TRANSPORTATION RESEARCH
CIRCULAR

Number 457 April 1996

Glossary of Highway Quality Assurance Terms

TRANSPORTATION RESEARCH BOARD / NATIONAL RESEARCH COUNCIL

TRANSPORTATION
RESEARCH
CIRCULAR

Number 457, April 1996
ISSN 0097-8515

GLOSSARY OF HIGHWAY QUALITY ASSURANCE TERMS

COMMITTEE ON MANAGEMENT OF QUALITY ASSURANCE

Charles S. Hughes, Chair
Ronald J. Cominsky, Secretary

Abdul Rahman A. Al-Azzam
Gabrielle E. Bedewi
Paul E. Benson
James L. Burati, Jr.
Michael I. Darter
Dale S. Decker
Robert P. Elliott
Ralph D. Ellis, Jr.
Foad Farid
Jim Gee
Dimitrios Goulias
Rosemary M. Ingram
Charles A. Kline
Peter A. Kopac
Rita B. Leahy
M. Lee Powell III
Orrin Riley
Gerald J. Rohrbach
Carlos E. Rosenberger
James M. Shilstone, Sr.
Clinton E. Solberg
Peter A. Spellerberg
Donald R. Tuggle
Richard M. Weed

Frederick D. Hejl, TRB Staff Representative

Subscriber category
IIIB materials and construction

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

CONTENTS

INTRODUCTION

Highway quality assurance, like many other specialized subject areas, has its own unique language containing numerous technical terms or expressions having very specific meanings. Some of these terms are not well understood, and their use is subject to a variety of different interpretations. The highway quality assurance language, moreover, is continually changing to keep pace with advances in quality assurance. As new terms come into general use, older terms must often be perceived in a new light. The terminology has grown and evolved steadily since the mid-sixties, when much of it was first introduced to the highway community; however, its growth and evolution have been to a large degree uncontrolled.

This document contains terms of common usage and accepted practice. The circular was generated by a subcommittee, chaired by Mr. Peter Kopac, of Transportation Research Board Committee A2F03, Management of Quality Assurance.

PURPOSE

The purpose of this publication is to provide a reference document containing a recommended standard for usage of highway quality assurance terminology. In developing this publication, TRB Committee A2F03 reviewed the evolution of the highway quality assurance language, assessed its current condition, and attempted to define not what the language is today but *what it should be.*

ORGANIZATION

This publication is divided into three parts: an index, a glossary of highway quality assurance terms, and a list of references. The major part is the glossary. The terms selected for definition include many terms that are frequently misinterpreted, misunderstood, or are generally confusing. The definitions provided are sometimes more than dictionary definitions; they attempt to clarify the sources of confusion. This was done by Committee A2F03 examining specific topics within highway quality assurance (for example, process control) and focusing on groups of related terms within a topic in order to develop a better understanding of each individual term. Thus, the glossary terms do not appear alphabetically but are grouped by topic; and within each topic, terms that need to be compared to point out their distinctions are located next to one another. Within some definitions, brackets are used to isolate comments provided by the committee not actually needed as part of a definition but helpful in establishing a better understanding of the term and/or the topic. Also, several key figures are provided to illustrate important concepts and strengthen the understanding of relationships among terms.

Because terms are not alphabetical in the glossary, the index can be used to assist the user in more quickly locating a term. The index shows the page number and topic under which a term may be found. It also identifies the references that were used to develop a definition. The committee, in forming definitions, examined many glossaries and publications containing definitions. It then took, from these existing definitions, what it believed to be the best thoughts and wording and most necessary features, making only minor changes, to create appropriate definitions for use today. Some judgment was used in determining which references should be cited. Because definitions found in the examined publications were seldom referenced, it was decided to cite publications of major standards-producing organizations (such as American Society for Testing and Materials, American Association of State and Highway Transportation Officials, and American Society for Quality Control) in all cases where there was agreement with the glossary definition, and to cite only the earliest (i.e. oldest) other publications that may have provided some element to, or be the sole source of, a glossary definition.

NEED FOR UPDATES AND COMMENTS

It is Committee A2F03's intent to periodically update the definitions. One aspect of the updating is simply to improve the quality of the definitions. Some such improvements of definitions are certainly anticipated once the glossary has been put to use and specific problems or shortcomings in definitions have been identified by the user. Another aspect of updating includes the addition of new terms that may come into use, along with the review and possible modification of existing definitions to accommodate new understanding resulting from the new term. This latter aspect will attempt to account for the dynamic nature of the highway quality assurance language. Still another aspect of updating may be the addition of new terms within topics not addressed in this publication; for example,

statistical terms. Many additional topics are possible for inclusion in future revisions of the glossary; some topics may require coordination with other Transportation Research Board committees to best establish suitable definitions.

