. Three construction projects in different areas of California were sampled and the test results analyzed. It was concluded that the current requirements of the cement content are restrictive and are not being met, however, the compressive strength of the materials and, consequently, the quality of the

cement treated base is adequate. Revised cement-content control limits are proposed and a specific frequency of testing and use of control charts are recommended.

12. Bicking, C. A.
The Sampling of Bulk Materials
Materials Research and Standards 7 (3): 95-116. 1967. (HRA 37 (9): 15. 1967.)

The problems of sampling of bulk materials are tested in two parts: the physical aspects and the statistical aspects. Although many physical models are very good, statistics can contribute to further improvement in the precision and economy of sampling. Bulk materials and the common methods of handling and sampling them are described. The various statistical methods that have been used to control sampling, to experiment with ways of improving sampling, and to measure the variability of materials are illustrated using a wide representation of materials.

13. Black, C. A.
Method of Soil Analysis. Part 1. Physical and Mineralogical Properties Including Statistics of Measuring and Sampling
Part 2. Chemical and Microbiological Properties
Monographs on Agronomy 9, Parts 1 & 2, 1572p. 1965.

This monograph, sponsored jointly by the American Society of Agronomy and the American Society for Testing and Materials, contains 113 sections by various authors. Where possible, specific directions for measurements are given, basic principles are stated and comments are made on such matters as limitations, pitfalls and precision. Each section gives literature sources for further study, but the general aim has been to produce a treatise that is self-sufficient.

14. Bloem, D. L.
How to Get Good Concrete
Civil Engineering ASCE 36 (3): 66-70. 1966.

Concrete of reliably high quality is needed for adequate performance in structures. The producer of ready-mixed concrete must be held responsible to specifications for: ingredients, properties of the fresh concrete, properties of the hard-concrete, and enforcement. The control of slump and batch proportions will provide a mixture that will achieve good appearance if properly placed, finished and cured. The guarantee of strength in terms of standard tests of the delivered product has become almost uniform for structure concrete. Real variations in strength can be attributed to differences in the ingredients and differences in production conditions.

Variations in the cement source and production are discussed. Ingredients, batching, mixing and delivery should be regulated by statistical techniques applied to strength tests. Several control charts are presented. Strength tests analyzed statistically are very useful for keeping track of concrete production control.

15. Bozarth, Ferrell M. and William E. Grieb
Study of Mixing Performance of Large Central Plant Concrete Mixers
HRA 35 (12): 57. December, 1965.

Field tests of concrete produced by large central plant concrete mixers are reported for nearly 400 test batches from four different construction jobs. Samples were taken at both plant and roadway and were tested for slump, air content, unit weight of fresh concrete, coarse aggregate retained on the No. 4 sieve after washout, and 28-day compressive strength of molded 6- by 12-in. concrete cylinders. Except for one project, all test batches were transported by non-agitating hauling units to the roadway for sampling after the batch was put in place.

At the plant, three samples per test batch were taken by intercepting the concrete flow during the mixer discharge. Data indicate that all four mixers produce good concrete at mixing times under 1 min if the plant achieves thorough blending (ribbon layering) of the aggregates during charging, including equally good parallel timing and uniformity in charging of cement and water. Failure to achieve proper charging of these materials results in uncertain performance of any of the mixers tested. Some of the tests yielded acceptable quality concrete (by most criteria) at 30 sec of mixing time, whereas concrete of poor uniformity was obtained at 180 sec of mixing time for one test series.

Two, and in one case three, roadway samples were taken from each test batch. Roadway samples do not show marginal quality concrete to be as inadequate as found by the plant tests. Specification test tolerances should recognize that variances between two samples are different from those among three samples.

Tests were made over a wide range of mixing times with a constant amount of air-entraining agent added. This resulted in extensive gains in air content at the longer mixing times, particularly at 180 sec. Strengths thus obtained were below that permitted by design requirements.

16. Bozarth, F. M.
Case Study of Influence of Imbalances in Charging of Cement and Water on Mixing Performance of Large Central Plant Concrete Mixers
California Division Highways HPR-(1/3), State F-8-1, BPR 2722 234.
May 1967.

Test objectives were to determine tolerable limits of deviation from good blending of cement and water with the aggregate ingredients of the batch during charging of the mixer. Blending appeared to be and was judged to be good for normal plant performance, but test results clearly demonstrated the appearance to be false. Results clearly confirmed the highly significant influence of blending the batch ingredients during charging of large (8 cubic yard) central plant mixers with horizontal drum axis and both ends open. When blending of batch ingredients during charging of the mixer was poor, the charging imbalances resulted in imbalanced distributions in mixed concrete, resulting in compressive strength imbalances that were in general proportional to the cement and/or water imbalances occurring in blending during charging. A quick and reliable method is needed for determining the uniformity of cement in plastic concrete, in order to effectively monitor the degree of blending of batch ingredients during charging of the mixer and thus assure good quality control of the concrete produced. Improved central plant equipment capabilities are also needed for improved assurance of good control in the blending uniformity for cement and water during charging.

17. Brakey, B. A.
A Vacuum Extractor for Bituminous Mixes
Materials Research and Standards 5 (12): 622-629. 1965.

Quality control tests of hot bituminous mixtures in the field should be speeded up by this new method developed by Colorado Department of Highways. The vacuum extraction test procedure and apparatus have the following disadvantages: (1) more solvent is required than for the reflux method, but about the same as for the centrifuge, for the same test specimen size, (2) the methylene chloride must be stored in a cool place because of its low boiling point, and (3) hot bituminous mixtures must be cooled to 130F before testing. The advantages of this procedure are: (1) the 12-in.-diameter filter is large enough for testing specimens weighing up to 3000 g. (2) the vacuum reduces filtering time to less than 15 min, (3) the filter is sealed to prevent significant loss of fines, and no correction need be made for such loss when doing routine control testing, (4) the use of diatomaceous silica speeds filtering on certain fine-grained mixtures, (5) eight tests or more, per shift, can be made with a single apparatus, (6) for mixtures containing less than 0.6 per cent moisture, no moisture test need be made, (7) it is at least as accurate as conventional methods, and (8) the cost per test is reasonable. The merit of the 20 vacuum extraction process has led to its adoption by the Colorado Department of Highways as one of three standard procedures.

18. Brenner, R., G. R. Fisher, and W. W. Mosher
Statistical Analysis of Accident Data as a Basis for Planning Selective Enforcement Phase 1
Presented at 46th Annual Meeting (HRA 36 (12): 93. 1966.)

Quality control techniques were applied to the analysis of traffic accident information. The underlying theory of control charts for accident data is presented. Several new theoretical conclusions relating to the statistical sensitivity of accident control charts were formulated. These same control techniques were also adapted to operational decision-making processes. A generalized system of control chart computer programs, designed to reduce the reported statistical techniques to operational practice, was developed and subsequently applied to a sample of accident data. Results suggest that for many accident data uses, a high alpha-error probability should be tolerated in order to realize a low beta-error probability concomitant with operationally defined lengths of roadway, realistic control chart time periods, and reasonable sensitivity to changes in accident producing potential. Such control charts would rarely fail to detect a small change in accident potential at the cost of having many of these change indications be spurious. The principle is that for many accident data applications, it is appropriate to tolerate many false indications of change in order to reduce the likelihood of failing to detect a real change.

19. Brown, W. R.
Nuclear Testing Correlated and Applied to Compaction Control in Colorado
HRA 31 (11): 21-22. December, 1961.

This paper describes the investigation made by the Colorado Department of Highways into the feasibility and practicality of using commercially available nuclear devices to perform moisture and density tests in the field on highway construction materials. The correlation found between nuclear and conventional methods is presented along with an explanation of the equipment and its basic functions. Electronic reliability is discussed and data concerning the amount of personnel irradiation while working in close contact with equipment containing isotopes of cesium and radium-beryllium are given. The use of a nuclear device to control the compaction of embankment material on a large project in western Colorado is described and acceptance of this new concept of testing by field personnel is related. Preliminary information concerning an attempt to correlate three different nuclear devices with the conventional method of determining the density of asphaltic concrete surface courses is also presented.

20. Brown, Wayne R.
Development of Nuclear Density Tests for Hot Asphalt Pavement
Highway Research Record 107: 25-36. 1966.

Development of a nondestructive test method for density measurements of hot asphalt concrete in the field using portable nuclear instrumentation is described. Also described are efforts to utilize existing nuclear density probes designed for testing soil to measure the compacted density of hot asphalt pavement.

A prototype nuclear asphalt density probe was developed. After testing the prototype on test sections with densities from 110 to 144 pcf, a production model asphalt density probe was designed and built. Heat-resistant electronics allowed density tests to be performed on material ranging in temperature from cold to 300 F. Source type and strength, as well as source-to-detector geometry, were optimized so that depth of penetration was restricted to approximately 1 and 3/4 to 2 in., allowing testing of thin asphalt surface courses without base course influence. Comparison data and compaction growth curves from various roller patterns set in the field using the asphalt density probe are included. Test results were available within 2 1/2 min after each roller pass.

21. Brumer, Milton and Frank Stahl
Quality Control of Structural Steel
HRA 37 (12): 71. December, 1967.

The development of steel technology has placed increased importance on the role played by quality control in the successful achievement of modern structures. The current practices for attaining quality control are reviewed in their three distinct phases.

In the mill, the producer has traditionally applied comprehensive controls on the metallurgy and manufacture of his product. Conformance to standards is reliable. Development of a continuous casting method promises the elimination of soaking pits and the elaborate checking required to avoid mixed steels.

Reliable inspection in the fabricating shop is ideally achieved through the cooperative, yet independent, efforts of shop forces and the customer's inspectors. Except in the larger shops, quality of inspection is found lacking. The authors believe the owner must be convinced of the necessity of good off-site inspection. A negotiated contract with a professional inspection agency, chosen noncompetitively on the basis of proved competence, is desirable. In addition to the traditional tasks, inspectors are now routinely required to perform and interpret non-destructive testing. Dye-penetrant, magnetic particle, radiographic, and ultrasonic methods are discussed. Efforts at standardization of test criteria are encouraged.

The actual construction of his designs should be inspected by the engineer himself; preeminently qualified, he should be thoroughly empowered to do so. The non-fashionable policy of engaging construction firms for on-site inspection is deplored.

22. Brunarskii, L.
Treatment of the Results of the Non-Destructive Testing of Concrete
Beton I. Zhelezobeton (USSR) 11 (7): 42-43. 1965.

Graphical methods of treating the results of non-destructive testing of concrete, developed in Poland are explained. Formulae are proposed and the values of terms listed for the various concrete qualities.

23. Buth, E., D. L. Ivey and T. J. Hirsch
Correlation of Concrete Properties with Tests for Clay Content of Aggregate
Highway Research Record, No. 124: 1-17. 1966.

The presence of clays in the fine aggregate used to make concrete is detrimental to the structural properties of the concrete. The Texas Highway Department currently uses the results of sand equivalent and loss by decantation tests as a means of detecting such clay and controlling the quality of fine aggregate used in Portland concrete cement. As an alternative to this, the sand equivalent test which separates the finer clay particles from the coarser particles and compares them on a volume basis may be used. These quality control tests were developed independently and the relationship between the numerical results of each test was not known. Since these two tests form independent bases for accepting or rejecting a material, the relationship between them is very important. This relationship was studied and concrete properties were correlated with these tests for clay content. The study concludes: (1) the strength of concrete is reduced as the quantity of contaminant in the aggregate is increased, (2) the strength of concrete is decreased as the liquid limit of the contaminant increases, (3) shrinkage of the siliceous aggregate concrete is increased as the contaminant quantity increases, (4) shrinkage of the siliceous aggregate concrete is increased as the liquid limit of the contaminant increases, (5) the dynamic modulus of elasticity of the concrete containing siliceous aggregate is decreased as the liquid limit of the contaminant increases, (6) the dynamic modulus of elasticity of concrete does not change significantly as the quantity of contaminant increases, (7) present Texas Highway Department specifications for concrete aggregate indirectly allow a 15 percent reduction in 28-day compressive strength and a 25 percent reduction in a 7-day modulus of rupture values, (8) some aggregates

meet present Texas Highway Department specifications by the loss by decantation test while failing the requirements of the sand equivalent test, (9) a relationship exists between loss by decantation results, liquid limit of the minus 200 mesh fraction, and sand equivalent value, and (10) clay activity, as indicated by liquid limit, as well as the amount of the clay present in the aggregate, influence concrete strength. The sand equivalent test is a better indicator of a combination of activity and amount of contaminant, whereas the loss by decantation test indicates only the amount. For this reason the sand equivalent test is a better indicator of the quality of fine aggregate for use in concrete. Loss by decantation results should be combined with liquid limit determinations to evaluate coarse aggregate.

24. Carlton, Paul F.
Application of Nuclear Soil Meters to Compaction Control for Airfield Pavement Construction
Amer. Soc. for Testing Materials. STP No. 293: 27-35. 1961. (HRA 32 (6): 2. 1962).

Ten years of research have resulted in the development of nuclear soil meters capable of measuring the moisture content and density of soils within the average accuracies required for engineered construction. This paper describes the use of surface-type nuclear soil meters for compaction control testing during the construction of new pavement facilities at Clinton County Air Force Base, Ohio.

This study was made using engineering models of the P-21 surface moisture probe and the P-22 surface density probe, manufactured by the Nuclear-Chicago Corp. Both cohesive and granular soils were tested. On the basis of use of the nuclear method at the Air Force Base it was concluded that the reliability of the nuclear method was comparable to that of conventional testing procedures for compaction control, time requirements per test were greatly reduced, and radiation hazard to operating personnel was negligible.

25. Centolani, G.
The New Bituminous Pavement Manual
Strade E. Traffico 13 (151): 7 pp., 1966.

The new manual, presented by the Touring Club Italiano and the Unione Petrolifera is briefly described. Its eight chapters deal with (1) materials, (2) bituminous mixtures, (3) the control of bituminous mixtures, (4) bituminous stabilization, (5) mastic asphalts, (6) surface treatments and penetration, (7) flexible pavement design, and (8) maintenance.

26. Cordon, William A. and K. B. Subbayya
Evaluation and Control of Concrete Quality for the Highways of the United States
HRA 29 (11): 53. December, 1959.

This paper analyzes the uniformity of results of compressive strength tests from 92 highway projects from various states of the United States, Puerto Rico, and Hawaii, and flexural tests from 26 projects. The significance of ACI Standard 214-57 in evaluating test results and in the preparation of specifications based on concrete performance, is discussed. Present variations in specifications among the different highway departments are summarized and suggestions are made regarding desirability of uniform specifications for concrete quality.

27. Covault, Donald O. and Paul K. Howard
Use of Neutron Activation and Neutron Backscatter to Determine Mineral Filler and Asphalt Content of Bituminous Concrete
HRA 33 (12): 102. December, 1963.

Many millions of dollars are spent each year by the construction industry for asphaltic concrete. This concrete is produced by a variety of concrete mixer designs. Uniformity of mixing is a good criterion by which to judge the quality of the bituminous mixture. In this research, mineral filler content of mortar, fineness modulus of the aggregate, and stability indicate the uniformity of the mixed concrete. With the exception of mineral filler content, all determinations of the physical characteristics of the concrete were made by conventional tests as specified by ASTM.

Mineral filler content of the mortar was determined by neutron activation analysis of Ca-49 produced in the calcium in the mineral filler.

28. Dantinne, R.
A Comparison of the Standards Adopted in Different Countries for the Testing of Stone Material Used in Road Making
Memoires DR C.E.R.E.S., Liege (Belgium) No. 10: 3-20. 1965.

Standards for testing stone material used in Belgium, France, the Netherlands, Federal Germany, Italy, Spain, Great Britain, the U.S.A. and Poland are examined. The tables are preceded by a proposed glossary on densities, and a vocabulary. They concern (1) coarse aggregates: terminology, samples, preliminary examinations,

chemical characteristics, cleanness, adhesion, physical characteristics, densities, grading, shape and aspects, behavior, mechanical resistance (compression, deflection, shock), friction, abrasion, polishing and hardness, (2) fine aggregates (sand): terminology, samples, preliminary examinations, chemical characteristics, cleanness, grading (size), physical characteristics (density, etc.) and (3) fine aggregates (fillers): terminology, sampling and various tests. (1 citation)

29. Dantinne, R. and P. Longueville
A Critical Study of the Quality Testing of Stone Used in Road Construction
Memoires DR C.E.R.E.S., Liege (Belgium) No. 10: 23-69. 1965.

Test methods for determining the quality of stone used in highway construction are examined with a view to finding the simplest and most adaptable procedures for tests carried out in quarries or at construction sites. Tests on the rock itself and on the crushed material are considered. The study bears on the main standardized methods of various countries, and in each case references of the documents consulted are given. (60 citations)

30. David, J. H.
Manual on Statistical Quality Control of Construction Tolerances
Bureau of Research and Development, Alabama State Highway Department, 63 p., May, 1964.

During the 1964 construction season the Alabama State Highway Department will thoroughly study three construction projects. These studies are designed to implement the inauguration of a statistical approach to highway testing and sampling within the Alabama State Highway Department.

The words "statistical analysis", "Quality Control", "Construction Tolerances", and like expressions are foreign to most Construction Engineering personnel within the Department. This paper has been prepared within the Bureau of Research and Development as an advance warning of some of the things which will become very familar to field Construction personnel within the next few years.

This paper is not intended to be a textbook in Statistical Analysis and no new or original work is included herein. It is intended, rather, to be a brief summary of information which is well known and is available in a variety of textbooks. (6 citations)

31. Davis, R. L.
Some Basic Considerations in the Application of Statistical Methods to Highway Problems
Virginia Highway Research Council Nat. Conf. Stat. Quality Cont. Methodology, 15 pp. May, 1966.

Statistical distributions, chance causes, assignable causes, specification intervals or limits, and the normal curve of distribution, basic concepts of statistical methods, were discussed and clarified. The following conclusions were reached: when only chance causes are operating in a process, it is useless to try to reduce the variation through increased supervision. When assignable causes are present in a manufacturing process, their elimination is of prime importance to the proper control of the process. (the elimination of assignable causes might be termed the essential feature of process quality control.) When only chance causes are present in a process, the pattern of process variation is stable, and the probability of the output of the manufacturing meeting any specification limits can be calculated. When assignable causes are present in a manufacturing process, such statistical parameters as the mean and the standard deviation of quality measurements on the process output are of limited value and the interpretation of their significance in process control is difficult.

32. Defoe, J. H. and R. C. Mainfort
Compaction Control of a Major Construction Project with the Michigan Nuclear Gauge
Michigan Department State Highways HPR, R-61 State, BPR 4722 102 September 1966.

During the 1965 field tests the Michigan combination-type nuclear moisture-density gauge proved to be a satisfactory means of embankment compaction control for all soil and aggregate materials tested. The testing time using the nuclear gauge was about one-half that required with conventional methods. The conventional Rainhart check test indicated proper job control with the nuclear method. Normal job sampling procedures were compared with statistically random sampling with promising results. Further experimentation is planned during 1966 operations on this project during which time more careful and complete evaluation of the statistical random sampling techniques will be performed.

33. Derdeyn, Conrad J. and James F. Todd
Acceptable Deviation in Density Control of Flexible Base
Departmental Research Report No. 63-2. 15 p. Texas Highway Department, Austin, Texas. July, 1963.

This report deals with three projects in District 14 for which frequency distribution curves and standard deviations were determined for density only. With this information as a criterion, routine tests could be made on a job with similar parameters and those results compared with the characteristic range of deviation. In this way, really significant variations in quality are filtered out and pinpointed.

Results are studied graphically so that test results can be evaluated at the time they are made. The record produced provides a ready reference which eliminates the need for reviewing stacks of test reports or long tabulations of figures. In addition, it is effective in illustrating to the layman the results achieved in the construction control

An example of the application of this system is given for construction control of bases. The normal frequency distribution curve for this material and the arithmetic mean of the test results from which it was constructed are shown. A typical analysis is made and explained. (5 citations)

34. Dillard, J. H.
The Implications of Several Types of Statistical Specifications
Virginia Research Council, BBR, PB-173 410 41 p. July, 1966.
(ASQC 24 (3): 192. September 1967.).

Discusses various types of statistical specifications and the practical implications of their adoption. Presents considered speculations on some of the ramifications that might accrue from selecting and adopting statistical techniques in highway construction.

35. Dillon, P.
Nuclear Moisture-Density Testing Methods
Illinois Highway Engineer 18 (2): 1-2. 1966.

Three nuclear gauges are being used for determining soil compaction and moisture content on construction projects in District 8 of the Illinois Division of Highways. The nuclear testing device is currently being used exclusively on moisture-density testing on several construction projects on Interstate 70. The operation of the nuclear moisture detection is based upon the special nature of the interaction between fast neutrons and hydrogen. Hydrogen is exceptionally effective in slowing down fast neutrons through collisions, to speeds associated with the random motion of a molecule or small component particle of a substance. The theory behind the nuclear method of determining soil density is based upon the absorption of gamma rays into the soil through the Compton scattering effect. The actual testing is fast and simple. Five minutes are required-three minutes for moisture determination and two minutes for density determination. Testing errors are minimized and quality control is easily obtained using

these tests. A speedier completion of construction projects result in economic benefits.

36. Doyen, A.
Consideration on the Quality Criteria of Bituminous Surfacings
Bitume Informations, Brussels (Belgium) No. 14: 31-50. 1965.

The author quotes Specification 108, which has been applicable in Belgium since 1/10/62, and emphasises the importance of inspection after completion, of contractors work. These criteria are based on a statistical framework and apply to the coefficient of transverse friction, uniformity, thickness, minimum binder content, apparent specific weight or index of voids, and the compression resistance of base course (coated material) aggregates, tested before and after completion of the base course. Research carried out at the Liege-Aix la Chapelle motorway site is aimed at the improvement and completion of the above mentioned specification, and concerns permeability and stability tests on extracted samples, void indices, and surface characteristics (uniformity, riding quality and roughness). (3 citations)

37. Doyle, P. C.
Yardstick for Guidance in Evaluating Quality of Asphalt Cement
Highway Research Record, No. 24: 164-181. 1963.

Samples of paving mixtures produced at various plants and using many different asphalt cements from different crudes and refineries were tested by the laboratory. Low temperature ductility provides a method of measuring the future services behavior of asphalts and the pavements in which they are incorporated. An improved laboratory method provides a tool whereby the simulation of the hot-mix pugmill operation on a laboratory basis can be duplicated. This procedure will allow an evaluation of the asphalt before it is placed. It was determined that any paving mixture which contains an asphalt which shows a ductility exceeding 8cm should be free from cracking. (68 citations)

38. Dunn, K. H. and N. G. Gaudette
Mixing Time Requirements for Bituminous Mixes as Determined by the Ross Count Method
Highway Research Record, No. 117: 1-22. 1966.

Tests were performed to determine the practicality of using the Ross count method of measuring aggregate coating in establishing a minimum wet mixing time for bituminous-concrete mixtures. The resulting effects of reduced mixing times on the mixture properties were measured by Marshall tests. A preliminary study was conducted in the laboratory before beginning field study which consisted of Ross count and Marshall property tests on bituminous-concrete surface mixtures produced from six hot-mix batch plants. Crushed gravel aggregate was in four of the mixtures and crushed limestone

in the other two. An 85-100 penetration grade asphalt cement was used in all mixtures. Five samples were given wet mixing time and at least three wet mixing times were used at each plant. Duplicate Marshall specimens were formed in the field for each of three samples obtained for any given wet mixing time. It was found that the Ross count method was a simple and practical procedure to use in the field with the reliability of results dependent on the experience and care of the operator. Statistical evaluation of the test results indicate that the reliability of any one Ross count decreases as the mixing time decreases. Marshall test results indicate the mixture properties of all six mixtures were not significantly affected when the wet mixing time was reduced to permit 97 percent aggregate coating. It is concluded that the practical approach offered by the Ross count method could be used to establish and control satisfactorily minimum mixing time requirements. (3 citations)

39. Eager, W. L.
Symposium-Thickness Variation of Asphalt Concrete-Part 2-Importance of Riding Quality-Emphasizing Riding Control While Improving Thickness Control
Assoc. Asphalt Paving Technol. Proc. 33: 27-29, 45-53. 1964.

Since the advent of procedures required for checking quality and quantity of materials on federal-aid highway projects, closer attention is being paid to actual thicknesses obtained, with tolerances from design thicknesses being officially or unofficially accepted. This has resulted in closer thickness control, but not necessarily in increased smoothness. Improved equipment and procedures to be described in this symposium will suggest possibilities in this regard.

40. Fairhurst, W. A. and A. Beveridge
The Superstructure of the Tay Road Bridge
Structural Engineering (UK) 43 (3): 75-82. 1965.

The paper describes the design, fabrication and erection of the welded steel box girders and concrete deck slab which form the composite superstructure of the bridge. The reasons for the various design features are stated. Mention is made of the use of models for the design stage and the results of a quarter-size model test to destruction are given. The welding procedure is outlined and the method of erection of the girders is explained. The routine tests carried out to check the quality of materials and workmanship are enumerated. Various features of the superstructure are then described and the paper concludes with an indention of possible developments in composite design references: fabrication and erection of the steelwork for the Tay road bridges, W. A. Fairhurst, Civ. Engng, Lond., 1965; 60 704 , 358-9, 361, 363.

41. Fletcher, Oren S.
Control and Acceptance of Hot Mix Asphalt Pavements by Statistical Methods in South Carolina
Paper at 13th Annual Convention, National Asphalt Pavement Association Los Angeles, California 37 p. February, 1968.

The surface mix which was produced and used on the I-85 project was very uniform in texture. The quality of the mix was very good and was equal to the quality which would have been obtained had we used routine quality control methods. According to our District Engineer under whose jurisdiction this work was conducted, the surfacing was the most satisfactory job that he had ever completed in his district. A great deal of this credit can be attributed to the Contractor's personnel for their excellent workmanship.

Control and acceptance of asphaltic plant mixes by statistical methods has a promising future. There will no doubt be problems to work out as additional experience is gained. A practical acceptance plan will be profitable to both the Contractor and the State.

In the system previously discussed, the pressure is taken off the Plant Inspector. He samples and tests the mix at random intervals and does not have to be overly concerned about stopping the plant when the mix is out of Specifications as is often done under routine job control. This system de-emphasizes the importance of individual test results and places the emphasis on grouped data. Another way to express it is to say that we look at the results of several tests instead of the result from one test.

This system will stand up under audit. It will not be necessary to write a letter to explain why a few individual test results are out of the Specifications. When test results are out of tolerance, the action to take is clearly defined.

After Contractors have had an opportunity to gain experience with this system, I believe that it will receive their endorsement. With the de-emphasis placed on individual test results, he will be able to operate his plant without unwarranted interruption. This will enable him to get a good day's production from which both he and the State will benefit financially.

42. Foster, Charles R.
Quality Control of Asphalt Pavement
Jour. of the Const. Div., Proc. ASCE 92 (CO3): 41-49. 1966.

In most industries, quality control testing is done by the manufacturer of the product and the purchaser does acceptance testing. In the paving industry the purchaser, usually a governmental agency does both the quality control and acceptance testing. In addition, the purchaser usually uses specifications which detail the characteristics

of the aggregates and cements, how they are to be mixed, hauled, and laid to such an extent that the purchaser is a substantial party in determining the satisfactoriness of the end-product.

This practice has limited the incentive for contractors to develop quality control testing capabilities. And probably of more serious concern, it has limited the incentive for contractors to produce consistent high quality of work because they must bid against all qualified bidders whose pre-qualification considerations are generally based on financial standing rather than proven quality of product and excellence of workmanship.

Two factors now operating provide a limited incentive for contractors to develop quality control testing capabilities. One is the practice of some states to require the contractor, as a part of the contract, to provide an equipped laboratory for use by the state forces. In the course of time, contractors use these laboratories in conducting tests on proposed materials for use in preparing bids. The other factor is the increased use of asphalt pavement in private work such as shopping center parking lots. Contractors are finding it necessary to test their mix to assure themselves and the private purchaser as to its quality.

The tests and inspection procedures used to control construction of hot-mix asphalt pavement vary with different agencies but all agencies test the asphalt cement, the individual aggregates, and the mixture. About half the agencies test the completed pavement for adequacy of compaction. Some of the tests, such as Los Angeles abrasion of the aggregate, are conducted only in the initial phases of a job; others, such as penetration (hardness) of the asphalt cement, are made on each shipment. Some tests, such as gradation of the aggregates in the hot-bin, are made at intervals during the day. The tests that are necessary for any job are those listed in the specifications. A typical set is given in the paper.

At the present no agency is using statistical procedures in establishing the frequency or location of the samples. With the high priority the Bureau of Public Roads has assigned to research on the development of statistical quality control specifications, we can look forward to seeing these being put into effect in the not too distant future.

Two items of automatic equipment have come on the market in recent years which have contributed to improved quality and reduced the required amount of inspection and testing. Automatic equipment is available which will draw the proper amount of asphalt and aggregate from the hot-bins, dump these into the pugmill, mix them the

required time, and then dump the mix. Sensors are available to determine if the individual weights are within allowable tolerances and there are interlocks to shut down the operation if weights are out of tolerance. Equipment is also available to print the weights of each ingredient, the batch weight, and the truck weight.

The other piece of equipment is the automatic screed control. A sensor, attached to the conventional paver, rides on a string line that is parallel to the desired surface. Automatic equipment operated by signals from the sensor make the necessary adjustments of the screed so that the finished surface conforms to the desired profile. A slope sensor controls the transverse slope to assure proper crown.

43. Fromm, H. J., W. A. Phang, and M. Noga
The Incidence of Stripping and Cracking of Bituminous Pavements in Ontario
Ontario Dept. Hwys. Jt. Hwy. Res. Prog. (Can) No. 109, 23 pp. 1965.

A statistical sampling covering the entire province of Ontario was conducted to determine the amount and extent of aggregate stripping in bituminous pavements. The type of stripping examined was that which starts at the pavement base and spreads slowly throughout the aggregate to weaken the entire structure. Stripping to some degree was evident in all areas examined and the incidence was more than was expected. It was more extensive over primed granular bases than unprimed or old pavement bases. It was also more pronounced where granitic aggregates predominated. No correlation was found, however, between the asphalt source and the amount of stripping. The frequency of random cracking was found, in general, to correlate directly with the severity of stripping. All of the survey data obtained was analyzed statistically and conclusions were made at a significant probability level. A procedure was also developed to assign a stripping rating to field survey samples. This rating describes the degree to which stripping has progressed in a sample. (14 citations)

44. Gartner, W., Jr., and R. W. Lindley, Jr.
Field Compaction Studies on Asphaltic Concrete
HRA 31 (11): 22. December, 1961.

This paper presents the results obtained from a project undertaken to evaluate the effect of varying the compactive effort of the intermediate rolling on asphaltic concrete. Both pneumatic-tired and steel-wheel vibratory rollers were used on a total of 26 test sections.

Results of the tests made with the pneumatic-tired intermediate roller indicated that maximum compaction is attained with six coverages, and a slight tendency for the material to decompact with additional coverages was noted. Results from the three sections in which no intermediate rolling was used showed that the average density attained exceeded minimum specification requirements. When the intermediate rolling was omitted but two extra coverages of the final steel-wheel rolling were applied, the average density attained was nearly as great as the average maximum density attained with the optimum number of coverages.

The results of permeability tests indicate no detrimental effect resulting from omission of the intermediate rolling.

The results obtained with the vibratory compactor were inconsistent and due to the lack of replication no evaluation of these results was attempted.

45. Ghosh, R. K., M. P. Dhir and M. R. Chatterjee
Quality Control of Concrete and Its Economics for Paving Projects
Indian Roads Congress Journal 29 (4): 573-601. 1966.

The various factors contributing to the variability in the quality of cement concrete on paving projects are discussed and suitable controls to reduce them are suggested. Reference is made to coarse and fine aggregate, batching, mixing, compaction, curing and testing, while details of strength data and their analyses are provided. It is recommended that both for road and airfield pavements the probability values of one in ten may be specified. It is also recommended that with good quality control a coefficient of variation of 15 per cent may be assumed for the initial design of the concrete mix in the laboratory. (13 citations)

46. Gillis, L. R.
Slip-Form Paving-2
California Division Highways 44 (3-4): 68-75. 1965.

In five years slip-form paving has become the most common technique used to construct concrete pavement in California. The authors describe experience gained with the slip-form paver in operation. Advice is given on the control of quality and uniformity of concrete, subgrade preparation, the use of vibration for satisfactory concrete density, pavement smoothness, finishing, and joint construction.

47. Glidden H. K.
Asphalt Shoulder Methods for An Iowa Freeway
Roads and Streets 108 (4): 74-145. 1965.

Asphalt shoulders constructed against concrete pavements described. The black top of the shoulder provides a colour contrast with the concrete pavement, and for this reason shoulders along asphalt pavements in Iowa are finished with white crushed limestone. Shoulders in Iowa are designed to carry the heaviest wheel loads, and special attention is paid to compaction and the quality of base course materials, to avoid subsidence and frost heave. The bituminous base for the project described had a mix of 70 percent crushed limestone passing 1 in. screen, 30 percent washed sand passing No. 4, and 4 to 5 percent of 120-150 penetration asphalt. Shoulders on all interstate roads are provided with a 3/4-in. armour or rumble coat, which serves to alarm and warn drivers who have drifted off the traffic lane. Quality control for asphalt shoulders was similar to that prescribed for asphalt pavements. Construction methods and equipment used are described.

48. Goldbeck, A. T. and J. E. Gray
A Method of Proportioning Concrete for Strength, Workability and Durability
National Crushed Stone Association No. 11, 36 pp. 1965.

A simple method of proportioning which will produce the desired quality of concrete, irrespective of type or grading of the aggregate, is described. It is considered to be easy to use, dependable and practical, an appendix is included on the method of test for unit weight of aggregate.

49. Graham, Malcolm D., William C. Burnett, and Jerome J. Thomas
Realistic Job-Mix Formula Tolerances for Asphalt-Concrete
Highway Research Record 184: 55-66. 1967.

In 1960, the Department initiated a study to determine the uniformity of asphalt-concrete top course mix to establish realistic gradation control specifications. During the years between 1961 and 1964 research crews visited 55 asphalt plants where they obtained 868 hot-bin samples and 682 mix samples. Data were processed and analyzed by electronic computer and from the results it is concluded that the mix gradation ($\bar{x}$, σ) depends on the method of testing (i.e., hot-bin analysis or extraction test). Neither method is totally superior to the other, but each complements the other. The hot-bin method is more meaningful when related to coarse aggregate than when related to fine aggregate, whereas the reverse is true with the extraction test.

Job-mix formula tolerances developed from this study are realistic and fair to both the producer and to the Department, and are now being used on a statewide basis. (19 citations)

50. Grant, N. T.
Ready Mixed Concrete (Part 1) Plant and Technical Control
Structural Concrete (UK) 2 (7): 299-308. 1965.

Reference is made to outputs in Great Britain and types of plant used. Some methods for determining quality of concrete are given and the application to control is indicated. Variations in quality are discussed. Closer co-operation between users and producers would ensure that the best technical and economic use is made of available material. (10 citations)

51. Gray, Hamilton
Development of Equipment and Methodology for Utilizing Nuclear Energy for Quality Control of Highway Materials
Ohio State University, Eng. Exp. Sta., Columbus, Ohio. Transportation Engineering Center Report No. 164-1, May 1961. 42 pp.
(HRA 32 (8): 1. 1962).

This report summarizes data previously presented in the form of 17 progress reports on this project. Certain of the data are repeated herein in order to facilitate comparisons, however, it should be realized that the data herein are typical rather than comprehensive.

The purpose of the project has been twofold: (1) to ascertain the accuracy, reliability, and economy of employing nuclear radiations to provide control of construction through the measurement of density and moisture content; and (2) to investigate the feasibility of reducing the time required to determine the "maximum" density of a soil prior to its use in construction.

Provided that field personnel are aware of potential sources of error and make reasonably frequent checks on the operation of the equipment, the surface density and moisture probes can be used to control construction operations. It should be realized, however, that the equipment has not yet been proven so reliable that it can be depended on to give accurate values of absolute density. Consequently, it is recommended that it be used for comparative purposes only, and then only under close supervision of a well-qualified supervisor.

