Glossary of Transportation Construction Quality Assurance Terms: Sixth Edition

DETAILS

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Introduction

Transportation construction quality assurance (QA), 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 transportation construction QA language, moreover, is continually changing to keep pace with advances in QA. 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-1960s, when much of it was first introduced to the transportation 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 of the Transportation Research Board's (TRB's) Management of Quality Assurance Committee (AFH20).

PURPOSE

The purpose of this publication is to provide a reference document for usage of transportation construction QA terminology. It is hoped that this publication will foster improved communications among those who are involved in transportation construction QA.

ORGANIZATION

This publication is divided into four parts: an index, a glossary of transportation construction QA terms, a list of abbreviations and symbols, and a list of references. The major part is the glossary. The terms selected for definition include many terms that frequently are misinterpreted, misunderstood, or generally confusing. The definitions provided are often more than basic definitions; they attempt to clarify the sources of confusion. This was done by examining specific topics within transportation construction QA (for example, process control) and, within each topic, focusing on groups of related terms in order to develop a better appreciation and understanding of the uniqueness 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 editorial comments not actually needed as part of a definition but helpful in establishing a better understanding of the term and therefore of 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 user may want to refer to the index to more quickly locate a term's definition. The index shows the topic under which the term is grouped as well as the page number where the definition may be found. It also identifies the reference(s) that were used to develop a definition. Many glossaries and publications containing definitions were examined in forming the definitions in this document. What is believed to be the best thoughts and wording and most necessary features were then taken from these existing definitions and 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 only the earliest (i.e., oldest) publications that provide some element of, or are the sole source of, a glossary definition, as well as to cite publications from major standards-producing organizations [such as American Society for Testing and Materials (ASTM), American Association of State and Highway Transportation Officials (AASHTO), American National Standards Institute (ANSI), and American Society for Quality (ASQ)] in those cases where there is general agreement with the glossary definition.

NEED FOR UPDATES AND COMMENTS

This publication is the fifth update of the 1996 *Transportation Research Circular Number 457*. The first update was *Transportation Research Circular E-C010* in 1999, the second was *Transportation Research Circular E-C037* in 2002, the third was *Transportation Research Circular E-C074* in 2005, and the fourth was the *Transportation Research Circular E-C137* in 2009. The Committee intends to continue to provide updates when necessary. One aspect of the updating is simply to improve the quality of the definitions. Such improvements certainly are anticipated once the definitions are put to use and specific problems or shortcomings are 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 attempts to account for the dynamic nature of the transportation construction QA language. Still another aspect of updating is the addition of new terms within topics not addressed in this publication. Many additional topics are possible for inclusion in future revisions of the glossary; some topics may require coordination with other TRB committees to best establish suitable definitions.

Closely related to the update of glossary definitions is improvement of the overall publication. For example, some of the referenced sources in this publication may not be entirely accurate in identifying the earliest document that should receive credit for creating a definition; therefore, some of the references may need to be revised. Comments or suggestions are welcome on how either the definitions themselves or any other parts of this publication can be improved to meet the users' needs or to better provide a reference document that fosters uniformity and understanding. Comments or suggestions should be directed to Tim Aschenbrener at timothy.aschenbrener@dot.gov.

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Glossary

QUALITY ASSURANCE ELEMENTS

Quality assurance (QA). (1) All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service; or (2) making sure the quality of a product is what it should be (Figure 1, page 11). [QA addresses the overall process of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, QA includes the elements of quality control (QC), independent assurance, acceptance, dispute resolution, laboratory accreditation, and personnel certification. The use of the term QA/QC or QC/QA is discouraged and the term QA should be used. QA involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, maintenance, and the interactions of these activities.]

Quality control (QC). The system used by a contractor to monitor, assess and adjust their production or placement processes to ensure that the final product will meet the specified level of quality. QC includes sampling, testing, inspection, and corrective action (where required) to maintain continuous control of a production or placement process. [QC may or may not be specified by the agency. Even when it is, the specified QC requirements or activities may not be adequate to ensure the final product will meet the specified level of quality. Thus a contractor may elect to conduct activities in addition to specified QC activities to ensure the specified level of quality. These additional activities are referred to as Process Control (PC) activities. Quality control measurements (sampling, testing, and inspection results) may or may be used with other factors as a basis for acceptance or payment. PC measurements are not used by the agency in acceptance (Figure 1, page 11).]

Acceptance. The process whereby all factors used by the agency (i.e., sampling, testing, and inspection) are evaluated to determine the degree of compliance with contract requirements and to determine the corresponding value for a given product. [Owner acceptance measurements (sampling, testing, and inspection) are always considered in the acceptance decision process. QC measurements (sampling, testing, and inspection results) may or may not be used in the acceptance decision process. PC measurements are not used by the agency in acceptance decision process.] [Where contractor test results are used in the agency's acceptance decision, the acceptance process includes contractor testing, agency verification and validation, and possibly dispute resolution.]

Inspection. The act of examining, measuring, or testing to determine the degree of compliance with requirements.

Independent assurance (IA). Activities that are an unbiased and independent evaluation of all the sampling and testing (or inspection) procedures used in the QA program. [IA provides an independent verification of the reliability of the acceptance (or verification) data obtained by the agency and the data obtained by the contractor. The results of IA testing or inspection are not to be used as a basis of acceptance. IA provides information for quality system management.]