Closely related to the update of glossary definitions is improvement of the overall publication. For example, the referenced sources in this publication, admittedly, may not be entirely accurate (primarily due to the difficulties in identifying the earliest document responsible for creating a definition); therefore, some of the references may need to be corrected. Another example of a possible improvement might be the creation of a separate section on symbols and abbreviations. Committee A2F03 welcomes any comments or suggestions on how either the definitions themselves or any other parts of this publication can be improved to meet the users' needs and to better provide a reference document that fosters uniformity and understanding. Comments or suggestions should be directed to Peter Kopac (telephone: 703/285-2432; fax: 703/285-2767; e-mail: pkopac@intergate.dot.gov).

INDEX OF TERMS

Term	Page	Topic	Reference
QC/QA specifications — see quality assurance specifications			
quality	14	Acceptance, Quality Measures	7,8,11,22
quality assurance	10	Quality Assurance Elements	1,17
quality assurance specifications	11	Types of Specifications	17,23
quality characteristic	14	Acceptance, Quality Measures	1,2,6,11
quality control	10	Quality Assurance Elements	19
quality index (Q)	15	Acceptance, Quality Measures	3
recipe specifications — see materials & methods specifications			
rejectable quality level (RQL)	14	Acceptance, Quality Measures	28
reliability	16	Test/Measurement Exactness	8,11,13,14
repeatability	16	Test/Measurement Exactness	4,20
reproducibility	16	Test/Measurement Exactness	20
secondary relationship	15	Pavement Performance Modeling	25
seller's risk (α)	14	Acceptance, General	3,4,15
specification limit(s)	15	Process Control	1,28
statistical control chart — see control chart			
statistically based specifications	11	Types of Specifications	27
statistically oriented specifications — see statistically based specifications			
statistical specifications — see statistically based specifications			
surrogate M&C variable	16	Pavement Performance Modeling	25
tolerance limits	15	Process Control	5
type I error — see seller's risk			
type II error — see buyer's risk			
variables acceptance plan	13	Acceptance, General	3,4
warning limits	15	Process Control	15

GLOSSARY

QUALITY ASSURANCE ELEMENTS

quality assurance. All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. Quality assurance addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, quality assurance involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interractions of these activities.

quality control — also called *process control.* Those quality assurance actions and considerations necessary to assess production and construction processes so as to control the level of quality being produced in the end product. This concept of quality control includes sampling and testing to monitor the process but usually does not include acceptance sampling and testing.

acceptance sampling and testing. Sampling, testing, and the assessment of test results done to determine whether or not the quality of produced material or construction is acceptable in terms of the specifications.

independent assurance. A management tool that requires a third party, not directly responsible for process control or acceptance, to provide an independent assessment of the product and/or the reliability of test results obtained from process control and acceptance testing. [The results of independent assurance tests are not to be used as a basis of product acceptance.]

TABLE 1 QUALITY ASSURANCE VERSUS QUALITY CONTROL

Quality Assurance	Quality Control
Making sure the quality of a product is what it should be (4, 16)	Making the quality of a product what it should be (4, 16)
Doing the right things	Doing things right
Includes quality control	A part of quality assurance
In highway construction, a highway agency responsibility	In highway construction, a producer/ contractor responsibility

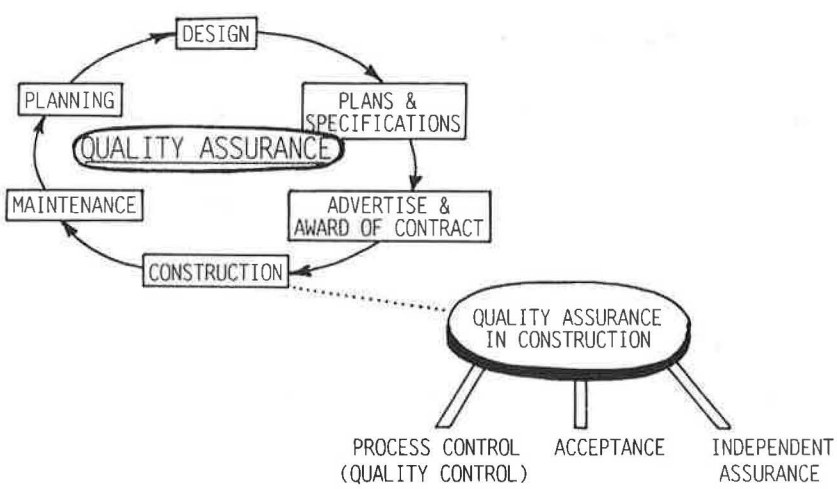

FIGURE 1 Quality assurance system elements (17,28).