In the interests of making the nuclear equipment more nearly self-sufficient and of establishing reliable calibrations involving absolute densities and moisture contents, it is strongly recommended that further "laboratory" studies similar to those heretofore reported on this project be conducted. From these the feasibility of making accurate determinations of absolute values may be assessed. If and when such accuracy can be attained with proper consistency, nuclear methods could entirely supercede the traditional ones.

A proposal for continued "laboratory" investigations has been submitted.

An investigation of the usefulness of high-frequency impacts in producing soil compaction appears to hold sufficient promise to warrant support. The results could lead to substantial reduction in the time required to establish the "moisture-density" characteristics of various soils.

The effect of long-continued compactive efforts on base courses is worth investigation, inasmuch as specification requirements ought to be based on a knowledge of such behavior.

52. Gonzalez-Asenjo, Florencio
Concrete Pavements: Statistical Analysis of Four Years' Experience
American Concrete Institute Journal 31 (6): 562-563. 1959.
(HRA 20 (5): 22. 1960).

Presents statistical analysis of tests carried out between 1950 and 1953. Parameters were computed from 11,437 compression tests and 9,243 measurements of pavement thickness. Author compares means and coefficients of variation with those computed from tests performed between 1943 and 1945 under different conditions of acceptance. The comparison shows a pronounced influence of control specifications on statistical parameters. Data are used to compute contractor's expected losses due to failure to meet specifications. For paper's purpose assumption of Gaussian distributions of strength and pavement thickness is satisfactory. Yet, author states chi-squared tests show this assumption to be significantly in error. Indeed, even histograms on arithmetic plot differ visibly from Gaussian distributions, particularly in the range of small strengths.

53. Hanna, S. J., J. F. McLaughlin and A. P. Lott
Application of Statistical Quality Control Procedures to Production of Highway Pavement Concrete
Highway Research Record, No. 160: 1-14. 1967.

Data collection by a systematic procedure for the purpose of evaluating the variability present in the manufacture of Portland cement concrete for highway pavements was investigated. Data were analyzed to provide information concerning the magnitude of the variance components for the Bureau of Public Roads: Data systems, and to provide information and illustrate procedures for the establishment of a quality control program that could be used by the Indiana State Highway Commission. (12 citations)

54. Hoover, J. M. and D. T. Davidson
Evaluation of Laboratory and Construction Control Methods of an Experimental Stabilized Soil Base Road, Webster County, Iowa
HRA 32 (11): 55. December, 1962.

This paper presents a portion of the results of an experimental stabilized soil road base program initiated by the Iowa State Highway Commission and the Webster County, Iowa, Engineers Office. The 8.058-mi long site chosen is typical of the Clarion-Nicollet-Webster soil association area materials found in hundreds of miles of farm to market roads in the north-central third of the State of Iowa.

The variable thickness base sections were constructed by using the in-place soil materials stabilized with type I portland cement, lime, lime-fly ash, and a combination of lime and portland cement. The surface course was a double bituminous armor coat using 3/8-in. crushed stone. Conventional construction practices were used. Water for standard Proctor optimum moisture content was applied through the spray bar of the milti-pass mixer.

The experimental project was divided into two primary objectives: (a) evaluation of conventional construction procedures, existing construction-inspection specifications and techniques, and recommendations for establishment and/or changes to each of these areas; and (b) evaluation of the constructed material by field and laboratory tests for determination of stability requirements in the development of design criteria for low-cost stabilized soil base roads. This paper deals principally with the area of the first objective. An evaluation of the construction techniques is presented as well as gradation specifications preceding introduction of the stabilizing agent(s); use of lime as a pretreating agent for reduction of plasticity and increase of friability; comparison of laboratory and field standard Proctor moisture-density relationships; in-place field density determinations using oil density and standard Proctor penetrometer methods; and variation of unconfined compressive strength of 7-day moist cure specimens with variations in moisture-density.

55. Huculak, N. A.
Quality Control of Asphalt Pavement Construction
Canadian Good Roads Association Proc. p. 238-250. 1964.

Because of the limited information available in the field of quality control of asphalt pavements, an intensive study was made of hundreds of test results from actual paving projects to determine the actual variations which do occur in control tests. The mean values and standard deviation values were calculated and histograms showing variation were plotted for asphalt penetration, asphalt content, aggregate gradation, surface density, air voids, Marshall

stability and flow, asphalt surface thickness variation. The test results were compared to design values and specifications. The results indicate the percentage of test results which can be expected to fall outside of specification limits and indicate the usefulness of quality control charts in interpreting data. (4 citations)

56. Humphres, H. W. and J. W. Jasper
A Critical Review of the Density Testing Program in Washington
HRA 36 (12): 109-110. December, 1967.

In recent years, Washington has used "end product" specifications for compaction of embankments and has carried out extensive training programs regarding control of compaction and density testing. To review the adequacy of the testing program and to determine the effectiveness of the training programs, a study of density requirements and results was initiated in 1963 and continued in 1964, requiring the review of over 23,000 field density tests.

A computer program based on statistical review of data was utilized to compute and plot curves which assisted in studying and evaluating the testing results for each project and district. A uniformity index was developed and used as a guide for comparing test results and determining what progress had been obtained in the testing program.

The paper describes the improvement throughout the state in density testing and control and summarizes the advantages of the bias testing program over other prepared procedures.

57. Hutchinson, B. G.
The Statistical Basis of Quality Control Charts
Canadian Good Roads Association Proc. p. 210-219. 1964.

The statistical principles and assumptions that form the basis of quality control charts are reviewed and the procedure for constructing these control charts is illustrated with an example. Special emphasis is placed on the processing of highway paving materials. The summary and conclusions of the paper indicate the application and limitations of the method in construction control and specification interpretation. (6 citations)

58. Hveem, F. N. and T. W. Smith
A Durability Test for Aggregates
Highway Research Record, No. 62: 119-136. 1964.

A laboratory quality control test has been developed to measure the mechanical durability of California aggregates in terms of a durability index. The degradation test was developed to measure the breakdown of aggregate that would occur during construction and under normal traffic. The equipment and procedures used are similar to those of the sand equivalent and cleanness value tests. The test results are correlated with the behavior of the aggregates in the field.

59. Ivey, D. L. and T. J. Hirsch
Effects of Chemical Admixtures in Concrete and Mortar
Texas Transportation Institute, Res. Rept. 70-3, 33 pp. March, 1967.

This paper reports physical effects of chemical admixtures on concrete and cement mortars, compares the variability of mortar tests with the variations encountered in concrete tests, and shows the degree of correlation of these tests with tests on concrete. The data presented provide a basis for utilizing a standard mortar for quality control tests of chemical admixtures. Most of the work is concentrated on compressive strength, shrinkage, and time of set. Also included are the results of durability tests on admixture concrete and a section on the control of chemical admixture uniformity. A theoretical solution for restrained shrinkage crack spacing is developed and a comparison of this theory with limited test data is shown.

60. Jahlstrom, I. O.
Review and Recommendations
Highway Research Record, No. 85: 27-29. 1965.

The speaker reviews the papers presented at the symposium on construction tolerances - structures. He discusses questions concerning inspection methods and tolerances for quality control. He concludes that we do not have to sacrifice quality to determine practical and reasonable limits or tolerances.

61. Javor, T.
Impulse Methods for Controlling the Construction Speed of Prestressed Concrete Bridges
Amer. Concrete Inst. Journal Proc. 64 (5): 240-243. 1967.

The application is described of two nondestructive impulse methods, viz., the ultrasonic and the sonic hammer methods for checking the quality of concrete. The two methods are compared giving their advantages and disadvantages especially in relation to speeding up the construction of prestressed concrete bridges.

62. Jorgensen, J. Frank and Robert O. Watkins
Compaction - Myth or Fact?
Division of Highways, California. 44th Annual WASHO Conference, Santa Fe, New Mexico. June 16, 1965. Paper pp: 1-36.

This study statistically examined the distribution of percent relative compaction obtained with current compaction control procedures. The survey included three embankment projects, the soils of which varied from homogeneous to very non-homogeneous material. These projects represented approximately the best and worst construction conditions, based on soil type, that would normally be expected in California.

The study followed as closely as practical the outline provided by the Bureau of Public Roads. Testing operations for each sampling location included two in-place density determinations by the sand volume method, and two maximum density determinations by the California impact method for each sand volume test. Fifty sampling locations were randomly selected on each project. Tests were performed only on those portions of fill already accepted by the resident engineer.

An analysis of percent relative compaction results for the three projects revealed average values of 92.9, 90.5, and 93.6 percent with standard deviations of 2.4, 3.1, and 5.5 percent, respectively. The greatest dispersion in results was found to exist for the heterogeneous soils. Statistical results agreed very closely with previously published data.

Factors contributing to the dispersion of percent relative compaction were found to be the variation inherent in both the testing procedure and the soil and compaction process. As the soil becomes more non-homogeneous, the effects of variation within the soil and compaction process become more pronounced. This is reflected in the relative compaction distribution curves for the three projects.

The discrepancy between construction control test results and accurate statistical estimates may be partially explained by (1) the accepted procedure of re-testing when a failure occurs, and (2) the bias introduced in control testing by non-random methods of selecting sampling locations.

Finally, a partial review of problems expected to be encountered in the development and use of statistical specifications is presented. (8 citations)

63. Kadiyali, L. R.
Design and Laying of a Dense Bituminous Carpet Between Cuttack and Nirgundi
Indian Roads Congress Journal 29 (3): 309-344. 1965.

The design and laying of a dense bituminous carpet using a semi-mobile hot-mix plant and a paver finisher is described. It deals with the measures undertaken to ensure quality control of work. A comparison of the output with the machinery and their rated capacity along with an analysis of the cost of the work based on actual data is also given. (5 citations)

64. Kantey, B. A. and R. K. Morse
A Modern Approach to Highway Materials Sampling
Intl. Conf. Soil. Mech. and Fdn. Eng. Proc. 1: 55-58. 1966.

Highway engineering, particularly in developing countries with inadequate staff, can benefit considerably by making full use of all available techniques. Two such techniques, air-photo interpretation applied to highway materials and statistical control of sampling and testing, have been used with success in South Africa. The authors describe the basic principles involved in the adoption of these tools and quote some examples to indicate the benefits that can be derived. (8 citations)

65. Kellogg, Frederic Hartwell
The Value of Statistical Control of Compaction
Engineering Experiment Station, Bulletin No. 5. 14 p. University of Mississippi, University, Mississippi. April, 1963.

A system of control of rolled earth fill is presented primarily from the viewpoint of the contractor. It permits selection of proper equipment during the planning stage, and indicates contingencies, delays, or changed conditions in ample time for remedial action. The fallacies inherent in normal specifications for compaction are indicated. Typical compaction patterns for three different compactors on two different projects are included.

66. Kerr, B. T. and G. G. Henault
Significance of Quality Control
Canadian Good Roads Association Proc. p. 233-238. 1964.

This paper describes the purposes of inspection and testing in highway construction, the general procedure for quality control,

the value of inspection and testing, the nature of samples, the value of test results, specifications and effectiveness of job control. It is pointed out that good quality control of materials and construction operations is of benefit to the owner, the engineer, the contractor and the materials supplier. The need for realistic specifications is discussed together with suggestions for achieving them.

67. Keyser, J. H. and P. F. Wade
Variability in the Testing and Production of Bituminous Mixtures
Highway Research Record, No. 24: 182-215. 1963.

The production of bituminous mixtures is subject to variation attributed to two major sources related to (1) mixing, composition and the characteristics of the constituents, and (2) sampling and testing. A laboratory study and a field investigation using statistical methods of two mixtures (surface and base) produced by two plants is reported by: (1) an analysis of the repeatibility of the Marshall stability and density tests and Rice's maximum density test, (2) an analysis of the variations occurring within a well-controlled production process, (3) a discussion of the influence of unavoidable process variation on mix design and the setting of specifications, and (4) a discussion of the use of statistical control charts. (44 citations)

68. Kirkham, R. H.
Present Trends in Research on Concrete Road Construction at the Road Research Laboratory, England
Australian Road Res. Board Proc. 2 (Part 2): 585-600. 1965.

The use of concrete for roads includes investigations into the properties of concrete and methods of designing a concrete mix, methods of controlling concrete quality, the design of concrete roads and bases, the efficiency of plant and methods of construction, and the maintenance of concrete roads. The review suggests that improved methods of measuring the workability and the durability of concrete may lead to better methods of mix design and suggests methods of mix design and suggests methods of testing by which the quality control of concrete may be improved. Changes in the design of conventional concrete slabs for heavily trafficked roads do not appear to be likely and new ideas are being considered such as prestressed concrete and continuously reinforced slabs. Continuously reinforced concrete bases have given satisfactory performance for a number of years under a bituminous surfacing, and the amount of cracking in the surfacing has been less than that in the surfacing over some lean concrete bases, the effect of the mix proportions on the performance of lean concrete bases is being investigated. Experiments to examine methods of obtaining

full compaction and good riding quality for conventional concrete slabs are described. The remaining problems are concerned with the compaction of lean concrete and the provision of a surface on a concrete slab which will have a high skidding resistance at high speed. Methods of repairing a spalled concrete surface are given. (8 citations)

69. Kjernsli, B. and I. Torblaa
The Venemo Asphalt-Faced Rock-Fill Dam
Norwegian Geotechnical Institute Publ. No. 69: 1-15. 1966.

The paper describes the design and construction of the Venemo dam, a dam with an impervious frontal facing of asphaltic concrete and a fill consisting of tunnel spoil. Compaction field tests on tunnel spoil were carried out and the compression of the rock fill was measured by means of cross arms installed in the fill. A description of the construction of the dam and of the asphalting is given together with the results of quality control. The performance of the dam after one year in service is checked by measurements of the seepage through the dam as well as of the compression of the fill. (3 citations)

70. Kraemer, P.
On the Construction of Bituminous Road Surfacings
Bitumen, Terre, Asphalte, Peche (Ger) 16 (4): 146-148. 1965.
Also 16 (6): 255-266. 1965.

The rules for the construction of bituminous surfacings are discussed individually. They include protective surfacings, tar and asphalt macadam to TVBIT 2/56 specification, asphalt concrete and sand-asphalt as well as tarred concrete laid hot, to TVBIT 5/57, cast asphalt to TVBIT 6/60, acceptance testing, guarantees and payments to TVBIT 7/64. The paper contains in the tabular material many hints on the selection of chippings, binders, methods of incorporating the requirement of materials, as well as quality testing. A separate chapter is devoted to renewal of surfacings on the federal motorways in cut and fill.

71. Kuhn, S. H.
Effects of Material Properties on Nuclear Density Measurements
HRA 33 (12): 102. December, 1963.

The paper describes laboratory and field investigations carried out to improve the practical application of the nuclear method in highway construction. Various factors have been studied,

including the effects of density gradient, source energy, and particularly soil type, on density measurements.

Two methods are described for the possible elimination of the effect of soil type in practical density measurements. In the first, direct transmission is used as an auxiliary test with backscatter measurements. Results are given to illustrate the advantages of this method for determining the correct calibration curve for the backscatter method and also for the evaluation of any density gradient in the soil layer.

In the second method introduction of a certain air gap between the surface probe and the soil surface is used to obtain a count ratio which, when plotted against density, gives a positive slope relationship independent of soil type for densities up to 400 pcf. This method only employs the backscatter technique and is therefore completely non-destructive. It is shown further how the air-gap method can be used for effective density measurements on soil layers. Measurements at predetermined air gaps further permit continuous records of density to be obtained by using a suitable ratemeter.

72. Kuhn, S. H. and R. W. Burton
Statistical Control of Dry Density
Reprint, Proceedings of the Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Cape Town, South African Council for Scientific and Industrial Research (Pretoria, South Africa), CSIR reference no. RR85, 1967. 4 p.

A simplified statistical approach for the control of dry density in road construction is presented. In the proposed sampling scheme a method is outlined whereby engineering decisions can be taken on the number of samples to be tested to satisfy various engineering requirements such as the error in test results and the desired limits of accuracy for a specified probability. Decisions based on the sampling scheme are also used to define the requirements for the design, specification and control of dry density in a road layer. By comparing the average density obtained from the specified number of observations with the specification density, a reliable decision can be taken immediately on the acceptance or rejection of the compacted layer.

73. Laguros, J.
Statistical Quality Control of Portland Cement Concrete Pavements
Oklahoma University, Oklahoma Department of Highways, HPR, No. 1483 State No. 64-02-2. BPR 4601 293. July, 1967.

Three construction projects studied, each built by a different contractor. The problem of quality control of portland cement concrete pavements was divided into sampling, testing and control criteria for a specific pavement design. Sampling of aggregates began at the stockpiles and the follow up system produced an excessive amount of sampling which was expensive and did not necessarily lead to identification of variations in the product. The study discussed a need to exercise more control at the system operation level than in the material. Some tests were found to be antiquated and others cannot be used to pinpoint lack of compliance with specifications. Recommended rapid site tests as more meaningful than laboratory tests. Gradation of aggregate problems are recognized but do not seem to be plausible answer to the problem. Recommended more research be done on processes to produce P.C. concrete pavements. Report presents summary of analysis of variance for the several characteristics for each of three unidentified projects.

74. Lefebvre, J. P.
For a Statistical Control of Crusher Run Material for Dense Graded Mix
Bull Liaison Labs Routiers (France) No. 11: 2.1-2.12. 1965.

Improvements in the quality of road materials can only be achieved by the use of statistical control methods. In the course of an acceptance control of 0-12.5 millimeter crusher-run material, the author has tried through statistical analysis to establish:

(1) That there was a correlation between dry and wet sievings and that the significant difference was small up to the 2 millimeter sieve,

(2) That a good approximation of the samples' average grading curve could be obtained by mixing and then quartering through a reducing sampler,

(3) That the size of the controlled material unit being taken as a cubic meter, one could obtain its average grading with a good degree of approximation by taking 5 samples of about 4 pounds each and determining their average grading,

(4) That there is a correlation between the 2 millimeter dry sieving and the filler content (wet) and that a possibility of indirect control of the greatest variations of the fines content can be inferred. These conclusions could lead to standards for a simple specification of (or acceptance) statistical control founded on the knowledge of a simplified grading (3 or 4 sieves) through dry sieving and on the creation of control cards.

75. Lieder, Nathan
Sampling Techniques Applicable to the Collection of Economic Data
Public Roads 30 (11): 246-249, 252-255. 1959.

Sample survey techniques are used in many data-collecting phases of highway research. However, not all who must practice sampling have been trained in modern sampling theory. This article presents an account of the theory and its application which is directed primarily to those engaged in sampling for economic data.

Included is a discussion of the basic concepts of sampling, and the advantages and disadvantages of several alternative sampling methods. Proportional stratified sampling and optimum allocation among strata are discussed. Criteria are offered for choosing between these 2 alternatives with some consideration given to cost factors.

The author suggests one possible application of the theory and offers an illustration based on hypothetical data.

76. Liu, T. K. and T. M. Thornburn
Study of the Reproductibility of Atterberg Limits
Highway Research Record, No. 63: 22-30. 1964.

The reproducibility of the Atterberg limit soil tests in highway engineering is questioned. A statistically controlled experiment was performed to investigate how well an operator can reproduce the Atterberg limits and the effects of an operator's experience on the test results. Two operators, one with considerable experience and the other with practically no experience, performed a series of liquid and plastic limit tests on three different soils. The statistical analysis of the test results revealed the following: (1) there are variations of small magnitude in the Atterberg limit values, (2) the experience of an operator does affect the variations of the Atterberg limit values, (3) the plasticity index values are most variable, and the liquid limit values are least variable with the plastic limit values occupying an intermediate position. The specific numerical values on which these general conclusions are based are discussed. A method based on quality control techniques is proposed for technician training in performing Atterberg limit tests. (6 citations)

77. Lyman, R. J.
Construction Tolerances-Prestressed Concrete
HRA 33 (12): 57. December, 1963.

For introduction purposes, the factors involved in the development of the tolerances section of the "Manual for Inspection of Prestressed Concrete," which was the result of considerable study of an AASHO-PCI Joint Committee, are briefly discussed. The pros and cons of existing specifications regarding tolerances are obviously many and there is considerable latitude as to what is acceptable or unacceptable even when compared to tolerance limits. Certainly the reason and judgment of the inspection force are factors in the application of tolerances.

Recommendations regarding the desirability of modifying existing tolerances resulting from current developments in materials and construction methods and based on contacts with prestressers, contractors, consultants, and various highway department bridge engineers, are presented.

Tolerances are usually intended for use as a guide to indicate a reasonable standard of performance; specific job conditions may require separate tolerances, either closer or more liberal. Possibilities of establishing primary ranges of tolerance for unqualified acceptance of work and secondary ranges for qualified acceptance subject to correction by the contractor or penalty to the contractor for noncritical departures from specified tolerances have been studied and results are presented.

Additional research, particularly with respect to camber, will be necessary to establish further appropriate tolerance values.

78. Maclean, D. J. and W. A. Lewis
British Practice in the Design and Specification of Cement-Stabilized Bases and Subbases for Roads
Highway Research Record, No. 36: 56-76. 1963.

Current British practice in the design and specification of soil-cement for use in the base or subbase for roads is described. The composition of the material, the structural design of roads incorporating soil-cement, and the methods used to control the quality of the material in practice are presented. The suitability of a soil for stabilization is based on requirements similar to those in the United States, good grading, low plasticity of the fines, and freedom from deleterious chemical constituents. The pedological classification of a soil profile is used to estimate the depth of soil unsuitable for stabilization, because of organic content. Measurements of the pH of a soil-cement paste 1 hour after mixing are used as a check on the presence of deleterious organic matter. Soil-cement has been widely used since 1945 for the construction of housing estate roads and low-traffic rural roads.

Cement-stabilized materials have also been used for the construction of main roads, in particular as the subbase of concrete and bituminous-surfaced roads. The quality control of soil-cement during construction is based largely on tests to check the strength and state of compaction of the laid material. (17 citations)

79. Mainfort, R. C.
Michigan's Experience With Nuclear Gages For Measuring Soil Compaction
Michigan Dept. State Highways, Res. Rept. No. R-612, 21 pp. November, 1966.

Michigan's research in nuclear methods for highway foundation compaction control is described from its inception in 1952 through a major field experiment in 1955-66 during freeway construction. The equipment used is discussed as well as gage calibration procedures, training of inspection personnel, field testing procedures, and safety precautions. The nuclear method has proved suitable for field use, in which it saves time and reduces operator fatigue. Special studies, in addition to development of the Michigan combination density-moisture gage, are outlined, including evaluation of other equipment and use of statistical control methods.

80. Mather, B.
Partially Compacted Weight of Concrete as a Measure of Workability
Amer. Concrete Inst. Journal & Proceedings 63 (4): 441-450. 1966.

A study of the compacting-factor method of measuring workability of small-aggregate concrete (1 1/2 in.) indicated that: (A) the degree to which concrete heaps when a mold is allowed to overfill from the discharge of a mixer reaches a maximum at an intermediate workability and decreases as the mixture gets either drier or wetter, and (B) the net, loose weight of concrete in a mold after strike off increases with increasing workability. The net, loose weight of concrete in a mold filled to overflowing and then struck off could form the basis for controlling workability of mixtures having a slump not greater than 3 in. Studies using mixtures with 6-in. aggregate indicated that heaping weight, struck-off weight, and compacting factor increase with increased water content until the slump reaches from 1 1/2 to 3 in. and then they decrease. Routine determinations of heaping weight or struck-off loose weight might be used to detect batches of excessive or deficient water content which could be rejected before delivery to the forms.

81. McDonald E. B. and D. Anderson
Statistical Quality Control Study-Base Course
South Dakota Department Highways BPR 4601 323 December 1966.

The purpose of the study was to establish a basis for setting future specification limits from collection of data from material analysis, to make statistical analysis of typical soil aggregate base course and to apply statistically obtained limits on a tentative basis in comparison with current specifications. Randomized samples were taken from the base courses of three widely separated projects. Determinations made for values of liquid limit, plasticity index and gradation on replicated samples. Statistical evaluation was made for variance of the material, sampling and testing. Acceptance limits of variation in the stated characteristics were tabulated. Normal distribution curves were shown for various sieve sizes and materials. The authors state that additional sampling and testing will be necessary to establish new acceptance limits as there seems to be considerable weakness between the statistically obtained acceptance limits and the existing specification limits.

82. McDowell, Chester
Density Control: Its Benefits and Complexities
HRA 36 (12): 110. December, 1966.

Texas employs the conpaction ratio (the ratio of the difference between roadway as compacted density (D_A) and the loose dry weight of the soil (D_L) determined by the Texas method to the difference between the max. laboratory density (D_D) under a compactive effort of 30 ft-lb/cu in.). The method results in high density requirements for non-swelling soils and lower, more suitable densities for swelling soils.

Soils and base materials are placed in three groups: uniform, nonuniform and erratic depending on the relation of their respective values to the D_A density. Plots are made of the deviation from average D_A vs percent of average D_A representing the three types of material. Reasonable compaction ranges are established for each group for use as a basis for control. Design and construction recommendations have been prepared for different types of soil and for some soils containing admixtures of stabliizing agents. Use is made of the Texas gyratory method for erratic materials.

Data have shown that increasing compactive effort from 4 to 30 ft-lb/cu in. increased density of a sandy soil by 9 pcf and increased the shearing resistance from 19 to 30 psi (for 20 psi normal stress).

The paper concludes that the compaction ratio method establishes the degree of density that is required and that is practical, that the results of high compactive effort tests are more nearly reproducible than those for lower effects, that density control of erratic materials is wishful thinking and that the Texas gyratory compactor offers good promise for measuring density properties.

83. Memmott, F. W.
Origin-Destination Survey Quality Control Methods
NY State DPW Subdiv. Transp. Plng. & Prog. pp 1-2. June 1966.

A quality control program for the origin-destination surveys is designed to maintain the accuracy and completeness of the reported travel information. Controlling complete reporting is more difficult because errors occur on the part of the interviewers and lack of communication within a household about trip making. Three levels of quality control are used: (1) telephone calls are made to households to check on the completeness of the information, (2) a thorough editing check of each form is made by a trained editor, and (3) interviewer performance records are kept on a weekly basis for analysis and possible corrective action. There is a temptation in travel surveys to increase the sample size and decrease the direct costs per sample. Sometimes this results in biased data. A fully developed quality control procedure directed toward both the interviewer and interviewee more than compensates for the added cost per sample unit.

84. Miller-Warden Associates
Development of Guidelines for Practical and Realistic Construction Specifications
National Cooperative Highway Research Program Report 17. pp. 109. Highway Research Board, NAS-NRC 1216. 1965.

A highway construction specification is a means to an end. Its mission is to provide the traveling public with an adequate and economical pavement on which vehicles can move easily and safely from point to point. A practical specification is one that is designed to insure adequate performance at minimum cost. A realistic specification is one that recognizes that there are variations in materials and construction which are inevitable and characteristic of the best construction possible today. The purpose of this report is to present guidelines for the preparation of a complete specification meeting these requirements.

Parts of specifications should be arranged in logical order in general conformance with Bureau of Public Roads Policy and Procedure Memoranda 40-3.1, 40-3.1(1) and 40-3.2. Full decimal systems of numbering paragraphs should be used. Specifications should be of the "end result," "materials and methods," or "restricted performance" types, depending on the conditions of acceptance. Only directions should be given, requirements should not be repeated, and the basis of acceptance or rejection should be clearly stated. Each statement should mean one thing only. The limits and tolerances established must be economically attainable, and acceptance plans should be designed, by use of the given methods,

to have a known risk of accepting material or construction not within these limits. Risks should be based on criticality of requirements for significant characteristics.

To achieve maximum economy, specification requirements must be geared to policy and cost considerations. To insure practicality, the given administrative and engineering guidelines should be consulted.

Gradation requirements for aggregates and mixtures of aggregates with other materials should be based on the control of size and quantity of voids, as determined by the given theoretical method, modified to include variations to be expected under normal construction conditions. Pavement smoothness requirements should be based on both the deviations from a straightedge, and their span, in accordance with slope-variance criteria developed at the AASHO Road Test. Tolerances and penalties for deficiency of thickness of pavement courses should be related to reduction in service life in terms of daily traffic. Theoretical loss of performance is twice the cost, on a fractional-inch basis, for flexible pavements and five times the cost for rigid pavements.

In addition to being technically competent, accurate and complete, specifications must be written as clearly and concisely as possible. The test should employ simple language, with contemporary usage and grammar, as suggested in the given editorial guidelines. (Extensive Bibliography)

85. Mills, W. H. and O. S. Fletcher
A System for Control and Acceptance of Bituminous Mixtures by Statistical Methods
Highway Research Record 184: 25-54. 1967.

The discrepancy between emphasis on strict compliance with specifications and knowledge that variations are inherent in materials, construction, sampling and testing was investigated by the South Carolina State Highway Department. Phase I included the development of random sampling procedures and statistical parameters on hot asphaltic mixtures. In Phase II the mixtures, as placed on the roadway, were investigated by sample survey techniques to verify the control procedures. A tentative system for process control and acceptance of bituminous mixtures was developed from the data and experience in Phase I and Phase II and this system was tested at four locations in Phase III. The tentative system was further refined as a result of this experience. Phase IV gives the details of the system as developed and a procedure for adjusting the unit price for lots of mixture which do not conform to the criteria. (10 citations)

86. Minor, Carl E.
Effects of Mixing Time, Batch Weights on Quality of Paving Concrete
Pacific Builder and Engineer 65 (6): 92-94. 1959.
(HRA 29 (9): 16-17. 1959).

Realizing that mixing time and batch weight specifications were the vital factors in the production of concrete paving, it was decided at the request of the Bureau of Public Roads, to participate in a cooperative study on an actual paving project.

The studies were conducted on the inside or passing lanes of a new 4-lane freeway through Olympia. The outer lanes had been paved previously and were open to construction traffic.

Since the standard specifications require a 60-sec mixing period and allow a 10 percent overload of the mixer, and since there was no desire to either increase the mixing time or reduce the allowable overload, it was determined that the study would be limited to mixing times of 45 and 60 sec and overloads of 10 and 20 percent. A minimum mixing period of 45 sec was used instead of the 30-sec period suggested by the BPR because it was feared that a 30-sec period was dangerously low, particularly since the concrete pavement was being placed on a portion of a freeway on the Interstate System. Tests were performed on concrete mixed according to the following schedules:

OCTOBER 1959: VOLUME 29, NUMBER 9

Series 1---60-sec mixing time---10 percent overload
Series 2---45-sec mixing time---10 percent overload
Series 3---60-sec mixing time---20 percent overload
Series 4---45-sec mixing time---20 percent overload

The data on uniformity of the fresh concrete show no advantage for the 60-sec mixing time over the 45-sec time.

All of the data indicate without exception that the concrete was not harmed when the mixing time was reduced from 60 to 45 sec. Not only were both compressive and flexural strengths higher at 45 sec than at 60 sec for the same batch size, but, in addition, the coefficient of variation of the 12 individual tests in the case of the flexural strength tests was much better at 45 sec than at 60 sec. For the compressive strength tests, however, the individual results on the 60-sec mix were slightly more uniform than the results on the 45-sec mix.

While the data indicate a definite advantage strengthwise to the 45-sec mix, that conclusion cannot be accepted without further tests. It is felt, however, that the data justify the conclusion that mixing time of 50 sec is sufficient to provide uniformly high quality concrete, provided the mixer is in good repair and an experienced operator is in charge.

It was the observation that a mixing time of 50 sec is a practical minimum. The operator had difficulty in reducing the time to 45 sec consistently and several batches that were to be mixed only 45 sec were not sampled because the time ran up to 50 or 51 sec before the batch could be discharged.

Following is a summary of the compressive and flexural strength results on each of the 4 series:

PSI STRENGTH IN 28 DAYS

	Compressive	Flexural
Series 1	4418	807
Series 2	4841	926
Series 3	4197	824
Series 4	5124	848

87. Mitchell, J. K., C. K. Shen and C. L. Monismith
Behaviour of Stabilized Soils Under Repeated Loading. Report 1. Background, Equipment, Preliminary Investigations, Repeated Compression and Flexure Tests on Cement-Treated Silty Clay.
Waterways Exp. Sta. Tech. Repts., Army C. E. Contract Report No. 3-145 VII, 122 pp. December 1965.

Current methods of pavement design using stabilized soils as components of the pavement structure generally base selection of both quality and thickness of those materials on static tests such as the California bearing ratio (CBR) procedure. To validate such procedures, the objectives of these studies are to evaluate the behavior of stabilized soils under dynamic loading conditions and develop improved criteria for quality design and thickness selection within a more rational framework. More specifically the study is concerned with examination of soil stabilization requirements established by the Corps of Engineers for military roads and airfields in the theater of operations within this framework. Vicksburg silty clay and Vicksburg buckshot clay were selected for study. To date, most of the dynamic testing has been performed on the treated silty clay. In general the results obtained thus far indicate that cement-treated soil designed to meet Corps criteria for CBR and compressive strength can withstand repeated compressive and flexural stresses of the magnitude and number prescribed for different classes of military operations. However, more detailed investigation of the influence of water content, mixing procedures, and method of compaction are required since the data obtained show that these variables significantly affect the strength and resilence characteristics of the cement-treated silty clay. (30 citations)

88. Moss, John P.
Progress Report on the Establishment of Tolerances on Highway Construction Specifications
HRA 33 (12): 56. December, 1963.

Highway engineers and contractors are being criticized for deviations from specifications, even though in many instances there are sound

engineering justifications for permitting the deviations. This problem underscores the need for tolerance on specifications. This is a progress report on the establishment of these tolerances.

89. Munro, G. E.
Some Answers to Ready-Mix Problems
Heavy Construction News (Canada) 9 (16): 4pp. April 1965.

Failure to understand the relationships between air, water and slump can cause havoc with quality control. Factors such as temperature and the number of revolutions a truck mixes concrete will alter the consistency. Waiting to pour on a job, an obvious, but important fault is often the cause of rejected batches. The article is a series of tips that may aid a contractor in supplying satisfactory ready-mixed concrete.

90. Neaman, D. and J. G. Laguros
Statistical Quality Control in Portland Cement Concrete Pavements
Highway Research Record 184: 1-12. 1967.

Quality control for portland cement concrete (pcc) pavements and their component parts was statistically studied in a field project approximately 8 miles long. Standard field tests on fresh concrete and standard laboratory tests on hardened concrete, coarse and fine aggregate, and cement were run on an adequate number of samples. Ninety-five pavement thickness measurements were taken, and 400 concrete cylinders were tested. For all the other characteristics, such as slump, air content, gradation, durability, Los Angeles loss, sand equivalent, fineness, and percent passing No. 200 sieve, 200 observations were made. The typical statistical parameters, i.e., testing, sampling and material variances, standard deviation and arithmetic mean, were calculated and frequency distribution curves drawn. In nearly all cases, the arithmetic mean of the measured characteristic complied well with the specifications. However, the relatively high values of standard deviation and of the testing variance should raise serious questions on the philosophy underlying the existing acceptance-rejection procedures in pcc pavements. Upper and lower control limits, especially those based on average value, show conclusively that unfit material is sometimes accepted. Also, large values of the testing variance suggest that standard tests need some refinement, if not a complete modification, to reduce their inherent variance. (8 citations)

91. Neubarth, E.
Quality Control for Roadway Concrete
Bauwirtschaft, Weisbaden (Germany) 19 (7): 13-14. 1965.

Detailed commentary is presented on the provisional rules for the preparation and supply of roadway concrete, ed. 1961, accepted

and introduced by most of the Federal Lander for inspection purposes, as amplified by suggestions in the light of the experience of quality control officials. Thus, the possibilities are examined of revising the specification schedules and the actual cubic-meter weights specified and the enumerated testing equipment required by inspectors of works. In quality control (either by the Quality Protection Association, Transport Association for preliminary checking of works contracts for their members, or by authorized building materials establishments) a distinction is made between preliminary control of the works specifications, first revision procedures and continuous works control. The forms to be used on site for summarizing the specifications and the suitability tests of the different concrete grades, the works journal and the weighing instructions are illustrated by samples with examples of entries. The same applied for the first testing program and the continuous works control in regard to the test sheets with the concrete test results. (1 citation)

92. Nicholas, J. H.
Control Compliance and Specifications
Queens Highway (UK) 31(2): 6-9. 1965.

The control of the quality of bituminous road mixtures by the manufacturer, and the acceptance-testing of the material by the customer, both depend on the analysis of samples of the material, the samples actually analysed being a very small proportion of the total material. Great care in taking the samples and in analysing them is absolutely essential if the results are to be of any use, but even with properly taken and analysed samples the interpretation of analysis results should be made with a due appreciation of the risks of all sampling techniques. The analysis-result of a single sample is meaningless and a succession of samples is needed to establish a pattern of the quality of the material. Complete (100 per cent) compliance of all the analysis results with the specification is highly unlikely unless the limits of the specification are set unrealistically wide and a statistical approach is needed to enable sensible interpretation to be made of a series of results. The paper was prepared at the Road Research Laboratory.