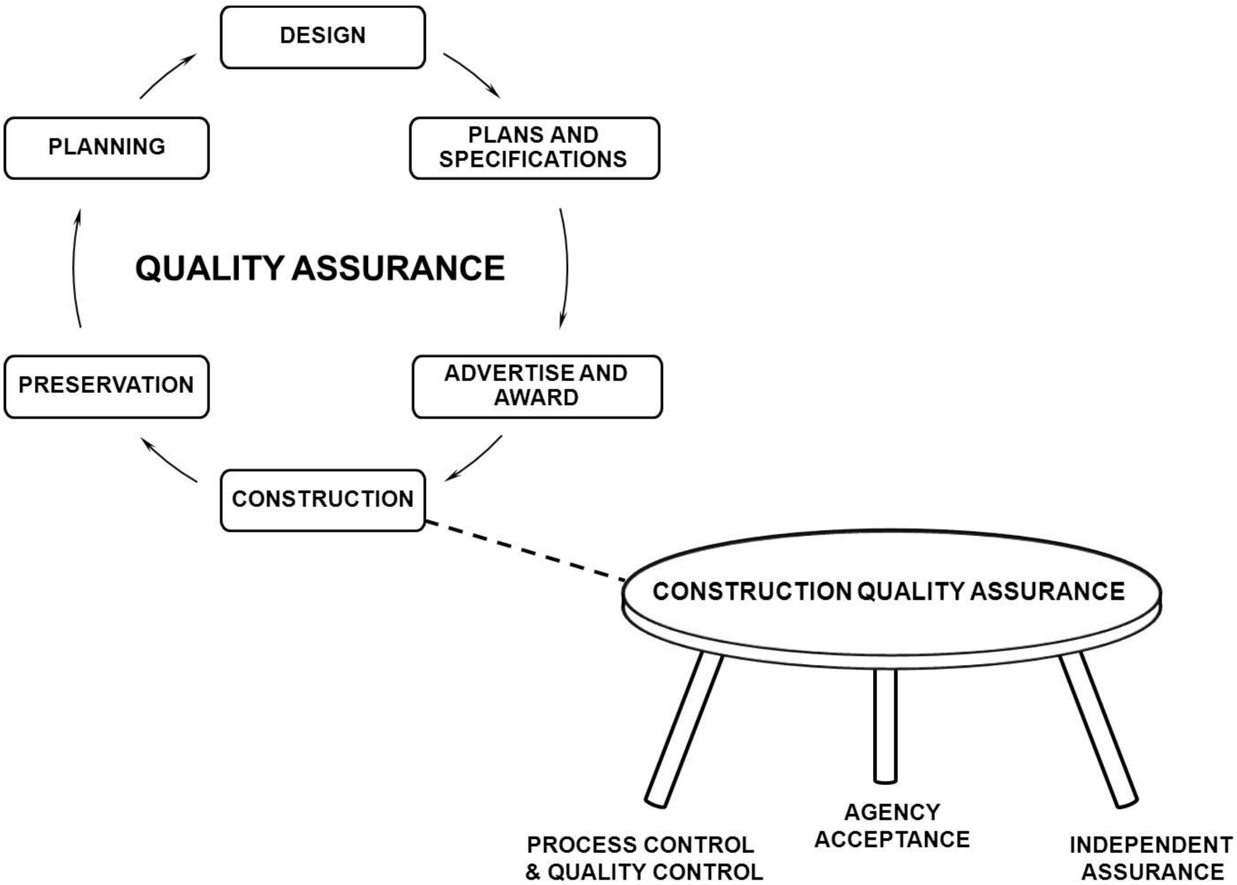

FIGURE 1 QA system elements (*26*, *42*).

Accredited laboratories. Laboratories that are recognized by a formal accrediting body as meeting quality system requirements including demonstrated competence to perform standard test procedures.

Certified technician. A technician certified by some agency as proficient in performing certain duties. [A certified technician is considered to be qualified. A qualified technician may or may not be certified. See *qualified technician*.]

Qualified technician. A technician who has been determined to be qualified (i.e., meeting some minimum standard) to perform specific duties. [A qualified technician may or may not be certified. See *certified technician*.]

Verification. The process of determining the accuracy of test results, by examining the data or providing objective evidence, or both. [Verification sampling and testing may be part of an acceptance program (to verify contractor testing used in the agency's acceptance decision).]

Validation. (1) The process of confirming the soundness or effectiveness of a product (such as a model, a program, or specifications) thereby indicating official sanction; (2) The mathematical comparison of two independently obtained sets of data (e.g., agency acceptance data versus contractor data) to determine whether it can be assumed they came from the same population [The *validation* of a product often includes the *verification* of test results.]

Dispute resolution. Also called **conflict resolution**. For QA programs permitting the use of contractor test results in the acceptance decision, an agreed-upon procedure to resolve conflicts resulting from discrepancies, between agency and contractor results, of sufficient magnitude to have an impact on payment. [The procedure may, as an initial step, include the testing of independent samples and, as a final step, third-party arbitration.]

Mixture design. The process of determining and quantifying the required characteristics of a mixture, including developing, evaluating, and testing trial mixtures to verify that the required characteristics can be met. For portland cement concrete (PCC) mixtures, some examples of required characteristics are workability, durability, and strength; and for asphalt mixtures, examples are volumetric properties, rutting resistance, and moisture susceptibility. [The mixture design process leads to the development of a job-mix formula to be adhered to on the project.]

Mixture proportioning. The identification of mixture ingredients and the selection of appropriate quantities of these ingredients to fulfill the mixture design. [The mixture proportioning process results in a quantification of the mixture ingredients by weight or by volume.]

TYPES OF SPECIFICATIONS

See Figure 2, page 13.

Materials and methods specifications. Also called **method specifications**, **recipe specifications**, or **prescriptive specifications**. Specifications that require 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 transportation agency. [Experience has shown this tends to obligate the agency to accept the completed work regardless of quality.]

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

Quality assurance specifications. Specifications that require contractor QC and agency acceptance activities throughout production and placement of a product. Final acceptance of the product is usually based on a statistical sampling of the measured quality level for key quality characteristics. [QA specifications typically are statistically based specifications that use methods such as random sampling and lot-by-lot testing, which let the contractor know if the operations are producing an acceptable product.]

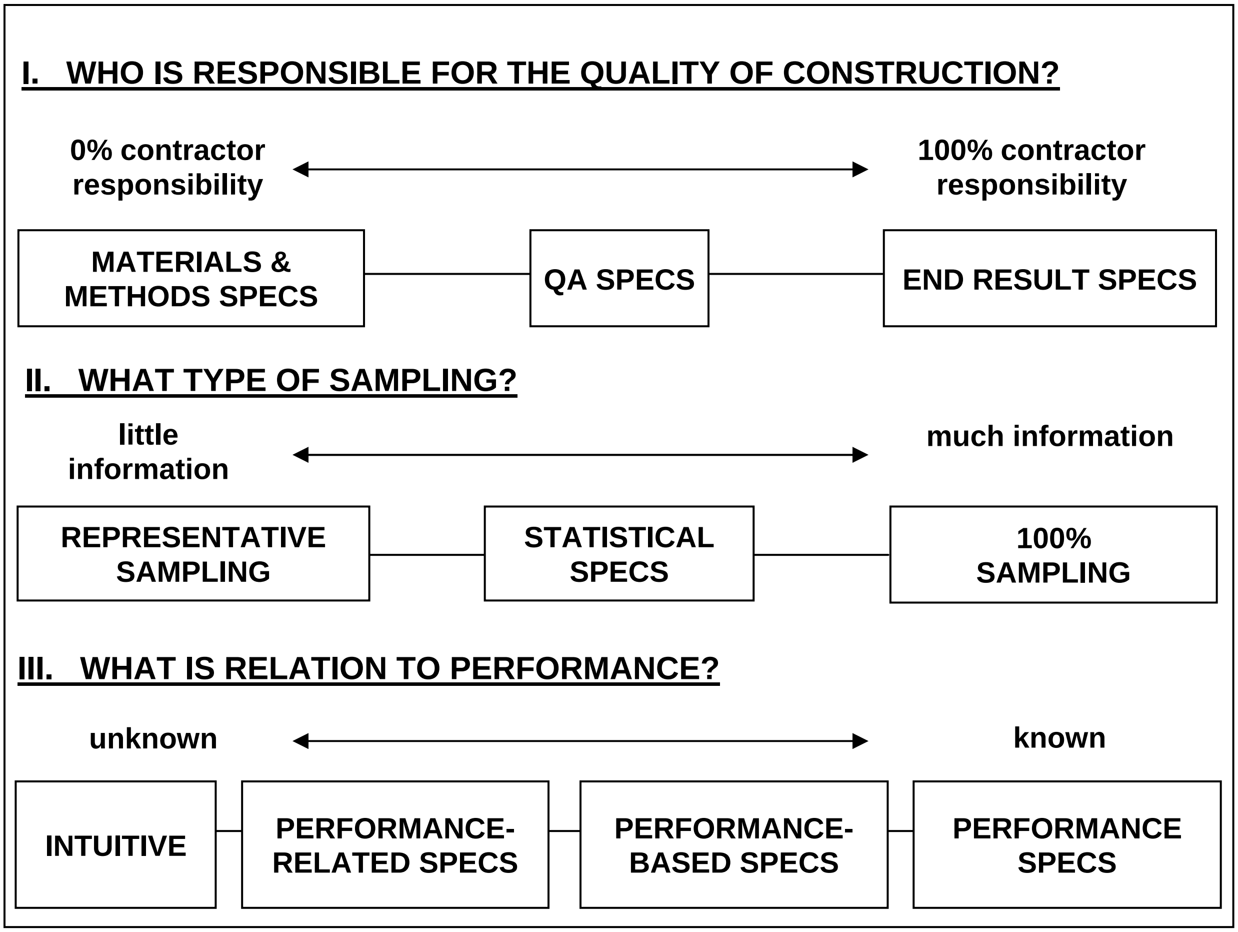

FIGURE 2 Classifying transportation construction specifications (*41*). Transportation construction specifications may be classified according to (I) who is responsible for the quality of construction, (II) the type of sampling employed, and (III) the relationship between quality criteria and constructed product performance. Thus, a 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 that is primarily performance-related might contain some performance-based acceptance criteria and some intuitively developed acceptance criteria.