TYPES OF SPECIFICATIONS

materials and methods specifications — also called *method specifications*, *recipe specifications*, or *prescriptive specifications*. Specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material. [Each step is directed by a representative of the highway agency. Experience has shown this tends to obligate the agency to accept the completed work.]

end result specifications. Specifications that require the contractor to take the entire responsibility for supplying a product or an item of construction. The highway agency's responsibility is to either accept or reject the final product or apply a price adjustment that compensates for the degree of compliance with the specifications. [End result specifications have the advantage of affording the contractor flexibility in exercising options for using new materials, techniques, and procedures to improve the quality and/or economy of the end product.]

quality assurance specifications — also called *QA/QC specifications* or *QC/QA specifications*. A combination of end result specifications and materials and methods specifications. The contractor is responsible for quality control (process control), and the highway agency is responsible for acceptance of the product. [Quality assurance specifications typically are statistically based specifications that use methods such as random sampling and lot-by-lot testing, which let the contractor know if his operations are producing an acceptable product.]

statistically based specifications — also called *statistical specifications* or *statistically oriented specifications*. Specifications based on random sampling, and in which properties of the desired product or construction are described by appropriate statistical parameters.

performance specifications. Specifications that describe how the finished product should perform over time. For highways, performance is typically described in terms of changes in physical condition of the surface and its response to load, or in terms of the cumulative traffic required to bring the pavement to a condition defined as "failure." Specifications containing warranty/guarantee clauses are a form of performance specifications. [Other than the warranty/guarantee type, performance specifications have not been used for major highway pavement components (subgrades, bases, riding surfaces) because there have not been appropriate nondestructive tests to measure long-term performance immediately after construction. They have been used for some products (e.g., highway lighting, electrical components, and joint sealant materials) for which there are tests of performance that can be rapidly conducted.]

performance-based specifications. Specifications that describe the desired levels of fundamental engineering properties (e.g., resilient modulus, creep properties, and fatigue properties) that are predictors of performance and appear in primary prediction relationships (i.e., models that can be used to predict pavement stress, distress, or performance from combinations of predictors that represent traffic, environmental, roadbed, and structural conditions.) [Because most fundamental engineering properties associated with pavements are currently not amenable to timely acceptance testing, performance-based specifications have not found application in highway construction.]

performance-related specifications. Specifications that describe the desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance. These characteristics (for example, air voids in asphaltic pavements, and strength of concrete cores) are amenable to acceptance testing at the time of construction. True performance-related specifications not only describe the desired levels of these quality characteristics, but also employ the quantified relationships containing the characteristics to predict subsequent pavement performance. They thus provide the basis for rational acceptance and/or price adjustment decisions.