93. Oglio, E. R. and J. A. Zenewitz
Variability in an Asphalt Concrete Mix
Public Roads, U. S. Bureau Public Roads 34 (1): 5-12. 1966.

The research reported in this article was conducted as part of the first phase in a broad program being undertaken by the Bureau of Public Roads to develop control and acceptance procedures, based on statistical quality control techniques, to all aspects of highway materials and construction. As the program is now constituted, the first phase calls for determination of two basic statistical parameters - the average and the standard deviation - for the materials and structural elements now being used in good highway construction. In the work reported here, averages and

variations in temperature, asphalt content, and aggregate gradation were determined in an asphalt concrete wearing course mix produced for a construction job. A statistical analysis was made to show the effect of test method, sampling procedure, and material (Batch-to-batch) variation on the overall variations obtained. (8 citations)

94. Orr, Charles I.
Liaison Insures Quality Control for Vehicle Assembly Building
Civil Engineering - ASCE 35 (10) 56-58. 1965. (Digest from Trans. ASCE 131: 778-774. 1966.)

Some people think that "quality control" means "inspection", but it means more than that. Preplanning, adequate supervision, and a competent work force are equally essential for the production of a quality product.

Many are not in accord with the statement that appears all too often in quality control procedures, "Quality control representatives are to maintain the highest possible standards of quality in all fabrication and work being performed by the contractor." Near perfection is not always economically feasible, and in many instances it is not necessary. The following statement in Military Specification MIL-Q-9858A is acceptable: "This specification requires the establishment of a quality control program by the contractor to assure compliance with the requirements of the contract."

Good judgment must be exercised in establishing quality controls consistent with the requirements of use. The function of the quality control representative is to enforce, in a reasonable manner, the criteria already established by the contract documents.

As orders were prepared for material for the huge Vehicle Assembly Building in Florida, conferences were held with the Corps of Engineers and their consulting engineers to reach agreement on the interpretation of the design drawings and specifications. A firm agreement relating to specific requirements at the beginning of the work was essential for maintaining the schedule, for mutual understanding of standards of quality in fabrication, and for economical fabrication.

The submission and approval of shop drawings is one area of quality control. At this time, all differences of opinion regarding interpretation of drawings and specifications should be resolved. Quality of materials was controlled primarily by the submission of mill test reports without further physical and chemical tests. Sonic testing was required on certain areas of plates and rolled shapes to detect any lamination that might exist. Fortunately, the sonic tests showed that laminations in the steel were practically nonexistent.

Material was fabricated by the American Bridge Division of U. S. Steel Corporation in plants in widely separated locations. Close control over scheduling of operations and methods of fabrication was required to produce a uniformly satisfactory product.

Unfortunately, schedules could not always be adhered to. There were customer changes and problems greater than had been originally anticipated. Although it is generally desirable to give several weeks prior notice of schedules and changes, this is often impossible under an expedited schedule such as that for the Vehicle Assembly Building. The customer's inspection must be geared to fit in with the fabrication, with minimum notice, in order to gain maximum quality control and minimum interference with the schedule.

Many details of fabrication presented problems of quality control including the accuracy of layouts to maintain required tolerances. The layout and assembly of fittings on the heavy columns presented a particularly difficult control problem. A device was developed that, in effect, projected theoretical center line of the member to the exterior faces, so that all fittings and connecting holes could be accurately located with reference to the projected line on each face of the columns.

About 800,000 lb of shop weld was deposited by automatic submerged arc equipment. The Corps used visual and magnetic particle inspection. Limited spot X-ray was used by American Bridge. Written weld procedures were required and were prepared by the American Bridge Division, and subsequently approved by the Corps before the start of the work.

Because the supply of skilled operators was not adequate, other operators had to be trained and qualified. However, the fact that a welder could pass a qualification test was no assurance that he could make a first-quality production weld. Supervisory personnel were therefore faced with the task of turning out a large volume of work, as well as training the less experienced operators.

To maintain uniform quality control over the blasting and painting operation, a central paint shop was established at Tampa, Fla. The specification for sandblasting listed the type and grade of sand to be used, and required a near-white blast finish. With the cooperation of the Corps of Engineers, the sandblasting operation was adjusted until an acceptable surface was obtained.

Quality control during erection consisted primarily of maintaining the required geometry and the proper tension in the A-325 high-strength bolts. Over 1,000,000 bolts were installed and were spot tested in the usual manner as specified by code. The geometry was checked by frequent surveys.

The structural steel frame for the Vehicle Assembly Building of Complex 39 has been erected and the remainder of the construction supported on the frame is proceeding rapidly. The quality control procedures employed during fabrication and construction have produced satisfactory results.

95. Pinto, C. D. and H. T. David
Statistical Allocation of Soil Specimens to Eliminate Inaccuracies in Differential Molding Time
Amer. Soc. Testing Matls. Proc. 64: 1068-1074. 1964.

Compression tests of stabilized soils can be influenced by molding time differences when several specimens are molded from one batch. If the time lag has a linear influence on the strength of the specimens, comparisons among test conditions are free of inaccuracies, due to molding time differences, when the average molding serial number is the same for each test condition. It is always possible to apply this rule to any experimentation. A pilot experiment with soil-cement mixtures showed that a random selection of specimens can yield inaccurate results, whereas the use of the systematic molding-time allocation is conducive to accurate results.
(2 citations)

96. Ponteville, G. et P. and S. Vallemont.
Rapid Control of Bitumen Content and Application to a Fabrication Statistic Control
Bull. de Laisondes Lab. Routieres, Ponts et Chaussees (58 Bd. Lefebvre, Paris, XV^{e}, France) (2): 1-12 (74). July-August. 1963.

St. Quentin Laboratory has studied a method for rapid control of the bitumen content in coated materials. That method has been applied to a statistic control of coated materials fabrication.

The method principle consists of measuring after stripping, the optical density of the solvent-bitumen solution with a spectrophotometer.

Experimentation has consisted first to verify that the Lambert-Beer law fitted with bitumen-xylen solutions, then to draw an adjusted graph, connecting spectrophotometer deviations to the concentration of bitumen-xylen solutions.

With the proposed testing method, 10 min are needed for one test; the error is not higher than 3 percent of bitumen weight.

Two trials of statistic control have been conducted from these measures. The first one was a Wald progressive, or sequential, control; it was proposed to conclude a good or poor setting of the bituminous mixing plant at a certain time. The second one allowed to make sure of the correctness of the average setting of the plant for a complete work day.

97. Preiss, K.
Analysis and Improved Design of Gamma-Ray Backscattering Density Gages
HRA 34 (12): 76. December, 1964.

The nuclear reactions that gamma radiation may undergo in a material of medium atomic weight, such as soil, are discussed and related to the properties of backscattering density gages. Theoretical reasoning and experimental evidence are presented to show that the effect of the chemical composition of the material may be eliminated when: (a) the detector "sees" material near the source, and (b) photons of energy below 0.1 Mev are not detected. This may be achieved with a scintillation counter and pulse selector or by placing iron filters in front of a Geiger-Muller tube.

The geometry defined by (a) causes the peak in the calibration curve to move to a density so high that count rate becomes a unique measure of density, rising over the entire range of density from 0 to 160 pcf. Errors in the density reading due to the statistics of nuclear counting and surface roughness are discussed.

98. Ralston, H. H. and M. C. Anday.
Nuclear Measurement of Soil Properties
HRA 33 (12): 102-103. December, 1963.

This study reports the results of the investigation of three commercially available nuclear devices for the measurement of soil density and moisture contents. The investigation was divided into three phases to properly evaluate the devices for their proposed use by the Virginia Department of Highways.

The first phase was an equipment and geometry evaluation. This included precision testing of the device itself, depth and area of influence determinations, and evaluation of the effect of air voids under the probes. The second phase was an attempt to calibrate the devices on representative subgrade and base course materials from construction projects in Virginia.

The third phase was field testing of the devices on construction projects throughout the State. Here again both subgrade and base course materials were used. Densities and moisture contents obtained with the nuclear devices were compared with those obtained by conventional water balloon methods.

Miscellaneous comments pertaining to maintenance, reliability, and radiation safety are also included.

99. Read, D. W.
The Use of a Nuclear Meter for the Control of Moisture and Density in Pavement Construction
Australian Road Research Board Proc. Paper 264, 29 pp. September 1966.

Three years experience with use of a nuclear meter for quality control of such elements as pavement construction and earthworks and for calibration of compaction equipment was described. Close correlation of results with those of other methods, which the meter has largely replaced, was illustrated by results from field construction. Operating procedures and sources of errors were discussed in detail.

100. Redus, J. F.
Study of Natural Variations in Highway Materials
Clark, Dietz, Painter & Associates Adm, CPR-11-1634, CPR-11-1634 PB 169 733, BPR 3721 024. 1965.

The purpose of this study was to obtain and analyze data concerning the natural variations in pertinent qualities of soil, base, and flexible pavement materials with a view to establishing specification limits to be used in statistical quality control of highway construction.

The data was obtained from the Corps of Engineers, from projects constructed for experimental purposes, as well as airfield construction projects. The data analyzed include density and moisture content of subgrades density, moisture content and gradation of base courses and density and aggregate gradation of asphaltic concrete pavement.

Statistical parameters were computed and a sample specification written for use in the control of compaction of subgrade soils.

101. Rooke, W.
Speedy Compact Concrete Pumping Units Produce Savings and a New Contractor
Heavy Construction News (Canada) 11 (15): 6-8. 1967.

Compact and mobile concrete pumping rigs are competitive in cost and speed - and often more easy to handle - than conventional

crane and bucket or truck and buggy combinations. Here are the benefits of pumping: (1) concrete placement tends to be a more steady, uninterrupted operation and is generally faster than conventional methods, (2) form pressures and wear are reduced because of elimination of surges, (3) concrete can be cast in locations otherwise completely inaccessible to crane or buggies, (4) costs are usually comparative with, or better than moving concrete by other methods. Labor requirements are also reduced, (5) the quality control of the mix built right into the pump means better and stronger final product, (6) cranes are freed from bucket-swinging duty to be more productively deployed. Conveyor systems are often teamed up with pumps for long distance or high volume pours, and (7) the pipelines deliver the mix right to the final location, and in such a manner that other trades or operations are not interrupted during the pour. Buggy runways are eliminated.

102. Rusch, H.
Statistical Quality Control of Concrete (In German)
Materialprufung 6 (11): 387-394. 1964.

Current standard procedures for evaluating tests on concrete are criticized on statistical principles. It is more useful to test strength on the basis of the poorest 5 percent of the samples tested instead of the average quality of all samples, as the former criterion reveals the standard deviation. The average value is no guide to the strength of the eventual structure, which fails at the weakest point. Selection of samples should be statistically random, there is no value in taking more than one sample from each mix. Average strength may be satisfactorily ascertained from 10 samples, but 30-50 samples are required to determine the standard deviation. This number may be reduced if additional data are available (e.g., results of identical tests carried out elsewhere).

103. Russam, K. and A. B. Baker
Deflection Beam Measurements on Roads in East and Central Africa
Rhodesia Institution Engineers Proc. 3 (3): 333-339.

The deflection beam is a simple instrument for the measurement of the transient deflection of road surfaces under a dual wheel-load. The paper gives results of deflection measurements on roads in East and Central Africa and discusses the application of such measurements in the estimation of the strength and future performance of roads. Even on roads of nominally uniform construction the deflection measurements showed considerable variation. Quality control methods of analysis were therefore used to determine the significance of the

variations and to formulate a procedure for road surveys with the deflection beam. Further work is required to obtain deformation performance histories of typical roads in Africa. The authors are on the staff of the Road Research Laboratory. (11 citations)

104. Sanders, W. W. and W. H. Munse
Study of Inspection Methods and Quality Control for Welded Highway Structures
Highway Research Record No. 110: 22-35. 1966.

A survey was conducted in 1960 of all state highway departments to determine which inspection methods were used for the various components and members of welded highway structures. This study was updated in 1963 and a summary is presented of the results of both surveys. The three categories of inspection methods are: destructive tests, proof tests, and nondestructive tests. The most widely used type of inspection method is the nondestructive test which is divided into the following classifications: visual, trepanning, radiography, dye penetrant, magnetic particle, and ultrasonic. These methods are discussed and suggestions made for development of welding inspection specifications. (14 citations)

105. Schevenels, L.
The King Baudoin Motorway. The Quality Control, Preparation and Laying of Bituminous Bases and Surfacings
Bitume Informations, Bruxelles No. 14: 17-30. 1965.

The first part of the article describes the continuous and batch production (at two different sites), of bituminous bases, base-courses and surfacings. The two sites had different types of equipment (Barber Greene and Wibau). The author outlines the problems of organization and supply, and compares the hourly output of the sites. The second part deals with tests and inspection of the coated material. An inspection laboratory at each site is provided with a Rotarex centrifugal binder extractor. Four comparative analyses are made of 1000 tons of material by the two site laboratories, a central reference laboratory, and one other outside laboratory. The tests are aimed at: (1) determining any standard difference in the results of each laboratory, (2) obtaining knowledge of the fluctuations of the different constituents, and (3) comparing continuous and batch production.

106. Schonfeld, R.
Construction of a Full-Scale Road Experiment as Part of a Unit-Price Contract
Canadian Good Roads Association Proc. Ontario Dept. Hwys., Downsview (Canada) Report RR 114, pp. 406-424, December 1966-67.

An experimental pavement comprising 36 test sections was constructed, as part of a unit-price highway contract, between May and September, 1965. Special provisions were introduced into the contract documents dealing with the special construction sequences, tolerances, testing, and the control of traffic during construction. Construction control and contract specifications are described and the degree of uniformity of materials, compaction, moisture contents, layer thicknesses, etc., achieved within the framework of the contract is reported. The special provisions are mentioned in this report and the degree of compliance, as measured by a comprehensive series of tests during comstruction, is described. It is concluded that a generally acceptable standard of control was achieved and the experimental pavement was constructed in a very short time.

107. Schwartz, A. E., J. D. Autrim, J. H. Moore, and J. P. Rostron
Rapid Test Methods for Field Control of Construction
Clemson University, NCHRP, No. 10-4, BPR 5720 002 1965.

The overall objective of this research project, conducted as part of the national cooperative highway research program, was to determine the state of the art in the development, need, and use of rapid test methods for field control of construction. The areas in which the need for rapid tests and sampling is greatest have been determined, the present knowledge and state of development of various methods of meeting these needs has been investigated, and those methods with greatest promise have been recommended for further development.

This research was initiated by conducting a literature search for information related to rapid test methods and to methods currently used for construction control. Specifications and testing manuals were obtained from nearly all state highway departments to assist in the study of current practice. A high percentage of these highway departments also responded to a construction control questionnaire in which their engineers were requested to outline and give priority to field test procedures which were most in need of rapid methods. To augment the information obtained from the literature search, testing manuals and specifications, and questionnaires, visits were made to highway departments across the country to observe their current practices for construction control and to discuss the areas in need of rapid tests with both their field and research personnel. Also, several research agencies were visited who were conducting projects related to the overall problem of quality control of highway construction.

108. Scurr, K. R.
Construction Tolerance for Structures: The Problem and the Approach
HRA 33 (12): 57. December, 1963.

Increased public and political interest in highway construction as a result of the Interstate Highway Program has created an atmosphere in which inspectors and engineers are becoming more reluctant to exercise "engineering judgment" in acceptance or rejection of work. Under such conditions it becomes more important to develop a "statistical basis" or "tolerance curve" as specification controls, recognizing that laboratory precision cannot be economically obtained under job site conditions.

109. Shah, S. C.
Quality Control Analysis. Part I. Asphaltic Concrete
Research Report No. 15, 48 p. Louisiana Department of Highways, November, 1964.

This is the first in a series of reports on the quality control analysis of highway construction materials. Subsequent parts will deal with the analysis of results of the physical characteristics of soils and concrete materials.

This report deals with the statistical evaluation of results from several hot mix plants to determine the pattern of variability with respect to bituminous hot mix characteristics.

Individual test results when subjected to frequency distribution indicated normal (Gaussian) distribution. Further analysis showed the overall variability of each characteristic for binder course mixes to be less than that for wearing course mixes. Also, the natural tolerances for bitumen content and aggregate graduation were outside the engineering (job mix) tolerances indicating a need for either a much closer control in plant operation and materials uniformity or a revision in engineering tolerances.

For bitumen content, a standard deviation of 0.2% would be normal and for 100% conformance a tolerance of 0.6% should be specified if 3σ is considered realistic specification limit. However, an allowable tolerance of 0.5% would cast off only 1% of the results. For aggregate graduation, if the inevitable variations due to crushing and screening operation, changes in stockpile and bin proportions, and sampling and testing are taken into consideration, then the limits for the job mix tolerance should be:

± 9% for No. 4 and larger sieves
± 7% for No. 10 sieve
± 6% for No. 40 sieve
± 5% for No. 80 sieve
± 3% for No. 200 sieve

The variability in the case of Marshall stability was considerably different for each plant. Furthermore, lack of uniformity was indicated as evidenced by considerable between-days variation.

If acceptance tolerances are to be written in the specifications, then the number of samples to be tested for a particular characteristic should be specified. For Marshall stability, eight random samples obtained from trucks representing a day's operation should be tested. Furthermore, if the minimum specifications are to be met 100 per cent of the time, then it is essential that the process average be maintained at 3σ above the minimum requirement, or 3(190) = 570 lbs. above the absolute minimum specified for the type of mix.

110. Shah, S. C.
Quality Control Analysis. Part II. Soil and Aggregate Base Course
Louisiana Department Highways, Research Report No. 23, 40 pp.
(HRA 37 (5): 8. July 1966.)

Statistical evaluations of results from several construction projects were made to determine the basic pattern of variability with respect to certain base course characteristics. On the basis of this variability, numerical limits have been established using statistical quality control techniques. The analysis indicated (1) that the frequency distribution of historical data for most of the characteristics tend to follow normal distributions, (2) that the variability for compaction and thickness is considerably different for different contractors, (3) that this variability for compaction is more pronounced for cement stabilized aggregate base course than for stabilized soil cement course, (4) furthermore, that for raw or unstabilized aggregate base course, the variability is less than that for stabilized base course.

111. Shah, S. C. and Verdi Adam
Statistical Evaluation of Highway Materials Specifications
HRA 37 (12): 72. December, 1967.

A statistical evaluation of some of the major highway materials specifications is reported in this condensed version of the overall study on quality control analysis. The data for analysis and evaluation were obtained from historical sources with a limited amount from research sources for asphaltic-concrete, base course, and concrete characteristics. The data were analyzed by computer and standard statistical procedures.

The analysis indicated that (a) most of the historical data tend to follow normal distribution; (b) in general, there is considerable variation in production and construction control for different contractors; and (c) furthermore, there is a lack of compatibility between currently used specification limits and statistical parameters.

The report attempts to show how the variables sampling plan can be constructed and applied for lot acceptance. The use of control charts for control and acceptance of portland cement and asphaltic-concrete is also demonstrated in the report. Some recommendations are made for implementation of the overall program of statistical specifications, including an educational program, and selection of a number of jobs for field evaluation.

112. Sharkey, R. H.
Contingency Checks of Land Use Survey Data
Chicago Area Transportation Study Research News 1 (17): 4-8. 1957.

A number of machine contingency checks were made of the data accumulated in the CATS LAND USE SURVEY. The checks were made on three categories, card accounting, internal consistency, and a real coverage. Methods used for this checking operation are described. These checks are considered to be an essential extension of the quality control program.

113. Shergold, F. A.
A Study of the Variability of Roadstones in Relation to Sampling Procedures
The Quarry Managers' Journal 47 (1): 3-8. 1963.

This article gives the results and conclusions from a study of the variability of roadstones, which was made with the object of devising a sampling procedure that would ensure that the samples of stone are representative of the material actually being produced at the time of sampling. Visits were paid to seven quarries and samples of lump stone were taken from a large number of points at the quarry face; samples of the finished aggregates were also taken from the output end of plants at intervals of time ranging from one hour to several months. The samples were tested by the British Standard methods for the determination of the polished-stone coefficient, the 10% fines value (a measure of resistance to crushing) and the aggregate abrasion value. (4 citations)

114. Sherman, G. B., R. O. Watkins, and J. J. Folsom
A Statistical Analysis of Concrete Aggregate Test Results
California Division Highways, HPR, BPR 4601 123, February 1967.

The report describes a statistical study to determine the reproducibility of current test methods and feasibility of using statistical quality control procedures for portland cement concrete

aggregate. Three bridge projects were studied, test results on randomly selected samples were statistically analyzed for variances. The conclusion was that sand equivalent and cleanness tests were satisfactory for field control. Large variances of material and sieving operations indicate need for modification of specifications. The report recommended the use of moving average based on the five most recent individual test results. The report contains valuable analysis of variance data characteristic of material, sampling and testing procedure.

115. Sherman, G. B., R. O. Watkins, and B. G. Page
A Statistical Analysis of Penetration Test Results for 85-100 Grade Paving Asphalt
Materials and Research Department, Division of Highways, California Research Report No. M & R. 210338-1 May 1965. p. 1-31.

This report deals with the present specifications, variation in test results, and control of testing procedures for 85-100 grade paving asphalts. Test records on file for the 85-100 grade paving asphalts were evaluated. It was found that all but one percent of the results fell in a normal distribution with a range of 78 to 106. It was concluded that this range represents reasonable control limits for acceptable material. A revised specification based on economic and statistical considerations which will allow the purchase of the material within this range is presented. It was also found that, in this case, full adherence to the principles of statistics is not warranted.

The need for some system to indicate laboratory operational control is cited and a method for setting up a statistical control chart procedure is presented.

116. Sherman, George B., Robert O. Watkins and R. H. Prysock
A Statistical Analysis of Embankment Compaction
HRA 36 (12): 109. December, 1966.

This study statistically examined the distribution of percent relative compaction obtained with current compaction control procedures The survey included three embankment projects, the soils of which varied from homogeneous to very heterogeneous material, thus approaching the most nearly uniform and most varied soil conditions that would normally be encountered in embankment construction in California.

The study followed as closely as practical the outline provided by the U. S. Bureau of Public Roads. Testing operations for each sampling location included two in place density determinations by

the sand volume method, and two maximum density determinations by the California impact method for each sand volume test. Fifty sampling locations were randomly selected on each project. Tests were performed only on those portions of fill already accepted by the resident engineer.

An analysis of percent relative compaction results for the three projects revealed average values of 92.9, 90.5, and 93.6 percent with standard deviations of 2.4, 3.1, and 5.5 percent, respectively. The greatest dispersion in results was found to exist for the heterogeneous soils. The distribution curves of percent relative compaction for the projects studied were found to agree generally with the results reported by the Bureau of Reclamation and the AASHO Road Test.

117. Shook, James F.
Significance of Test Results Obtained From Random Samples
Statistical Methods for Quality Control of Road and Paving Materials, ASTM Special Technical Pub. No. 362: 13-30. 1963. (HRA 35 (2): 6. 1965.)

Problems associated with applying test data obtained from random samples to highway specifications are discussed. Illustrations are given using data from the AASHO Road Test and other sources. Infrequent randomly chosen tests may be of little value, but routine quality control tests made frequently as material is produced and placed should provide adequate information for acceptance of materials. A statistical procedure for routine acceptance of material or highway work is introduced.

118. Simon, L. L.
Reduction in the Cost of Concrete Pavement Through Quality Control
Constructional Review (Australia) 38 (1): 20-25. 1965.

This paper deals with the reduction of the cost of concrete roads without loss of quality and durability. Theoretical consideration and analyses of tests (including the AASHO road test), show that this is made possible by the use of unreinforced concrete of high flexural strength and low cement content, and by obtaining a high degree of uniformity through strict quality control. Details are given of the methods used and results obtained in Australia by the New South Wales branch of the Commonwealth Department of Works. In addition to a saving in overall cost a reduction in pavement thickness was achieved without loss of performance. (13 citations)

119. Smith, P.
Concrete Paving Practices In Ontario
Ontario Dept. Hwys, Downsview (Canada) DHO Rept. No. RR116, 27 pp. October 1966.

In recent years there has been increasing interest in building heavy duty concrete pavements in Canada. New designs have been introduced which involve the use of reinforcing steel in the slabs, and load transfer devices at every joint. In addition, improved construction techniques, principally the use of long wheel-based finishing machines, have resulted in higher standards of initial pavement smoothness. Performance to date suggests that such pavements will, with little maintenance, prove to be durable and will retain an acceptable riding quality for many years. This report describes the concrete pavement design generally used in Ontario, discusses the manufacturing operations required and outlines some of the salient points of construction, inspection and quality control. In addition, developments such as preformed neoprene compression seals to give improved joint sealing, the use of central-mixed or ready-mixed concrete and improvements in equipment and techniques are also discussed. (15 citations)

120. Smith, P.
Computer Evaluation of Concrete Quality
Ontario Dept. Hwys, Downsview (Canada) DHO Rept. RR125, 25 pp. January 1967.

Problems and pitfalls of present specifications and procedures for control testing of concrete are discussed and it is suggested that these are in need of review to place them on a sounder statistical basis using accelerated tests, especially for concrete strength wherever possible. Modern methods of data processing, storage and retrieval are shown to offer potential for faster handling of information. New reporting systems have been established to feed concrete data to a computer. The data are then processed, stored, retrieved and evaluated as needed for the control of quality at the time of construction, the selection of concrete best suited to a particular structural design or for the study of performance. The short term benefit is in better control of concrete quality at the time of construction. The long term, and perhaps even more important benefit, should be that the properties of concrete which influence performance can be identified and better specifications prepared for future work. (17 citations)

121. Smith, P., and H. Tiede
Earlier Determination of Concrete Strength Potential
Ontario Dept. Hwys, Downsview (Canada) (Presented at the 46th Annual Meeting HRA 36 (12): 55. 1966.)

Waiting 28 days to determine the compressive strength of concrete from normally cured cylinders may be inconvenient, embarrassing or disastrous depending on how the concrete has been used, how

deep it is now buried, and the results obtained in relation to the strength anticipated. The purpose of this paper is to advocate alleviation through accelerated strength testing. The paper reviews attempts over the last 40 years to find a satisfactory method of accelerating strength development so that an estimate of the 20-day strength may be obtained within a day after the concrete is placed. Special attention is paid to procedures known to be in current use which are providing a worthwhile additional control on the quality of concrete. A new procedure under development by the authors is presented. Called autogeneous curing, it involves placing the cylinders in a well-insulated container which retains the heat of hydration of the cement sufficiently to provide acceleration of strength development. Relationships are presented between normal 28-day and the accelerated strengths for a number of variations on the basic procedure, including 22 hours or 46 hours of autogeneous curing alone, of 22 hours of autogeneous curing followed by 24 hours of hot water curing, together with supporting data on temperature-time relationships for concretes with a variety of cements, cement factors, w/c ratios, and admixtures. Results indicate that an autogeneous curing procedure has potential not only as an accelerated strength testing method, but may also be a means to greater uniformity in the handling, storage, and shipping of field cylinders. For the 48-hour test cycle, which includes 46 hours of autogeneous curing, the relationship found between the normal 28-day strength (R_{28}) and the accelerated strength (Ra) is $R_{28} = 1.6\ Ra + 500$. From the evidence presented on accelerated strength testing methods either in use or under investigation, it is concluded that there is a good possibility that the whole concept of 28-day strengths may be replaced sooner or later by an accelerated strength determination as the measure of the strength potential of concrete. The advantages that would then accrue demand that full evaluation of either existing procedures or research to develop a more satisfactory one become a matter of prime concern.

122. Stephens, J. E.
Reduction of Apparent Aggregate Variation Through Improved Sampling
Connecticut University, School of Engineering, Report JHR 66-1
84 pp. May 1966.

An improved method of sampling aggregates in bulk is established. It is simple, economically feasible, and more consistent than those used in the past. The materials engineer is given a reliable measure of the material used and is permitted accurate design of mixes. The improved reliability of the samples will reduce the frequency of erroneous work stoppages and thus benefit the supplier.

The method is statistically oriented, based on the principle that extreme values are less probable in large samples. In principle, a truck load of material is the sample. Whether drawn from bins or loaded from stock piles, it will more nearly represent the bulk of the material. The frequency of sampling can be reduced, as statistically the frequency is interrelated with standard deviation. A reduction in deviation will permit reduced sampling. It was necessary to determine the number of samples from a single truck required to give a high statistical confidence that the mean of the samples truly represents the truck load. Finally, in order to keep the volume of testing within bounds, the samples from one truck are combined into one sample which reduces the testing by mechanically averaging the individual samples.

123. Stephenson, H. F.
Testing for the B.S.I. Certification Mark Scheme on Group A. Street Lanterns Made to B.S. 1788.
Public Lighting (UK) 31 (135): 214-224. 1966.

This article describes the methods used to test street lanterns. At the present time the current B.S. 1788, and the code of practice C.P. 1004 give the basic specifications for the mechanical, electrical and thermal designs of street lanterns for group A. roads. The B.S.I. certification mark or kite-mark, is awarded after an inspection of the existing quality control in the works and an independent test on selected samples obtained on the open market. Photometric and environmental tests are carried out in the independent B.S.I. photometric and lighting equipment laboratory at Hemel Hempstead. Results have shown that most manufacturers succeed in meeting photometric requirements. In the rainproof tests, failures were due to mechanical design. This scheme is paid for by the manufacturer-there are some initial approval costs and annual charges. The amount spread over the total lantern production lead to a figure per lantern of one to two percent of its selling cost. (6 citations)

124. Stone, J. F., R. H. Shaw and D. Kirkham
Statistical Parameters and Reproducibility of the Neutron Method of Measuring Soil Moisture
Proc., Soil Science Soc. America 24 (6): 435-438. 1960. (HRA 32 (1): 8. 1962).

Laboratory and field experiments were carried out to measure the intrinsic reproducibility of a neutron device previously reported. The degree of accuracy of results can be increased by taking a large enough count to provide a sufficiently small random counting error. The coefficients of variation for reproducibility in the field were of about the same magnitude as for reproducibility in the

laboratory. Field experiments were also carried out in which neutron measurements were compared with gravimetric sampling at the same location. Owing to limitations of bulk density determination there was poor agreement within locations but the over-all average difference in moisture was less than 0.1 in. of water per 6-in. soil depth. In a set of plots where sampling locations were randomized, a comparison of the gravimetric and neutron methods of determining moisture showed that the use of seven gravimetric sites for each neutron site gave a comparable standard error of the mean.

125. Thomas, J. J., W. C. Dixon and W. H. Clark
Asphalt Concrete Mixing Time
New York Dept. Pub. Works, BU Phys. Res. Phys Res. Rept. RR 65-8, November 1965.

In 1963 the New York State Department of Public Works sponsored a research project at Cornell University to determine whether the total mixing time of 60 seconds, then required by the specifications for asphalt concrete, could be shortened without affecting the quality of the mixes. If mixing time could be reduced lower costs would result from the increased production. Based on the results of 1963 and 1964 studies, the department issued an addendum to the 1962 specifications allowing a reduction from the formerly specified minimum of 15 seconds of dry mixing (from start of adding aggregates) followed by 45 seconds of wet mixing (from start of adding asphalt). The addendem permits a reduction in total mixing time if specialized requirements are met: base course shall be dry mixed for at least the time necessary to charge all aggregates and wet mixed until 90 percent of coarse aggregates are fully coated or finish mixing time exceeds 10 seconds, whichever is longer. Top and binder course shall be dry mixed for at least the time necessary to charge all aggregates or 10 seconds, whichever is longer. It shall then be wet mixed until 95 percent of coarse aggregates are fully coated or finish mixing time exceeds 10 seconds, whichever is longer. In no case shall the cycle time be so short as to result in a rate of production exceeding the operating capacities of the plant.

126. Thornburn, Thomas H., and Wesley R. Larsen
A Statistical Study of Soil Sampling
Jour. of the Soil Mechanics and Foundations Division, ASCE 85 (SM5): 1-13. 1959. (HRA 30 (4): 7. 1960).

This is a study undertaken to determine the number of samples needed to obtain reasonable correlations between pedologic soil types and their engineering properties. Data from 4 DeWitt County soils give a quantitative indication of the value of pedologic information in planning, designing, and constructing highways and airports in Illinois.

127. Todor, P. C. and William Gartner, Jr.
Evaluation of Direct Transmission-Type Nuclear Density Gage for Measuring In-Place Densities of Soils
Highway Research Record 107: 13-25. 1966.

The direct transmission-type nuclear density gage has proved to be more accurate and faster than conventional methods. The use of the direct transmission principle seems to eliminate the necessity for several calibration curves. Density tests conducted by research personnel are usually made in areas where the contractor is having difficulty obtaining specified density. The nuclear equipment with its inherent speed has provided a means whereby the once time-consuming task of repeated density tests is considerably reduced. The equipment is also useful for setting up compaction equipment schedules and procedure. The amount of coverage required by a given type of compaction equipment to obtain specified density for an entire job can be determined quickly from one test section, provided extensive moisture or material changes are not encountered. (3 citations)

128. Trudeau, R. T.
Quality Control In Autoroute Construction
Canadian Good Roads Association Proc. P. 189-199., October 1964.

The quality control procedures employed by the Quebec Autoroute Authority in the construction of toll roads is described. The standards for materials and construction are indicated as well as allowable deviations. The application of quality control charts is illustrated. These procedures are applied to subgrade construction, rigid pavement construction, flexible pavement construction, concrete mixes, asphalt mixes, aggregate gradation. The Authority pays consultants a lump sum for quality control inspection which amounts to between 2 and 2.5 percent of the total value of the contract.

129. Turnbull, W. J.
Suggested Procedure For Incorporating Statistical Control of Compaction in Specifications.
U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 12 p. February, 1964.

A discussion of the part played by field exploration and sampling, laboratory testing, design, specifications and evaluation of finished product upon the incorporation of statistical control of compaction.

130. Turnbull, W. J., J. R. Compton, and R. G. Ahlvin
Quality Control of Compacted Earthwork
Am. Soc. Civil Engr. J. Soil Mech. Div. 92 (SM 1) 93-103. 1966.

Quality control of compacted earthwork is the complete process by which the satisfactory construction of an earth structure is gained. There is a growing awareness of the random variation of pertinent soil properties in earthwork construction, such as water content and density, and considerable interest is being shown in the statistical evaluation of these variables. Many earth structures have been constructed in a satisfactory manner without the use of statistical analyses, but because of uncontrolled random variation, there is an element of unrealism in past practice of setting absolute minimum and maximum limits or both, on measured soil properties. Although statistical methods can be a valuable tool in evaluating earthwork compaction quality, they do not provide a complete method for quality control. Typical variations of soil properties that have been experienced in successfully constructed earth fills are presented. These variations are greater than have been thought acceptable by many engineers for satisfactory behavior of structures.

131. Varma, Man M. and George W. Reid
Determination of Asphalt Contents in Asphaltic Pavement By Thermal Neutrons
HRA 33 (12): 103. December, 1963.

The purpose of this research was to determine the feasibility of measuring the asphalt content of bituminous paving by the neutron bombardment-counting technique. The correlation of neutron count and asphalt percentages depends primarily on the chemical content of the asphalt. Because the chemistry of asphalt is that of a variable mixture, it can be expected that data collected will fluctuate to some degree with changes in the asphalts tested.