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 suitable 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 suitable tests of performance.]

Performance-based specifications. QA 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 transportation construction.]

Performance-related specifications. QA 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 asphalt concrete (AC) and compressive strength of PCC] 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 as-constructed pavement performance. They thus provide the basis for rational acceptance/pay adjustment decisions.]

Warranty specifications. A type of performance specifications that guarantees the integrity of a product and assigns responsibility for the repair or replacement of defects to the contractor. [Warranty specifications can be written to guarantee either materials and workmanship or product performance.]

Materials and workmanship warranties. Specifications that hold the contractor responsible for correcting defects in work elements within the contractor’s control during the warranty period. [The length of the asphalt pavement warranties is typically 1 to 3 years. Under materials and workmanship warranties, the transportation agency is responsible for the pavement structural design. The contractor assumes no responsibility for pavement design or those distresses that result from the design. Some responsibility is shifted from the agency to the contractor for materials selection and workmanship.]

Performance warranties. Specifications that hold the contractor fully responsible for product performance during the warranty period. [Short-term asphalt pavement warranties are typically 5 to 10 years and long-term warranties are typically 10 to 20 years. Under performance warranties, the contractor guarantees that the pavement will perform at a desirable quality level. The contractor assumes some level of responsibility, depending on the specific project, for the structural pavement or mix decisions.]

ACCEPTANCE PLANS

Acceptance plan. Also called **acceptance sampling plan** or **statistical acceptance plan**. An agreed upon process for evaluating the acceptability of a lot of material. It includes lot size and sample size (i.e., number of samples), quality measure, acceptance limit(s), evaluation of risks, and pay adjustment provisions.

Attributes acceptance plan. A statistical acceptance procedure in which the acceptability of a lot of material or construction is evaluated by (1) noting the presence or absence of some characteristic or attribute in each of the units or samples in the group under consideration and (2) counting how many units do or do not possess this characteristic.

Variables acceptance plan. A statistical acceptance procedure in which quality is evaluated by (1) measuring the numerical magnitude of a quality characteristic for each of the units or samples in the group under consideration and (2) computing statistics such as the average and the standard deviation of the group.

Standard deviation–known acceptance plan. A variables acceptance plan developed with the assumption that the standard deviation of the process is known and consistent from lot to lot. [This method is appropriate when the process has been running for some time and when a state of statistical control exists with respect to process variability. Therefore, it is particularly important to monitor the stability of the process variability using control charts. With the standard deviation assumed known, the normal distribution is used to estimate percent within limits or percent defective.]

Standard deviation–unknown acceptance plan. A variables acceptance plan developed with the assumption that the standard deviation of the process is unknown. [Typically, for transportation construction processes, the standard deviation cannot be presumed to be known. With the standard deviation unknown (and the mean unknown), the beta distribution is used to estimate percent within limits or percent defective.]

Lot. A specific quantity of material from a single source which is assumed to be produced or placed by the same controlled process.

Population. A collection of all possible individuals, objects, or items that possess some common specified characteristic(s) which can be measured.

Replicate sample. Two or more samples taken under ideal conditions. [Replicate samples may be taken to estimate sampling and testing variability, for possible use if a dispute arises, or simply because they are required to calculate a test result (e.g., the average of two cylinders to calculate the compressive strength of concrete).]

Split sample. A type of replicate sample that has been divided into two or more portions representing the same material. [Split samples are sometimes taken to verify the acceptability of an operator’s test equipment and procedure. This is possible because the variability calculated from differences in split test results is composed solely of testing variability.]

Independent sample. A sample taken without regard to any other sample that may also have been taken to represent the material in question. [An independent sample is sometimes taken to verify an acceptance decision. This is possible because the data sets from independent samples, unlike those from split samples, each contain independent information reflecting all sources of variability (i.e., materials, sampling, and testing).]

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 contractor's bid price per unit of work, but may also be given as direct dollar amounts (Table 1, below).

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 or decreases to provide the contractor sufficient incentive or disincentive for high or low quality.]

Incentive–disincentive provision (for quality). A pay adjustment schedule that functions to motivate the contractor to provide a high level of quality. [A pay adjustment schedule, even one that provides for pay increases, is not necessarily an incentive or disincentive provision, as individual pay increases or 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. [This same concept also can be used to justify pay increases for superior quality above the level specified.]

Pay factor. A multiplication factor, often expressed as a percentage, used to determine the contractor's payment for a unit of work, based on the estimated quality of work. [Typically, the term "pay factor" applies to only one quality characteristic.]

TABLE 1 Understanding Pay Adjustment Schedules and Related Terms

- A pay adjustment schedule typically refers to only one quality characteristic. A pay adjustment system refers to more than one schedule or to a schedule that considers several quality characteristics.
- Pay adjustment schedules may be categorized as
  - Graduated (stepped) schedules versus continuous schedules.
  - Tabular schedules versus schedules in equation form.
  - Schedules that provide pay factors versus schedules that provide pay adjustment dollar amounts.
- Pay adjustment schedules, including those that allow pay increases, do not necessarily function as incentive or disincentive provisions.
- Pay adjustment schedules may or may not be based on liquidated damages.

Pay adjustment. The actual amount, either in dollars or in dollars per area/weight/volume, that is to be added or subtracted to the contractor's bid price or unit bid price.

Composite pay factor (PF). Also called **combined pay factor** or **overall pay factor**. A factor obtained from two or more quality characteristics and often expressed as a percentage, to be multiplied by the bid price to determine the contractor's final payment for a unit of work. [Methods typically employed to arrive at this factor are (1) calculate either a standard or a weighted average of individual PFs, (2) multiply individual PFs, or (3) use the lowest individual PF. Composite pay can also be calculated by adding the sum of individual pay adjustments to the bid price, as would likely be the case when pay adjustments are expressed in direct dollar amounts.]

Operating characteristic (OC) curve. A graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and either (1) the probability of its acceptance (for accept/reject acceptance plans) or (2) the probability of its acceptance at various payment levels (for acceptance plans that include pay adjustment provisions) (Figure 3, page 18).

Expected pay (EP) curve. A graphic representation of an acceptance plan that shows the relation between the actual quality of a lot and its EP (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) (Figure 3). [Both OC and EP curves should be used to evaluate how well an acceptance plan is theoretically expected to work.]

Seller's risk (α). Also called **contractor's risk**, **risk of a Type I**, or **alpha (α) error**. The risk to the contractor of having acceptable quality level (AQL) material or workmanship rejected. [For an accept/reject acceptance plan, it is the probability that an acceptance plan will erroneously reject AQL material or workmanship with respect to a single acceptance quality characteristic. For variables acceptance plans using adjusted pay schedules, it is equivalent to α PF, where PF = 100. It is the probability that a variable payment acceptance plan will erroneously accept AQL material or workmanship at less than 100% pay with respect to a single acceptance quality characteristic.]