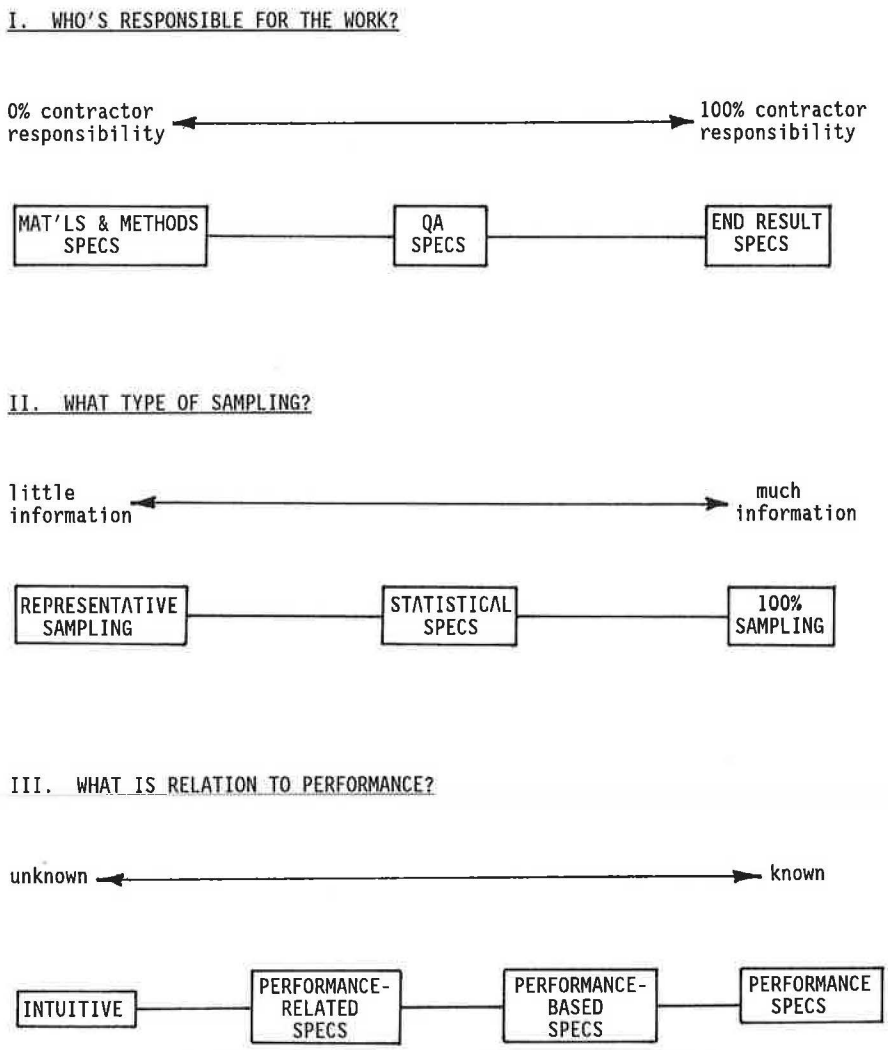

FIGURE 2 Classifying construction specifications (27). Highway construction specifications may be classified according to (I) who is responsible for the work, (II) the type of sampling employed, and (III) the relationship between quality criteria and constructed product performance. Thus, a *quality assurance (QA)* specification according to classification (I), for example, might be a *statistical* specification for classification (II), and contain *intuitive* specification limits and pay adjustments for classification (III). A specification might also, and usually does, contain one or more features within the same classification. For example, a specification which is primarily *performance-related* might contain some *performance-based* acceptance criteria and some *intuitively* developed acceptance criteria.

ACCEPTANCE

General

acceptance plan. An agreed-upon method of taking samples and making measurements or observations on these samples for the purpose of evaluating the acceptability of a lot of material or construction.

attribute acceptance plan. A statistical acceptance procedure where the acceptability of a lot of material or construction is evaluated by noting the presence (absence) of some characteristic or attribute in each of the units or samples in the group under consideration, and counting how many units do (do not) possess this characteristic.

variables acceptance plan. A statistical acceptance procedure where quality is evaluated by measuring the numerical magnitude of a quality characteristic for each of the units or samples in the group under consideration, and computing statistics such as the average or the average and standard deviation of the group.

pay adjustment schedule (for quality) — also called *price adjustment schedule* or *adjusted pay schedule.* A pre-established schedule, in either tabular or equation form, for assigning pay factors associated with estimated quality levels of a given quality characteristic. The pay factors are usually expressed as percentages of the original contract bid price.

pay adjustment system (for quality) — also called *price adjustment system* or *adjusted pay system.* All pay adjustment schedules along with the equation or algorithm that is used to determine the overall pay factor for a submitted lot of material or construction. [A pay adjustment system, and each pay adjustment schedule, should yield sufficiently large pay increases/decreases to provide the contractor some incentive/disincentive for high/low quality.]