132. Volin, M. E. and Bart Park
The Problems in Sampling Gravel Aggregate
Cement Lime and Gravel: 339-348. October, 1965.

A paper which was presented at the 49th Annual Convention of the U. S. National Sand and Gravel Association (25-28 January 1965). It examines problems inherent in the inspection sampling of gravel aggregate, theoretical considerations, sources of variation in gravel samples; suggests procedures for improving sampling reliability and answers questions concerning the customer's risk.

133. Wahls, H. E.
Current Specifications, Field Practices and Problems in Compaction For Highway Practices
North Carolina State University

A current status of highway specifications and field practices for compaction of embankments, subgrades and granular bases is summarized. The information has been obtained from the published standard specifications of the 50 states and from an extensive interview program with state highway engineers. Construction specifications and procedures for embankments, subgrades and granular bases are summarized and followed by discussions of the problems related to the practical application of the specifications to field construction. Quality control procedures and related problems also are discussed. The review indicates that the majority of embankment and subgrade compaction is accomplished by controlling lift thickness and moisture conditions and by specifying minimum density requirements, usually as a percent of the maximum density determined from the AASHO T-99 test. The major problems are encountered in silts, very wet clays of high plasticity and expansive clays. Construction practices to overcome these problems are noted. Control problems noted include the time required for conventional field density measurements and the difficulty in estimating the proper AASHO T-99 maximum density for heterogeneous field materials. The role of statistical quality control techniques is discussed. The relation of engineering judgment to statistical procedures is presented. A summary of the major compaction problems as determined from interviews with many highway engineers is also included.

134. Wahls, H. E., C. P. Fisher, and L. J. Langfelder
The Compaction of Soil and Rock Materials for Highway Purposes
North Carolina State University, CPR 11-0954, NCS-ERD-197-25, BPR 3723 993. August 1966.

The many factors related to the phenomenon of soil and soil-aggregate compaction in the presence of moisture and the behavior of the soil-moisture mass when subjected to stress are reviewed. The report provides a review of current knowledge of the equipment and processes that influence the compaction operation and the properties of the resultant mass both in the laboratory and in the field. No original research was done in this phase. The authors compiled and analyzed current state highway department compaction specifications and field practices, and reviewed compaction control procedures. Methods were offered to determine the variability and control of quality of compacted masses by statistical quality control disciplines. On the basis of knowledge of the state of the art of soil compaction, the authors offer recommendations for current practices and specifications as well as for future research.

135. Walker, R. D.
Identification of Aggregates Causing Poor Concrete Performance When Frozen (Interim Report)
Highway Research Board NCHRP Reports 12: 1-47. 1965.

Improved quality tests for aggregates were developed from analysis of 32 different concretes containing coarse aggregates ranging from crushed trap rock and limestone to a variety of gravels from glacial and non-glacial sources. Concrete specimens were fabricated and exposed to alternate cycles of freezing and thawing while in water to observe destructive volume changes of the coarse aggregates. The specimens were measured for length, weight, and dynamic modulus at the end of specified numbers of cycles. From the data obtained, an attempt was made to correlate durability as measured by dynamic modulus with certain characteristics of the temperature-length change curve. The slope of the length change-time curve of the deep-freeze specimens also correlated well with the durability factor. It was concluded that the Whittemore strain gage and a deep-freeze unit could be used as basic equipment for a quick preliminary evaluation of a coarse aggregate.

136. Walters, H. W. and T. H. Qureshi
Nuclear Asphalt Content Determination at the Job Site and Discussion
Highway Research Record, 117: 54-70. 1966.

Quick asphalt content determinations immediately after the asphalt surface course has been placed are necessary for quality control of the amount of asphalt cement in the hot mix. Modern hot plants capable of producing 200 tons or more per hour turn out significant quantities of asphalt concrete between the time a sample to be tested for asphalt content is obtained and the test results are reported.

Correlation with the reflux extraction tests and plant checks is reported in this paper, as well as the procedure involved when using the neutron probe. Asphalts used were 85/100 and 120/150 penetration grade from three different suppliers. Aggregates used came from six different sources. Projects on which this new method was tried ranged in location over a 200-mile area of southeastern Colorado.

Although this new method has not been adopted as standard procedure in Colorado, it is being used as a quick field check on asphalt content in CDH District Two with good results.

137. Warden, W. B., and L. D. Sandvig
Tolerance and Variations of Highway Materials From Specification Limits
Statistical Methods for Quality Control of Road and Paving Materials, ASTM Special Tech. Pub. No. 362: 31-43. 1963. (HRA 35 (2): 11. 1965).

The application of statistical quality control techniques has proved to be a valuable management tool in the control of highway materials. An enforceable specification must be realistic statistically, in the sense that the required tolerance limits reasonably reflect the random variation inherent in the material itself and the error of measurement (sampling and testing). In addition, each specification requirement should satisfy some useful engineering or control purpose. The comparison of the results of the analysis of actual test data with existing specification requirements can provide a measure of how well a specification is being met and can indicate the suitability and practicality of the required limits or tolerances. This paper discusses and illustrates methods of comparing specification limits with actual variation of the properties of selected materials and mixtures as shown by the results of field and laboratory tests. The data used were obtained from the results of tests made in various States on bituminous paving mixtures, on asphalt cement and aggregate for flexible pavement, and on subbase material.

138. Warden Engineers, Incorporated
Study in the General Field of Quality Control Engineering
HPS HPR-1(25), V-A, 14 Bureau of Public Roads (U. S.) 472 0003
March 1965.

This report describes current methods of control for various construction materials and applications of random sampling techniques for the use of these materials.

Research areas for additional development were defined from limited studies in many areas rather than exploring a few areas to their fullest extent and those studies included were:

A. Instruction of state road department personnel in methods and applications of statistical analysis
B. Asphalt penetration and viscosity control tests
C. Bituminous mix materials control tests
D. Evaluation of record test data
E. Random sampling techniques
F. Research problem testing areas recommended for additional study were:

(1) Asphalt extraction testing, (2) Marshall stability mixing temperatures, (3) comparative moisture determination methods, (4) moisture-density test repeatability, (5) Florida bearing value test, (6) nuclear density calibration curve development.

139. Warden Engineers, Inc.
Quality Control Engineering Procedures for State Road Department of Florida (A study in the general field of quality control engineering.)
Raleigh, North Carolina. Final Report, September 129 pp. 1965.

The objectives of the work performed under this Agreement were to study the current procedures of the Department for control of the quality of materials and their application in construction, to review and recommend applications of random sampling with respect to where and to what extent this technique should be applied, and intensive indoctrination of Department personnel in the methods and application of statistical analysis.

To accomplish these objectives most effectively, the work was directed towards the development of general plans applicable to various Florida materials and to the instruction of Department personnel in the application of these plans. To insure the broadest possible scope, limited studies were initiated in many areas rather than exploring a few areas to the fullest extent. The statistical methods used were selected with respect to their practicality and usefulness in such applications as determining more realistic specification limits, in better control of quality of materials and construction, and in locating areas where testing frequency could be reduced without jeopardizing quality. In order that these methods can be applied on a continuing basis, this report has been prepared in such detail as to be in effect, a manual for use in solving future problems.

In fulfilling the primary objectives of the work, accomplishments included discovery of an area where material costs could be reduced, areas where current control techniques were in need of improvement (and where the indicated direction or method of improvement was outlined), and areas where control would be maintained after eliminating ineffective sampling procedures. (9 citations)

140. Warren, P. F.
Ready Mixed Concrete (3) Some Practical Considerations
Structural Concrete (UK) 2 (7): 315-319. Jan.-March, 1965.

Advantages and disadvantages are examined, with special reference to space, time, handlings, quality control, delays, size of receiving project, labour, ordering, winter working and costs.

141. Warris, Birger
Sampling as Related to Statistical Treatment and Evaluation of Test Results
Swedish Cement and Concrete Research Institute at the Royal Institute of Technology. Reprint 14. 1961. (In Swedish) (HRA 32 (6): 2. 1962).

The purpose of this paper is to give a general outline of the application of statistics to concrete testing problems.

In Part 1, Introduction, and Part 2, the elementary principles of statistical calculations are summarized (mean, standard deviation, t-test, distribution function). In Part 3, these principles are applied to some present-day problems in concrete testing. Part 4, describes the methods of acceptance control, and the acceptance criteria for strength tests stated in the Scandinavian standard regulations are discussed on the basis of these methods. Part 5 deals mainly with the use of control charts for concrete properties. Part 6 deals with some aspects of sampling -- representativity, sample size and frequency of sampling. The principles are illustrated by practical examples.

142. Weber, W. G. and R. E. Smith
A Basic Study of the Nuclear Determination of Moisture and Density
California Division Highways HPR, F-4-1, 74 BPR (PB 172991) BPR 4722002. 1966.

A laboratory project was designed to study factors affecting the results obtained by using nuclear gauges to determine soil moisture and density. Both backscatter and transmission type nuclear soil density gauges were studied. The study consisted of conducting readings on laboratory compacted soil samples, using six different soil types. Tests indicate that the compacted soil samples had a soil density variation with a standard deviation of about two pounds per cubic foot. The density calibration curves obtained by nuclear methods indicate a standard deviation of 4 1/2 pounds per cubic foot for the backscatter, and 2 1/2 pounds per cubic foot for the transmission type gauges. By collimation of the source, the standard deviation of the backscatter type gauge calibration was reduced to 2 1/2 pounds per cubic foot. No effect of soil type upon the calibration curves was noted in this study. The effect of surface roughness was studied by use of regularly spaced grooves on the soil surface. The readings obtained with backscatter type gauges were very sensitive to surface roughness while the transmission type gauges were only slightly affected by surface roughness. The volume of the soil affecting the nuclear readings was determined to be about 0.05 cubic foot for both the backscatter

and transmission type gauges. The moisture readings were much less affected by the various items, such as surface roughness, than the density readings were. The standard deviation of the moisture readings was about one and one-half pounds of water per cubic foot.

143. Weber, W. G., Jr., and Travis W. Smith
Practical Application of the Area Concept to Compaction Control Using Nuclear Gages
HRA 36 (12): 108. December 1966.

The rate of placement of earthwork in highway construction has greatly expanded since World War II; however, the acceptance or rejection of this earthwork compaction has been based on prewar methods that are geared to lower production rates. The California Division of Highways has been developing a new test method for accepting or rejecting earthwork compaction. This method has three important facets: (a) a modified statistical approach, (b) the use of nuclear soil gages, and (c) an area concept.

The statistical approach consists of obtaining several in place densities of the compacted earthwork in an area to be tested. The acceptance or rejection is based on the average relative compaction and the percentage falling below the required relative compaction value. The test sites are somewhat randomly selected in an area ready for testing. The area is passed or failed according to the test results. The density of the compacted material is determined by use of nuclear soil moisture and density gages. This new test method was used experimentally on a project during 1964 and the results were satisfactory. After some modification of the test procedure it was used on several projects in the 1965 and 1966 construction seasons. This compaction control concept was successful from both the state and contractor's points of view.

144. Whiffin, A. C.
The Use of Physics in the Design and Construction of Roads
Institute Structural Engineers (UK) 17 (4): 105-115. 1966.

Some of the physical methods developed by the Road Research Laboratory for the purposes of research into the quality of the materials used in road construction and the supporting power of the soil beneath roads are described. The topics discussed are: soil moisture, soil compaction, soil density and moisture content measurement, density of concrete, resonance tests, ultrasonic tests and the rational design of roads. A brief mention is made of temperature measurement and weighing vehicles in motion. (21 citations)

145. Williamson, T. G. and M. W. Witczak
Factors Influencing the Application of Nuclear Techniques to Soil Compaction Control
HRA 36 (12): 108. December, 1966.

The use of nuclear backscatter moisture-density gages for soil compaction control has gained a great deal of favor during the past several years. However, before this type of equipment can be applied to routine field control, several factors influencing the operation of the gage must be investigated.

Various techniques for expressing nuclear results were studied, and the results indicate that the use of count ratio at constant high voltage should be adopted. This technique, along with the use of standard calibration blocks, provides for reproducibility of results and accounts for aging to some extent. These factors are especially important from the standpoint of recalibrating the gages.

Results of tests performed on various materials and calibration blocks of different chemical composition indicate that material composition has a major effect on the development of calibration curves for the density gages. This was not found to be true for the moisture gages. Soil pH as an indication of soil type was investigated, and calibration curves based on this parameter were developed. The effect of grain size distribution resulted in a different calibration curve for coarse-grained versus fine-grained soils.

Along with typical calibration curves, guidelines for field application were developed. A statistical decision theory based on a t-test was also developed to aid in making a decision involving the validity of using a given calibration curve.

146. Williamson, T. G. and E. J. Yoder
An Investigation of Compaction Variability for Selected Highway Projects in Indiana
Purdue & Ind. State Hwy. Comm. JHRP No. 5, 107 pp, BPR 4601 163. March 1967.

Compaction control of subbase and subgrade elements as used in rigid pavements were studied to gather data to determine what level of compaction was achieved using the present standards of inspection and enforcement and to develop a statistical quality control program from these data. To insure that a realistic

estimate of the true level of compaction and its associated variability was being obtained, approximately one hundred field density tests were performed on each of the six selected projects. Maximum density values for the field density tests were obtained to compute the percent compaction values. Results obtained indicated that the overall level of compaction was lower than specified. Also, the overall variability in compaction was relatively large indicating a condition of nonuniform compaction. The data showed that more uniform compaction was obtained on the subbase elements than on the subgrades showing an effect of material type. The factor of operator variance in performing the field tests was more pronounced for the subgrade elements. The compaction data were used to develop a typical statistical quality control program. The main problem was to insure that the tests are properly performed, that the location chosen is truly representative, and that the results obtained are enforced. (21 citations)

147. Winnitoy, W. E.
Development of Asphalt Specifications
Technical Report 2, 49 pp, Saskatchewan Dept. Hwys, Regina (Canada) May, 1966.

Factors affecting or influencing the development of penetration and liquid asphalt specifications are discussed. Three main factors are crude source or type method of refining, and performance of asphalt in a pavement. Evaluation of tests to identify desirable or undesirable characteristics of asphalts is discussed. In discussion of the more common tests, the statistical variability and desirable limits of the tests are discussed. In conclusion, some thoughts on the control of quality of asphalts are expressed.

148. Wischers, G.
Development of Ready-Mixed Concrete in Germany
Beton-Herstellung-Verwendung (Germany) 15 (7): 291-299. 1965.

The development of truck-mixed concrete in Germany started in 1953 with two factories, in Cologne and Stuttgart. At the end of 1964 more than 500 such factories produced about 13 million cubic metres of truck-mixed concrete for this purpose more than 10% of the West German cement production was used. The factories for truck-mixed concrete can be subdivided into three groups: large factories producing more than 40 cu.m. per hour, medium-sized works with 20 to 40 cu.m. per hour, and small works (stations) having a capacity of 10 to 15 cu.m. per hour. Large factories having in some cases more than 100 cu.m. per hour were constructed only at the commencement of this development in the large towns and concentrated areas: their total number may be about 100.

The stiffer concrete is expediently transported in dumper trucks but which, however, necessitates a stationary mixer. Truck-mixers are approved for concrete of all three consistency ranges: more than 80% of truck-mixed concrete is transported by these mixers. More than half of the truck-mixed concrete falls to the concrete grades B 225, but B 160 and B 300 are also delivered to a wide extent. More than 50% of such ready-mixed concrete is demanded in the consistency K 2 (plastic). With very few exceptions the subdivision into three consistency ranges is quite adequate in practice. Truck-mixed concrete must be controlled for quality in accordance with the provisional regulations introduced by the principal supervisory authorities. In addition to one's own supervision a control (surveillance) by expert, neutral agencies is laid down (an officially approved material testing institute or quality protection group). (13 citations)

149. Worona, V. and W. Gunderman
Field Evaluation of Nuclear d/M Gages Used in Compaction Control of Embankments
HRA 33 (12): 103. December, 1963.

This study was designed to evaluate nuclear moisture-density gages under actual field conditions. Many reports have been submitted on this technique but the data have been limited by either quantity of samples or by quality of personnel. Tests performed directly under supervision of professors or research engineers will yield more reliable data than those performed by average construction inspectors in the field. Because these gages would be used in the field by field inspectors, it was felt that they should be evaluated under these conditions.

A preliminary evaluation of one Nuclear-Chicago d/M system showed favorable results, hence in the following construction season a more extensive study was conducted with eleven additional nuclear gages. A complete d/M system was assigned to each of Pennsylvania's engineering districts and used on varied construction and soil types. These gages were used in the field for one full year and the results were compared to the sand cone method for determining soil density and the oven drying and speedy moisture method of determining moisture content.

Test results were submitted to the central laboratory, where the information was compiled and tabulated by computers, isolating variables that affect correlation of nuclear to sand cone results. These variables are soil type, soil gradation, construction type (embankment, soil-cement, subbase, etc.), and different d/M systems.

Standard deviations were computed for series of grouped tests to determine the repeatability of both methods of measuring moisture and densities of construction materials.

150. Worthington, Samuell Thomas, Jr.
Control of Soil Compaction by Density Measurements
Report to Graduate School, Southern Methodist University as part of M. Sc. requirements. pp. 1-41. 1963.

The degree of soil compaction is presently being determined by density measurements. There are several different density instruments available. The sand cone and balloon volumeter are being replaced with nuclear instruments. The nuclear instruments are more convenient since they can be placed directly on the surface of the compacted material and the readings taken almost instantaneously. The sand cone and balloon volumeter require the digging of a hole in the material so that the volume can be measured and a time consuming process of drying out the material taken from the hole.

All density and moisture instruments, whether nuclear or otherwise, should be calibrated for the particular material they are to test. On nuclear instruments, constant checks should be made on the accuracy of the instruments themselves.

There is an inherent variability in all highway base and sub-base materials. This variability plus possible differences arising out of compaction techniques and the density tests themselves produce an irregular pattern of density results. The variable density determinations do not necessarily indicate that the densities are substandard.

Inherent variability should be recognized and controlled by statistical sampling and analysis. The fact that many tests can be taken with the nuclear instruments in a relatively short period of time therefore indicates that nuclear instruments should be used with statistical sampling. In statistical analysis, a large number of samples produce a better estimate of the mean than does a small number. Accurately calibrated nuclear instruments can easily furnish density determinations in large quantities. (4 citations)

151. Zascuk, I. V. and E. F. Nefedova
Quality Control of Asphaltic Concrete by Acoustic Methods
Avtomobil Nye. Dorogi (USSR) No. 3: 8-10. 1966.

The authors describe the application, studied at the Dornii, of acoustic methods (measurement of speed of ultrasonic waves) for the quality control of asphaltic concrete, at the point when this is used on the road or aerodrome-control not possible using

traditional processes. A correlation has been found experimentally between degree of compaction, speed of sound in the material and its temperature (proportionality between temperature on the one hand and the hyperbolic tangent of a multiple of the 4th power of the speed of propagation on the other, very little information being given on how to obtain the constant coefficients). This correlation enables indirect and immediate measurements of compaction to be made with a precision of 1%. Transformation of experimental data is made easier by a compact battery operated transistorised computer, which can be placed in the compacting workshop and which can form a link in the automation of the operation. This has shown in particular a maximum energy of compaction for asphaltic concretes (except for the finest). Beyond this point, there is fragmentation of the grains of the mineral structure which decreases the ultrasonic propagation speed and this in turn modifies the structural mechanical properties. (10 citations)

152. A Guide to the Structural Design of Flexible and Rigid Pavements in Canada
Canadian Good Roads Association 65 pp.

This document suggests methods for the structural design of conventional flexible and rigid pavements for roads with rural cross-sections which will, within 10 years after construction, have annual average daily traffic volumes per lane of 1,000 or more vehicles including 10 percent or more trucks and buses. The design procedures are based upon the results of a 7-year program of research on the performance of thousands of sections of pavement of various designs on the primary highways in all provinces of Canada, supplemented with data from other sources such as the AASHO road test. The flexible pavement design procedure is based on limiting values of pavement surface Benkelman Beam rebound. The rigid pavement design recommendations are based upon designs which are currently being used with success in Canada. The guide contains standard procedures for measuring Benkelman Beam rebound, for estimating the strength of a section of flexible pavement and for determining the present performance rating. Examples of design and construction control are given. In the guide, equal attention is given to construction control. Evidence indicates that the uniformity of construction is the primary variable controlling pavement performance. (10 citations)

153. ASTM Manual on Quality Control of Materials
ASTM Committee E-11, American Society for Testing Materials, Special Technical Publication 15-C, 133 p. January, 1951.

Bearing in mind that no rules can be laid down to which no exceptions can be found, the committee believes that if the recommendations below are followed, the presentations will contain the essential information for a majority of the uses made of A.S.T.M. data.

Recommendations for Presentation of Data.-Given a set of n observations of a single variable obtained under the same essential conditions:

1. Present as a minimum, the average, the standard deviation, and the number of observations. Always state the number of observations.
2. If the number of observations is large and if it is desired to give information regarding the shape of the distribution, present also the value of the skewness k, or present a grouped frequency distribution.
3. If the data were not obtained under controlled conditions and it is desired to give information regarding the extreme observed effects of assignable causes, present the values of the maximum and minimum observations in addition to the average, the standard deviation, and the number of observations.
4. Present as much evidence as possible that the data were obtained under controlled conditions.
5. Present relevant information on precisely (a) the field within which the measurements are supposed to hold and (b) the conditions under which they were made.

(9 citations)

154. Bituminous Concrete Surface Course Aggregates
Wisconsin State Highway Commission HPR-1 (2), No. R-843, No. 9
Bureau of Public Roads (US) 4721112 66 December 1965.

Analyses were made of the aggregate gradation and asphalt content variability in hot bituminous concrete surface mixtures consistent with those guide principles set forth by the BPR task force on quality control. A summary of statistical data was included for the arithmetic mean material, sampling and testing variance, overall variance and overall standard deviation (Sigma) of each sieve size and asphalt content used (on each project) in each mixture.

155. Guide for Sampling Inspection
Quality and Assurance Handbook, H53, 56 p., June 30, 1965. Office of the Assistant Secretary of Defense, Department of Defense, Washington, D. C. 20301.

This is a guide for sampling inspection. It discusses some of the basic principles of sampling inspection. The purpose of this handbook is threefold:

a. to describe basic sampling procedures.
b. to explain the basic principles underlying sampling inspection, and
c. to demonstrate how the sampling plans established by applicable military standards, handbooks and related documents are used in arriving at appropriate inspection and quality assurance decisions.

This handbook may be useful to quality managers, engineers, specification writers, inspectors, and others who are concerned with sampling inspection problems. It discusses some of the basic principles of sampling inspection and provides the framework necessary for proper application to sampling inspection. Amplification of MIL-STD-105 is provided in Section 2 of the handbook. Also a bibliography is furnished as Appendix A.

This handbook has been specifically prepared for use by inspection personnel responsible for inspection decisions of an operational nature. It may be used as a guide in establishing procedures for determining conformance of operations, data inventory control, etc., to prescribed quality standards. (9 citations)

156. Introduction to Statistical Methods for Quality Control of Concrete Cement & Concrete Association Adv. Notes No. 8, 9 pp. May, 1965.

This note gives statistical methods of use in assessing the results of various control tests used in the concrete industry. Particular reference is made to cube test results.

157. Materials and Construction (The ASSHO Road Test. Report 2) Highway Research Board Special Report 61B. National Academy of Sciences -- National Research Council, Publication 951. Washington, D. C., 1962.

This report, while giving an outline of the overall project, concentrates upon the more statistical aspects of the data collected. Summaries are given in terms of means, bar graphs, and cumulative frequency curves, to name a few. It is indicated that the original mass of data collected is available if the reader wishes to pursue a particular problem in depth.

The several chapters have as their subject matter the following major topics: (1) Embankment specifications -- procedures, summaries of data on material and construction control and the characteristics as constructed. (2) Subbase for flexible and

rigid pavements -- the sand-gravel mulch used is characterized as a material with control and test data summarized. (3) Base course -- consisted primarily of crushed stone, although several other base materials were investigated; gradation, moisture, compaction, density, thickness were the principal characteristics studied, the special base material considered was a prepared gravel-sand mix alone, and stabilized with asphalt and with cement. (4) Surfacing with flexible pavement used a limestone coarse aggregate, a coarse sand, a fine sand and a limestone dust filler, these were mixed with asphalt to required specifications; records on asphalt extracted, compactive effort, compaction achieved, thickness of surfacing also form a part of the construction record. (5) Surfacing with rigid pavement -- was with reinforced and non-reinforced portland cement concrete; the material and construction specifications are summarized as well as information pertaining to construction control. Slump, air content, flexural and compressive strengths, 14-day cylinder strengths and pavement thicknesses were collected on the concrete surfacings. (6) a variety of bridge structures were constructed and many construction measurements assembled. (7) Methodological descriptions are included such as sampling for compaction control, measuring maximum by density, a cooperative materials testing program, BPR tests, and stress and static yields on structural steels.

158. Procedures for Using Statistical Methods for Process Control and Acceptance of Bituminous Mixtures
South Carolina State Highway Department HPR-1 (2), 518 Bureau of Public Roads 4721293 66, February 1966.

This study on ways and means of application of statistical methods for process control and acceptance of hot-mix bituminous mixtures was prompted by the fact that the South Carolina State Highway Department had put strong emphasis on strict compliance with specification control while realizing that variations are inherent in materials, construction procedures, sampling and testing. Phase I developed statistical quality control procedures for process control and acceptability from actual projects employing hot-mix asphaltic paving materials. Phase II investigated the completed components to verify the procedures. Phase III prepared a tentative system of process control and acceptance of mixtures and testing of four projects at different locations. Phase IV used the data and experience gained in the preceding parts of this study to develop a system for process control and acceptance of asphaltic mixtures and a procedure for adjusting the unit price for unacceptable lots of material. Model specifications, employing statistical concepts, were presented.

159. Quality Assurance Through Process Control and Acceptance Sampling
Bureau of Public Roads (US) 79 pp. April 1967.

Quality assurance for highways include proper ordering of the things necessary to perform the services and assurance that what was ordered will be received. The specific characteristics that must be controlled and their quantitative level or uniformity of dimensions or performance are investigated. Because of the volume, speed, legal and financial requirements of highway construction, improved quality assurance methods are needed. Statistical definitions and concepts needed for application in specification writing are given.

160. Quality Control
Idaho Department of Highways, Research Project No. 11, 34 pp, May 1967. (HRA 37 (10): 16. October 1967).

The purpose of this quality control study was to make a realistic appraisal, using statistical methods, of acceptance specifications for crushed mineral aggregate. Samples from two sources were tested for their sampling variance, testing variance, and material variance. A direct relationship was found between the sampling variance and sampling method. Samples obtained by means of an automatic sampling device produced lower sampling variances than samples obtained manually. Sampling variances also showed more uniformity when an automatic sampling device was used. The splitting method used and the testing variance also showed a direct relationship. Samples which were cross-split (split twice and opposite quarters combined) showed a lower testing variance than samples which were split only once.

161. Quality Control Analysis, Part 2, Soil and Aggregate Base Course
Louisiana Department Highways, HPR-1 (3), 63-1G, Bureau of Public Roads (US). 4721183 66

An attempt has been made to determine the extent of variability of soil and aggregate base course characteristics using data collected from completed project files. On the basis of this variability, numerical limits have been established using statistical quality control technique. The historical data tend to follow the normal distribution. Unstabilized aggregate base course has less variability than stabilized base courses and the Sigmas are considerably different for different contractors.

162. Quality Control Analysis, Part 3, Concrete and Concrete Aggregates
Louisiana Department Highways, Research & Development Section, HPR 1 (4), 63-1G Bureau of Public Roads (US) 4721183 66 September 1966.

This is the third and last report on the quality control analysis of highway construction materials. It deals with the statistical evaluation of data from several construction projects to determine variability of slump and of aggregates. The analysis indicated (1) that the frequency distribution of most of the data tend to follow the normal distribution, (2) that there is considerable variation in concrete production from batch to batch, (3) that for fine aggregate, the stockpile component of variance contributes more to the overall variance than samples within stockpile component, and (4) that in the case of coarse aggregates the sample within stockpile components show larger variance than between stockpile components. The study revealed how control charts can be used for control and acceptance of P.C. concrete. The report includes an analysis of thickness of pavement and analysis of bituminous hot mix density and discharge temperature.

163. Quality Control Techniques
Highway Conference on Research and Development of Quality Control and Acceptance Specifications. Volume 1, 504 pages. April 5-7, 1965. Bureau of Public Roads, U. S. Department of Commerce

This volume contains some 43 presentations made to the conference, not all are directly addressed to the title but it does represent the opinions and thoughts of people intimately connected with highway construction, both from the standpoint of the contractor and of the state highway officials who have to take final action regarding the final product produced. This is a good place to start for an overall view of the magnitude of the quality control problem in highway construction. JGD

164. Quality Controlled Concrete
Civil Engineering and Public Works Review 53 (626): 907-908. 1958. (HRA 28 (10): 5-6. 1958).

One of the main difficulties in the production of concrete is the large number of variables, which may give rise to large differences in the strength and other characteristics of the end product from day to day or even from batch to batch. The aim of Quality Control is to reduce the variations as far as possible, and not necessarily, as many people assume, to produce concrete of specially high strength.

As the other important characteristics of concrete (permeability, resistance to weathering) vary, by and large, directly with the crushing strength, it is the normal practice to judge concrete by its 28-day crushing strength. The immediate target of control

is to produce a material the strength of which will vary from the average by only a reasonable percentage---say 25 to 30 percent up or down. It is not uncommon for uncontrolled concrete to vary by more than 50 percent up or down.

The two principal innovations which are usually considered as a part of quality control are weight batching and vibration. Quality can actually be controlled without using either technique but control is simplified and cheapened by both. The main advantages of quality control are (1) more uniformity in strength, better appearance and improvements in other desirable qualities; (2) less poor work which has to be made good; (3) either savings of cement, or better workability, or both; and (4) possible additional cement savings due to more accurate batching, as many contractors suspect that even with nominal mixes such as 1:2:4 by volume, much extra cement is used in error.

First it must be assumed that the design of the structure requires that the strength of the concrete should not fall below a certain value at 28 days, usually 3,000 psi for normal reinforced concrete. It should be noted, however, that an absolute minimum strength cannot be guaranteed as there is always a chance of a low result occasionally, and if the average is not to be unnecessarily high, up to one test in about 20 to 25 must be allowed for below the minimum asked for.

The main factor influencing the strength is the ratio of water to cement usually measured by weight, and referred to as the water-cement ratio. Poor control on the site would lead to large variations in the water-cement ratio, with consequent variations in the strength of the concrete about its average value. The larger the variations, the higher the average has to be raised to keep the lower variations above the minimum required. That is to say, poor control necessitates a high average strength and therefore, a low average water-cement ratio, and this in turn means either a drier mix or a mix richer in cement.

Conversely, good control allows a lower average strength and a high average water cement ratio, the effect on the mix being either to improve the workability or enable a leaner mix to be used

Thus the idea that quality control necessarily means a very dry concrete is wrong; in fact it could lead to costs being reduced through a more workable concrete. Generally, quality control should enable a workable mix to be adopted with a saving of cement as well.

When to Use Quality Control

1. In all cases where a water-retaining structure is required, or where the structure will be exposed to weathering.
2. Where the minimum strength required is 4,000 psi or greater, quality control could be expected to be financially advantageous provided the quantity of concrete required a 10/7 or larger mixer.
3. Where the minimum strength required is 3,000 psi it is more difficult to decide for reasons mentioned, and because the size of the job, rate of output, and type of work all vary from job to job and are so interwoven that it is impracticable to generalize. However, it is doubtful if quality control could be justified on short term economic grounds alone for jobs of less than 2,000 cu yd of concrete with weekly outputs of less than 150 cu yd. Many jobs, of course, have basements which would justify quality control, whereas the superstructure would not, and in such cases, it might pay to continue the measures adopted in the basement.
4. On any job of any size the contractor should consider the advantages to be gained from improving the batching and mix design. Much cement is lost through poor batching and much cutting out and making good due to faulty mix proportions. Output is also lost through batches deficient in all materials.

165. Road Research Needs in Canada: 1965.
Canadian Good Roads Assoc. Tech. Bull. No. 27, 10 pp. May 1965.

This document defines the principal road research needs and their relative priorities in Canada in 1965. Of the 44 problems included in the list of road research needs, the highest priority was given to the following: (1) deterioration of bridge decks and superstructures by deicing chemicals, (2) statistical quality control procedures for construction, (3) causes, effects and control of transverse and longitudinal cracks in bituminous pavements, (4) determination of the significant properties of bitumens and the development of tests for their measurement, (5) structural design of flexible pavements for low traffic volume roads, (6) determination of the necessary and reasonable assumptions for planning transportation systems, (7) relationship of geometric design features of roads to accident rates, and (8) passing sight distance requirements. The needs were defined to encourage road research organizations throughout Canada to undertake intensive investigations of these problems.

166. Some Suggestions for Preventing Concrete Surface Blemishes
Concrete Construction 12 (3): 82-84. 1967.

While concrete mix design and quality control remain important blemish-preventing factors, the appearance of a concrete surface may be improved by careful attention to formwork detail. Probable causes of surface blemishes are reviewed and recommendations made for the prevention of surface blemishes.

167. Statistical Parameters Research Project-Quality Control Study on Asphalt Pavement Research Project
Colorado Department Highways, Planning and Research Division, HPR, BPR-1407, State-4 Bureau of Public Roads (US) 4772004 67. July 1967.

This report summarizes the statistical parameters calculated from the results of laboratory tests upon 200 samples obtained over a 12,600 foot section (4,297 tons) of the intermediate course of a typical 3 course asphalt pavement. The samples consisted of two original pairs of 6 inch cores and two duplicate pairs, taken at 50 randomly selected sites. Tests were run in the central laboratory for thickness, conventional density, asphalt content, graduation, nuclear density and air void content. A statistical analysis of variance was run upon the test data to obtain the testing, sampling, material and total variance components. Standard deviation, mean, median, mode, and range were also calculated. Sieve analyses on extracted aggregates were run in accordance with the AASHO T-30 test method. Analysis of variance was run on extracted aggregated data to study the relation between the percent passing the No. 4 sieve and the corresponding asphalt content of sample cores taken from the 50 test sites. It was estimated that a 1% variation in the minus 4 aggregate will result in a corresponding 0.1% variation in asphalt content. Standard deviations calculated for all sizes of aggregates from minus 4 to minus 200 showed that the state tolerances for these sized are very close to the theoretical values.

168. Statistical Quality Control
Nebraska Department Roads, Materials & Tests Div, Project F-56(20) 64-4 Bureau of Public Roads (US) 4721263 66.

This project was Type 1, Special, an asphaltic concrete surfacing 3 inches thick and 24 feet wide with a total length of 12 miles. A continuous batch plant was employed using crushed sand-gravel and crushed limestone rock with the asphalt at a design value of 4.9%. Random samples were obtained to determine temperature, thickness and density in the field, and to determine values of stability, graduation, voids and asphalt content in the laboratory. Field and laboratory data sheets are presented. Statistical

parameters include standard deviation, variance due to material sampling and testing, and the overall coefficient of variation. These parameters disclose any weakness of uniformity of material, sampling or testing for the project. The data will supplement the Public Roads reservoir of similar data for use in future specifications and construction control. The state offers no conclusions or recommendations at this time on this type of construction.

169. Statistical Quality Control F-145 (21)
Nebraska Department Roads 64-4, Bureau of Public Roads (US) 4721263 67, April 1967.

This was conducted Type 1 Special (A) asphaltic concrete surface course 3 inches thick and 24 ft. wide for a distance of 7.4 miles. A continuous batch plant was employed to prepare the crushed limestone - sand - asphalt mixture. The mixture was placed with a Barber-Greene paver with an automatic leveler. This is the 3rd project of this type of construction and the data of all three will be correlated for averages, sigmas and variances of gradation, asphalt content, density, thickness and stability from randomly selected samples and measurements. The statistical parameters disclose non-uniformity of material sampling or testing procedures, thus designating areas needing corrective measures to produce uniformity of final pavement material. No conclusions or recommendations are offered at this time, perhaps the final report on the whole study will offer recommendations.