Buyer's risk (β). Also called **agency's risk**, **risk of a Type II**, or **beta (β) error**. It is the risk to the agency of accepting rejectable quality level (RQL) material or workmanship. [For an accept/reject acceptance plan, it is the probability that an acceptance plan will erroneously accept RQL material or workmanship with respect to a single acceptance quality characteristic. For variables acceptance plans using adjusted pay schedules, it is equivalent to β PF, where PF = 100. It is the probability that a variable payment acceptance plan will erroneously fully accept RQL material or workmanship at 100% pay or greater with respect to a single acceptance quality characteristic.]

Alpha sub pf (α_{pf}). For acceptance plans with pay adjustments, the probability that AQL material or construction will be assessed a PF less than pf with respect to a single acceptance quality characteristic. For example, α_{100} for a compressive strength pay adjustment acceptance plan is the probability AQL compressive strength material will be assessed less than 100% pay for compressive strength; this probability includes the probability of rejection, α, with

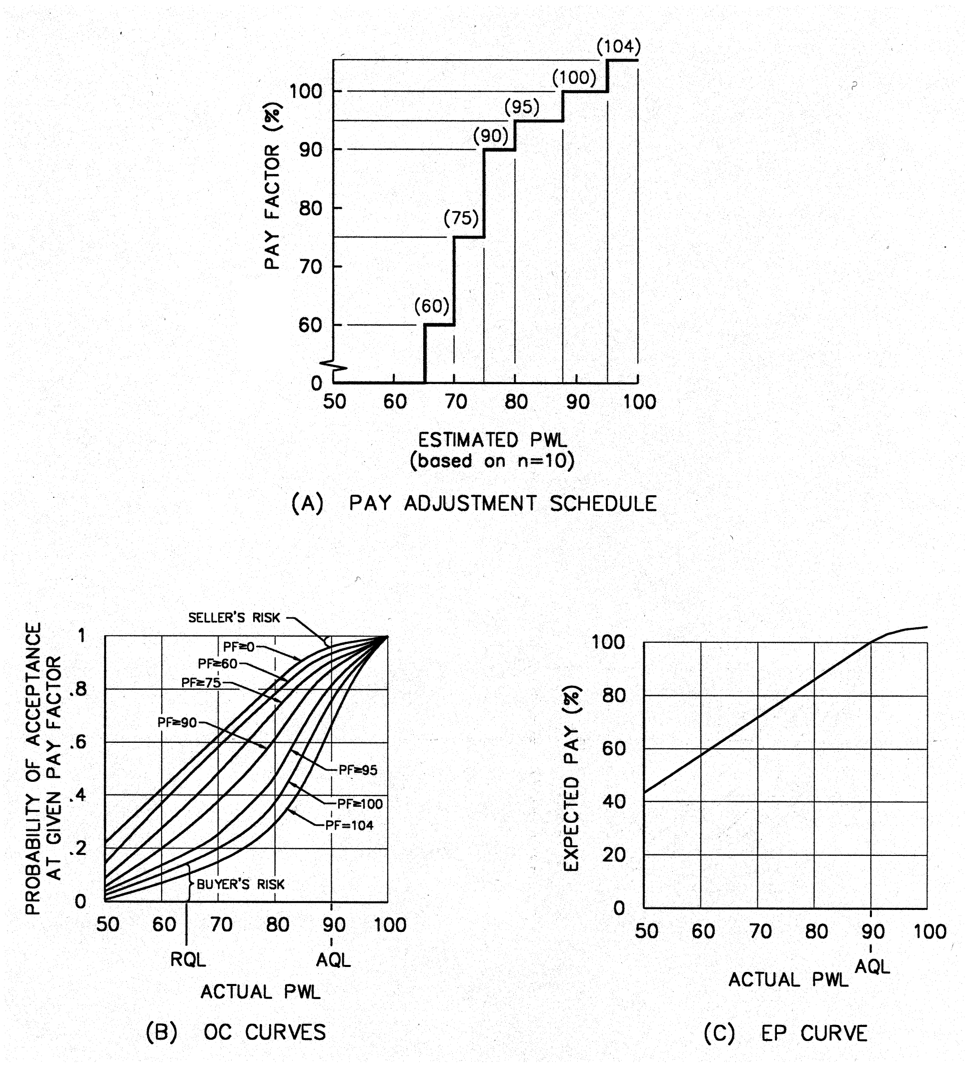

FIGURE 3 Graphic summaries of an acceptance plan (*25*). Shown above are three types of graphs used to summarize a typical acceptance plan containing a pay adjustment schedule. (*a*) describes the pay adjustment schedule. (*b*) and (*c*) present the corresponding set of OC curves and the corresponding 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. In addition, note that specific β_{pf} and α_{pf} risks can also be identified; for example, β_{90} is about 29%, and α_{90} is about 9%. Both the OC curves and the EP curve should be developed and evaluated to assess how an acceptance plan is (or will be) working. By itself, the EP curve for an acceptance plan may seem satisfactory but the OC curves could show β_{pf} and α_{pf} risks that are too high. (NOTE: AQL = acceptable quality level; RQL = rejectable quality level; OC = operating characteristic; EP = expected pay; PWL = percent within limits.)

respect to compressive strength. [The use of α_{pf} addresses the need to quantify, for pay adjustment acceptance plans, the probabilities associated with each possible pay decision regarding AQL material (e.g., whether to pay 0%, 70%, 80%, 90%, 100%, or 105% for AQL).]

Beta sub pf (β_{pf}). For acceptance plans with pay adjustments, the probability that RQL material will be assessed a PF greater than or equal to pf. For example, β_{100} for a compressive strength pay adjustment acceptance plan is the probability RQL compressive strength will be assessed 100% pay or more for compressive strength. [The use of β_{pf} addresses the need to quantify, for pay adjustment acceptance plans, the probabilities associated with each possible pay decision regarding RQL material (e.g., whether to pay 0%, 70%, 80%, 90%, 100%, or 105% for RQL).]

MEASURING QUALITY

Quality. (1) The degree 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. When the quality characteristic is measured for acceptance purposes, it is an **acceptance quality characteristic (AQC)**; when measured for process control (QC) purposes, it is a **process control quality characteristic**.

Quality measure. Any one of several mathematical tools that are used to quantify the level of quality of an individual quality characteristic. [Typical quality measures used in QA are selected because they quantify the average quality, the variability, or both. Examples of quality measures that may be used include mean, standard deviation, percent defective (PD), percent within limits (PWL), average absolute deviation (AAD), and moving average. PWL or PD is the quality measure that is recommended for use in QA specifications.]

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

$Q_L = (\overline{X} - \text{LSL})/s$ where Q_L is the quality index relative to lower specification limit (LSL),

or

$Q_U = (\text{USL} - \overline{X})/s$ where Q_U is the quality index relative to upper specification limit (USL).

Percent defective (PD). The percentage of the lot falling outside specification limits. [PD may refer to either the population value or the sample estimate of the population value.]

Percent within limits (PWL). The percentage of the lot falling above the LSL, beneath the USL, or between the LSL and the USL. [PWL may refer to either the population value or the sample estimate of the population value. PWL = 100 – PD.]

Percent nonconforming. For attributes acceptance plans, the percentage of units having at least one departure of an attribute from its intended level.

Percent conforming. For attributes acceptance plans, the percentage of units having no departure of an attribute from its intended level. (Percent conforming + percent nonconforming = 100.)

Quality-level analysis (QLA). A statistical procedure that provides an estimate of the percentage of a given lot that is within specification limits (PWL) or outside specification limits (PD).