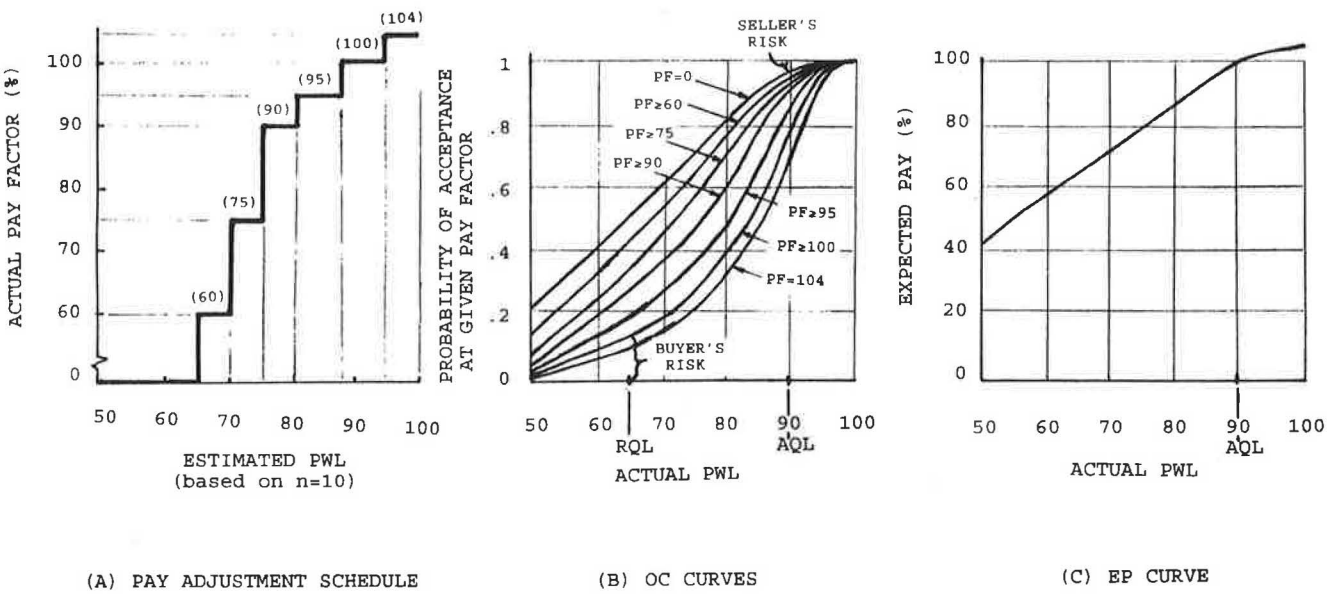

FIGURE 3 Graphic summaries of an acceptance plan (18). Shown above are three types of graphs used to summarize a typical acceptance plan containing a pay adjustment schedule. Figure (a) describes the pay adjustment schedule. Figures (b) and (c) present, respectively, the corresponding set of OC curves and the corresponding EP curve for the acceptance plan. The OC curves show the probability that a contractor working under the acceptance plan will receive a given payment for various levels of actual (not estimated) submitted lot quality. The EP curve, on the other hand, shows the contractor's average payment in the long run for various levels of actual (not estimated) submitted lot quality. Note that information regarding the buyer's and seller's risks is found in the OC curves, and information regarding average payment in the long run is found in the EP curve. Since both types of information are needed to assess how an acceptance plan is (or will be) working, both the OC curves and the EP curve should be examined. For instance, the EP curve may seem satisfactory for an acceptance plan; however, this acceptance plan could have OC curves which show the buyer's and/or seller's risks are too high (indicating too small a sample size).

incentive/disincentive provision (for quality). A pay adjustment schedule which functions to motivate the contractor to provide a high level of quality. [A pay adjustment schedule, even one which provides for pay increases, is not necessarily an incentive/disincentive provision, as individual pay increases/decreases may not be of sufficient magnitude to motivate the contractor toward high quality.]

liquidated damages provision (for quality). A pay adjustment schedule whose primary function is to recover costs associated with the contractor's failure to provide the desired level of quality.

operating characteristic (OC) curve. A graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and either (a) the probability of its acceptance (for accept/reject acceptance plans)or (b) the probability of its acceptance at various payment levels (for acceptance plans that include pay adjustment provisions).

expected pay (EP) curve. A graphic representation of an acceptance plan that shows the relation between the actual quality of a lot and its expected pay (i.e.; mathematical pay expectation, or the average pay the contractor can expect to receive over the long run for submitted lots of a given quality.) [For an acceptance plan that includes pay adjustment provisions, both OC and EP curves should be used to evaluate how well the acceptance plan is (or will be) working. For any acceptance plan, however, OC and EP information need not be (and sometimes can not be) shown in graphic (curve) form.]

seller's risk (α) — also called *type I error* or *α error.* The probability that an acceptance plan will erroneously reject AQL material or construction with respect to a single acceptance quality characteristic. It is the risk the contractor or producer takes in having AQL material or construction rejected.

buyer's risk (ß) — also called *type II error* or *β error.* The probability that an acceptance plan will erroneously fully accept (at 100 percent pay or greater) RQL material or construction with respect to a single acceptance quality characteristic. It is the risk the highway agency takes in having RQL material or construction fully accepted. [The probability of having RQL material or construction accepted (at any pay) may be considerably greater than the buyer's risk.]