170. Statistical Quality Control in Highway Construction
Engineering News Record 178 (2): 28-32. 1967.

Statistical quality control (SQC) is a probability-based method of developing and enforcing specifications. Specifications based on SQC consider the normal variations of test results, the inherent deviations of the material or processes and the random errors of sampling and testing. Highway specifications fall into three categories: 100% compliance within certain limits, acceptance based on engineering judgment, and substantial compliance within definite limits. The burden of judgment still rests on the engineer. The Bureau of Public Roads formed a task force to study the feasibility of applying SQC techniques to highway construction and to devise research plans. Several states are investigating test procedures and variations in construction material and methods. All states agree that SQC would increase substantially the cost of some tests if present procedures are used. Compaction control specifications by nuclear measurements are used in several states

with good results. Step-by-step testing procedures using statistical concepts were developed to write specifications. A drawing of statistically based acceptance specifications is presented.

171. Statistical Quality Control of Bituminous Plant Mix Surface Construction Montana State Highway Commission 4722002, 7913 PA7. Bureau of Public Roads (US) 4720003 65.

The project was performed to: (1) determine the optimum position in the production process from which to procure samples for accepted testing of the material, and (2) to obtain information with which to revise specifications concerning acceptance testing of bituminous pavements.

The report contains statistical information concerning samples of a Type 3 plant mix obtained randomly from three (3) positions in the process: (1) the truck bed (2) the screw of the paver and (3) the finished mat.

Statistical information concerning random samples taken from the truck bed at two other projects are also reported.

Recommended specifications for the statistical quality control of the material are presented.

172. Statistical Quality Control Report on Data Obtained by Random Sampling Type 1 Special Asphaltic Concrete Surface Course Nebraska Department Roads 64-4, Bureau of Public Roads (US) 4721333 66. March 1966.

Asphaltic concrete 3 in. thick, 24 ft.wide, 6.8 miles long was laid in a surface course, north of Union Corner, Nebraska. Material was prepared in a continuous batch plant using crushed limestone with crushed sand, asphaltic content 5.1 percent (design). Random sampling was performed to obtain data on temperature, thickness and density in the field. Laboratory tests on stability, gradation, asphalt content and voids were performed. Data sheet copies as well as the compilation of the statistical parameters for material characteristics are included. The statistical parameters include standard deviation, variance due to material, sampling and testing, and overall coefficient of variation. They will disclose any weakness of uniformity of materials, sampling or testing procedures.

173. Stone and Ready Mix Supplied the Modern Way Constructioneer pp. 34-38, June 27, 1966.

The Buffalo Crushed Stone Co. operations in supplying stone and ready-mix are reviewed. Automation and recordation techniques plus testing facilities insure complete quality control. Constant checks are made on each product line and everything, except the cement and asphalt, which are furnished from outside sources, is tested. An IBM computer which handles production scheduling, billing and other detail work also helps operations.

174. The Statistical Approach to Quality Control in Highway Construction
Bureau of Public Roads (US) 43 pp. April 1965.

Quanitative values of statistical parameters for highway materials and processes are needed to apply statistical concepts to quality control in highway construction. Background information is given concerning the development of an overall plan for application of the statistical approach. The relatively large amount of sampling and testing required to establish the significant parameters involved will not be required when specifications are based on statistical concepts. The methods of application of statistical principles to specific control problems in highway construction have not, as yet, been selected.

175. Winnipeg Tests Rust Inhibitor
Engineering and Contract Record (Canada) 79 (4): 41 pp. 1966.

Metropolitan Winnipeg is testing a new rust inhibitor to give protection against salt damage to cars during the winter. A chemical is sprayed on the salt during mining operations. As the salt melts ice, the slush splashes onto cars and the steel surface reacts with the chemical to form a protective oxide coating. The treatment increases the cost of salt by four dollars per ton, but is reputed to give 85% protection. Manitoba is also testing an infrared spectrophotometer to check on quality and pavement performance of the province's highways.

APPENDIX 2

LISTING OF CURRENT RESEARCH PROJECTS RELATIVE TO STATISTICAL QUALITY CONTROL IN HIGHWAY CONSTRUCTION

1. Title: Quality Control of Construction by Statistical Tolerances.
Agency: Bureau of Research and Development, Alabama State Highway Department. (930-024, BPR 4721103)
Personnel: J. H. David
Period: 1964-1967
Objective:

To supplement regular sampling and testing procedures with a concurrent statistically designed sampling and testing operation. To determine the variations in present construction.

2. Title: Study of Statistical Methods of Quality Control
Agency: Materials and Research Department, California Division of Highways (14033, BPR 4721123)
Personnel: R. O. Watkins
Period: 1964-1966
Objective:

To statistically measure the results of present construction practices and specifications, and to consider the use of statistical methods of control in highway construction. The items studied include embankment compaction, base, subbase and concrete aggregate, plastic concrete, portland cement, galvanizing and paving asphalt.

The study of the last four items involves a review of the data on file. The other items are being analyzed using the construction sites for each item.

Reports: (1) Watkins, R. O. and B. Page. A Statistical Analysis of Penetration Test Results (85-100 Grade Paving Asphalt).

(2) Jorgensen, J. F. and R. O. Watkins. Compaction -- Myth or Fact.

(3) Sherman, G. B., R. O. Watkins, and R. H. Prysock A Statistical Analysis of Embankment Compaction.

3. Title: Quality Assurance Research
Agency: California Division of Highways (F-1-3, BPR 4641413)
Period: 1967-1969
Objective:

The use of forceful specifications based on the scientific estimates of quality requirements and performance capabilities of materials and structures is being developed and implemented. Methods of estimating performance based on statistical principles are being improved.

4. Title: Applications of Statistical Quality Control Methods
Agency: Materials and Research Department, California Division of Highways (19-631146, HPR-1(4))
Personnel: G. B. Sherman and R. O. Watkins
Period: 1966 plus

Objective:

Of this study will be to find a method of using statistical quality control methods to advantage in highway construction. The project will be conducted in three phases: (1) Method of controlling manufactured items such as cement and asphalts will be investigated, (2) The value and accuracy of the record sampling program will be studied, and (3) The use of statistical methods in contract control will be evaluated.

5. Title: Investigation of Plastics for Use in Waterstops
Agency: Materials and Research Department, California Division of Highways (19-636404, HPR-1(4))
Personnel: J. R. Nordlin and J. R. Stoker
Period: 1966 plus
Objective:

A number of failures have occurred in elastomeric compounds used for waterstop in bridge structures. Natural rubber, synthetic rubbers, and polyvinyl chloride materials have all exhibited problems. The objective of this study is to determine the proper configuration of the waterstop and the proper material to be used for the application, and to develop test methods and specifications to control the quality of the product.

6. Title: Quality Control
Agency: District of Columbia Department of Highways and Traffic (BPR 4721133)
Personnel: N. G. Smith
Period: 1964-1967
Objective:

To establish quality control procedures and limits for those construction materials manufactured by the contractor and used in construction.

7. Title: Quality Control
Agency: Miller-Warden Associates, Raleigh, N. C. (for Florida State Road Department) (M-5-66, BPR 4601453)
Period: 1966-1968.
Objective:

The application of statistical quality control procedures is being developed in the preparation of specifications for materials and construction procedures.

8. Title: Statistical Approach to Quality Control
Agency: Idaho Department of Highways
Personnel: H. L. Day
Period: 1964-1966

Objectives:

Part I - Investigation of variations in aggregate gradations of two sizes of base materials and of sand equivalent values of these materials. Two different sources of material are used.

Part II - Investigation of variations in test values at refinery and a set of 3 duplicates taken at 1/2 points of truck tanker at point of delivery.

9. Title: Behavior of Welded Highway Structures
Agency: Civil Engineering Department, University of Illinois. Urbana, Illinois (IHR-64, BPR 4613412)
Personnel: W. H. Munse
Period: 1960-1967.
Objective:

Welding and welded highway structures are being studied in order that more economical highway structures may be constructed, and to make it possible to use welding more efficiently. Studies have been conducted in the following areas: (a) Fatigue Behavior of Welded Reinforcing Bars, (b) Inspection Methods and Quality Control for Welded Highway Structures, (c) Evaluation of Low-Alloy Steel for Highway Bridges, and (d) Effect of Geometry on Fatigue Behavior of Welded Joints.
Reports: (1) Sanders, W. W., Jr., R. J. Hoadley and W. H. Munse Fatigue Behavior of Welded Joints in Reinforcing Bars for Concrete. Welding Journal, December, 1961.

(2) Sanders, W. W., Jr., A. T. Deracho and W. H. Munse. Effect of External Geometry on Fatigue Behavior of Welded Joints. Welding Journal 44 (2). February, 1965.

(3) Walls, J. C., W. W. Sanders, Jr., and W. H. Munse. Fatigue Behavior of Butt-Welded Reinforcing Bars in Reinforced Concrete Beams. Journal of American Concrete Institute Proc. 62(2). February, 1965.

(4) Study of Inspection Methods and Quality Control for Welded Highway Structures. Highway Research Board Record No. 110, 1966.

10. Title: Improved Quality Control in Highway Construction
Agency: Bureau of Materials, Illinois Division of Highways (IHR-83)
Period: 1964-1967
Objective:

To develop a practical system for the improved control of quality in highway construction by measuring the variations using statistical methods.

11. Title: Quality Control Applied to Highway Construction
Agency: Purdue University (BPR 4601163)
Period: 1962-1967.
Objective:

The quality levels of various materials and facets of highway construction are being ascertained.

12. Title: Development of a Laboratory Durability Test for Asphalt
Agency: Engineering Experiment Station, Iowa State University (HR-124)
Personnel: L. H. Csanyi
Period: 1966-1967
Objective:

A relatively rapid laboratory test is being developed which will enable the design engineer to select an asphalt according to quality and to make a correct estimate of the service life of a selected asphalt when used in a specific paving mixture.

13. Title: Quality Control Concepts and Their Application to Highway Specifications and Construction
Agency: Kentucky Department of Highways (KYHPR-65-36, BPR 4721173)
Personnel: J. H. Havens and R. C. Deen
Period: 1966 plus
Objectives:

(1) To compile pertinent test data from acceptance records,
(2) To analysis the statistical validity of tolerances and limits currently specified.

14. Title: Quality Control Analysis
Agency: Louisiana Department of Highways (63-2G, BPR 4721183)
Personnel: S. C. Shah
Period: 1963-1968.
Objective:

To revise currently used highway materials specifications on the basis of statistical findings using data collected from project files (historical).
Reports: (1) Shah, S. C. Quality Control Analysis, Part I - Asphaltic Concrete. Louisiana Department of Highways, November, 1964. (2) Shah, S. C., Quality Control Analysis, Part II - Soil and Aggregate Base Course. Louisiana Department of Highways, July, 1966.
(3) Shah, S. C. Quality Control Analysis, Part III - Concrete and Concrete Aggregates. Louisiana Department of Highways, November, 1966.

15. Title: Mixture Results Analysis by Process Control
Agency: Maine State Highway Commission (471, BPR 4601072)
Period: 1967-1968
Objective:

The feasibility of adopting a method using statistical control charts as a means of determining control and accpetance for bituminous mixtures is being determined.

16. Title: Specification Writing, Construction Control, Material Control and Quality Control by Statistical Methods.
Agency: Maryland State Highway Commission (AW65-74-46, BPR 4721 203)
Personnel: Parrish
Period: 1964-1966
Objective:

To conduct investigations exploring the feasibility of the use of statistical methods in the control of materials and their application to highway construction. Present specifications and acceptance criteria will be studied and compared with appropriate statistical plans.

17. Title: Bituminous Pavement Research
Agency: Massachusetts Institute of Technology (1(21)R2-23)
Period: 1962-1965
Objective:

To determine service suitability of various materials and combinations thereof in flexible layered pavements and to analyze stresses and strains in layered pavements under static and dynamic loads. Practical methods of quality control are being developed which will ensure safer, longer lasting and smoother riding pavements, together with economy of construction, reconstruction and maintenance. The effect of viscosity of asphalt on the properties of compacted bituminous mixtures is being investigated.
Reports: (1) Hagstrom, J. and R. E. Chambers. The Influence of Support Conditions on the Behavior of Elastic Plates. R65-10, May, 1965. (2) Tons, E., R. E. Chambers and M. A. Kamin, Layered pavement design method for Massachusetts. C. E. Dept. Report R64-27, MIT, January, 1965.

(3) Bikerman, J. J. and J. P. Chen, Effect of Water on Asphalt-rock Adhesive Joints. C. E. Dept. Report R65-08, MIT, March, 1965.

(4) McGarry, F. J., Engineering Properties of Materials for Layered Bituminous Pavements Systems, Materials Research Laboratory, 1965 (?).

18. Title: Bituminous Pavement
Agency: Massachusetts Institute of Technology (BPR 4811 221)
Period: 1963-1966
Objective:

Service suitability of materials for flexible layered systems is being determined. An analysis of stresses and strains under static and dynamic loads is being made and practical methods for quality control are being developed.

19. Title: Highway Quality Control Program
Agency: Research Laboratory Division, Michigan Department of State Highways. (63 G-123, BPR 4721 213)
Personnel: F. Copple, D. C. Church, C. A. Zapata
Period: 1963-1966
Objective:

To delineate specific areas in the field of highway materials and construction where quality control is practical and advantageous, and to develop suitable quality control programs in these areas and write quality control methods into existing materials and construction specifications.

Reports: (1) McLaughlin, W. W., Michigan's Quality Control Program. Paper presented at 4th Annual Highway Conference, Michigan College of Mining and Technology, October, 1963.

(2) McLaughlin, W. W., Highway Quality Control Program Michigan. Paper presented at ASCE Construction Division and St. Louis Section Conference on Quality in Engineered Construction, St. Louis, Missouri, June 16-18, 1965.

20. Title: Development of Nuclear Methods for Quality Control of Highway Embankment Construction
Agency: Michigan Department of State Highways (61-E22, BPR 4722 003)
Personnel: R. C. Mainfort, R. L. Felter
Period: 1964-1966
Objective:

To determine the type and size of radioactive source most suited for measuring soil properties to determine the most suitable geometry for instrument components, and to develop a statistical method for handling data to obtain quality control of highway construction. The study will include nuclear device modification to permit better adaptation of the nuclear method to highway engineering.

21. Title: Development of Procedures for Process Inspection of Heavy Media Benefication Plants for Coarse Aggregate
Agency: Michigan Technological University, Michigan Department of State Highways. (R-153, 65-827)
Personnel: M. E. Volin and E. L. Michaels
Period: 1965-1967
Objective:

Aggregate benefication process control is being developed and demonstrated to assure a high quality product and to replace sampling inspection with occasional process inspection. HMS plants were observed and laboratory tests were made to determine operational variables and methods of measuring and controlling these variables. A continuous pilot plant test (with process variables measured and controlled) will demonstrate those controls equivalent to process inspection and quality control.

Reports: Michaels, E. L., and M. E. Volin. Development of Procedures for Process Inspection of Heavy Media Benefication Plants for Coarse Aggregate. Michigan Technological University, August, 1966.

22. Title: Study of Practical Measurements of Aggregate Quality
Agency: Institute of Mineral Research (for Michigan Department of State Highways). (BPR 4816 003)
Period: 1967
Objective:
The possibility of developing a method of testing the quality of concrete aggregate, which can be applied to field procedures, is to be explored.

23. Title: Nuclear Test Equipment Investigation
Agency: Materials and Test Division, Nebraska Department of Roads (64-5, BPR 4722 004)
Personnel: W. J. Ramsey and D. I. Inghram
Period: 1964-1966
Objective:
To develop and use non-destructive testing techniques using various types of nuclear equipment for compaction quality control data for soils, bases and asphalt mixes. The investigation also includes the determination of asphalt content of asphalt concrete.

24. Title: Statistical Quality Control
Agency: Nebraska Department of Roads. (64-4, BPR 4721 263)
Period: 1966
Objective:
To provide background data and experience as a basis for changing current specifications and method of inspection, sampling and testing.
Reports: Based upon data obtained by random sampling of the asphaltic concrete surface course during construction and issued by the Division of Materials and Tests. Nebraska Department of Roads for the following projects:
F-95(6), Enders - Wouneta, September, 1965;
S-755(4), Wisner - Bancroft, October, 1965;
F-253(3). Minden - West. December, 1965;
F-28(8), Union - Murray, March, 1966;
F-56(20), York - Aurora, June 1966.

25. Title: Statistical Approach to Quality Control
Agency: New Jersey State Highway Department (7711, BPR 4721 283)
Personnel: W. R. Bellis, R. A. Pege, K. Afferton
Period: 1964-1967
Objective:
To establish, by the use of statistical methods, the necessary sampling required to maintain adequate quality control of construction.

26. Title: Quality Control of Central Mix Concrete During Mixing and Transporting
Agency: New York State Department of Public Works (42-330, BPR 4723 004)
Personnel: I. F. Rizzuto, W. P. Chamberlin and D. E. Gordinier
Period: 1965-1966
Objective:
The department is evaluating its current specifications governing the production of Central-Mix Concrete. The study includes a literature summary and a review of cement practice to determine whether field studies are necessary to gather additional related information.

27. Title: Statistical Quality Control
Agency: North Dakota State Highway Department (2-67, BPR 4601 483)
Period: 1967-1968
Objective:
Variations in the control parameters are being determined for quality control on asphaltic concrete construction and compacted embankments.

28. Title: Statistical Quality Control
Agency: Department of Civil Engineering, North Dakota State University
Personnel: J. L. Jorgenson
Period: 1967
Objective:
Two areas of highway construction are being investigated to determine the variation in the controlling parameters of each type of construction studied. The results will furnish a basis for determining the average quality level to be expected in normal construction and what variations can be tolerated. The results should lead to a change in specifications. Field and laboratory tests of the materials used and the results obtained in construction are being made.

29. Title: To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete
Agency: Building Research Laboratory, Engineering Experiment Station, Ohio State University. (6-6)
Personnel: R. W. Bletzacker
Period: 1963-1965.
Objective:

Methods of securing pertinent information related to the mixing, placing, and curing of concrete at the earliest desirable or feasible age are being provided. An early knowledge of such information as air, water, and cement content will aid in better control of concrete mixing and placing. Other factors relative to quality control are being studied, and measurement techniques are to be developed, if deemed desirable.

Several series of tests are performed to determine uniformity of mortar samples taken from the same concrete batch. One series concerned the variation of fines between samples while another concerned the variation in the water/fine ratio. A subsequent series will be performed to determine the water/cement ratio, however, the tube separator will have to be modified for this purpose. Further experiments will determine the consistency of test results from air meters, and several A. E. 55 meters were obtained for this purpose. The Pachometer tests and tests to determine the loss of volume associated with water-alcohol mixtures were continued.

30. Title: Statistical Analysis of Aggregate Size Distribution
Agency: Engineering Experiment Station, Ohio State University (EES298)
Personnel: K. Majidzadeh
Period: 1967
Objective:

The size-distribution in the coarse aggregate used for asphaltic concrete and portland cement concrete is being studied. The variability in the size distribution of the aggregates obtained from a selected number of stockpiles is to be analyzed. Establishment is to be made of appropriate acceptance and rejection criteria, sample size, and random sampling techniques, all based on statistical concepts. Appropriate recommendations for the application of these analyses to the quality control of the aggregate will be made and suitable procedures for material acceptance and the contract payment adopted.

31. Title: Statistical Quality Control of Portland Cement Concrete Pavements
Agency: School of Civil Engineering, Oklahoma University (1483, BPR 4721293)
Personnel: J. G. Laguros
Period: 1964-1967

Objective:

Statistical evaluations for the establishment of limit quality criteria for use in the construction of Portland cement concrete pavement will be carried out. The various constituents of Portland cement concrete are being sampled near the finished product at the construction site and their specific properties determined. Field sampling, field testing and laboratory analyses will be carried out.

32. Title: Mineral Aggregate Quality Control Research
Agency: Oregon University
Period: 1964-1965
Objective:

Statistical analysis of historical samples on four projects each incorporating 400 or more samples taken on a generally continuous basis and of current samples on one large project taken randomly with dual samples divided for testing.

33. Title: An Investigation of the Reliability of Prequalified Fillet Welding Procedures for Welded Steel Bridges
Agency: Oregon State Highway Department (20-15, BPR 4613434)
Personnel: D. S. Berger
Period: 1966
Objective:

To obtain information to test the validity of the assumptions presently being made in regard to prequalified fillet welds.

Fillet weld reliability in welded steel bridges is based on the assumption that prequalification of the welding procedure combined with careful visual shop inspection will consistently produce fillet welds of uniform good quality throughout the work.

Collapse of the John Day bridge near Rufus, Oregon, during the December floods of 1964 has provided a source of full size welded steel bridge members which may be examined by both destructive and non-destructive means. These members consist of I, H. and Box sections which are composed of various thicknesses of ASTM A373 and A441 steels as well as weldable, heat treated steel of 115,000 to 135,000 psi ultimate strength and 100,000 psi yield strength.

Due to the rapid increase in fabrication of welded steel bridges, it is of considerable urgency that advantage be taken of this unique opportunity to appraise the reliability of fillet weld quality control methods. Findings of such an investigation would serve both as a comprehensive study of the reliability of prequalified fillet weld procedures as applied to this particular instance, and as an indication of the reliability which may be placed on other similar work.

Reports: (1) An Investigation of the Reliability of Prequalified Fillet Welding Procedures for Welded Steel Bridges. Bridge Division, Oregon State Highway Commission, September, 1966.

34. Title: Nuclear Bituminous Concrete Research
Agency: Pennsylvania Department of Highways. (64-15, BPR 4722003)
Personnel: V. Worona
Period: 1964-1968
Objective:

A determination is to be made of the feasibility of using nuclear gages for construction quality control of density and asphalt content measurements of bituminous concrete mixes.

35. Title: Quality Control of Asphaltic Concrete Mixes
Agency: Puerto Rico Department of Public Works
Period: 1964-1966
Objective:

To establish a statistical approach to the control of the quality of asphaltic concrete mixes.

36. Title: Statistical Quality Control of Materials Study
Agency: South Dakota Department of Highways (616, BPR 4721323)
Personnel: E. B. McDonald and D. Anderson
Period: 1964-1966
Objective:

A study is being conducted to develop a method of material analysis which will provide a more realistic approach for setting specification limits for control of materials production.

37. Title: A Study of Vermiculite Concrete as a Shock-Isolating Material
Agency: Structural Mechanics Research Laboratory, University of Texas (ENG-342393)
Personnel: J. N. Thompson and E. Smith
Period: 1962-1966.
Objective:

The purpose of this study was to develop information from which vermiculite concrete could be evaluated as a shock-isolating material. The study consisted of a literature survey, an exploratory phase, an experimental phase, a cost analysis, the development of two mix design methods, and the determination of field tests necessary for construction controls. In order to insure that homogeneous vermiculite concrete with preselected shock-isolating characteristics could be continuously produced, investigations of parameters that affect the homogeneity, workability, dynamic compressive stress, maximum strain, and quality control of vermiculite concrete had to be performed. This study provided substantial evidence that lightweight vermiculite concrete maintains reasonable shock-isolating characterisitcs for ages up to six months. It also provided evidence that lightweight vermiculite concrete might be designed such that concrete could be produced and adequately controlled with a wide range of dynamic compressive stresses and maximum strains.

Reports: (1) Thompson, J. Neils and Eugene Smith. A Study of Vermiculite Concrete as a Shock-Isolating Material. University of Texas, October, 1963.

38. Title: Deleterious Materials in Concrete
Agency: Texas Transportation Institute (2-5-63-71, BPR 4816153)
Personnel: D. L. Ivey
Period: 1963-1966
Objective:
This project is concerned primarily with aggregates and such ingredients in the aggregates that may have deleterious effects upon strength and durability of portland cement concrete. The quantitative effects upon durability of known deleterious materials will be determined so tolerable limits can be established. An evaluation of certain existing quality control tests for detecting deleterious materials will be made.
Reports: (1) Buth, E., D. L. Ivey and T. J. Hirsch Correlation of Concrete Properties with Test for Clay Content of Aggregate. Texas Transportation Institute No. 71-1.

39. Title: Statistical Quality Control
Agency: Virginia Highway Research Council (BPR 4721333)
Personnel: J. H. Dillard
Period: 1964-1967
Objective:
An evaluation of the implications of statistical methodology for highway construction and material control is continuing.
Reports: (1) Dillard, J. H. The Implications of Several Types of Statistical Specifications. July, 1966.

40. Title: An Application of Statistics in the Quality Control of Steam Cured Concrete
Agency: Virginia Highway Research Council (0284(Phase 4), BPR 4721333)
Personnel: H. E. Brown
Period: 1965
Objective:
The value and practicability of applying such statistical quality control procedures as regression analysis, control charting, variance analysis and principles of variation flow analysis are being determined as a means of measuring and controlling the quality of steam cured concrete.
Reports: (1) Brown, H. E. An Application of Statistical Evaluation Techniques for Quality Control of Steam Cured Concrete. Presented at National Conference on Statistical Quality Control Methodology in Highway and Airfield Construction, Charlottesville, Virginia, May, 1966.

41. Title: Field Study of Nuclear Device on Bituminous Concrete
Agency: Virginia Highway Research Council (2762)
Personnel: C. S. Hughes
Period: 1967
Objective:

The purposes of the study were: (1) to evaluate the use of a statistical quality control technique for field control of compaction, (2) to evaluate the use of a portable nuclear device as the test method used in the technique, and (3) to evaluate the practicality of using the technique and device in combination. The study was limited to the compaction of bituminous paving material on a single job. A control strip was constructed on the roadway with the material to be used throughout the project, utilizing the same equipment and environment as the remainder of the roadway.

Reports: (1) Hughes, C. S. and H. H. Ralston. Field Testing of a Nuclear Density Device on Bituminous Concrete. Proceedings, AAPT, 32, February, 1963.

(2) Ralston, H. H. and M. C. Anday. Nuclear Measurement of Soil Properties. 43rd Annual Meeting of the Highway Research Board, January, 1964.

(3) Hughes, C. S. and H. H. Ralston. Field Bilot Study with Nuclear Moisture Density Guages. October, 1964.

42. Title: Quality Control Study
Agency: Washington Department of Highways
Personnel: C. E. Minor
Period: 1966
Objective:

To assess the variation of asphalt content and aggregate gradation in typical production of asphalt concrete.

43. Title: Quality Assurance
Agency: U.S. Bureau of Public Roads (BPR 2601112)
Personnel: T. F. McMahon
Period: 1963-1973.
Objective:

Realistic enforceable specifications are being developed based on scientific estimates of quality requirements and performance capabilities of materials and structures. Improved method of estimating conformance based on statistical principles are being developed.

44. Title: Development of New and Rapid Methods for Controlling the Quality of Highway Materials
Agency: U.S. Bureau of Public Roads
Period: 1964-1967

Objective:

New rapid and reliable test methods for quality control of materials are being developed. Non-destructive methods of testing fabricated highway components are being developed and evaluated.

45. Title: Statistical Parameter Data Research
Agency: Philosophy Science (sponsored by U.S. Bureau of Public Roads)
Personnel: J. F. Redus
Period: 1964
Objective:

This project is designed to obtain and analyze file data acquired by the Corps of Engineers in their construction and research projects pertaining to compacted highway construction materials, and to use the statistical parameters obtained in the analysis to write construction specifications on bases and embankments. Data has been obtained for soils and base materials, tabulated, punched on IBM cards and is being analyzed. Data for flexible pavements has been obtained and is in the process of being tabulated and punched. This project will enable the writing of specifications, in statistical form, concerned with densification of highway pavement base courses.

46. Title: AASHO Material Reference Library
Agency: U.S. National Bureau of Standards
Period: 1965-1966
Objective:

Nationwide uniformity in testing equipment and test procedures will be promoted to improve the quality and economy of Federal-Aid highway construction.

47. Title: Production Studies
Agency: U.S. Bureau of Public Roads (BPR 2723204)
Period: 1967
Objective:

Equipment time utilization, procedures, and operating characteristics data are being developed, to foster improvement in economy and efficiency of construction, promote adoption and use of new developments, and better train junior engineers in quality control and other construction methods and procedures.

48. Title: Application of Statistical Quality Control in Pavement Construction
Agency: Waterways Experiment Station, Army C.E. (U.S.)
Personnel: W. J. Turnbull, A. A. Maxwell and D. N. Brown
Period: 1965

Objective:

Application of statistical quality control methods to the interpretion of inspection test data are being examined as to use in establishing compliance with job specifications. Attempt is to be made to determine the variations in inspection test data (standard deviations) which represent normal or expected variations resulting from the most and least efficient construction procedures. A draft guide specification is to be prepared showing typical specification requirements for statistical quality control of one (probably density) or more specified quantities. Review of technical literature, participation in pertinent meetings and conferences, and knowing applications of statistical quality control to construction of pavements are requirements.

49. Title: Uniformity Control of Soil-Lime Mixtures
Agency: Buenos Aires Prov. Highway Department, Argentina
Personnel: R. A. Duarte and C. L. Ruiz
Period: 1965
Objective:

The pH method to determine the percentage of lime has been used as a means of rapid control in situ of the uniformity of soil-lime mixtures. The method is exactly the one used for soil-cement mixtures. It consists of the determination of the lime in the mix by means of pH curves.
Reports: (1) Study of the Control of Soil-Lime Mixtures by the Potenciometric Method. Buenos Aires Prov. Highway Department, Argentina

50. Title: Quality Control of Commercial Limes
Agency: Buenos Aires Prov. Highway Department, Argentina
Personnel: F. J. Felli and C. L. Ruiz
Period: 1968.
Objective:

It is proposed to use new criteria to judge the quality of limes with regard to soil stabilization. Lime index is defined as the percentage of basic alkaline earth compounds, expressed as CaO or $Ca(OH)_2$ present or freed by hydrolysis, and being able to be neutralized by an acid solution under the testing procedure.
Reports: (1) Criteria of Quality and Basis of the Acquisition of Limes to be Used in Soil Stabilization. DVBA No. 48. June, 1965.

51. Title: Quality Evaluation of Fillers
Agency: Materials Testing and Tech. Investigation Laboratory, Buenos Aires Public Works Ministry, Argentina
Personnel: H. Langard and H. A. Suarez
Period: 1965

Objective:

The existing tests to evaluate the quality of fillers for asphalt concrete do not furnish complete assurance of their behavior once they are subjected to actual traffic. This research will thoroughly investigate several different kinds of fillers with regard to chemical composition, differential thermic properties, grading, shape of particles, and adherence to bitumens. Different asphalt concrete mixes are being made and their behavior correlated to each type of filler.

52. Title: Design of Viscometers for Bituminous Substances
Agency: Highway Engineering School, New South Wales University, Australia
Personnel: W. H. Cogill and J. Dunlop
Period: 1963-1967
Objective:

The design of viscometers is being studied with the object of developing apparatus suitable for control testing and for the study of changes in properties of bituminous materials during weathering. Apparatus for use with bituminous emulsions is also under development. Optical and electronic methods of measurement are employed.

53. Title: Quality Criteria and Acceptance Tests for Asphaltic Concrete
Agency: Service Des Researches Speciales, Contre Richerches Routieres, Belgium
Personnel: J. Huet
Period: 1964-1966.
Objective:

Quality criteria and acceptance tests are being formed for asphaltic concrete by measuring samples from surfacings. A failure test by diametral compression is being conducted on disks and permeability. Water resistance and adhesion to base courses tests will be conducted.
Reports: (1) Huet, J. Resistance Mechanique en Compression Diametrale des Enrobes Hydrocarbones Fermes pour Couches de Revetements, Rapport de Recherche No. 135, Centre de Recherches Routieres, Brussels, 1966.

54. Title: Statistical Control of Bituminous Mixtures
Agency: Nationa Highway Department, Brazil
Personnel: S. Birman
Period: 1965
Objective:

Tolerance of the specifications for bituminous mixtures will be verified through statistical processes. Apparent density, Marshall stability, and fluency of the bituminous mixtures will be taken into consideration in the evaluation of the quality of the mixes.

55. Title: Production Quality Control - Soil Cement Base
Agency: Alberta Department of Highways, Alberta Research Council, University of Alberta, Edmonton, Alberta, Canada
Personnel: J. M. Dacyszyn and B. P. Shields
Period: 1961-1965.
Objective:

Production quality of soil cement base construction is being evaluated by simultaneous measurement of physical parameters on a production unit basis. These parameters include cement and water contents, per cent standard AASHO compaction, material gradation, 7-day strength development. Control charts and limits are prepared as data becomes available on the project. General analysis of annual production on a project and material source basis consists of compilation of control statistics for all parameters and correlation to design and field strength levels. Long term strength development and pavement performance are being evaluated.
Reports: (1) Unpublished Report, Highway Research Division, Alberta Research Council, Edmonton, Alberta, Canada, April, 1965.

56. Title: Performance Evaluation of Cement-Stabilized Base Pavements
Agency: Alberta Department of Highways, Alberta Research Council, University of Alberta, Edmonton, Alberta, Canada.
Personnel: B. P. Shields
Period: 1961-1965
Objective:

Uniform, one thousand foot sections selected by examination of construction quality-control data, coring and deflection tests, are examined seasonally and annually for strength development, sub-surface moisture and density changes, faulting, warping, rutting, and performance by both subjective measurements and by a Bureau of Public Roads' Roughometer and for bearing capacity changes by Benkelman Beam deflection tests. Each uniform section is replicated, and duplicate observations are conducted simultaneously on conventional flexible pavements of equivalent design where they are available in the immediate area. Several such section groups, distributed over the main highway system, are currently under observation. Additional sections are added seasonably as pavements are constructed in other regions of the province.
Reports: (1) Canadian Good Roads Association Proceedings, 1961.

57. Title: Accelerated Concrete Strength Tests
Agency: Research Branch, Ontario Department of Highways, Downsview, Ontario, Canada
Personnel: P. Smith and B. Chojnacki
Period: 1958-1965.
Objective:

Concrete cylinders are placed in boiling water 20 minutes after the concrete has reached a pull out bond strength of 12 psi or a Proctor

needle penetration resistance of 3,500 psi. After the cylinders are placed in the water, it is brought to boiling in 2 hours. After 16 hours of curing in water the cylinders are removed from the boiling water and tested for compressive strength within one hour. Since the delayed time before the cylinders are placed in boiling water is based on the degree of set of the concrete, variations due to differences in cements and admixtures are accommodated. For the materials and variables tested, the relationship of accelerated (RA) to 28 day (R28) compressive strength is R28 = (26160RA)(RA 11620)*. Recent work includes the evaluation of procedures using water at 100 degrees F and 140 degrees F. It was found that only with the former could a delay period and hence overtime work be avoided. A different accelerating principle is being evaluated in which the heat of hydration is retained by placing the specimens inside well insulated containers for 48 hours. Preliminary results give a good relationship between accelerated and 28 day strength. R28 = 1.6 RA 500*. Since the 28 day strength is an arbitrary measure of the quality of the concrete, a suitable accelerated curing procedure could offer a more convenient and realistic way of ascertaining if the concrete will satisfy the purpose for which it was designed.

[Editorial note: The formulas marked * are both suspect as to correctness but are as reported in the original (computer report) seen.]

Reports: (1) Smith, P. and B. Chojnacki. Accelerated Strength Testing of Concrete Cylinders. D.H.O. Report No. 35 (ASTM Proceedings 63: 1079-1101. 1963)
(2) Tiede, T. F. Quick Concrete Quality Control. A.P.E.O. Registration Thesis.

58. Title: Concrete Mixer Efficiency Studies
Agency: Research Branch, Ontario Department of Highways, Downsview, Ontario, Canada
Personnel: P. Smith
Period: 1961-1965
Objective:

An investigation of the efficienty of concrete mixing has been undertaken to establish if the uniformity and quality of ready-mixed concrete is suitable for use in pavements and to specify mixing times required for all classes of mixer. Samples of plastic concrete obtained from three points within a batch were tested for unit weight of air free mortar, slump, air content, aggregate content, cement content, compressive strength, and temperature. Specification limits have been developed and applied in routine field concrete control procedures.

Reports: (1) Smith, P., and H. A. Vandusen. How Good is Your Mixer?--A Study of the Mixing Efficiency and Performance of Ready Mix Concrete Trucks. D.H.O. Report No. 48, April, 1964. (See also Proceedings of the Ready-Mix Association, 5th Annual School of Concrete Technology, 1964.)