Specification limit(s). The limiting value(s) placed on a quality characteristic, established preferably by statistical analysis, for evaluating material or construction within the specification requirements. The term can refer to either an individual USL or an LSL, called a single specification limit, or to USL and LSL together, called double specification limits.

Acceptance limit. Also called **rejection limit** in accept/reject acceptance plans. In variables acceptance plans, the limiting upper or lower value, placed on a quality measure, which will permit acceptance of a lot. [Unlike specification limits placed on a quality characteristic, an acceptance limit is placed on a quality measure. For example, if a concrete compressive strength lot is deemed acceptable once QLA indicates that at least 70% of the lot has compressive strength above 3,000 psi, this defines the acceptance limit as PWL = 70 and the LSL as 3,000 psi.]

Acceptable quality level (AQL). For a given quality characteristic, that minimum level of actual quality at which the material or construction can be considered fully acceptable. [For example, when quality is based on 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 that AQL material will receive an EP of 100%.]

Rejectable quality level (RQL). The level of established actual quality for a quality characteristic that is rejectable when using a particular quality measure. [For example, when the quality measure used is PWL, the RQL is the established (not estimated) PWL at which the quality characteristic is rejected. It is desired to require removal and replacement, corrective action, or the assignment of a relatively low PF when RQL work is detected.]

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

Acceptance constant (*k*). The minimum allowable quality index (Q). [The acceptance constant k is the acceptance limit associated with the quality index quality measure. In other words, for acceptance, Q must be greater than or equal to k.]

Sample standard deviation (*s*). A measure of the dispersion of a series of results around their average, expressed as the square root of the quantity obtained by summing the squares of the deviations from the average of the results and dividing by the number of observations minus one.

$$s = \sqrt{\sum (X_i - \overline{X})^2 / (n - 1)}$$

Root mean square deviation (RMS). A measure of the dispersion of a series of results around their average, expressed as the square root of the quantity obtained by summing the squares of the deviations from the average of the results and dividing by the number of observations.

$$\text{RMS} = \sqrt{\sum (X_i - \overline{X})^2 / n}$$

[Both s and RMS give biased estimates of the population standard deviation (σ). However, the sample variance (s^2) provides an unbiased estimate of the population variance (σ^2), while $(\text{RMS})^2$ is the maximum likelihood estimator of the population variance (σ^2).]

Standard error (of statistic). The standard deviation (s) of the sampling distribution of a statistic. For example, the standard error of the mean ($\overline{X}$) is the standard deviation of the sampling distribution of $\overline{X}$ (i.e., $s/\sqrt{n}$).

Standard error of estimate (SEE). In regression analysis, the standard deviation of the errors of estimate in dependent (response) variable Y.

$$\text{SEE} = \sqrt{\sum \left(Y_i - \hat{Y}_x\right)^2 / (n-2)}$$

Residual. Also called *residual error*. The difference between the observed value and the fitted value in a statistical model.

Conformal index (CI). A measure of the dispersion of a series of results around a target or specified value, expressed as the square root of the quantity obtained by summing the squares of the deviations from the target value and dividing by the number of observations.

$$\text{CI} = \sqrt{\sum (X_i - T)^2 / n}$$

[While the standard deviation is a measure of precision, the CI is a measure of exactness (accuracy) or degree of conformance with the target.]

Average absolute deviation (AAD). For a series of test results, the mean of absolute deviations from a target or specified value. [A low AAD implies both good accuracy and good precision; a high AAD, however, does not necessarily imply both poor accuracy and poor precision (i.e., accuracy or precision, but not both, might be quite good).]

Skewness. The lack of symmetry in a probability distribution. When the distribution has a greater tendency to tail to the right, it is said to have positive skewness. When the distribution has a greater tendency to tail to the left, it is said to have negative skewness. For the normal distribution (as well as for any other symmetrical distribution), the **skewness coefficient** equals 0 (Figure 4, page 22).

Population skewness coefficient: $\gamma_1 = \sum (X_i - \mu)^3 / 2n\sigma^3$

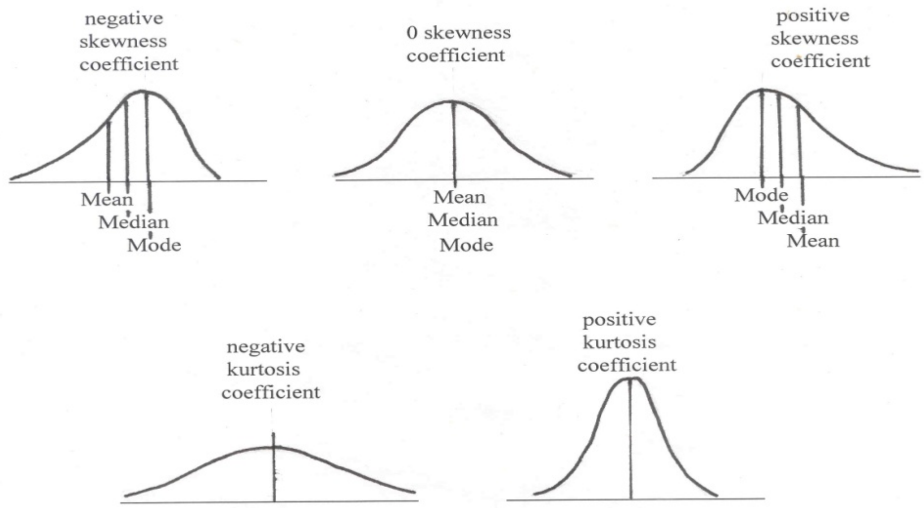

FIGURE 4 Skewness and kurtosis.

Sample skewness coefficient: $g_1 = n\sum(X_i - \bar{X})^3/[s^3(n-1)(n-2)]$

Kurtosis. The degree of peakedness in a probability distribution. For the normal distribution, the **kurtosis coefficient** equals 0 (mesokurtic). A positive kurtosis coefficient indicates a relatively peaked distribution (leptokurtic) in comparison with the normal distribution, while a negative kurtosis coefficient indicates a relatively flat distribution (platykurtic) (Figure 4).

Population kurtosis coefficient: $\gamma_2 = [\sum(X_i - \mu)^4/n\sigma^4] - 3$

Sample kurtosis coefficient:

$$g_2 = [n(n+1)\sum(X_i - \bar{X})^4/s^4(n-1)(n-2)(n-3)] - [3(n-1)^2/(n-2)(n-3)$$

CONTRACTING FOR QUALITY

Design–bid–build (DBB). A project delivery system in which the design is completed either by in-house professional engineering staff or a design consultant before the construction contract is advertised. [The DBB method is sometimes referred to as the traditional method.]

Design–build (DB). A project delivery system in which both the design and the construction of the project are simultaneously awarded to a single entity. [The main advantage of the DB method is that it can decrease project delivery time.]

Design–build–finance–operate–maintain (DBFOM). A project delivery system in which the design, construction, financing, operations, and maintenance of the project are awarded to a single entity. This is a type of public–private partnership (P3) concession. [The main advantage of the DBOFM method is that it can utilize private capital to help finance a project and decrease project delivery time.]

Construction manager at risk (CMR). Also called **construction manager–general contractor (CMGC)**. A project delivery system that entails a commitment by the construction manager to deliver the project within a guaranteed maximum price (GMP), in most cases. The construction manager acts as consultant to the owner in the development and design phases and as the equivalent of a general contractor during the construction phase. [When a construction manager is bound to a GMP, the general nature of the working relationship is changed. In addition to acting in the owner's interest, the construction manager must manage and control construction costs to not exceed the GMP, which would be a financial loss to the construction manager.]