Quality Measures

quality. (1) The degree or grade of excellence of a product or service. (2) The degree to which a product or service satisfies the needs of a specific customer. (3) The degree to which a product or service conforms with a given requirement.

quality characteristic. That characteristic of a unit or product that is actually measured to determine conformance with a given requirement.

percent defective (PD) — also called *percent nonconforming.* The percentage of the lot falling outside specification limits. It may refer to either the population value or the sample estimate of the population value.

percent within limits (PWL) — also called *percent conforming.* The percentage of the lot falling above a lower specification limit, beneath an upper specification limit, or between upper and lower specification limits. It may refer to either the population value or the sample estimate of the population value. PWL = 100 - PD.

acceptable quality level (AQL). That minimum level of actual quality that is considered fully acceptable as a process average for a single acceptance quality characteristic. For example, when quality is based on percent within limits (PWL), the AQL is that actual (not estimated) PWL at which the quality characteristic can just be considered fully acceptable. [Acceptance plans should be designed so AQL material will receive an expected pay of 100 percent.]

rejectable quality level (RQL). That maximum level of actual quality that is considered unacceptable (rejectable) as a process average for a single acceptance quality characteristic. For example, when quality is based on percent defective (PD), the RQL is that actual (not estimated) PD at which the quality characteristic can just be considered fully rejectable. [It is desired to require removal and replacement, corrective action, or the assignment of a relatively low pay factor when RQL work is detected.]

acceptance number (c). In attributes acceptance plans, the maximum number of defective units in the sample that will permit acceptance of the inspected lot or batch.

acceptance constant (k). The minimum allowable quality index (Q) for a variables acceptance procedure.

quality index (Q). A statistic which, when used with appropriate tables, provides an estimate of either percent defective (PD) or percent within limits (PWL) of a lot. It is typically computed from the mean and standard deviation of a set of test results as follows:

$Q_L = (\overline{X}-L)/S$ where $\overline{X}$ = sample mean
S = sample standard deviation
or L = lower specification limit
$Q_U = (U-\overline{X})/S$ U = upper specification limit

PROCESS CONTROL

control chart — also called *statistical control chart.* A graphical method of process control which detects when assignable causes are acting on a continuous production line process and when normal, expected variation is occurring.

assignable cause. A relatively large source of variation, usually due to error or process change, which can be detected by statistical methods and corrected within economic limits. [When assignable causes are identified and removed, the production process is "under control."]

chance cause. A source of variation that is inherent in any production process and cannot be eliminated as it is due to random, expected causes.

controlled process — also called *process under statistical control.* A production process in which the mean and variability of a series of tests on the product remain stable, with the variability due to chance only. [A process might be "under control" but produce out-of-specification material if the specification limits are tight. Conversely, a process might be "out of control" in that the mean or variability is outside of control limits, yet the specification limits might be wide enough that the material produced is within specifications.]

specification limit(s). The limiting value(s) established, preferrably by statistical analysis, for evaluating material or construction acceptability within the specification requirements. It may be expressed as either an upper (U) or a lower specification limit (L), called a single specification limit; or both upper and lower specification limits, called a double specification limit.

tolerance limits. Limits that define the conformance boundaries for a manufacturing or service operation. [The distinction between tolerance limits and specification limits is tolerance limits apply to process control and specification limits to acceptance testing.]

control limits (upper, lower) — also called *action limits.* Boundaries established by statistical analysis for material production control using the control chart technique. When values of the material characteristics fall within these limits, the process is "under control." When values fall outside the limits, there is an indication that some assignable cause is present causing the process to be "out of control."

warning limits (upper, lower). Boundaries established on control charts within the upper and lower control limits, to warn the producer of possible problems in the production process that may lead to the process going out of control.

PAVEMENT PERFORMANCE MODELING

pavement performance. The history of pavement condition indicators over time or with increasing axle load applications.

pavement condition indicator — also called *pavement distress indicator.* A measure of the condition of an existing pavement section at a particular point in time, such as cracking measured in feet per mile, or faulting measured in inches of wheelpath faulting per mile. When considered collectively, pavement condition indicators provide an estimate of the overall adequacy of a particular roadway.

primary relationship. An equation that can be used to predict pavement stress, distress, or performance from particular combinations of predictor variables that represent traffic, environmental, roadbed, and structural conditions. Some examples of predictor variables are annual rate of equivalent single axle load accumulation, annual precipitation, roadbed soil modulus, and concrete flexural strength.

secondary relationship. An equation that shows how one or more M&C variables are related to at least one predictor variable. The equation $S_f = 9.5\sqrt{S_c}$ (where S_f is concrete flexural strength and S_c is concrete compressive strength) is an example of a secondary relationship.

materials and construction (M&C) variable. A characteristic of materials and/or construction that can