59. Title: Factors Affecting the Life of Surface Treatments
Agency: Ontario Department of Highways, Downsview, Ontario, Canada
Personnel: A. Leslie
Period: 1962-1965
Objective:

Initial phase of this study consisted of evaluating the characteristics of several types of distributors. The uniformity of distribution was studied by placing absorbent pads beneath the distributor bar and weighting them after the distributor has passed. The calibration station has been built to calibrate asphalt distributors to ensure more uniform application of the bituminous materials.
Reports: (1) Leslie, A. Performance of Bituminous Distributors. Proceedings, 1964 Annual Convention of the Canadian Good Roads Association, 270 MacLaren Street, Ottawa, Ontario, Canada.

60. Title: The Incidence of Stripping of Bituminous Pavements in Ontario
Agency: Research Branch, Ontario Department of Highways, Downsview, Ontario, Canada
Personne: H. J. Fromm
Period: 1964-1966
Objective:

A statistical sample which covered the entire province of Ontario was selected to determine the amount and extent of aggregate stripping in bituminous pavements. The type of stripping examined was that which starts at the pavement base and spreads slowly throughout the bituminous concrete to weaken the entire structure. Stripping was more pronounced where granitic aggregates predominated. No correlation was found between the asphalt source and the amount of stripping. The frequency of random cracking was found to correlate directly with the severity of stripping but was not found to correlate between stripping and other types of cracking. All of the survey data obtained was analyzed statistically and conclusions were made at a significant probability level. A procedure was also developed to assign a stripping rating to field survey samples. This rating describes the degree to which stripping has progressed in the sample.
Reports: (1) Fromm, H. J. The Incidence of Stripping and Cracking in Bituminous Pavements in Ontario. D.H.O. Report 109. (Presented at the 1965 Annual Convention of the Canadian Technical Asphalt Association.)

61. Title: Statistical Quality Control
Agency: Ontario Department of Highways, Downsview, Ontario, Canada
Personnel: R. Schonfeld
Period: 1966-1967
Objective:

The variability of the degree of compaction, and of other characteristics of earth fills, sub-bases and bases was evaluated by means of a statistically planned test series. The test program used was that proposed for this purpose by U.S. Bureau of Public Roads (Research Guides, The Statistical Quality Control Task Force, April, 1965). The objective of the tests was to obtain statistical parameters for use in the quality control of highway construction contracts in southern Ontario. The variability of per cent standard compaction reflected in the test series can be used in compaction control based on the acceptance of a degree of variability of earth fills and granular base courses found on contracts which have had an amount of inspection considered to be normal. Test procedures based on this concept are being elaborated.

62. Title: The Production, Design, and Performance of Asphaltic Concrete
Agency: Construction Engineering and Architectural Branch, Canadian Department of Transport, Ottawa, Ontario, Canada.
Personnel: G. Y. Sebastyan
Period: 1964-1965
Objective:

This is a review of the current specifications of the federal and provincial highway departments in Canada for the procuring of the materials, production and construction control of flexible pavements. The project is part of the activities of the Subcommittee on Production, Design and Performance of Asphalt Pavements of the Canadian Good Roads Association. The production and design requirements of the various specifications has been collected and analyzed and this phase of the study is completed. Work is progressing on the sections dealing with quality and construction control requirements and a degree of compliance with the specifications required by the various agencies. It is proposed to extend the study to include consideration of evaluation of asphalt wearing surface performance as carried out by the various agencies.
Reports: (1) Report on Comparison of Pavement Construction Specifications for Sub-base, Base and Asphaltic Concrete Surface Courses. Engineering Design Section, Department of Transport, September, 1965.

63. Title: The Effects of Freezing and Thawing on the Durability of Asphaltic Concrete Mixes
Agency: Queens University, Kingston, Ontario, Canada
Personnel: C. D. Holmes and G. P. Luke
Period: 1965

Objective:

The objective of the project was to investigate the validity of the Freeze-Thaw Test as an indicator of durability. Durability is a complex term when applied to asphaltic concrete, and hence only the strength aspect is pursued in this study. Unconfined compression tests on cylinders measuring 2.85 inches in diameter by 6 inches high which were prepared by the static load double plunger method and three different aggregate gradations were studied. Two hundred and ten samples have been prepared. Sixty were subjected to the compression tests shortly after the curing process to determine the basic characteristics of the material in each gradation and asphalt content. The remaining specimens have been saturated at 70 degrees F for four days and then subjected to the freeze-thaw cycles. Samples were tested in the unconfined compression apparatus after one cycle, four cycles, eight cycles, sixteen cycles, and thirty-two cycles. Each cycle is 24 hours in length and the cylinders were dried and allowed to come to laboratory temperature for 24 hours before testing.

Relationships in the test data collected to date are somewhat obscured by statistical variation but generally those samples below optimum asphalt content showed an immediate increase in strength. These above and at optimum showed a steady decline in strength up to 8 cycles, but then increased substantially after 16 cycles.

Reports: Unpublished M. Sc. Thesis, G. P. Luke, Queens University, 1966.

64. Title: Base Course Quality Control
Agency: Service Des Sols et Materiaux, Quebec Department of Roads, Canada
Personnel: R. Robitaille and J. Normand
Period: 1963-1966
Objective:

Present practice utilizes proof-rolling to check pavement layer strength during construction. The interpretation of the proof-rolling results is based on opinion and the observed results are often difficult to interpret. Benkleman Beam deflection and rebound tests produce quantitative results which can be used as measures of the uniformity of construction. Measurements on the various layers of different types of pavement construction are underway to evaluated the use of this device for this application and to develop standard techniques.

65. Title: Moisture Density Tests with Nuclear Means
Agency: Materials-Research Section, Saskatchewan Department of Highways, Regina, Seskatchewan, Canada
Personnel: R. W. Culley
Period: 1962-1965

Objective:

A program of carrying out routine moisture-density testing with small portable and larger vehicle mounted nuclear radiation devices is being performed on subgrades, granular subbases, stabilized granular base and asphaltic concrete surface courses. The units have been used on various projects throughout the province under various working conditions to determine the feasibility of adopting this method of quality control. Results to date indicate that little testing quality would be lost if these methods were adopted as routine procedures. Complete evaluation is continuing.

Reports: (1) Culley, R. W. Determination of Soil Densities and Moisture Contents by Nuclear Means in Saskatchewan. Proceedings of the Soils and Surfacing Group, Western Association of Canadian Highway Officials.

(2) Culley, R. W. Compaction Control with Mobile Nuclear Radiation Equipment. Proceedings of the 1965 Annual Meeting of the Canadian Good Roads Association.

66. Title: Factors Which Determine the Quality of Asphalt Concrete Surfacings

Agency: State Institute of Technical Research, Finland

Personnel: J. M. I. Hyyppa

Period: 1959-1967

Objective:

Factors which determine the quality of asphalt concrete surfacings are studied. The study is divided into three parts: the first one deals with factors used in the assessment of the quality of asphalt concrete surfacings, volume, weight, voids content and Marshall-stability. The second part deals with raw materials, binders, and mineral aggregates, and the third part with the structural properties of the surfacing such as segregation, quality of joints, quantity of material and evenness. A large number of external factors such as prevailing conditions, climate, machines and methods used influence the quality of the surfacing.

Reports: (1) Hyyppa, J.M.I. On Factors Which Decide the Quality of Asphaltic Concrete Surfacings Based upon Experience Gained in Finland. The State Institute for Technical Research, Publication 105, Helsinki, 1966.

67. Title: The Application of Statistical Control Methods to Mass-Produced Materials

Agency: Technical Department, Colas Road Contracting Company, France

Personnel: Langumier, Pellion

Period: 1965

Objective:

An investigation is being conducted into the application of statistical quality control methods for the manufacture of bituminous road surfacing materials.

68. Title: Valuation of Accident Damage in City Streets
Agency: Cologne Engineering Office, Germany
Personnel: Ludke
Period: 1960-1965
Objective:

Official statistics give the number of accidents in cities only for the whole urban area. For this reason no investigations have been made of accident frequency on road sections of different width in relation to the volume of traffic. The author presented accident data for certain streets in Cologne at the International Road Congress in Rio de Janeiro. Based as they are on results from a single city, the figures are subject to chance errors, and in consequency do not permit generally valid conclusions. During the present program, accident frequency data on major and secondary roads of about 25 cities will be studied. The work is of special importance because of the lack of data on accidents on city streets in relation to traffic volumes.

69. Title: Investigations of Moisture Fluctuations in Road Bases
Agency: Federal Institute of Road Research, Germany
Personnel: H. Behe
Period: 1962-1965
Objective:

The moisture content fluctuation in road bases and subbases is being recorded at various depths and locations beneath the pavement, and in cuts and fills. As the quality of pavements is largely dependent upon the moisture content of underlying layers, it is important to know the seasonal fluctuations in moisture content at various levels. Nuclear depth gages, capable of measuring to depths of 20 meters, were employed in the study. Measurements were made year-round at frequent intervals.

70. Title: Investigation on Quality Standards of Paving Materials
Agency: Public Works Research Institute, Construction Ministry, Japan
Personnel: O. Kondo
Period: 1966
Objective:

Quality standards of bituminous materials for highway use are being established. Asphaltic materials are sampled at paving work sites, sent to the laboratory, and physical and chemical properties tested. Relations between engineering and physical and chemical properties of asphaltic paving materials are sought to obtain information on the quality requirements for highway paving asphaltic materials.

71. Title: Quality Control of Construction Materials
Agency: Engineering Institute, Structural Dynamics Section, National University of Mexico
Personnel: O. A. Rascon
Period: 1965

Objective:

Using Bayes Theorem, a probability distribution is obtained for different materials. The distributions are chosen in advance taking into account the information on hand and the expected values of the parameters that characterize the material. The final distributions are expressed in terms of the nominal value of the material strength and will be used to establish specifications for quality control of construction materials.

72. Title: Removal of Low Quality Particles From Gravel
Agency: State Road Laboratory, Norway
Personnel: A. Gronhaug
Period: 1967
Objective:

The quality of gravel is being improved by a separation process which removes low quality particles. This method of separating gravel is taken from a Russian publication. The main part of the apparatus being investigated is a rotating steel-drum on which gravel is allowed to fall, grains having shapes near to a cubic form, high elastic qualities and a high crushing strength are reflected off the drum in a direction against the direction of rotation. Elongated grains and grains having inferior strength and elastic qualities are carried away on the drum in the direction of rotation. This was first studied on the laboratory scale and a prototype machine has been built at a cost of 10,000 kr. Experimental studies will be carried out with this equipment.
Reports: (1) Gronhaug, A. Fremstilling av Slitesterke Strinmaterialer fra Forekomster av Varierende Kvalitet: Sovjet-Samveldet Litteraturrefat, Statens Vaginstitut, Stockholm. Special Rapport 25, pp. 18-19, 1964.
(2) Gronhaug, A. Fremstilling av Slitesterke Steinmaterialer fra Forekomster av Darligkvalitet, Veglaboratoriet Meddelser, NR 21, OSLO, pp. 16-22, 49-50, 1964.

73. Title: Statistical Quality Control of Highway Construction
Agency: Construction Division, Public Works Ministry, Spain
Personnel: Vicente F. Lozand, Vargas G. Carrillo, and J. A. Guitart y de Gregoria
Period: 1965
Objective:

The standard specifications for highway construction are insufficient to guarantee good quality in highway works. New specifications based on statistical quality control techniques are being studied.

74. Title: Sampling Method for Determining Traffic Work (Daily Vehicle Miles) on Rural Roads
Agency: Office of Swedish Council Road Safety Research, Stockholm Technical University, Sweden
Personnel: S. Erlander
Period: 1964

Objective:

An attempt is being made to develop a method of deriving traffic activity or work in terms of vehicle miles from traffic count data. Data from routine spot volume counts is being used and a method is being developed for projecting these data to reflect total activity in terms of vehicle miles by breaking routes into segments. The statistics of the method of sampling and calculation will be studied.

75. Title: Standards for Soil Stabilization
Agency: Geotest Ag Bern, Switzerland
Personnel: H. Eindler
Period: 1964-1966
Objective:

Four new standards for soil stabilization with lime, cement, bituminous binders and general information on soil stabilization including definitions, range of application, suitability and quality testing, payment and guarantee, and machine data for carrying out the work are formulated.
Reports: (1) Draft Standard, September, 1966.

76. Title: Controlling the Quality of Concrete
Agency: Road Research Laboratory, Ministry of Transport, London, United Kingdom
Personnel: R. H. Kirkham
Period: 1965
Objective:

It is proposed to develop further the existing methods of analyzing fresh concrete, to improve their reliability and rapidity. It is also proposed, with other laboratories, to try to standardize methods for analyzing hardened concrete. Co-operative tests are proceeding on early-strength tests of concrete using accelerated curing at elevated temperatures. It seems that the most satisfactory method uses moderate curing temperatures up to, possibly, 48 hours. It is proposed to examine whether tests at two maturities would lead to improved forecasting. The density of concrete cores cut from roads has been measured with the recently developed core scanner. It seems likely that the test would be useful in detecting variations in density.
Reports: (1) Kirkham, R. H. The Analysis of Fresh Concrete. Concrete Constr. Engng 44 (2): 54-60. 1949

77. Title: Quality Control of Bituminous Materials and Construction Procedures
Agency: Road Research Laboratory, Ministry of Transport, London, United Kingdom
Personnel: D. H. Mathews, G. D. Goodsall and R. Hardman
Period: 1965

Objective:

A scheme has been prepared for quality control and compliance testing of rolled asphalt wearing-courses and is being field tested. Similar schemes for other materials are being developed. A study has been started of methods of sampling bituminous mixtures at the laying site. The quality-control and compliance testing techniques will be developed and tested so that they can be used in specifications, with particular attention being paid to the problems of smaller jobs. The sampling research will continue until reliable methods are developed. Trials are being undertaken in Scotland to investigate the effect of sampling procedure on the analyses of rolled asphalt base course materials. The application of charts for the control of bituminous materials on a statistical basis is being studied with rolled asphalt wearing course materials. The use of statistical bases will be extended to other bituminous surfacing materials. The possibility of using radioactive methods for measuring the density and binder content of bituminous layers in a road is being explored.

APPENDIX 3

MANAGEMENT OF THE QUALITY CONTROL FUNCTION

1. Adams, Clifford C.
What is Total Quality Control?
Industrial Quality Control 22 (7): 341-341. 1966.

Total Quality Control encompasses the following functions: engineering, procurement, planning, production, inspection, personnel, maintenance, accounting, sales, administrative and management. J.G.D.

2. Bayer, Harmon S.
Quality Control Programs should be Cost Reduction Programs
Industrial Quality Control 17 (9): 4-8. 1961.

Few developments in the science of management require more sound definitions than the concept of the goal of a quality control program. Clearly, quality control programs cannot be considered effective unless they produce substantial cost savings for the organization. All too frequently this basic fact is not understood by those who administer these programs. Unfortunately, a large number of quality control managers still measure the effectiveness of their programs by the number of reports and studies, and the use of other questionable criteria. It is not surprising, therefore, that many of these systems are considered by management to be wasteful. And as a result, the mortality rate of their managers is quite high.

It would perhaps be helpful, therefore, to consider step-by-step methods that management can employ to assure that a quality control program is, in fact, doing its job--producing savings by reducing losses due to poor quality.

3. Beach, N. F.
Management and Quality Control
Industrial Quality Control 22 (10): 503-505. 1966.

The author presents a challenging view of what function the quality control personnel in an organization may perform. A good team will see the need to review the necessity for changing specifications, will conduct continuous evaluation of the product, question if new measurement techniques are needed, investigate the causes of and make recommendations for correction of defects, be a catalyst in the system and a force for overall improvement of the product. J.G.D.

4. Belcher, D. W.
Quality Control Without Conflict
Industrial Quality Control 16 (8): 9-12. 1960.

Industrial psychology and sociology, in the social sciences, have investigated human aspects which should be borne in mind when implementing a quality control program. The size of group, degree of individual participation, knowledge of what happened, job integrity, are discussed in relation to the success of a quality control program. J.G.D. (18 citations)

5. Bicking, Charles A.
Quality control as an Administrative Aid
Industrial Quality Control 14 (11): 36-43. 1958.

Stated in general terms, the use of statistical and graphic techniques provides a method for reaching decisions and directing action to control costs. The further down the managerial ladder we go, the less organization we find for decision, action and cost control. We pay well for administrative ability and for the statistical information on which administrative decisions are founded. Through a quality control program, the same advantages are obtained down to the lowest supervisory level on a self-paying basis. A highly respected administrative tool is extended in its scope and usefulness. Because it represents an extension of an essentially managerial function, it should be directed from a policy-making level. Since very often in industry administrators arise from the ranks, the extension of the appreciation of the value in statistics will provide a means of training for administrative responsibilities. (2 citations)

6. Bicking, Charles A.
The Team Approach In Quality Control Investigations
Industrial Quality Control 16 (5): 5-9. 1959.

The use of the team approach to quality problems is propounded in this article. The success of this approach depends upon the selection of personnel who are willing to cooperate and work toward a common goal. Examples from the chemical and defense industries are cited. J.G.D. (6 citations)

7. Bicking, Charles A.
Quality Control as a System
Industrial Quality Control 23 (11): 538-543. 1967.

This article discusses quality control not as an organizational element of a company but as a functional subsystem within the larger industrial enterprise system. Analysis of the various functions of quality control and flow diagrams of both paper-work and operations show that responsibility for many of the functions lies with departments other than the quality control group. The problems of managing such a group of functions as a system concept are also discussed. (8 citations)

8. Bingham, Jr., Richard S.
Ten Minutes With Your Top Management
Industrial Quality Control 18 (4): 5-8. 1961.

Some good advice is offered by the author when presenting quality control principles and problems to management. J.G.D.

9. Bourquin, James F.
Uses of total quality control in Top Management Decision Making
Industrial Quality Control 15 (8): 15-20. 1959.

Cases have been shown of how management direction can be helped through effective use of quality control in the four major aspects of our work. These examples come from all the major portions of the total quality picture starting with design evaluations through processed and purchased material controls, quality audits and the sources of vital information through field service reporting.

In outlining quality control contributions to management, situations have been used from Whirlpool activities. However, it is reasonable to assume that similar steps are being performed in some form by nearly all industry. Wherever manufacturing operations are carried out, an ever increasing amount of attention is being given to quality. This is accompanied by steadily mounting pressures for better techniques, education, and controls. The growth beyond the level of merely pinpointing plans and long-range objectives, to a new position of vital force in management direction, is a solid indicator of the quality function's rising stature in today's industry.

10. Brown, Dr. Charles S.
What Management Expects of Quality Control in the Chemical Industry
Industrial Quality Control 21 (3): 144-147. 1964.

The author issues a broad challenge to the quality control group. They should assimilate usage data, process control data, etc. and summarize it so that it can be a useful guide to the designer. They should take the lead towards greater uniformity. Quality planning, not just total inspection, should be the central theme, including design and usage. The quality group should be on the alert for situations where more sophisticated treatment of data will reveal not only where the problem lies but what direction will lead to improvements. Careful consideration of the statistical capabilities of an industry and their exploitation can lead to less rather than more regulation by government agencies. J.G.D.

11. Budne, Thomas A.
SQC can be made more effective
Industrial Quality Control 15 (6): 10-12. 1958.

When the systematic activity has removed the largest source of quality loss and the second largest and so on down the line, a point must finally be reached at which the reduction of the next largest source of quality loss would no longer justify the expenditure of QC dollars. If the major causes contributing to quality losses, as uncovered, are placed under a reliable system of operating or process control, and if specifications on operating conditions are written or re-written to include the important discoveries, an economic quality level once attained can be maintained at relatively low QC costs.

A complete QC program, as mentioned above, must begin at the earliest conception of the product and follow through to the consumer. The science of quality control is sufficiently advanced to supply equally effective programs in every key quality area. QC losses on new products would be at a minimum if effective QC planning were brought in at the ground floor.

When the quality losses are high because of the absence of a complete and effective QC system, management will not disregard a program based on facts in dollars and cents, but will support one which makes sense as well as dollars.

This is the kind of program which must and can be sold to top management. (3 citations)

12. Cannon, Hon. Howard W.
Quality Control
Industrial Quality Control 19 (11): 7-9. 1963.

The role of quality control and reliability are placed in perspective with respect to global political considerations. There is no doubt but what the author recognizes the part played by these in military and space capabilities and its role in domestic production of goods. J.G.D.

13. Chapel, Theron T.
A Quality Philosophy
Industrial Quality Control 19 (4): 10-12. 1962.

The article is philosophical in nature, the major theme being that of using quality control procedures to effect product improvement. Testing is a necessary part but true quality control involves not only the

accumulation and analysis of test data but also the taking of positive action towards correcting the causes which bring about test failures. A careful quality audit is recommended to give management a comprehensive picture, not only of the level of quality but its cost and customer acceptance of the product. J.G.D.

14. Collins, William R. and Samuel S. J. Skolnik
Quality Control - The Evolution of an Occupation
Industrial Quality Control 18 (10): 4-8. 1962.

An account of how the widespread adoption of quality control functions by government agencies has had an impact upon job classifications and manpower requirements. J.G.D.

15. Cook, Lawrence E.
The Quality Assurance Pre-Production Conference
Industrial Quality Control 22 (8): 408-411. 1966.

This approach in military contracts has been beneficial in smoothing the relations between the contractor and the government. Prior to work on a contract, the two parties select key people who meet for the purpose of carefully reviewing the terms of the contract, the responsibilities of each, inspection, quality control specifications, packaging, shipping and all the myriad details which go to make up the fulfilment of a mutually satisfactory contract. J.G.D. (10 citations)

16. Cowan, A. F.
Quality Control - Is It a Management Service?
Industrial Quality Control 14 (7): 12-14. 1958.

Management is actually the customer of quality control but the selling of the technique may be difficult. The article suggests an effective approach to sell the product to management. J.G.D.

17. Craig, C. C.
What is Quality Control?
Industrial Quality Control 15 (1): 5-7. 1958.

Content of a speech by C. C. Craig, one of the pioneers in introducing and selling quality control to industry. J.G.D.

18. Crosby, Philip B.
Quality Control from A to Y
Industrial Quality Control 20 (7): 4-16. 1964.

The article discusses quality control from the following points of view: (1) what is it; (2) how should you plan for it (since it doesn't just happen); (3) how do you control vendors who are in the business of supplying you with raw material, components, etc.; (4) corrective action depends on feedback of information and seeing that proper action is taken; (5) the organization of quality control involves people and their responsibilities. J.G.D.

19. Cue, Dale A.
Some Frustrations and Difficulties in Applying the Total Quality Control Concept
Industrial Quality Control 18 (10): 12-14. 1962.

A discussion of what is required to achieve 'total quality control' which entails feed-back to new design, control of incoming material, control of the product, process studies, inspection and testing and innovation of new tests and equipment. The suggested criteria for reviewing these activities is recommended to be that of "Does it add value?" to the product. J.G.D.

20. Eidukonis, Edward R. and John L. Kidwell
The Inspection Training Program
Industrial Quality Control 23 (12): 622-628. 1967.

Formal inspection training, in addition to the traditional methods of experience and guidance training, is essential for the development of individual skills so that industry can keep pace with technological growth. Such training has been successfully employed for several years, and this article describes the techniques of developing such a program, with guidance as to how training should be conducted, and how the greatest benefits can be achieved. It also describes a training program for Inspectors which is intended to minimize what has long been accepted as "inevitable human error." (8 citations)

21. Enrick, Norbert Lloyd
What A Quality Control Program Means to Management
Industrial Quality Control 19 (8): 21-23. 1963.

The stated purpose of the paper is to describe what effective statistical quality control means and how it can bring about actual cash savings and improved salability of the product. One must look at the sources of quality, the important factors in installing a good program, provide management support, and how to use statistical aids effectively. J.G.D. (4 citations)

22. Epstein, Herbert B.
The Conscience of a Company
Industrial Quality Control 18 (11): 30-49. 1962.

The company that contracts to supply a 'quality' product must develop a quality conscience throughout all aspects of its operation. J.G.D.

23. Erhardt. C. C.
Introducing Quality Control
Industrial Quality Control 20 (11): 10-13. 1964.

The author adds his own flavor to that offered by reputable quality control text books, on how one goes about introducing a quality control program. J.G.D. (6 citations)

24. Erhardt. C. C.
How to Prepare a Quality Control Manual
Industrial Quality Control 21 (7): 349-352. 1965.

In recent years much has been said and written about quality control manuals. Almost everyone agrees that properly prepared written procedures are a very important part of a good quality control system. In some government contracts there is a clearly defined stipulation for the contractor to maintain written procedures. Yet there still exists today much confusion as to what a quality control manual is, or is supposed to be, what the basic ingredients should be, and how much ground it should cover. This article, aimed particularly at groups preparing a manual for the first time, will attempt to answer those questions by describing a practical approach to this problem. This article further presupposes that a quality control system already exists but that the system has never been formally documented in writing. It is inevitable, of course, that once the system is transformed to the written word, various weaknesses will come to light and changes will necessarily follow. (3 citations)

25. Feigenbaum, Dr. A. V.
The Professional Work of the Quality Control Engineer
Industrial Quality Control 14 (8): 5-6. 1958.

A discussion of what quality control engineering consists of, what has to be done to earn professional recognition. The thinking of a committee written report is presented regarding establishing this activity on a professional basis. J.G.D.

26. Feigenbaum, A. V.
Professional Quality Control Engineering
Industrial Quality Control 16 (5): 22-26. 1959.

A description of the role of the professional quality control engineer and how he has a important part to play in modern manufacturing of many complex consumer items. J.G.D.

27. Feigenbaum, A. V.
The Increasing Significance of Total Quality Control
Industrial Quality Control 20 (4): 4-9. 1963.

The presentation looks at Business General Management, Government, the Consumer and Academicians, Scientists, Engineers and Mathematicians with respect to past growth and future developments in total quality control. J.G.D.

28. Feigenbaum, A. V. and R. M. Berg
Professional Engineering Status for the Quality Control Engineer?
Industrial Quality Control 16 (4): 17-23. 1959.

A report by the special committee on professional development for ASQC. A program for action is set forth. J.G.D.

29. Gray, Leonard E.
A Vendor Rating System For Material of Any Complexity
Industrial Quality Control 17 (3): 26-30. 1960.

This is a description of a vendor-rating system developed and being used by a medium-sized company whose products are small quantities of high-quality electronic and precision electro-mechanical equipments made to military specifications and rigid company requirements. Because it purchases, for use in production, not only simple stock items but also some complicated and expensive sub-assemblies with many characteristics to inspect, the company needed a rating system that could be used for purchased units of any complexity.

30. Graziano, Peter, P.
Statistics aren't Everything in Quality Control
Industrial Quality Control 18 (4): 24-25. 1961.

The problems in quality control include defining the problem itself, to do this the author stresses the need for bringing together all the talent and all the facts to arrive at the definition of the problem. The successful quality control program is a result of salesmanship and the embroiling of personnel from other disciplines. J.G.D.

31. Green, Albert
The Legal Framework for Inspection Under Government Contracts
Industrial Quality Control 17 (6): 5-8. 1960

The legal aspects are discussed in layman terms replete with a number of examples. J.G.D. (24 citations)

32. Hill, David A.
Communicating Quality Control Ideas
Industrial Quality Control 16 (11): 21-24. 1960.

A discussion on how best to convey the ideas and operational features of a quality control program. Communication skills, persuasiveness, the ability to deal with people in the promotion of change, a listener, a team worker, these are mentioned as a few of the qualifications necessary for the advancement of quality control within an organization. J.G.D. (5 citations)

33. Hofstead, Robert M.
What Kind of People?
Industrial Quality Control 18 (2): 37-38. 1961.

Not everyone is qualified innately to be successful in the profession of SQC. Personal attributes are required beyond mere training and experience just as is the case with other professional fields. Thought should be given to this situation in readiness for the future when formal education (e.g. QC Engineering) is available in our universities. (2 citations)

34. Hutter, R. G.
Inspection Manpower Planning
Industrial Quality Control 22 (10): 521-523. 1966.

The article lists eleven inspection evaluation factors which can be utilized to plan manpower needed for quality assurance on a specific project. Following this approach will indicate number of inspectors required based on a realistic look at the various factors. J.G.D.

35. Jacobson, Henry J.
Quality Control Management of Small Business
Industrial Quality Control 19 (9): 5-9. 1963.

To summarize briefly, we know that most business failures are caused by poor management. Management means people, and a poor manager is one who does not take advantage of all the new scientific and proven methods available to him. He is one who makes his decisions on a guesstimate basis rather than a factual one. He does not keep abreast in his field. He has stopped learning and is now coasting. There are unfortunately too many people in this category and too many business failures to prove it.

Everything, then, is based on a manger's ability to read and to absorb. To learn from others and profit by their examples. To accept what he can use at the moment and to file away, but not reject, ideas for which he has no immediate need. Management is not a game that we play for eight hours a day, five days a week. It is a challenge to our ability as individuals to do a continuously better job today than we did yesterday.

36. Juran, J. M.
Cultural Patterns and Quality Control
Industrial Quality Control 14 (4): 8-13. 1957.

A discussion of the impact of a quality control program on an organization. It meets with resistance sometimes because of misapplication but often from underlying cultural patterns of the worker and the seemingly 'natural' resistance to change. Studies in the social sciences have dealt with how best to introduce innovations. J.G.D.

37. Juran, J. M.
The Two Worlds of Quality Control
Industrial Quality Control 21 (5): 238-244. 1964.

The article discusses at length the two areas of planning and control of quality, a management activity, and the execution of the broad quality plan, a technical activity. The dispersion of these two functions over many human beings has resulted in many organizational variations. The view presented is that quality is primarily a business problem and should be included in the upper levels of management, at the same time it is pointed out that many quality control personnel get so wrapped up in the technical side of quality control that they lose sight of or neglect to prepare themselves to perform a management function. J.G.D.

38. Kall, Harold L.
The Attainment of Quality Discipline - A Case History
Industrial Quality Control 21 (7): 346-348. 1965.

A good quality control manual is a must. Personnel must be enthusiastic, willing and able to work closely with production personnel--not as policemen but to guide them in using suitable quality control aids so that they can be almost self-policing. Availability of specialists aids in the development of new testing procedures as needed. Effective communication between production, customer, government inspector, etc. keeps everyone informed. J.G.D.

39. Karleback, Herman
Human Relations Problems Encountered in Quality and Reliability Control
Industrial Quality Control 18 (6): 27-32. 1961.

The problems encountered in quality control are classed by the author into organizational, technical and cultural. The article deals in the main with the cultural aspects such as resistance to change, there is little doubt that introduction of quality control is going to involve changes. J.G.D.

40. Law, Charles W.
Standardization of Quality Assurance Practices in a Decentralized Corporation
Industrial Quality Control 21 (6): 295-297. 1964.

This article describes one company's approach to coordinating quality assurance practices in a decentralized multiplant operation.

A council, made up of plant quality managers and middle management people from quality control operations, achieves its objectives through task groups drawn from line quality control personnel in various plants. This approach is somewhat unique in that decisions on corporate quality control operations are being created by people right on the line.

Also described are some of the problems that were encountered and approaches that were developed.

41. Lieberman, William L.
Some Non-Random Observations on the Organization and Administration of a Quality Control Program
Industrial Quality Control 18 (7): 27-30. 1962.

Whatever organizational position is assigned to the Quality Control Department, it must be remembered that the Quality Activity is essentially informative only. The production department is still running the plant, and management is still running the company even though a quality control department has been given specific responsibilities relating to production processes and product qualtiy. Quality information is a tool which can be used to obtain more efficient over-all operation, but it must be recognized that in the final analysis responsibility for the resolution of any quality problem lies with those who create quality at the points of design and manufacture.

When all is said and done, the objective of any Quality Program is the continuing economic production of consistent product which meets both specification and customer requirements. Any activity which truly furthers this objective may properly be called Quality Control.

42. Lieberman, William L.
Basic QC Procedures
Industrial Quality Control 20 (6): 4-6. 1963.

A framework for basic quality control is outlined and should help in understanding and applying the procedures. The reader is warned that quality control methods should always be directed toward informing design, production and top management by providing information which will assist in maintaining or improving quality levels and reducing costs. J.G.D. (5 citations)

43. Lobsinger, Dale L.
Quality Control and People
Industrial Quality Control 17 (1): 13-15. 1960.

The theme of the article is that, in dealing with people, some of the precepts of the quality control practicioner could be very useful in removing the causes of some of the 'excessive' behaviors we encounter. J.G.D.

44. Marguglio, Benjamin W.
Quality Systems Audit
Industrial Quality Control 20 (1): 12-15. 1963.

This article presents a history of the development, implementation and operation of a Quality Systems Audit Program. Emphasis is given to the operational ground rules, techniques and tools of systems audit; the objections to audit; the means by which they were overcome - in general, the initial failures and subsequent successes of the program during its first three years. Audit is defined as: the independent evaluation of any operating criteria, which could directly or indirectly affect quality, to determine the adequacy of and conformance to this criteria with respect to contractural and mission quality requirements, quality controls and their economy.

45. Masser, W. J.
The Quality Manager and Quality Costs
Industrial Quality Control 14 (4): 5-8. 1957.

Quality costs arise from prevention (not letting defects occur), from appraisal (continuing evaluation of the outgoing product, and from failures (defective materials and products which don't meet the desired quality level). The article lists the activities chargeable under each of these three areas. These costs may be used to measure quality performance, analysis of where quality money is spent, for programming quality improvements, and a tool for budget preparation. J.G.D.

46. Miller, Robert S.
Quality Control as a Service Department Responsibility
Industrial Quality Control 18 (8): 22-24. 1962.

The quality control program was designed so that a clearly defined method of feed-back from the company's service department was included as an integral part of it. Thus problems of warranty, customer dissatisfaction, frequencies of specified failures are brought directly back into the design and manufacturing stage. J.G.D.

47. Nixon, Frank
Organization, Man and Reliability
Industrial Quality Control 19 (2): 15-21. 1962.

A comparison of the American and British approaches to quality control in industry. In quality control and industrial management the American segment is years ahead of the British, in reliability the gap is not so wide. A plea is made for retaining 'pride of workmanship' as a basis upon which to produce a quality product. J.G.D. (7 citations)

48. Osinski, Ralph Von
Build A Quality Team
Industrial Quality Control 17 (12): 16-17. 1961.

The quality team approach is propounded in this article. The who, how and why are each touched on. J.G.D.

49. Palmer, Barry A.
The Procurement Specification as a Tool for Supplier Evaluation
Industrial Quality Control 18 (6): 35-36. 1961.

The author proffers the view that a well written procurement specification, including details of inspection plan, test equipment, how discrepant material will be dealt with, and the supplying of test data by the subcontractor, will be of material value in evaluation of subcontractors. Their reaction to the specification and their ability to perform under it will assist in evaluation. J.G.D.

50. Palmer, Barry A.
Quality Control Engineering
Industrial Quality Control 20 (11): 17-19. 1964.

The activities of the quality control engineer are outlined and these are discussed in relation to professional status. J.G.D. 2 citations)

51. Pappas, Robert L.
Management's Dilemma
Industrial Quality Control 16 (2): 11-13. 1959.

The discussion is addressed to the position of the quality control function in a company, the need for capable personnel, their training, management's responsibility. J.G.D.

52. Paterson, E. G. D.
Quality Control Engineering in Product Evaluation
Industrial Quality Control 16 (11): 11-20. 1960.

The final in a series on professional development, sponsored by the ASQC Committee on Professional Development, it discusses mainly product evaluation. The quality control engineer, to be effective, must have considerable knowledge about the product, must develop quality rating schemes, be conversant with sound statistical principles - a mass of many parts, not the least of these the ability to inspire and promote cooperative effort. J.G.D. (12 citations)

53. Peck, George A.
Management Looks At Quality Control
Industrial Quality Control 16 (11): 42-47. 1960.

The management of quality control is an important part of its overall effectiveness. This article reflects a company experience touching on a wide range of topics: automation, personnel, military procurement, training, management structure, operations research and the attitude of management. J.G.D.