Public–private partnership (P3). A government service or private business venture that is funded and operated through a partnership of government and one or more private-sector companies. A P3 concession is an alternative way for a public agency to deliver a public-purpose project. A P3 concession has three primary elements: a concession goal, a compensation structure, and a term or length of time. Each element is established by the public agency that implements the P3 concession, sometimes in negotiation with the private partner.

Requirement. A capability to which a product or service must display to fulfill the product's or service's intended purpose.

Partnering. A structured process that creates an owner–contractor relationship focused on achieving mutually beneficial goals.

Value engineering. The systematic review by qualified agency and/or contractor personnel of a project, product, or process so as to improve performance, quality, safety, and life-cycle costs.

Cost-plus-time bidding. Also called **A + B bidding**. A bidding procedure that selects the low bidder based on a monetary combination of the traditional bid price (A) and the time (B) needed to complete the project or a critical portion of the project. A cost-plus-time contract can be devised to actually pay the contractor either only the A portion of the bid or the A portion plus or minus an agreed-upon incentive–disincentive amount for early or late completion; this latter form of the contract is sometimes referred to as a **cost-plus-time with incentives or disincentives (A + B + I/D) contract.** [The intent of either form is to provide an incentive for the contractor to minimize delivery time for high-priority roadways.]

Multiparameter bidding. Also called **A + B + C bidding**. A bidding procedure that selects the low bidder based on a monetary combination of the traditional bid price (A), the completion time (B), and other elements (C) such as construction quality, safety, and life-cycle costs. Quantification of the elements and bidder evaluation methodology are included in the procedure.

PROCESS CONTROL

Process control. A method for keeping a process within boundaries and/or the act of minimizing the variation of a process. Process control activities may include sampling, testing, inspection, and corrective action performed by a contractor in addition to QC requirements to improve the likelihood that the final product will meet the specified level of quality. [For example, a contractor may measure, monitor, and control the gradation of individual aggregate hot bins or coldfeed collector belt samples as a process control activity when QC or agency acceptance measurements are required on postplant aggregates from an ignition asphalt content sample.]

Control chart. Also called **statistical control chart**. A graphical plot of QC measurements or test results used to identify variation in a production or placement process due to either chance causes or assignable causes. (Control charts have statistically derived control limits. Plotted values may be for individual measurements or the averages of groups of measurements. The control limits can be established statistically based on sample sizes of $n = 1$ or $n > 1$. Sample sizes of $n > 1$ are preferred, with sample sizes of $n = 3$, 4, or 5 being the most common.)

Assignable cause. A 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 cause only. [A process might be "under control" but produce out-of-specification material if the specification limits are tight. Similarly, 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.]

Tolerance limit(s) (upper, lower). Also called **tolerance(s)**. The limiting value(s) placed on a quality characteristic to define its absolute conformance boundaries such that nothing is permitted outside the boundaries. [A distinction between tolerance limits and specification limits is that tolerance limits apply to process control and specification limits to statistical acceptance.]

Control limit(s) (upper, lower). Also called **action limit(s)**. Boundaries established by statistical analysis for material production control using the control chart method. When values of the material characteristic fall within these limits, the process is "under control." When values fall outside the limits, this indicates that there is some assignable cause for the process going "out of control."

Warning limit(s) (upper, lower). Boundaries established on process 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."

Target value (*T*). A number established as a goal for the quality level to be achieved during construction. [The contractor's target value for a quality characteristic may not be the same as the agency-established design value (obtained from structural or mixture design, or both) or the specified (i.e., AQL) value.]

Design value. A number assumed during the design process or an output of the design process.

Specified value. A number that represents the quality level, or minimum quality level, that the specifying agency wants.

STATISTICS

Estimation

Parameter. A constant or coefficient that describes some characteristic of a population. Some examples of parameters are the population standard deviation, the population mean, and the population regression coefficients. [In most transportation QA applications, the true population parameter value is unknown. The parameter value can be estimated by calculating a statistic from sample data.]

Statistic. A summary value calculated from a sample of observations. Some examples are the sample standard deviation, the sample mean, and the regression coefficients estimated from the sample.

Estimator. A statistic used to estimate a parameter to help describe the population. [The estimate may be given as a point estimate or as an interval estimate.]

Unbiased estimator. A statistic whose mathematical expected value (i.e., average value over the long run) is equal to the value of the population parameter being estimated. For example, the sample mean is an unbiased estimator of the population mean. On the other hand, the sample range is a biased estimator of the population range.

Consistent estimator. A statistic whose standard error becomes smaller as the sample size increases. [An unbiased estimator is not necessarily a consistent estimator, and a consistent estimator is not necessarily an unbiased estimator. For example, the sample root mean square variance $(RMS)^2$ is a consistent estimator of the population variance, but it is not an unbiased estimator.]

Efficient estimator. A statistic having a small standard error. If one considers all possible estimators of a given parameter, the one with the smallest standard error for the same sample size is called the **most efficient estimator** of the parameter. [An efficient estimator is a consistent estimator. Efficient estimators may or may not be unbiased for finite samples. As an example, the sample mean and the sample median are consistent and unbiased estimators of the population mean when the population is normally distributed. However, the distribution of the sample mean has a smaller standard error than that of the sample median and is thus the more efficient estimator of the population mean.]

Sufficient estimator. A statistic that contains all the information that can be obtained from the sample regarding the population parameter. Sufficient estimators occur only in special distributions. An example of a sufficient estimator is the sample mean to estimate the population mean from a population having a Poisson distribution (since the Poisson distribution depends only on the mean).

Maximum likelihood estimator. A statistic that is more likely to result in an estimate equal to the population parameter than in any other estimate. As an example, the sample proportion of successes is a maximum likelihood estimator of the population proportion of successes from a binomial distribution.

Confidence interval. An estimate of an interval in which the estimated parameter will lie with prechosen probability (called the confidence level). The end points of a confidence interval are called **confidence limits**.

Confidence level. If a large number of confidence intervals are constructed, the proportion of time that the estimated parameter will lie within the interval. [A confidence level is usually expressed as a percentage, typically ranging from 90% to 99%. Confidence level = 1 – **confidence coefficient** (α).]

Hypothesis Testing

Significance level (α). The probability of rejecting a null hypothesis when it is in fact true. [This probability, often denoted by α, is generally specified before any samples are drawn, so that results will not influence the level selected.]

Hypothesis. A tentative theory or supposition provisionally adopted to explain certain facts and to guide in the investigation of others. [For example a statistical hypothesis is a statement concerning the value of a population parameter that can be tested statistically to determine the validity of the statement.]

Null hypothesis (H_0). The hypothesis being tested. [Contrary to intuition, the null hypothesis is often a research hypothesis that the analyst would prefer to reject in favor of the alternative hypothesis. The null hypothesis can never be proved true. It can, however, be shown, with specified risks of error, to be untrue. If it is not disproved (i.e., not rejected), one usually acts on the assumption that there is no reason to doubt that it is true.]

Alternative hypothesis (H_a). The hypothesis to be accepted if the null hypothesis is disproved (i.e., rejected).

Type I error. Erroneous rejection of the null hypothesis. Also, see **seller's risk** (α).

Type II error. Erroneous acceptance of the null hypothesis. Also see **buyer's risk** (β).

Power curve. A curve, used in hypothesis testing, to indicate the probability of rejecting a hypothesis. The curve shows the relation between the probability (1 – β) of rejecting the hypothesis that a sample belongs to a given population with a given characteristic and the actual population value of that characteristic. [If β is plotted instead of (1 – β), the curve is analogous to the OC curve used in accept/reject acceptance plans.]