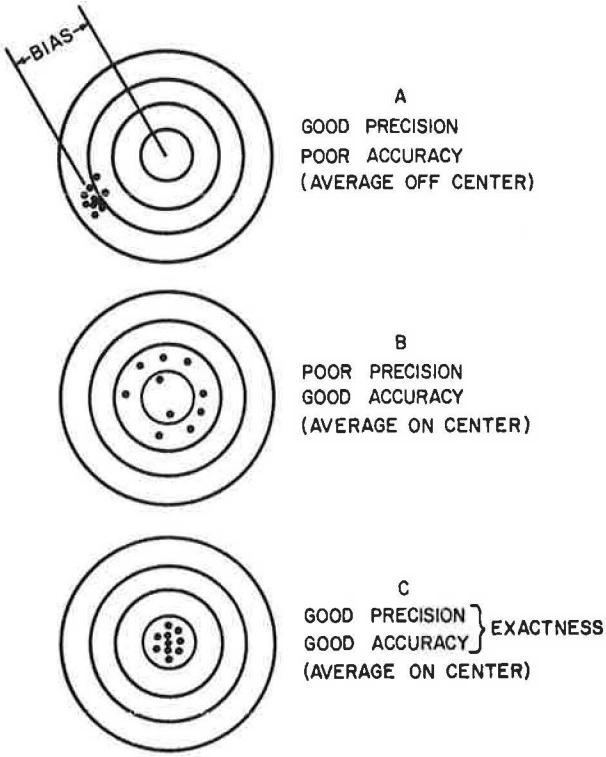

FIGURE 4 Exactness of measurement (13).

be directly or indirectly controlled. Thickness is an example of an M&C variable that is controlled directly; compressive strength is an example of one controlled indirectly.

performance-related M&C variable. A characteristic of materials and/or construction that has an influence on pavement performance, either by itself or interactively when in combination with other M&C variables. Any M&C variable that is a primary or secondary predictor is a performance-related variable.

process control M&C variable. A characteristic of materials and/or construction whose specification enhances the control of another M&C variable. An example of a process control M&C variable is soil moisture content to control density and compaction.

surrogate M&C variable. A characteristic of materials and/or construction that can be used to substitute for a performance-related M&C variable. For example, concrete compressive strength can be a surrogate for concrete flexural strength.

TEST/MEASUREMENT EXACTNESS

accuracy. The degree to which a measurement, or the mean of a distribution of measurements, tends to coincide with the true population mean. [When the true population mean is not known, the degree of agreement between the observed measurements and an accepted reference standard may be used to quantify the accuracy of the measurements.]

bias. An error, constant in direction, that causes a measurement, or the mean of a distribution of measurements, to be offset from the true population mean.

precision. (1) The degree of agreement among a randomly selected series of measurements. (2) The degree to which tests or measurements on identical samples tend to produce the same results.

reliability. The degree to which a test produces consistent or dependable results. Test reliability is increased as both precision and accuracy are improved. Reliability can also refer to product reliability, defined as (1) the degree of conformance or failure of the specific product to meet the consumer's quality needs; and (2) the probability of a product performing without failure a specified function under given conditions for a specified period of time. In (1) and (2), reliability is that aspect of quality assurance which is concerned with the quality of product function over time.

reproducibility. Degree of variation among the results obtained by different operators doing the same test on the same material. In other words, it measures the human influence or human error in the execution of a test. The term reproducibility may be used to designate interlaboratory test precision.

repeatability. Degree of variation among the results obtained by the same operator repeating a test on the same material. The term repeatability is therefore used to designate test precision under a single operator.