54. Purcell, Warren R.
Who Controls Quality . . . and How?
Industrial Quality Control 15 (4): 18-21. 1958.

The control of quality is pictured as a joint proposition. The following groups and how each functions: general management, accounting, research and development, design, planning, purchasing, production, production control, industrial engineering and sales, are considered. J.G.D.

55. Purcell, Warren R.
Management's Corner - The Internal Quality Control Consultant
Industrial Quality Control 19 (4): 38-40. 1962.

The quality control consultant as a salaried employee, to function effectively, must gain the confidence of the management to whom he is responsible and also that of the management at his level and below, before he can function effectively towards achieving the goal of improved quality. J.G.D.

56. Purcell, Warren R.
Satisfying Industrial Quality Control Training Needs
Industrial Quality Control 23 (12): 634-636. 1967.

A company's training program should be built from an analysis of the company's training needs. The needs should be listed first, then the training sources selected. Whether the leader of a particular phase of the training program should be an employee or an outside consultant is not in itself an important consideration, provided the one selected has the necessary breadth and depth of knowledge in the specific subject, the ability to present the subject effectively, the proper environment for good training, and the ability to impart to others not only the required knowledge, but also the skills needed for its successful application.

57. Raymo, Chester T.
SQC vs. Intuitive Inspection
Industrial Quality Control 17 (7): 8-10. 1961.

Quality is not a matter of opinion but a result of objective methods of specifying and measuring, this is the theme expressed in the article.

58. Reis, P. S. and S. I. Fahrenbruch
Quality Audit - An Effective Management Tool
Industrial Quality Control 22 (8): 402-407. 1966.

The basic quality audit concept and the methods and considerations by which it is used as an effective management tool as required by Aerojet-General Corporate Policy is specifically discussed. Details of the article include: (1) use of an impartial team of auditors who have no specific line responsibilities; (2) development and distribution of audit reports; (3) methods which are used for weighting nonconformancies detected during the audit; (4) practices employed to obtain corrective action for nonconformancies detected during the audit; (5) placement of the audit function in the organization structure to ensure maximum effectiveness in operation with the related quality systems and training functions; (6) desired working relationship between audit personnel and affected managerial personnel and the importance for managers to view the audit effort as a support function rather than a disciplinary force; (7) the qualifications required by an individual to be selected as an auditor. The article concludes with an explanation of a quality audit and how it can be compared in need and principle to the more widely known accounting audit. (7 citations)

59. Reynolds, E. A.
Starting Improved Quality Control
Industrial Quality Control 22 (7): 336-340. 1966.

The suggested place to start is to first find where the larger problem areas are. This may be done by an examination of cost and accounting records if these are adequate, on the spot estimates with the aid of plant personnel. Next a more detailed examination should be made to ascertain the nature of the problem and then a plan devised for its correction. Competent personnel should be trained or brought in, starting with the quality manager. The program may be plant wide or started in a single department and then given perhaps two years to realize quality benefits - measurable in terms of lower production costs, fewer quality losses. J.G.D. (5 citations)

60. Rice, William B.
Reliability and Statistical Control
Industrial Quality Control 18 (2): 10-11. 1961.

The article endeavors to put quality control in perspective insofar as the system, within which it is being applied, is concerned. J.G.D.

61. Riordan, John J.
Quality Control Management in the Department of Defense
Industrial Quality Control 16 (6): 11-13. 1959.

The management structure of inspection and quality control in the Department of Defense is outlined. The operational principles are that this pertains to all material being supplied, that it is directed towards preventing the receipt of defective material and to improve productivity and effect cost reductions, that collaboration with industry is more productive than duplicating the industry efforts, that final decisions rest with DOD regarding acceptability, and that the performance of products in service is the final measure of quality. The prime contractor and DOD form the chief links in the chain. J.G.D. (12 citations)

62. Schneider, Colonel J. G.
What Does the Air Force Expect of Contractors?
Industrial Quality Control 15 (5): 12-14. 1958.

The Air Force lays down a quality control specification then offers various aids to the contractor in conforming to the specification. The position and effectiveness of the quality control function is reviewed before the contract is awarded and recommendations made for improvement. They use a vendor rating system involving preaward surveys as well as post award evaluation of quality effectiveness. The result of this is that the contractor is encouraged to build in quality and reliability by constant surveillance, by him, of his production process. J.G.D.

63. Schneider, J. G.
Quality Planning - the Key to Pursuit of Perfection
Industrial Quality Control 24 (1): 4-6. 1967.

The content of this Edwards Medalist address gives some insight into the development of Military Quality Standards as contributed to through the activities of the author as a member of the Air Force inspection group. J.G.D.

64. Schrock, Edward M.
Management Bench Marks for Quality Control
Industrial Quality Control 16 (8): 4-8. 1960.

Management often asks 'where should we start in quality control?' and this article recommends that they need to acquire some knowledge. The need for quality control is diagnosed by analyzing the costs in terms of bad product, where it originates, etc. Decisions on the extent of the quality control function are discussed in terms of prescribing action, organization, promotion and appraisal. J.G.D. (5 citations)

65. Shecter, Edwin S.
The First DoD Conference on Quality and Reliability Management
Industrial Quality Control 24 (5): 250-252. 1967.

In August of 1966, the first Defense Conference on Quality and Reliability Management was held by the Department of Defense. More than 130 individuals from various government agencies, including Department of Defense, National Aeronautics and Space Administration, Federal Aviation Agency, General Services Administration, and National Bureau of Standards participated in this extensive review. In addition to the participants, there were more than 100 guests from the Atomic Energy Commission, Food and Drug Administration, National Security Agency and Logistics Management Institute. Nine panels developed 166 recommendations for action. A number of the more important of these recommendations are discussed here. (2 citations)

66. Simon, Leslie E.
The Role of Quality Control as Moderator of Applied Science
Industrial Quality Control 17 (5): 9-14. 1960.

A discourse on the ramifications of quality control in an organization, its duties, its management, its responsibilities in respect to other management units. J.G.D.

67. Simon (Ret.), Major General Leslie E. and Charles A. Bicking
Company Standards and Quality Control
Industrial Quality Control 18 (9): 15-19. 1962.

Describes the place of quality control in a manufacturing company and how its quality standards depend upon attainable specifications and how statistics is used to arrive at these specifications. The position of quality control in the organization relative to central staff level, technical branches, and in the manufacturing level, is discussed. Feed-back of performance information from the sales branch is emphasized. J.G.D. (6 citations)

68. Sindelar, F. J.
Management Planning and Control for an Effective Quality Function
Industrial Quality Control 18 (3): 28-29. 1961.

The management of the quality control function as a integral unit in the organization structure is described. J.G.D.

69. Smiley, R. W.
Government and the Inspector
Industrial Quality Control 20 (10): 4-7. 1964.

Modern missile and space programs require high reliability, but experience in mnay programs has shown that to attain it advances are needed not so much in design as in inspection. These advances are not new inspection technology, but increased rigorousness of inspection. Part must come from the inspector, but management also has to step up to its responsibilities.

70. Soule, Ralph T.
Developing Quality Consciousness
Industrial Quality Control 17 (11): 11-13. 1961.

The stimulation of a quality attitude on the part of employees is the subject of this paper. The roles of direction (objectives), personal contact and selling, and use of advertising are stressed as the main roads to a successful development of the desired state of mind. J.G.D.

71. Stawski, E. and J. Birecki
Operationalism in QC
Industrial Quality Control 17 (10): 20-22. 1961.

The versatility and adaptability of the Defect Control System has supported its plant-wide application. The development of the system has also made it possible to instruct inspection personnel more effectively and to assign work loads more equally. It has established a higher degree of effective communication among all levels of inspection and production personnel, resulting in improved quality perfor-

mance. Through its simplicity, the system has gained complete plant acceptance, and the consequent mutual understanding has led to outstanding reductions in quality costs to the plant and to the corporation.

72. Stroop, Vice Admiral Paul D.
Quality Control Impact on Military Hardware
Industrial Quality Control 21 (6): 298-304. 1964.

To sum up, the huge losses associated with substandard and unreliable hardware are constantly brought to our attention. They represent an ever increasing burden - on our civilian economy and on our combat readiness.

Although proven quality control techniques and methods abound, all too many government and industry units continue to pay lip service to the "Quality Control" concept. When these techniques, together with a determined management approach, are employed, quality and reliability goals are generally met or exceeded.

In spite of automation and other technical advances made in the last decade, a major element in achieving our quality - reliability goals is to obtain the full contribution of all the people involved in the process. The industrial world has become so complex that it is difficult for the individual to recognize his personal responsibility for the end product. Every device available should be employed to focus attention on the contribution that should be made by each employee - no matter what his particular job may be. He must be able to identify his own well-being with the success of the product. He must be persuaded to couple his own reputation to that of his employer. He must be made to feel morally obligated to do his best on his job for the good of his community and his country.

73. Vinson, Arthur F.
Responsibility to Management
Industrial Quality Control 15 (5): 14-16. 1958.

The role of quality control management is examined to see what is in the future. Quality production must be achieved at the lowest possible cost. The advent of automation will require careful analysis of designs to evaluate their quality-ability, much tighter specifications on incoming material will be needed. Close attention to the management of the quality control function and its costs will be required. J.G.D.

74. Walworth. R. B.
Relationship Between Procurement and Quality Control
Industrial Quality Control 18 (1): 26-28. 1961.

The problems of procurement interlaced with quality control is discussed in the article. The problems are viewed through the eyes of procurement by an author sympathetic and understanding of quality control practices and objectives.

75. Wortham, A. W.
Management Development through Quality Control
Industrial Quality Control 17 (12): 5-7. 1961.

The role of the quality control man as a potential source for new management personnel is pointed out. The opportunity must be recognized by the personnel involved since they are in a unique position to learn about all facets of the business operation. J.G.D.

76. Ziegler, Manfred
A Closed Loop Quality Trend Reporting System
Industrial Quality Control 24 (3): 163-167. 1967.

The author describes the steps by which daily inspection and test records and the weekly tab department reports are converted to meaningful indexes for the Monthly Quality Trend Reports for management. Also described are intermediate reports used for personnel evaluation and training and for the company's Product Excellence Program.

APPENDIX 4

SOME TECHNIQUES AND APPLICATIONS OF QUALITY CONTROL IN BUSINESS AND INDUSTRY

1. Altman, Irving B.
The New MIL-STD-414 Sampling Inspection by Variables
Industrial Quality Control 14 (4): 23-27. 1957.

The new standard was prepared to meet a growing need for the use of uniform sampling plans for inspection by variables in Department of Defense operations. The variables sampling plans may be applied in determining conformance of a single quality characteristic when it can be measured on a continuous scale and this measurement data is normally distributed. It is anticipated that the sampling procedures incorporated in this standard will have particular applicability for inspection and testing that is costly or destructive.

2. Altman, Irving B.
Progress in Department of Defense Reliability Programs
Industrial Quality Control 18 (9): 10-15. 1962.

The first part of the article summarizes the DoD program for developing and publishing a comprehensive series of statistical sampling standards for application in quality control and reliability testing. These applied mathematical procedures have been the fruits of a joint research program supported by Department of Defense activities for the past eleven years. Many of these sampling procedures have been used extensively both in Government and industry not only in the United States but also in various countries abroad.

The second part discussed significant developments and progress in DoD reliability programs as evidenced by recent publications issued by the Office of the Secretary of Defense and the Army, Navy, and Air Force activities. (31 citations)

3. Auerbach, M. E., E. L. Bauer, and F. C. Nachod
Spectrophotometer Wavelength Reliability
Industrial Quality Control 20 (11): 45-47. 1964.

A study of calibration data on spectrophotometers displays the range of values that may arise among laboratories. Operator variations within laboratories were examined graphically. J.G.D. (3 citations)

4. Baker, Robert A.
Subjective Panel Testing
Industrial Quality Control 19 (3): 22-28. 1962.

Subjective measures are used when there is either no quantitative measure available or when the quantitative measure is extremely costly and time consuming. The article discusses the use of panels,

their selection, training, size, motivation, fatigue factors, observer interactions. Statistical treatment of such data is discussed, methods of testing and methods of scoring. Some of the basic ideas expressed apply to other areas where subjective panel evaluations are made as a measure of customer satisfaction. J.G.D. (23 citations)

5. Barker, Capt., J. A.
Slicing the Pie
Industrial Quality Control 18 (12): 4-6. 1962.

A discussion of reliability and the role of people in its achievement. J.G.D. (2 citations)

6. Barter, K. E.
Sample Sizes for an Acceptance Number of Zero
Industrial Quality Control 24 (6): 322-324. 1967.

If you are required to accept or reject small isolated lots based upon examination of the smallest possible sample, this method will be of interest to you. Upon specifying the desired probability of acceptance for a given number of defectives in a particular lot size, the required sample is easily obtained as a function of two tabled factors. (2 citations)

7. Bauer, William C.
A Simple Practical Method for Chart Control
Industrial Quality Control 16 (9): 12-13. 1960.

A description is given of a simple control chart which includes the specification limits as well as the usual control chart thus necessitating the use of only one chart. No calculations are required but sample range is evaluated through use of a bull's eye, a rigid circle whose radius is equal to the upper control limit for the range. J.G.D.

8. Bicking, Charles A.
Statistical Aids to Decision Making
Industrial Quality Control 15 (2): 7-12. 1958.

This article describes a direct application of probability concepts to management decisions. The basic principles used are similar to those applied in statistical quality control and design of experiment at operating and technical levels of business. A general pattern of analyzing problems, described popularly as Design for Decision, has been applied to real examples of decision making.

The aim is to combine careful estimates of costs and of returns with equally carefully estimated probabilities of the occurrence of various outcomes of alternative courses of action. When costs, returns and probabilities are combined, the value or desirability of the alternatives are expressed in quantitative terms. A comparison of the desirabilities of the several possible courses of action enables the manager to choose the most favorable one. (2 citations)

9. Bicking, Charles A., Charles M. Bicking, Timothy A. Donovan, and Theodore S. Sosnowski
Information Retrieval for Quality Control and Related Fields by SWIFT LASS and SWIFT SIR
Industrial Quality Control 24 (4): 212-217. 1967.

SWIFT LASS, an adaptation of the Key Word in Context system of literature searching, employs a permuted alphabetical listing of selected signal words from the titles of articles in periodicals. In addition, a code for field of application based on the ASQC Literature Classification System provides another strong clue in searching for articles on Quality Control or other specialized subjects. Ten different information categories are indexed. An example is given for articles on the subject of interlaboratory testing.

SWIFT SIR, a similar system for retrieval of scientific information, adapted for finding internal reports or data files, employs an alphabetical listing of selected signal words from the report titles. In addition, each item is identified by field of application using a code broad enough to cover the range of interests of the organization. Twelve other information items relating to each report, including a sequence number, are identified by an appropriate code. An example is given of an actual index of reports issued during a trial period. (5 citations)

10. Bingham, Jr., R. S.
Practical Aids - Tolerance Limits and Process Capability Studies
Industrial Quality Control 19 (1): 36-40. 1962.

This note emphasizes the advantageous use of statistical tolerance limits as the final step in a process capability study. Latest tables using the range and average range are illustrated. The actual confidence level of a statement of the type $X \pm 3R/d_2$ is discussed. (6 citations)

11. Bingham, Jr., R. S.
Quality Control Applications in the Coated Abrasives Industry
Industrial Quality Control 19 (5): 5-12. 1962.

The application of statistical quality control discussed ranges from the very simplest form of control chart to the use of sophisticated experimental designs to study a complex process. The use of product variation to learn about the production process and what it can tell the production worker with respect to improvement of the product is interestingly told. J.G.D. (9 citations)

12. Bingham, Jr., Richard S.
SQC Training for the Chemical Industry
Industrial Quality Control 18 (10): 15-18. 1962.

This article discusses what chemists and chemical engineers need to know about statistical quality control and other statistical methods, where they should seek these ideas, what types of training should be of interest to them, kinds of problem orientation they are apt to have, the pros and cons of undergraduate and postgraduate training, the possibilities of on-the-job training, what's being done by interested societies and what's missing. With such tremendous scope, it should be evident that this article aims to stimulate discussion, not exhaust it.

13. Brabant, Edward M.
Does Small Business Need QUALITY CONTROL?
Industrial Quality Control 18 (12): 6-10. 1962.

An interesting account of the variety of production problems in a small business before the installation of quality control. The author's conclusion is 'yes', small business can and indeed must use quality control to remain competitive. J.G.D.

14. Breunig, H. Latham
Some Uses of Statistical Control Charts in the Pharmaceutical Industry
Industrial Quality Control 21 (2): 79-86. 1964.

Statistical control charts instituted seven years ago in the Analytical Chemical Control Laboratories of a full-line ethical pharmaceutical house have proven extremely useful not only for routine quality control in this and other areas, but also in directing attention to situations where process studies have led to better control of the finished product. Control charts have proven to be a valuable tool in dramatizing the results of special studies for management. (21 citations)

15. Burrows, G. L. and C. Silber
Tolerance Limits for Small Lots
Industrial Quality Control 19 (8): 16-20. 1963.

The selection of an attributes sampling plan which will provide the desired assurance, with a minimum sample size and in the face of less than perfect inspection classification, is augmented by the material in this article. Minimum sample sizes and operating curves are presented for the cases of one-sided and two-sided imperfect inspection. J.G.D. (6 citations)

16. Budd, Jr., Edward G.
Quality in the Automotive Industry
Industrial Quality Control 17 (12): 8-10. 1961.

The author's opinion, as expressed in this article, relative to the importance of quality control is summarized in his closing statement.

"The American Society for Quality Control and its members, by developing and propagating the principles of quality control, is doing a great deal to help American industry meet the rigorous challenge of the newly re-established and re-equipped industrial nations of the world. It is helping to teach a fundamental truth - that it is cheaper to make a good article than a poor one."

17. Cafaro, J. A. and H. D. Voegtlen
The Measurement and Specification of Product 'Abilities"
Industrial Quality Control 18 (9): 20-26. 1962.

The problem of evaluating customer satisfaction is discussed. A suggested outline for quality administration and coordination is discussed under the aspects of quality maintenance and quality improvement and the steps required to achieve increased reliability and maintainability of the product. The necessity for identification, measurement, specification, control, and improvement of the product is stressed. J.G.D. (3 citations)

18. Cartin, T. J.
Quality Capability at less cost
Industrial Quality Control 18 (8): 14-16. 1962.

A case example describing how a statistical approach to a quality problem resulted in reduced costs for inspection and an improved product. The plan involves rapid feed-back of inspection information. J.G.D.

19. Chateauneuf, Robert
Modern QC Pays Off in Woodwork
Industrial Quality Control 17 (3): 19-25. 1960

The organization of statistical quality control in a cabinet factory is traced, based on the principle of quality cost vs. production value. A plant-wide quality-consciousness was created first. Quantity of inspection was replaced by an emphasis on superior quality. Control charts were used and performance reported at all levels, with resulting savings.

20. Clark, C. R. and W. J. Zimmer
Two Approaches to AOQ
Industrial Quality Control 20 (7): 23-33. 1964.

There are two distinctly different approaches to the AOQ concept as applied to lot sampling. The difference in these approaches depends on the definition of the abscissa of the AOQ curve. The abscissa can be regarded as either the exact fraction defective of lots submitted for inspection or as the process average of lots submitted for inspection when each lot can be considered a random sample from a universe having a given fraction defective (the process average). Many authors are rather vague on this distinction and a few appear to be incorrect in their interpretations. This article discusses the differences between these approaches and their effect on the AOQ and derives equations for the AOQ for several different situations within each approach. (11 citations)

21. Clifford, Paul C.
Control Charts Without Calculations
Industrial Quality Control 15 (11): 40-44. 1959.

The usual control chart for variables requires a separate data sheet, a reasonable amount of arithmetic, and two charts. The computation of control limits frequently requires the elimination of some of the original data. And for shop personnel there is still confusion between control limits and specification limits. A method is presented in which individual measurements are plotted, thus eliminating the data sheet. Control limits are established by a process of measuring and counting. Such charts lend themselves to a variety of applications, some of which are considered. In particular this procedure gives a simple comparison of process capability and process achievement. (8 citations)

22. Cocca, O. A.
An International Standard for Attribute Sampling
Industrial Quality Control 21 (5): 249-253 1964.

An examination of MIL-STD-105D in terms of how it has been modified from 105C. The operational mechanics and needs of the user are discussed. This reflects the work of the American-British-Canadian

Working Team in the development of an international standard for sampling attributes. J.G.D. (7 citations)

23. Cone, A. F. and H. F. Dodge
A Cumulative-Results Plan for Small-Sample Inspection
Industrial Quality Control 21 (1): 4-9. 1964.

While application of the cumulative-results plan is not a panacea, it does furnish a systematic and automatic method for attacking quality problems and for evaluating the effectiveness of the solutions and actions designed as corrective measures. In addition, a substantial improvement in the quality of accepted material has been realized without resorting to either increases in sample sizes or attempts to screen good product from bad, both of which are time-consuming and expensive operations.

The Quality Assurance Agency has incorporated the inspection suspension feature of the lot-by-lot cumulative-results plan into continuous sampling. Furthermore, a study is in progress to determine whether cumulative results should be extended to all submitted material, with consideration being given to the possibility of employing reduced inspection for material that is verified as having been produced by a satisfactory process.

The cumulative-results plan presented herein as an addendum to the normal lot-by-lot acceptance procedures and criteria can be quite generally applied. This method should be especially advantageous for application to standard inspection systems for percent defective (or defects per hundred units) inspections in those situations where small sample sizes are necessary, as, for example, when destructive and/or costly tests are involved. (15 citations)

24. Connell, Jr., F. M.
Statistical Quality Control of Clerical Operations
Industrial Quality Control 24 (3): 154-162. 1967.

This article describes in some detail the quality control program and procedures which were developed to permit Blue Cross personnel to do a better, more accurate and more effective job of processing Blue Cross insurance applications and claims. The benefits to the company and improvements in customer service are summarized. (12 citations)

25. Craig, C. C.
Performance Characteristics of Acceptance Sampling Plans for In-Use Testing of Electric Meters
Industrial Quality Control 18 (3): 18-20. 1961.

The paper describes the performance of a sampling plan for electric meters. The operation of the plan is that a sample from a population of meters believed to have the same characteristics is drawn each year; these are tested, if the sample passes no further action,if it fails a 100% inspection and ractification program is gotten under way. This is in contrast to 100% inspection on a periodic basis. (1 citation)

26. Danziger, L.
Graphic Sampling Plans For Consumer Acceptance of Electronics Components
Industrial Quality Control 21 (6): 312-317. 1964.

Sampling plans have previously been derived for testing a minimum mean life with a guaranteed consumer protection. These non-replacement plans are examined in a different light, expanded, graphed, and compared to replacement plans. A table is derived for quickly approximating the operating characteristic curve for any choice of consumer-oriented plan, thus enabling one to evaluate the protection that the plan affords the producer. All of the plans are based on the assumption that the distribution of times-to-failure is exponential. (5 citations)

27. DeBusk, Ralph E.
Experience in Evolutionary Operations at Tennessee Eastman Company
Industrial Quality Control 19 (4): 15-21. 1962.

A report of experience in using the evolutionary operation approach in studying the influences of different factors on a production process. It was applied to fifteen or more different processes with the general experience that production was increased, the experimental costs were low compared to the savings produced, and the operating personnel gained a much better understanding of the important operational variables and why it was important to follow the recommended operating procedures. J.G.D. (6 citations)

28. DiPolo, E. John
Quality Attitudes - Turn Concepts into Benefits
Industrial Quality Control 18 (11): 49-55. 1962.

A series of examples are given displaying how an effective quality control function in a company can contribute to the quality image of the organization. J.G.D.

29. Diviney, Thomas E. and Nasim A. David
A Statistical Technique for Product Acceptance
Industrial quality Control 18 (8): 16-18. 1962.

This article exemplifies the use of the Kolmogorov-Smirnoff test diffentiating between acceptable and not acceptable raw material in a manufacturing process. J. G. D.

30. Diviney, Thomas E. and Nasim A. David
A Graphical Application of Military Standard 414
Industrial Quality Control 19 (10): 13-14. 1963.

This article shows the kind of acceptance-rejection region one gets in two-limit acceptance sampling. As a graphical approach, it provides a sample method for an inspector to determine Lot Disposition when using MIL-STD-414.

31. Eagle, E. L.
Reliability Sequential Testing
Industrial Quality Control 20 (11): 48-52. 1964.

The author has found that the Reliability Analysis Chart is a very useful tool for reliability testing of all kinds of equipment. The advantages are:

1. Being sequential the data can be plotted on the chart as soon as they come from the test, consequently test costs for very good or very poor equipment can be minimized by early termination because the chart will indicate a quick decision.

2. For equipment that is close to the MTBF-requirement, where the test is apt to run on indefinitely before a decision can be made, the procedure provides a means for terminating and decision-making after ten or more Θ-units of time.

3. Because the time axis of the chart if plotted in normalized Θ-units rather than actual operating time, a simgle chart can be used to analyze several equipments at once even though they may have different MTBF requirements.

32. Ennerson, Jr., Fred and Mark Manning
Test Performance Charts
Industrial Quality Control 16 (3): 8-9. 1959.

The test performance chart is described and its simplicity is emphasized. The plotting is simple enough that it can be kept up to the minute and is instantly revealing of any adverse trends so corrections may be made promptly. J.G.D.

33. Enrick, Norbert L.
VARIATIONS FLOW ANALYSIS for Process Improvement
Industrial Quality Control 19 (1): 23-29. 1962.

Variations Flow Analysis is a technique for evaluating the transfer of variations in stock, when the product from several machines at one processing stage is fed randomly to the several machines of the succeeding stage. This article describes procedures, based on modifications of range methods for analysis of variance, which have been found of value in a large number of applications. The methods are illustrated with examples from yarn manufacture, but parallel applications in chemical processing and other industries are apparent. (15 citations)

34. Ferrell, Enoch B.
A Median, Midrange Chart Using Run-Size Subgroups
Industrial Quality Control 20 (10): 22-25. 1964.

The properties of control charts are here applied to the situation where the observations are taken in serial order and then the occurrence of runs up and down is plotted. This offers a device for separating short-term from long-term trends. Some mathematical developments are presented together with some results from simulation studies. J.G.D. (2 citations)

35. Finley, Arnold D.
The Old Order Changeth
Industrial Quality Control 19 (6): 5-7. 1962.

A plea for reliability to become a fact of life in the tooling and machining industry. J.G.D.

36. Foster, Julie A.
Kolmogorov-Smirnov Test For Goodness of Fit...what it is...how to apply it
Industrial Quality Control 18 (7): 4-8. 1962.

The Kolmogorov-Smirnoff test is a distribution-free procedure. The only assumption necessary is that the distribution be continuous. The test requires the fitting of the cumulative distribution for the data and for the hypothesized distribution and observing the point of maximum difference between them. This maximum absolute difference is compared to tabulated values in testing for goodness of fit. The paper presents examples for the exponential and normal distributions. J.G.D.

37. Freund, Richard A.
Acceptance Control Charts
Industrial Quality Control 14 (4): 13-23. 1957.

The acceptance control chart provides a means of establishing acceptance criteria that can be used to control shifts in process levels. It is useful whenever there are sources of variability in addition to the random, inherent variability that must be expected to enter into a production process and that can be tolerated within certain bounds. The Acceptable Process Level (APL) and Rejectable Process Level (RPL) values, which are described in Acceptance Control Chart procedures, provide specific information concerning the degree of process-level shifts that will be tolerated before a process is rejected as unsatisfactory. The Acceptance Control Limit (ACL) is the line that serves as the acceptance criterion; an average plotting inside the Acceptance Control Limit indicates that the process is operating at an acceptable level, while an average plotting outside the limit indicates that the process is too far from standard to be acceptable and can be expected to yield too high a percentage of unsatisfactory product. In addition to these acceptance functions, this technique maintains many of the control elements of the usual control chart procedures.

Although only four examples have been included in the description of this technique, the field of applications is felt to be very great. The technique should be useful not only for any type of batch or small-lot production, but also for many of the "continuous" processes where replenishment of chemicals is made periodically, raw material from different batches added, mechanical adjustments made, etc. In addition, this approach should prove quite practical in the analysis of interlaboratory or interplant studies in which some allowances usually must be made for different laboratory or plant process-levels. (6 citations)

38. Freund, Richard A.
Variables Control Chart
Industrial Quality Control 16 (11): 35-41. 1960.

Quality control problems in the chemical (and other) industries often require the use of techniques not commonly cited in the literature. One such technique that should be of particular value for the control of either batch-process or continuous-process operations is the Acceptance Control Chart. The Acceptance Control system is designed to provide action criteria that are based on consideration of the risks of accepting unsatisfactory processes as well as the risks of rejecting acceptable ones. Recognition is given the fact that a certain amount of variation in process level often can be tolerated in addition to the normal random variability, and that assignable causes producing level shifts within some acceptable range should not be flagged as "out of control." In essence, the process control operation is related to the quality requirements defined in the specifications.

A review of the fundamental assumptions of the Shewhart system is undertaken in order to contrast the purposes of the Shewhart Control Chart with those of the Acceptance Control Chart. This review is followed by a description of the Acceptance Control system and a specific detailed example of its application. (6 citations)

39. Freund, Richard A.
Graphical Process Control
Industrial Quality Control 18 (7): 15-22. 1962.

The purpose of this article is to consider some recent work in the area of control charts and to show the relationship of these newer developments to the Shewhart Chart. The new charts to be discussed are the Cumulative Sum Chart, the Geometric Moving Average Chart, and the Acceptance Control Chart. (17 citations)

40. Gause, G. R.
The Quality Survey
Industrial Quality Control 20 (7): 17-20. 1964.

The quality survey is used to detect and identify the conditions which need to be corrected. It is, in the case reported, a co-operative activity by all segments involved in the product. Experts are used in each area to make the survey, and participate in preparing the report of the survey. The formal organization and the setting aside of a specific amount of time for the survey is more productive than attempting to operate on the basis of daily or routine observations by these same experts. J.G.D.

41. Gilman, James R.
Quality Reports to Management
Industrial Quality Control 19 (11): 15-17. 1963.

Describes quality reports to management which give ratings on each inspector each week, with the weekly ratings displayed in chart form for the year to date. J.G.D.

42. Gilmore, Harold L.
Vendor Quality Rating
Industrial Quality Control 18 (8): 19-21. 1962.

The formulation and use of a vendor rating scheme is described. Each vendor rating was made dependent upon current information so that changes in vendor quality would be readily apparent. J.G.D.

43. Gilmore, Harold L.
Cost Reduction and Control in the Proposal Stage
Industrial Quality Control 18 (10): 23-24. 1962.

A proposal specification is suggested which would take a careful look at all facets of the item under consideration and permit of realistic cost estimates. J.G.D.

44. Gilmore, Harold L.
Controlling Inspection for Better Quality and Improved Reliability
Industrial Quality Control 19 (1): 7-9. 1962.

The application of inspection personnel to improve quality and reliability is outlined. This was accomplished through use of a carefully prepared quality control manual and the use of inspection detail cards. Possible defects are described, acceptable quality levels established and inspection and test procedures standardized. A routine procedure for inspecting and maintaining test equipment was established. J.G.D.

45. Gilmore, Harold L. and Laurent Paquin
Vendor Rating For Missile Reliability
Industrial Quality Control 20 (3): 13-16. 1963.

Many of you, I am sure, have listened to talks on quality control techniques only to make the observation that the techniques discussed do not appear to be practical day-to-day tools.

It is with this idea in mind that I have presented this article. I feel that we can safely say that this vendor rating program really accomplishes its purpose.

To date the system has satisfied its intended function, i.e., providing a means of evaluating and controlling vendors, and thus insuring that vendor supplied items will not degrade inherent missile reliability due to poor quality. Proof of this is the fact that AVCO has satisfactorily demonstrated the contractual reliability requirements of its re-entry vehicle on the Titan and Minuteman Missile Programs. In addition, this system and the management report has been put to a great many other management uses some of which have been pointed out earlier. Both vendors and AVCO purchasing personnel approve of the system and respond in a positive manner to the recommended action resulting from the various analyses. This action in the area of procured material has definitely contributed towards the attainment of the above-mentioned contractual reliability requirements.

Vendor rating is not offered as the answer to missile reliability. But when a product consists of a high percentage of procured items, the operational reliability for the most part lies in the hands of the vendors. Unless they are properly controlled, rated and monitored inherent reliability will no doubt be degraded and there will be no basis upon which to select those vendors contributing most to the maintenance of system reliability. (10 citations)

46. Ginsburg, H. and Shaffer, D. H.
An Interpretation of Truncated Sequential Life Tests
Industrial Quality Control 21 (4): 186-191. 1964.

Sequential life-test procedures possess an average efficiency which is greater than that for non-sequential procedures. However, life-test programs must sometimes be prematurely terminated. This article offers methods for extracting meaningful information from the test data already obtained by the time the test had to be stopped. Approaches using the likelihood function and prior knowledge are given. (6 citations)

47. Greb, Donald J.
Sequential Sampling Plans
Industrial Quality Control 19 (11): 24-48. 1963.

Sequential sampling by attributes is an excellent industrial inspection method. Its use has been limited by the somewhat difficult calculations associated with setting up inspection. This article presents sixty plans with AOQL as the primary functional characteristic. These plans cover the range of normal usage and no calculations are necessary to use them. The appendix covers the formulation of the plans and includes some hitherto unpublished theoretical aspects of sequential sampling plans. (10 citations)

48. Gumbel, E. J.
A Simple Analysis of Fatigue Data
Industrial Quality Control 20 (11): 14-17. 1964.

In a recent paper Alan Plait published elaborate tables of the Weibull distribution and gave graphical methods of estimating the parameters. The aim of this article is to derive an analogous graphical procedure which disperses with the use of these tables and to show a simple method for estimating the parameters which requires only a minimum of basic analysis.

Our aim is to equip the engineer interested in the study of fatigue, reliability and similar phenomena, with a quick and safe method which

has successfully been applied for years. It requires only the use of a probability paper. The table necessary for the estimation of the parameters is given in the text. The calculations needed are conventional, namely the use of the mean and standard deviation. The method is applicable provided that the minimum life is zero. (4 citations)

49. Hecht, Bernard
The "SWAP" System of Quality Improvement
Industrial Quality Control 18 (11): 15-21. 1962.

A system of quality improvement in a company is described. The basic premise is that by feed-back of information on discrepancies a rapid improvement in quality can be achieved. The adoption of the procedure depends on a careful indoctrination of management and all workers involved in the program will need to be prepared psychologically to cooperate in the program since its success in part depends on this. J.G.D.

50. Heeremans, J. H.
Determination of Optimal In-Process Inspection Plans
Industrial Quality Control 18 (12): 22-37. 1962.

Describes the development of an in-process inspection plan taking into account costs of inspection, cost of rework, sample size to give optimum plans under various conditions. J.G.D. (4 citations)

51. Hickey, Jr., William J.
An $X00,000 Saving by Sampling Paperwork
Industrial Quality Control 20 (12): 6-9. 1964.

An account of a sampling scheme applied to travel vouchers in the U.S. Department of Agriculture. All vouchers were examined on the one hand and on the other a sample of these were examined. There was a considerable savings by using a sample and paying out on the low percentage (8.6%) of vouchers that were not correct in contrast to complete examination. J.G.D.

52. Hill, David A.
Quality Engineering Applied to Incoming Material
Industrial Quality Control 16 (9): 17-29. 1960.

The basis and reasons for using vendor ratings as a means of improving the quality picture is described and discussed at length. The article is illustrated with a series of bar charts and is written in a non-technical style. J.G.D. (17 citations)

53. Hillier, Frederick S.
$\bar{X}$ Chart Control Limits Based on A Small Number of Subgroups
Industrial Quality Control 20 (8): 24-29. 1964.

A common rule of thumb is that conventional $\bar{X}$ chart control limits should be based on at least 25 subgroups. This article presents information for evaluating these control limits when they are based on a small number of subgroups. Then, a method is presented for setting $\bar{X}$ chart control limits that can be reliably used regardless of the number of subgroups. (17 citations)

54. Huitt, Ralph K.
The Federal Government and Quality Control
Industrial Quality Control 24 (3): 151-154. 1967.

There are three principal areas of activity in our modern economy which require the application of quality control that involve the Federal Government. These are the quality control of natural resources, of manufacture of goods and products where public health or safety are involved, and of internal governmental operations and programs themselves.