Regression

Simple linear regression. A means of fitting a straight line to data so that one can predict a dependent (response) random variable Y, using a known independent variable X. $Y = aX + b$ is an example of a simple linear regression equation.

Multiple linear regression. A means of predicting a dependent (response) random variable Y, using more than one known independent variable X_i. [The so-called independent variables are independent of Y but not necessarily independent among themselves. $Y = a + bX_1 + cX_2$, where $X_2 = \sin X_1^2$, is an example of a multiple linear regression equation. Note that in all cases X_i may be any function, not necessarily of the first degree. The concept of linear is that used in linear algebra—namely the parameters occur linearly.]

Nonlinear regression. A means of predicting a dependent (response) random variable Y, using an equation in which the parameters do not occur linearly. The exponential equation, $Y = ae^{bx+c}$, is an example of a nonlinear regression equation. [However, by taking the logarithm to the base e, the equation can be transformed into the form $\log_e Y = \log_e a + bX + c$. Such a model is called intrinsically linear. On the other hand, $Y = e^{-ax} - e^{-bx}$ cannot be transformed; such a model is called intrinsically nonlinear.]

Polynomial regression. A means of predicting a dependent (response) random variable Y, using a known independent variable X, through a polynomial equation. $Y = aX^2 + bX + c$ is an example of a linear, polynomial regression equation.

Correlation coefficient (r). A measure of the linear relationship between a single dependent (response) random variable Y and a known independent variable X (Figure 5, page 28). [The correlation coefficient ranges in value from –1 to +1, indicating a perfect negative linear relationship at –1, absence of linear relationship at 0, and perfect positive linear relationship at +1. Thus, when Y varies directly with X, the correlation coefficient is positive; when Y bears an inverse relationship to X, the correlation coefficient is negative.]

Coefficient of determination for linear regression (r^2). A measure of the linear relationship between a single dependent random variable or response Y and a known independent variable X. It represents the proportion of the total variation of Y due to X. For instance, if $r^2 = 0.81$ ($r = \pm 0.9$),

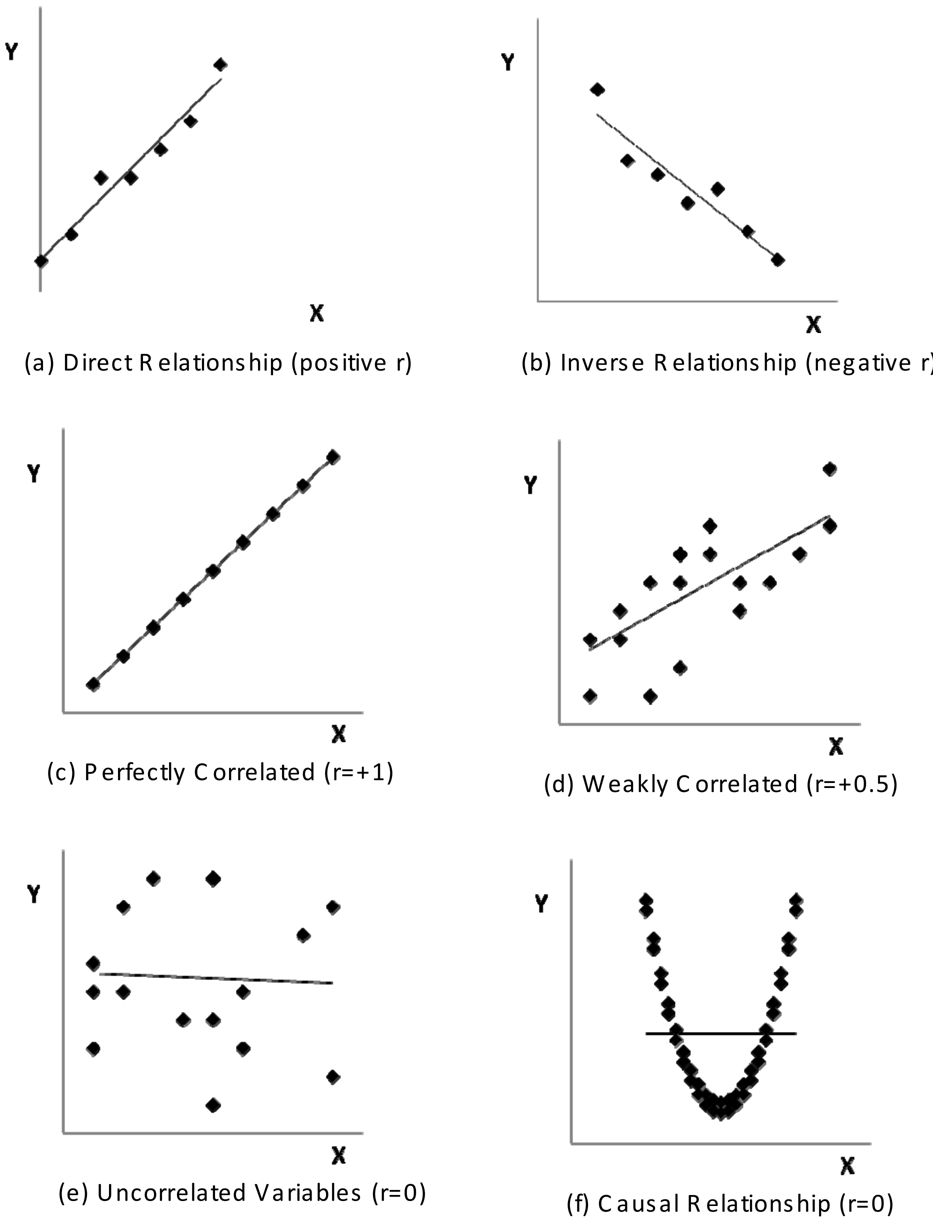

FIGURE 5 The correlation coefficient *r* is a measure of linear relationship (*19*, *23*): (*a*) direct relationship (positive *r*); (*b*) inverse relationship (negative *r*); (*c*) perfectly correlated (*r* = +1); (*d*) weakly correlated (*r* = +0.5); (*e*) uncorrelated variables (*r* = 0); and (*f*) causal relationship (*r* = 0).

then 81% of the variation in the values of *Y* may be accounted for by the linear relationship with the variable *X*. [The value of r^2 from a regression model cannot be evaluated as good or bad in singularity; it can only be judged relative to other models that have been estimated on similar phenomena. Thus, an r^2 of 0.30 for one phenomenon might be extremely informative, while for another phenomenon it might be uninformative.]

PAVEMENT PERFORMANCE MODELING AND PAY SCHEDULE DEVELOPMENT

Model. A mathematical or numerical description of an object or phenomenon that shares important characteristics with the object or phenomenon.

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 in meters per kilometer), or faulting measured in inches of wheel path faulting per mile (or in millimeters per kilometer). [When considered collectively, pavement condition indicators provide an estimate of the overall adequacy of a particular roadway.]

Empirical model. A model developed from performance histories of pavements. [An empirical model is usually accurate only for the exact conditions and ranges of independent variables under which it was developed.]

Mechanistic model. A model developed from the laws of mechanics, in which the prescribed action of forces on bodies of material elements are related to the resulting stress, strain, deformation, and failure of the pavement.

Mechanistic–empirical model. A model developed from a combination of mechanistic and empirical considerations. The basic advantage is that it provides more reliable performance predictions.

Deterministic model. A model that does not consider chance or probability. In a deterministic model, each independent variable is treated as a single value.

Stochastic model. Also called **probabilistic model**. A model containing one or more independent variables that are treated as having a range of possible values. [A useful technique for computing the output from a stochastic model is Monte Carlo simulation.]