REFERENCES

1. American Society for Testing and Materials, *Compilation of ASTM Standard Definitions,* Fourth Edition, Philadelphia, PA, 1979.
2. Special Committee on Nomenclature, *AASHO Highway Definitions,* American Association of State Highway Officials, Washington, D.C., 1968.
3. "Standard Recommended Practice for Acceptance Sampling Plans for Highway Construction, AASHTO Designation R 9-90," *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part I Specifications,* Seventeenth Edition, American Association of State and Highway Transportation Officials, Washington, D.C., 1995.
4. "Standard Recommended Practice for Definitions of Terms for Specifications And Procedures, AASHTO Designation R 10-92," *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part I Specifications,* Seventeenth Edition, American Association of State and Highway Transportation Officials, Washington, D.C., 1995.
5. American Society for Quality Control, *American National Standard ANSI/ASQC A2-1987: Terms, Symbols, and Definitions for Acceptance Sampling,* Milwaukee, WI, 1987.
6. American Society for Quality Control, *American National Standard ANSI/ASQC Z1.9-1980: Sampling Procedures and Tables for Inspection by Variables for Percent Nonconforming,"* Milwaukee, WI, 1980.
7. *The American Heritage Dictionary,* Second College Edition, Houghton Mifflin Co., Boston, MA, 1987.
8. Hanson, Bertrand L., *Quality Control: Theory and Applications,* Prentice-Hall, Inc., Englewood Cliffs, NJ, 1963.
9. Miller-Warden Associates, *NCHRP Report 17: Development of Guidelines for Practical and Realistic Construction Specifications,* Highway Research Board, National Research Council, Washington, D.C., 1965.
10. Statistical Quality Control Task Force, *The Statistical Approach to Quality Control in Highway Construction,* Bureau of Public Roads, Washington, D.C., April, 1965.
11. Statistical Quality Control Task Group, *Quality Assurance Through Process Control and Acceptance Sampling,* Bureau of Public Roads, Washington, D.C., 1967.
12. DiCocco, John B. and Bellair, Peter J., *Acceptance Sampling Plans for Rigid Pavement Thickness,* Research Report 70-11, New York State Department of Transportation, Albany, NY, April, 1971.
13. Hudson, S.B., *Handbook of Applications of Statistical Concepts to the Highway Construction Industry, Part I,* Report Number MAT-RES-DEV-WGAI-71-660-1, Federal Highway Administration, June, 1971.
14. Grant, Eugene I. and Leavenworth, Richard S., *Statistical Quality Control,* Fourth Edition, McGraw-Hill Book Company, New York, NY, 1972.
15. Willenbrock, Jack H. et al, *Statistical Quality Control of Highway Construction, Volume 2,* Pennsylvania Department of Transportation, Harrisburg, PA, December, 1974.
16. Bowery, Frank J. and Hudson, S.B., *NCHRP Synthesis of Highway Practice 38: Statistically Oriented End-Result Specifications,* Transportation Research Board, National Research Council, Washington, D.C., 1976.
17. Willenbrock, Jack H., *Statistical Quality Control of Highway Construction, Volume 2,* Federal Highway Administration, Washington, D.C., January, 1976.
18. Willenbrock, Jack H. and Kopac, Peter A., *A Methodology for the Development of Price Adjustment Systems for Statistically Based Restricted Performance Specifications,* Report Number FHWA-PA-74-27(1), Pennsylvania Department of Transportation, Harrisburg, PA, October, 1976.
19. Halstead, Woodrow J., *NCHRP Synthesis 65: Quality Assurance,* Transportation Research Board, National Research Council, Washington, D.C., October, 1979.
20. National Institute for Transport and Road Research, *TMH 5 Sampling Methods for Road Construction Materials,* Pretoria, South Africa, 1981.
21. National Institute for Transport and Road Research, *TRH 5 Statistical Concepts of Quality Control and their Application in Road Construction,* Pretoria, South Africa, 1987.
22. Dumas, Roland A., "Organizational Quality: How to Avoid Common Pitfalls," *Quality Progress,* Volume 22, Number 5, May 1989, pp. 41-44.
23. "Good Specs is the Road to Quality Performance," *Rural Transportation Technology,* Center for

Technology Transfer Quarterly Newsletter, Jackson State University, Volume 5, Number 1, Winter 1989.

24. Anderson, David A. et al, *NCHRP Report 332: Framework for Development of Performance-Related Specifications for Hot-Mix Asphaltic Concrete,* Transportation Research Board, National Research Council, Washington, D.C., December, 1990.
25. Irick, Paul et al, *Development of Performance-Related Specifications for Portland Cement Concrete Pavement Construction,* Publication Number FHWA-RD-89-211, Federal Highway Administration, McLean, VA, May, 1990.
26. Afferton, Kenneth C. et al, "Managing Quality: Time for a National Policy," *Transportation Research Record Number 1340,* Transportation Research Board, National Research Council, Washington, D.C., 1992, pp. 3- 39.
27. Kopac, Peter A., "Performance-Related Quality Assurance Specifications," Presentation at American Society of Civil Engineers Convention, Dallas, TX, October, 1993.
28. Burati,James L. and Hughes S., *Construction Quality Management for Managers,* Demonstration Project 89, Publication Number FHWA-SA-94-044, Federal Highway Administration, Washington, D.C., December, 1993.
29. Federal Highway Administration, *Contract Administration Core Curriculum: Participant Manual and Reference Guide,* 1994.
30. AASHTO Joint Construction/Materials Quality Assurance Task Force, *AASHTO Quality Assurance Guide Specification,* American Association of State and Highway Transportation Officials, Washington, D.C., December, 1994.
31. Chamberlin, William P., *NCHRP Synthesis 212: Performance-Related Specifications for Highway Construction and Rehabilitation,* Transportation Research Board, National Research Council, Washington, D.C., 1995.