55. Jacobs, Richard M.
Low Cost Multiple Sampling
Industrial Quality Control 14 (10): 11-13. 1958.

This article has attempted to present a proposal for reducing the administrative costs of using low cost multiple sampling techniques without altering to any great extent the consumer and producer risks.

The proposed system, utilizing the combined sampling plans for critical, major and minor defects has the same degree of success for any combination of selected AQL values for the three classifications as long as they are two steps apart as illustrated.

The weighting factors, as proposed, permit the use of one sampling plan per component and the total number of defects is a summation of the proportionate values of each defect found. This summation, when compared with the acceptance and rejection number in the sampling plan determines acceptance or rejection of the lot.

It also allows the manager to more readily stabilize his inspection load as the size of samples per lot would not be indeterminate. They would be more constant and scheduling becomes another cost saving feature. Thus the ratio of one critical, two majors or four minors for each rejection or acceptance number allowed was evaluated and found to be economically feasible. A multiple sampling plan complete

with accompanying instructions on the face of the plan is illustrated in Table II.

The method described has been successfully used in three major industries and in about ten companies for the past eight years. It has been accepted by some inspection service of the Government as fulfilling the quality control requirements of incoming inspection operations.

56. Jacobs, Richard M.
Potential Applications of Reliability Techniques in Commercial Product Lines
Industrial Quality Control 19 (2): 11-14. 1962.

This describes possible applications of reliability techniques in commercial situations rather than to space or defense situations. Use of design of experiments, product design reviews, analysis of field data (feed-back) are indicated as means of improving the customer's product. (13 citations)

57. Jacobson, A. F.
Establishing Performance Indexes
Industrial Quality Control 16 (12): 4-6. 1960.

The use of quality control for providing a measure of the quality of service rendered by a telephone company is discussed. The use of service indexes is described and their influence on management decisions is indicated. (See also R. A. Newman IQC 16: 7-10. 1960) J.G.D.

58. Jacobson, Henry J.
Management Methods of Inspection Control
Industrial Quality Control 21 (1): 24-28. 1964.

1. Accuracy of any analysis depends on the accuracy of the original data.
2. Just because a part has been inspected and passed by an inspector does not mean that particular part is good or that it meets specifications.
3. Our data is only as accurate as the instruments we use, the caliber and physical fitness of the inspector and the conditions under which the inspection was made.
4. Inspectors are not born to the job. Most of them drift into it without proper training and learn little thereafter.
5. You can select psychological tests, which, when matched with supervisors ratings, actual tests for defects and visual acuity or hearing tests, can give you a picture of the kind of inspec-

tion you have and what you can do about it.
6. Visual testings is a must for all inspections and should be made a job requirement.
7. You can convince the union to go along with your program if you approach them in the right manner.

59. Jaquez, Ron
K Factors For Computing Tolerance Limits For Normal Distributions
Industrial Quality Control 19 (5): 27-28. 1962.

Tolerance limits involve the use of K factors which adjust the lengths of the intervals to allow for sampling errors in the mean and the variance. Using an approximation formula for K a table of values ranging from a proportion of 0.80 to 0.99998 was computed for a range of sample sizes. The table based on the approximation showed rather good agreement with more precise tables with the values from the approximation being larger than the correct values. J.G.D. (2 citations)

60. Johnson, N. L. and F. C. Leone
CUMULATIVE SUM CONTROL CHARTS - Mathematical Principles Applied to their Construction and Use
Industrial Quality Control 18 (12): 15-21. 1962.

This article, which will be published in three parts, gives much of the mathematical development behind cumulative sum charts. It makes valuable reading for the serious student of control chart techniques and related statistical methods. It will also help anyone wishing to make use of the cumulative sum control chart to know the assumptions, characteristics and field of usefulness of the methods. Part II will appear in the July issue and Part III will appear in the August issue.

Cumulative sum control charts are related to sequential sampling procedures. Construction of such control charts for the mean are described, together with the requisite tables. A comparison with standard control charts indicates that the cumulative sum control chart is more sensitive to changes in the mean. J.G.D. (13 citations)

61. Johnson, N. L. and F. C. Leone
CUMULATIVE SUM CONTROL CHARTS - Mathematical Principles Applied to their Construction and Use Part II
Industrial Quality Control 19 (1): 29-36. 1962.

Cumulative sum control charts are applied to sample variances and sample ranges. The mathematical details are given together with a table of control limits. An example is presented using ranges. J.G.D.

62. Johnson, N. L. and F. C. Leone
CUMULATIVE SUM CONTROL CHARTS - Mathematical Principles Applied to Their Construction and Use - Part III
Industrial Quality Control 19 (2): 22-28. 1962.

The use of cumulative sum control charts is, in this third and last paper in a series, applied to Poisson and Binomial variables each with an example and appropriate tables. In addition the establishment of control limits by various empirical methods is described.

The three papers represent a comprehensive collection on the theory and use of cumulative sum control charts. J.G.D.

63. Katke, M. L.
Customer Quality Requirements
Industrial Quality Control 20 (12): 4-5. 1964.

General interest article on the quality view of a large automobile manufacturer and how this is related to the extended warranties now offered. J.G.D.

64. Kazmierski, A. S.
Visual Defects - A Case Study
Industrial Quality Control 23 (11): 530-531. 1967.

The problem of acceptable limits on visual defects in a consumer product has been attacked from many different angles. Certainly many such decisions, despite the analysis used, are arbitrarily made only from within the organization responsible for making and selling the product. Such an approach is liable to lead to standards that are extremely conservative and therefore expensive. In this article, a survey-type approach is outlined in which the consumer played a major role in deciding to what standards a manufacturer should work. The results were both surprising and profitable.

65. Keefe, Gordon J.
Attribute Sampling - MIL-STD-105
Industrial Quality Control 19 (10): 7-12. 1963.

The historical development of MIL-STD-105 is presented. Much of the thinking that went into the various revisions and modifications is displayed in the discussion. From the American development under the Department of Defense has come a proposed international standard which reflects a joint American-British-Canadian effort to offer such a document. J.G.D. (4 citations)

66. Kidwell, John L., Nicholas L. Squeglia, and H. J. Lavender
Escape Probability as a Systems Design Consideration
Industrial Quality Control 23 (4): 166-171. 1966.

Escape Probability is defined as the chance of a defective item getting past an inspector and causing a system failure. The use of this concept in both design and production stages is shown to be a powerful tool for upgrading quality. Practical applications are given. (22 citations)

67. Larson, John A.
Improving Supplier Performance
Industrial Quality Control 19 (10): 4-7. 1963.

Although much care may be exercised in selecting the best potential suppliers, it often happens that these suppliers are not capable of meeting the buyer's exacting requirements. This is evidenced by delayed deliveries and the production of defective material. The question which naturally follows is, "What can be done to improve supplier performance?"

Experience shows that most supplier-buyer problems develop from three conditions. Some arise as a result of misunderstanding or misinterpretation of product requirements, others are caused by the lack of adequate facilities and production capabilities, while still others result from a breakdown of manufacturing and administrative controls over the production process.

This article suggests a program for minimizing these problem areas and thereby improving supplier performance. The basic elements of this program include (1) a complete definition of the product to be made, (2) an indoctrination of the supplier to assure a complete understanding of the buyer's requirements, (3) an evaluation of the supplier's capabilities with reference to the buyer's requirements, (4) the removal or correction of any incompatibilities between the supplier's capabilities and the buyer's requirements, (5) an appraisal of the supplier's performance, and (6) the promotion of the supplier's continued growth.

The supplier assistance and development process is no simple task but requires a continuing effort to assure a satisfactory supplier-buyer relationship. Only in this way can the procurement goals of acceptable quality, timely delivery, and reasonable cost be attained.

68. Lieberman, Alfred
Sequential Life Testing Plans for the Exponential Distribution
Industrial Quality Control 16 (2): 14-18. 1959.

The construction of plans, the choice of a plan, an example, are some of the topics covered. The plans under consideration are sequential and for life testing where the exponential distribution may be assumed. J.G.D. (3 citations)

69. Lieberman, Gerald J.
Tables for One-Sided Statistical Tolerance Limits
Industrial Quality Control 14 (10): 7-9. 1958.

The construction of one-sided tolerance limits is described, a table of tolerance factors for the normal distribution is included. J.G.D. (6 citations)

70. Lundvall, D. M.
Control Potential Cost Measurement
Industrial Quality Control 20 (4): 14-20. 1963.

A description of a quality capability and a quality cost evaluation system applied to a large manufacturing company. J.G.D.

71. Maltenfort, George G. and R. E. Boedeker
Sampling of Paper and Paper Products
Industrial Quality Control 14 (11): 19-23. 1958.

The procedures of sampling to select the sample units from a lot are described. Aids are given for determining sample size. The process is exemplified by an example carried through from sample solution to final disposition, accepted or rejected. J.G.D. (10 citations)

72. Mandelson, Joseph
Sampling
Industrial Quality Control 19 (1): 5-6. 1962.

An elementary discussion on use of samples, size of sample, simple random sample, stratified random sample and of acceptance sampling. J.G.D.

73. Mandelson, Joseph
The Statistician, The Engineer, and Sampling Plans
Industrial Quality Control 19 (5): 12-15. 1962.

The author criticizes recent developments in sampling plans in that the consequences of using a particular plan may not be understood by the user. J.G.D. (8 citations)

74. Mandelson, Joseph
Sampling Plans for Destructive or Expensive Testing
Industrial Quality Control 23 (9): 440-450. 1967.

The author presents a simple "cook-book" procedure that can be used directly by engineers or other non-statisticians for designing single- and double-sampling plans for destructive or otherwise expensive testing. These plans are referred to as "optimum" sampling plans because they are based on minimizing the sum of the cost of testing plus the cost of rejection. The sampling concepts of lot tolerance fraction defective, producer's risk, consumer's risk, and their associated costs are discussed only enough to understand how to work with the plans. (5 citations)

75. Marash. Stanley A.
Performing Quality Audits
Industrial Quality Control 22 (7): 342-347. 1966.

The quality audit may be applied to the operations that result in the end product - for example welds in a ship-yard. Thus a sample of welders selected and then carefully rated on their welding practices. Each individual is scored on a list of agreed upon elements of the job, these together with a weight attached to each element can be used to produce a quality rating for each individual. This furnishes a means of upgrading training and, eventually, of the final product being produced. J.G.D.

76. Marguglio, Benjamin W.
Tolerancing by the Engineering Semi-Graphic System
Industrial Quality Control 18 (10): 30-35. 1962.

Describes a simple, engineering oriented method of arriving at tolerances for multi-piece assemblies. J.G.D.

77. Martin, Cyrus A.
The Cost Breakeven Point in Attribute Sampling
Industrial Quality Control 21 (3): 137-144. 1964.

A scheme has been described whereby cost estimates can be used to compute a critical point. This criterion can be used to make a decision--whether to accept lots with only enough inspection for surveillance and observation of the process average, or whether to impose a tight plan. This is important information. It is wasteful to over-inspect where the consequence of failure is slight. It can be quite costly to inspect insufficiently where the consequence of failure is considerable.

Any selected sampling plan gives some assurance of a degree of quality in the product being turned over to the consumer. It also has a psychological value in that it creates a climate of responsibility for the producer. However, to fail to gear the cost of the plan with its measure and worth of assurance is like setting traffic speed limits without considering the zone. (17 citations)

78. Masser, W. J.
Quality Control Engineering in New Designs
Industrial Quality Control 16 (7): 10-13. 1960.

Quality must be built into the product from its inception. Thus a strong plea is made here that the quality control engineer be included as a member of the team when assessment is made of the product. His experience and knowledge of trouble spots in the past will help to zero in on possible quality problems which could be eliminated or reduced by revision of the product design. J.G.D.

79. McClure, J. Y.
Practical Statistical Quality Control in the Airframe Industry Part I
Industrial Quality Control 15 (10): 11-14. 1959.

The use of statistical quality control on incoming materials can be achieved through use of sampling using such as MIL-STD-105 A. A statistical evaluation of supplier quality should include a program of aiding the supplier to establish an effective quality control program in his own plant. The suppliers should be rated in some way and this used as a basis for selecting suppliers. Tools can be subjected to a quality audit to isolate trouble, formulate work schedules, etc. Diagnostic techniques such as control charts can be used to isolate trouble spots so that corrective action may be taken. J.G.D. (8 citations)

80. McClure, J. Y.
Practical Statistical Quality Control in the Airframe Industry Part II
Industrial Quality Control 15 (11): 17-24. 1959.

Process control can be enhanced by a statistical approach to the process with the objective of learning how it operates, optimum operating conditions, etc. Once the process is operational it should be policed by statistical techniques to detect discrepant product. The individual operators should be provided with test equipment so they can police their own output. An example is described in considerable detail exhibiting the use of simple control charts. J.G.D. (7 citations)

81. McClure, J. Y.
Practical Statistical Quality Control in the Airframe Industry Part III
Industrial Quality Control 15 (12): 5-9. 1959.

The assembly of an aircraft from its component parts will bring out mating problems. Sampling and use of simple charts can be of help in minimizing these. Pre-flight inspections can be aided by examining individual systems, components, geographical areas as e.g. tail assembly, and using a chart showing defects per unit. Another device is to divide the entire aircraft into areas and use an area sampling procedure, i.e., selecting the areas at random at say a rate of 20%. Quality audits should be made to advise management on a cost basis. Everyone from worker to top management should receive suitably designed reports. The three articles by this author indicate the ways statistical quality control can be extremely beneficial in offering a high quality product at a lower cost. J.G.D. (4 citations).

82. McMullen, J. W.
Quality Budget Control
Industrial Quality Control 21 (11): 558-559. 1965.

A discussion of ways to hold down the cost of the quality control function. Effective inspection is least costly, correct defects where they originate, careful design of forms and keep their number to a minimum, look for new inspection techniques, tools, etc., evaluate the quality control unit's effectiveness - all these can reduce quality costs. J.G.D.

83. Meyer, Joseph J.
Statistical Sampling and Control For Safety
Industrial Quality Control 19 (12): 14-17. 1963.

This is a novel application of the concepts of quality control to the field of safety. Plant areas are selected at random and inspected by a small team, hazards, house-keeping, personnel actions are all taken into account under the program rules. Control charts are kept by area and by the entire plant and these focus attention on accident potential, actual occurrences, etc. Valuable information is also obtained respecting the safety attitude of the employees involved. J.G.D.

84. Miller, Jr., R. L. and Albert Woodward
Administration of Plastics Product Standards in 1967
Industrial Quality Control 24 (1): 9-16. 1967.

This article describes the administrative programs by which product quality is achieved and maintained in a global, multiplant plastics operation. The facets described range from raw materials to qualification of products from new plant facilities. The administrative

programs are mutually derived by production and Product Standards management specifically for plastics operations, but may be applicable to other products. The goals of the programs are high caliber statistical quality control systems and people, interplant uniformity, and consistent product performance. (9 citations)

85. Mitten, L. G. and A. Sanoh
The X Warning Limit Chart
Industrial Quality Control 18 (2): 15-19. 1961.

The article discusses a chart form, its construction, and the relevant mathematics. The following quotation describes the advantages:

"$\bar{X}$ charts with optimally placed warning limits are extremely simple to construct and to use. When compared to conventional $\bar{x}$ charts or non-optimal warning charts, they permit very substantial reductions in the amount of inspection required while maintaining the desired level of protection against undetected shifts in the process average."

86. Moore, W. N.
Collection Of Inspection Data Through The Use of Computers
Industrial Quality Control 20 (12): 10-13. 1964.

The use of a computer to summarize daily reports is described. It can be used to generate a variety of useful reports as well as scrutinize the incoming information for accuracy of reporting (data editing). J.G.D.

87. Moyer, John W.
Workmanship - The Key to Improving Quality
Industrial Quality Control 19 (1): 11-17. 1962.

The significance of poor workmanship in industry is demonstrated in this article not only by means of an actual case study, but also by general examples of industry's concern with the problem, as evidenced by the various attempts that have been made to cope with it. Following a discussion of the reasons for the change in worker attitudes and the causes of poor workmanship in modern industry, suggestions are made as to the steps that can be taken to improve the workmanship situation. (32 citations)

88. Nelson, Lloyd S.
Nomograph for Two-Sided Distribution-Free Tolerance Intervals
Industrial Quality Control 19 (12): 11-13. 1963.

The construction of tolerance limits is expedited by use of the prepared nomograph where one is not prepared to assume a specific underlying distribution. J.G.D. (12 citations.

89. Nelson, Lloyd S.
A Simplified Sequential Procedure For Process Adjustment
Industrial Quality Control 20 (1): 15-18. 1963.

An imaginative use of sequential sampling to adjust a process to bring about control is described. The effectiveness of the sequential process in bringing about control is displayed in a table and by graphs. J.G.D. (5 citations)

90. Nelson, Wayne
The Truncated Normal Distribution - With Applications to Component Sorting
Industrial Quality Control 24 (5): 261-268. 1967.

Easy-to-use formulas and graphs are given for the calculation of the mean, standard deviation, and variance of a truncated normal distribution from the mean and standard deviation of the original normal distribution. The formulas and graphs are employed in a number of illustrative problems involving component sorting. (15 citations)

91. Neter, John
Nonsampling Errors In Administrative Applications
Industrial Quality Control 20 (2): 20-26. 1963.

Nonsampling errors can be an important source of error in accounting, auditing, and other administrative applications. Studies cited from outside the field of administrative applications have shown the importance of nonsampling errors in other fields, stressing the need for more work in measuring and controlling nonsampling errors in the administrative applications fields.

Since much effort has been required to demonstrate the importance of statistical sampling methods in the fields of accounting, auditing, and other administrative applications, there may be a tendency to stress sampling errors at the expense of nonsampling errors. This may be particularly true because the statistical methods for measuring and controlling sampling erros have been well developed by now, whereas this is still not the case with respect to nonsampling errors. However, one must always remember that the accuracy of the survey result is affected by both sampling and nonsampling errors and, therefore, that measurement and control of errors should involve both of these types. Since administrative applications are well on the way to using sound probability

sampling procedures, the time is at hand to begin to concentrate more heavily on nonsampling errors, on studying ways of measuring and controlling such errors and, if necessary studying means of reducing them. (11 citations)

92. Newman, R. A.
Establishing Performance Indexes
Industrial Quality Control 16 (12): 7-10. 1960.

The techniques used in the construction of indexes are described. Problems have been met in constructing index rating curves, comparability within and between departments, choice of sampling procedures, gaining acceptance of indexes, the approaches to solution are indicated. (This is a companion paper to A. F. Jacobson IQC 16: 4-6. 1960)

93. Norquist, Warren E.
Improve Material Utilization - Engineer Your Scrap Accounts
Industrial Quality Control 18 (11): 27-29. 1962.

Describes a systematic approach to the minimization of losses through unavoidable scrap. Such materials as paint, plastic and enamel have proven controllable by the same procedure being applied to them. J.G.D.

94. Noyes, Charles E.
Quality Control Analysis of Individuals
Industrial Quality Control 19 (6): 15-17. 1962.

The suggestion is made that perhaps the employee can be subjected to studies similar to those applied in the quality control of production variables. That is, take a positive approach to the handling of 'human relations'. J.G.D.

95. Obstfeld, Fredric A.
Scheduling Polymerization Reactions
Industrial Quality Control 18 (7): 14-15. 1962.

Use of process performance charts to chart the progress of a chemical reaction by checking at particular times after start of the reaction. Comparison of the observed value against an average and limits calculated from past data is used on a go-no-go basis for continuance of the reaction under the given conditions or modification of the conditions to complete a successful batch. J.G.D.

96. Olmstead, Paul S.
Statistical Evaluation
Industrial Quality Control 18 (8): 9-13. 1962.

This article reviews in a general way the use of statistics and quality control in presenting historical data, in making discoveries and in making predictions. Certain weaknesses in many predictions are traced to failure to make tests relating to the assumptions on which these predictions are based. Illustrations are given of the use of such tests in a few simple cases and the modification in the predictions resulting therefrom. Finally, a way for providing approximate probabilistic measures for such treatment is outlined. Thus, statistical evaluation is justified on engineering grounds where the assumption of statistical control is untenable unless it can be demonstrated. (12 citations)

97. Ott, Ellis R.
Practical Aids - Prospecting
Industrial Quality Control 20 (5): 13-19. 1963.

There are many vital ways in which statistical methods can be applied to the problems of industry. The particular technique of Prospecting is presented as a quick method to help an engineer or production manager identify his problem. Many will recognize the technique simply as a practical adaption of the well-known acceptance sampling plans. There is a great need for other statistical techniques inspired by scientists and technologists. (5 citations)

98. Pabst, Jr., W. R.
MIL-STD-105D
Industrial Quality Control 20 (5): 4-9. 1963.

A description of the revised sampling plan developed by the American-British-Canadian Working Party. The various modifications from the previous standard are documented. J.G.D.

99. Paterson, E. G. D.
Quality Control - Quality Assurance vs Reliability
Industrial Quality Control 19 (4): 5-9. 1962.

A general discussion on the three areas of activity indicated by the title. The author's conclusion is that, no matter how it is arrived at or what it is called, the chief contribution comes from "... seeing that what needs to be specified is specified and that what is specified is done." J.G.D. (12 citations)

100. Paterson, E. G. D.
Reliability and Quality in Communications
Industrial Quality Control 20 (9): 15-38. 1964.

The article constitutes a rather historical review of the spread of reliability and quality considerations in the communications industry. J.G.D. (45 citations)

101. Plait, Alan
The Weibull Distribution - with tables
Industrial Quality Control 19 (5): 17-26. 1962.

The Weibull distribution has been found useful as a descriptor of such occurrences as equipment failures. This article describes how to fit the distribution and applies it to an example. The mathematical properties are described, tables for the probability density function and for the cumulative distribution function are given. Construction of special graph paper is also described. J.G.D. (8 citations)

102. Pringle, J. B.
SQC METHODS in Telephone Transmission Maintenance
Industrial Quality Control 19 (1): 18-22. 1962.

An excellent description of the use of statistical quality control procedures in a communications network. The histogram, control charts and sampling were used to pin-point the problem and to systematically bring it to a state of satisfactory control.

103. Proschan, F. and I. R. Savage
Starting a Control Chart
Industrial Quality Control 17 (3): 12-13. 1960.

A brief, clear presentation of how to start a control chart, statistical aspects are stressed. J.G.D. (6 citations)

104. Purcell, Warren R.
Quality Cost Control
Industrial Quality Control 18 (11): 22-26. 1962.

In order to be able to list "quality expenses" a detailed list of quality control work elements was drawn up. From these basic elements a quality cost report is prepared and these are recorded on control charts. It serves to focus attention on quality costs and they in turn are subjected the same effort as are all other produc-

tion costs in order to keep them as low as is consistent with a satisfactory product. J.G.D.

105. Retterer, B. L. and R. L. McLaughlin
Maintainability Prediction and Measurement
Industrial Quality Control 20 (6): 16-20. 1963.

An approach to the construction of a maintainability index is described. Indices which were time related, cost related and capability related were considered. Information gathered on military equipment was used and the feasibility of predicting maintainability was checked on independent units. The prediction equations were developed using regression procedures. J.G.D. (9 citations)

106. Rhodes, Raymond C.
An Outgoing Quality Probability Limit (OQPL) Sampling Plan
Industrial Quality Control 21 (3): 122-131. 1964.

Available sampling plans are usually applicable when considerations is given either to individual lots or to a large series of lots. These plans do not provide the desired assurance that a finite series of lots, or sublots, meets certain quality requirements. An OQPL (outgoing quality probability limit) sampling plan is developed to provide the most "economical" plan with adequate assurance for this intermediate sampling situation. (2 citations)

107. Rickover, H. G.
The Never-Ending Challenge
Industrial Quality Control 20 (2): 12-17. 1963.

The report of a speech which centers on the problems of nuclear reactors and other military components. Cases of mistaken identity of materials are cited as food for quality control. Poor workmanship is found to be a frequent cause of failures. J.G.D.

108. Roth, R. C.
Practical Process Control
Industrial Quality Control 20 (2): 18-20. 1963.

The steps in process control are enumerated and explained as follows: (1) provide an adequate plan, (2) make it easy, (3) give adequate instructions, (4) assure compliance. J.G.D. (3 citations)

109. Shakun, Melvin F.
The Cybernetic Approach to Business Operations
Industrial Quality Control 17 (3): 9-11. 1960.

In this article the practice of quality control is related to the science of cybernetics. A discussion of its (quality control) use in business management is presented. J.G.D. (3 citations)

110. Simonds, Thomas A.
Design Qualification
Industrial Quality Control 20 (8): 11-15. 1964.

Within the past 15 years, qualification testing has become a major concern to aircraft and missile manufacturers in their acquisition of production contracts from the military. When correctly applied and executed, these tests form a sound basis for demonstrating the integrity of a weapons system design. When incorrectly applied or executed, the tests can lead to incorrect decisions regarding the capabilities of that weapons system.

The intent of this article is to indicate that much qualification testing today is in fact either incorrectly applied or executed, or both. This has arisen through a basic misunderstanding of the purpose of qualification testing and little application of statistical principles.

Specifically, this article will discuss the following topics in connection with this problem: Qualification versus other forms of testing - Sample size in qualification testing - Sample selection in qualification testing.

111. Snodgrass, L. E.
Intergrating the Quality Control Contribution in Research and Development Operations
Industrial Quality Control 18 (11): 55-60. 1962.

Using the typical product growth cycle as a reference, the preproduction quality control contribution is discussed from the management viewpoint as a defect prevention tool. The idea that program success is largely dependent upon joint action by several engineering specialities is developed around the team approach, and is related to some very basic engineering and management principles common to business operations.

The very title of this article begs the question of desirability - is the quality control effort properly applied in the product design and development phase? As we examine the conception, design, manufacture and use segments of the typical product growth cycle, do we not make best use of quality control knowledge in the manufacturing and inspection phases where it will help us obtain conformance to

specifications?

Perhaps the most important observation we can make about integrating quality control in the pre-manufacturing stages is that failure to do so marks the loss of an opportunity to get the quality point of view into the design, the drawings and specifications, the manufacturing process planning, the tooling, gaging and test equipment, and the product acceptance criteria. In short, we lose a substantial dividend from our quality control investment through failure to put it to work in a defect prevention sense. (5 citations)

112. Sussman, Bernard
Quality Information Equipment - The Tools That Make Total Quality Control Work
Industrial Quality Control 21 (1): 10-16. 1964.

The plea is made for using automated test equipment tied to information equipment to produce higher quality at lower cost. The differences between high, medium and low volume businesses are discussed. The activities of the Quality Information Equipment Committee within the American Society for Quality Control are described. J.G.D.

113. Swaton, L. and W. Weaver
Five Steps to Supplier Quality Control
Industrial Quality Control 22 (11): 611-616. 1966.

Controlling the quality of procured hardware is a serious quality problem that companies must face. Success in this phase of the quality program is based on meticulous attention to each step and to the understanding that the elimination of any one step will undermine the total program. The following five-step plan is now being used successfully at Martin-Orlando:

(1) Categorize Materials
(2) Determine quality requirements to impose on manufacturers
(3) Apply these requirements to the purchase document
(4) Plan for and receive procured hardware
(5) Follow up on corrective action on defective hardware

This plan is readily adaptable to big and small companies in the hard goods industry.

114. Taylor, Ervin F.
A Special Case of Percentage Sampling
Industrial Quality Control 20 (10): 13. 1964.

An application in attribute sampling based upon the hypergeometric distribution, and particularly applicable to the case where destructive testing must be used. J.G.D.

115. Topp, J. P.
Effective Communication - Its Relationship to Employee Performance and to Corrective Action
Industrial Quality Control 24 (6): 309-312. 1967.

Employee error is bound to occur when job requirements are not fully understood. Such understanding, by itself, cannot be expected to guarantee acceptable employee performance. However, such understanding is a prerequisite to acceptable performance.

This article points out that in an atmosphere of confusion resulting from unclear work instructions, acceptable employee performance is unattainable and durable corrective action is not possible. (16 citations)

116. Torgersen, P. E. and G. B. Thomas
Simulating An Acceptance Sampling Plan
Industrial Quality Control 20 (6): 27-32. 1963.

A simulation of an acceptance sampling plan is described as a means of stimulating interest in a study of acceptance sampling. The participants can be expected to stimulate interest in studying operating characteristic curves, average outgoing quality and other aspects of quality control. J.G.D. (5 citations)

117. Toulouse, Julian H.
Psychological Bias in Attribute Sampling
Industrial Quality Control 14 (12): 5-12. 1958.

An examination of sources of bias in sampling for attributes is described. The kinds of bias are pointed out, methods for detecting evidences of bias are described. Some theoretical aspects of bias are discussed. The author made use of simulation to examine the effects of biases in sampling. J.G.D.

118. Truax, H. Mack
Cumulative Sum Charts and Their Application to the Chemical Industry
Industrial Quality Control 18 (6): 18-25. 1961.

This is a detailed discussion of the use, construction and effectiveness of the cumulative sum chart. Caution in their use is advised but they are recognized as having a place in the practicioner's tool box. J.G.D. (13 citations)

119. Van Eck, Leonard F.
Evolutionary Operations - A Path to More Effective Use of Process Data
Industrial Quality Control 19 (2): 8-10. 1962.

The urgent need to increase the rate of process optimization in the chemical process industries is cited. The role of Evolutionary Operation in furthering achievement of this essential objective is discussed with particular emphasis on its contribution to the development of a "climate of receptivity" for the application of statistical techniques.

Some related experience is described and suggestions are made on the selling of statistical services to manufacturing.

120. von Osinski, Ralph
Use of Median Charts in the Rubber Industry
Industrial Quality Control 19 (2): 5-8. 1962.

A description of the introduction and use of median charts in a plant situation. The results noticeably reduced the product variation and the amount of time the machine operators spent adjusting their machines. J.G.D.

121. Waddell, Joseph J.
Quality Control in the Construction Industry
Industrial Quality Control 17 (7): 12-15. 1961.

The control of strength in concrete is used as the example for a discussion of quality control as a tool in the construction industry. J.G.D. (3 citations)

122. Ward, R. Vance
SQC Applications In The Chemical Industry
Industrial Quality Control 20 (1): 4-8. 1963.

The use of quality control techniques in the control laboratory constitutes a good place to start. Tabulation of routine information in such a simple way as a frequency distribution can display unsuspected errors in test procedure, test equipment operator variations. The entire emphasis is upon use of very elementary quality control procedures to achieve control of routine procedures used in a chemical plant. J.G.D. (9 citations)

123. Way, C. B.
Statistical Quality Control Applications in the Food Industry
Industrial Quality Control 17 (11): 30-34. 1961.

The incoming material to the food industry is in the form of raw product which must be processed in its original form, thus incoming

quality is not as controllable as in the manufacturing industries. Nevertheless, as this article indicates, there are many actual and potential applications of quality control in the food industry. J.G.D. (36 citations)

124. Werkowski, S. J.
Sampling Evaluation of Textile Quality using demerit points
Industrial Quality Control 18 (7): 22-26. 1962.

Textile materials inspected for defects was scored using a demerit point system. On the basis of demerit points per defect an acceptance plan using an upper point tolerance was developed. The element of judgement as to "what is a defect" is not removed but it provides a scoring system which minimizes the judgement error. (Noteby abstractor - this suggests a method of setting up a final acceptance scheme for highway surfaces.) J.G.D. (2 citations)

125. West, J. V.
Semi-Automatic Sequential Sampling Instrument
Industrial Quality Control 20 (9): 10-15. 1964.

A description of a combination of sequential sampling and use of automatic sampling devices is given. Sequential sampling generally requires less inspection than other sampling schemes. Considerable detail on sequential sampling procedures is presented, also on the equipment used. J.G.D.

126. Wies, Harold M., Jr., and Burr, Irving W.
Simple Capability Acceptance Test - A Sequential Test on Ranges
Industrial Quality Control 21 (5): 266-268. 1964.

Given a process or machine that is known to be reasonably well in control, the question often arises as to whether it can meet a specified tolerance for a given job. Thus a lathe may have shown control on a number of different materials and diameters. Can it hold the specified tolerance on a new job? Even where control has not been proven, if the process passes the test, then achieving improved control would only help, not hinder.

If the process standard deviation should be as much as a sixth of the tolerance, then there will be very little room for the process level to be off from the nominal dimension. On the other hand if the process standard deviation is, say, a tenth of the tolerance or less, then the process can comfortably meet the specifications with some allowance for set-up error and tendency to drift. This article provides a convenient test for distinguishing between these two cases. It is a simple application of a sequential test by Cox, which uses the sum of the sample

ranges as test criterion. To use the test, the only thing needed is to multiply the critical values in the table by the given tolerance, and then begin drawing samples. (5 citations)

127. Woodward, Albert
Administration of a Plastics Control Laboratory
Industrial Quality Control 23 (2): 68-71. 1966.

This article discusses combining process control and product quality control analytical functions into one laboratory. It advocates the use of operator-performed analyses for in-process quality control. Criteria are provided for the evaluation and selection of control methods. It treats the laboratory as a continuous process and outlines procedures for laboratory control of testing procedures. Source information on available product and test technology for the newcomer is given. (9 citations)

128. Youden, W. J.
Graphical Diagnosis of Interlaboratory Test Results
Industrial Quality Control 15 (11): 24-28. 1959.

A simple graphical technique is described for examining the test results from different laboratories on the same material. It is rapid yet quite efficient in directing attention to the discrepant laboratories. J.G.D.

129. Zimmer, William J. and Irving W. Burr
Variables Sampling Plans Based on Non-Normal Populations
Industrial Quality Control 20 (1): 18-26. 1963.

Acceptance sampling plans for variables such as those in Techniques of Statistical Analysis (1), Bowker and Goode (2), and Military Standard 414 (3), assume that the population from which the sample is drawn is normal. This article extends these methods to a wide class of non-normal populations. In fact, although the methods are here developed for one general class of functions, they are equally applicable to most other types as well.

As in earlier work, this plan is concerned with controlling the percent beyond one specification limit. Let us suppose that this is an upper specification, U. If the true proportion above U is some small fraction, say p_1, we want to accept the lot a proportion $1 - \alpha$ of the time, while if it is p_2, then we wish to accept only a proportion β of the time. Then the usual approach, if we know the population standard deviation σ, is to compare $\bar{x} + k\sigma$ with U which if it is below U we accept, or if above U we reject. Thus to use the plan, all that

is necessary is to find the sample size n and coefficient k. These will depend upon p_1 and p_2 and the risks α and β. It will be seen that although non-normality has some effect upon k, it is more strongly felt in the sample size n.

Tables presented enable one to find the appropriate k and n for a variety of distributions, if one can estimate or approximate the degree of skewness and/or kurtosis in the population.

Also the case of acceptance sampling with σ unknown is covered, and is also easily applied. (6 citations)

130. Acceptance Sampling of Lots by the median, quasi-range method
Industrial Quality Control 15 (1): 8-11. 1958.

The purpose of this report is to introduce the Median, Quasi-Range Method for controlling lot average and lot standard deviation. The method applies when the characteristic is adequately described by the normal distribution. (3 citations)

131. ASQC Standard A1 (Proposed) Definitions, Symbols, Formulas and Tables for Control Charts
Industrial Quality Control 24 (4): 217-223. 1967.

This sets forth a collection of terms, together with their definitions, which are in common usage among quality control practioners. Published here for the membership to review and make comments on before being incorporated in a quality control document aimed at standardization of terminology. J.G.D.

132. Summary Technical Report, August, 1960
National Bureau of Standards, Washington, D. C.
Intercomparison of Laboratory Test Methods
Industrial Quality Control 17 (8): 17-18. 1961.

The National Bureau of Standards has developed a mathematical model for statistical analysis of factors involved in variability in inter laboratory test results. The method is used to distinguish between random and systematic laboratory differences that cannot be represented by constant biases. Although designed primarily for the study of a single test method or an inter laboratory scale, it can be used for inter laboratory comparison of two alternative test methods. (4 citations)