Model calibration. The process of checking parameters that have been estimated for a similar model and making adjustments for use in one's own model, for the purpose of optimizing the agreement between observed data and the adjusted model's predictions.

Empirical performance-related specifications (PRS) method. Also called **expected life method**. A procedure to develop performance-related transportation construction specifications by first developing mathematical models based on empirical performance data, and then applying life-cycle cost analysis to establish pay adjustment provisions related to predicted performance.

Performance matrix method. A mathematical procedure involving the solution of a set of simultaneous equations using a matrix of empirical performance data to derive an exponential model giving expected service life as a function of a set of two or more quality parameters. [This function, which is an integral part of the empirical PRS method, can be accessed as part of the new SpecRisk software.]

Primary prediction 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 prediction relationship. An equation that shows how one or more materials and construction 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, a predictor variable, 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 be controlled directly or indirectly. 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 or construction, or both, 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 M&C variable.]

Process control M&C variable. A characteristic of materials or construction, or both, 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 or construction, or both, 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 (Figure 6, page 31). [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.]

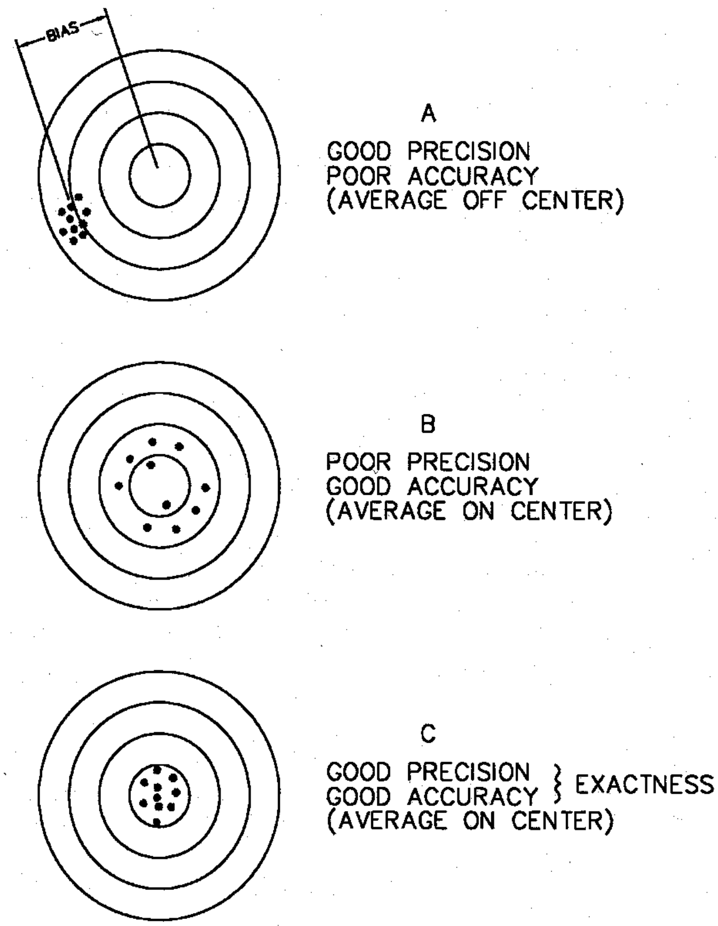

FIGURE 6 Exactness of measurement (*17*).

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 (Figure 6).

Resolution. The smallest discernible difference between any two measurements that are reported within the working range of a test method.

Reliability. The degree to which a test produces consistent or dependable results. [Test reliability is increased as both precision and accuracy are improved.] Reliability also can 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 QA that is concerned with the quality of product function over time. Still another quality assurance usage of the term reliability is within the context of pavement design, where a **reliability factor** is employed to address the uncertainty associated with predicting pavement performance at the time of design.

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.

Robustness. Insensitivity of a statistical test to departures from underlying assumptions. [If departures from underlying assumptions do not materially affect the decisions that would be based on the statistical test involved, the test is considered robust. For example, tests based on an assumption of normality that compare averages generally are robust even though the underlying distribution of individual items in the population is not normal.] The term robustness also can refer to the condition of a product or process design that remains relatively stable, with a minimum of variation, even though factors that influence operations or usage, such as environment and wear, are constantly changing.

Ruggedness. Insensitivity of a test method to departures from specified test or environmental conditions. [An evaluation of the ruggedness of a test method or an empirical model derived from an experiment is useful in determining whether the results or decisions will be relatively invariant over some range of environmental variability under which the test method or the model is likely to be applied.]

SIMULATION

Computer simulation. Use of a computer to generate conditions approximating actual or operational conditions. [Computer simulation is a powerful and convenient tool to solve certain problems that are intractable by other methods.]

Monte Carlo simulation. A simulation technique (usually performed by a computer and particularly useful for QA applications) that uses random numbers to sample from probability distributions to produce hundreds or thousands of scenarios (called iterations, trials, or runs). [A complete Monte Carlo *simulation* thus uses each result from each individual *iteration*.]

Iteration. (1) The act or process of repeating something; replication. [*Iteration*, as opposed to *replication*, is the preferred term for use with respect to Monte Carlo simulations.] (2) The method of independent successive trials, the increasing number of which when analyzed collectively produces a gradually more precise measure of the effect being measured.

Replication. (1) The act or process of duplicating or repeating something; iteration. (2) The execution of an experiment more than once to increase precision and to obtain a better estimate of the residual variation (i.e., the remaining variation in a set of data after the variation due to certain effects, factors, and interactions has been removed). [*Replication*, as opposed to *iteration*, is the preferred term for use with respect to experimental design.]

RISK MANAGEMENT

Risk. (1) Also called **statistical risk**. The probability of suffering harm or loss. [Seller's and buyer's risks (α and β) are probabilities; they are examples of statistical risks.] (2) Also called **engineering risk**. A function that represents the expected cost associated with a risk event. Engineering risk = (probability of event occurring) × (economic consequences of event). [An example of engineering risk is (the probability the contractor will not complete on schedule) × (the economic consequences of not completing on schedule).]

Risk event. An uncertain event or condition that has negative (or positive) consequences if it occurs. ["The contractor will not complete the project on schedule" is an example of a risk event with negative consequences. "The contractor will complete the project ahead of schedule" is an example of a risk event with positive consequences.]

Risk management. A scientific approach to dealing with engineering risks by anticipating possible losses and designing and implementing procedures that minimize the occurrence of loss or the financial impact of losses that do occur.

Risk assessment. A component of risk management that uses risk event identification and risk analysis in support of risk allocation.

Risk analysis. (1) Measuring the probability of risk events. [This definition applies to statistical risks.] (2) Measuring the probability and consequences of risk events and estimating their implications. [This definition applies to engineering risks. The analysis may be qualitative (e.g., risk events are assigned high, moderate, or low priorities) or quantitative (e.g., risk events are characterized by probability distributions).]

Risk allocation. The distribution of engineering risk among the various participants in a project.

Risk reduction. Also called **risk mitigation.** All techniques that are designed to reduce the likelihood of loss, or the potential severity of those losses that do occur.

Risk transfer. The process of shifting engineering risk from one party to another who is more willing to bear the risk. Risk transfer is often accomplished by the use of contracts or insurance.

Risk aversion. A concept in economics, finance, and psychology related to the behavior of individuals or organizations under uncertainty. Risk aversion is the reluctance to accept an option with an uncertain payoff rather than another option with more certain, but possibly lower, expected payoff.

Risk tolerance. The degree of uncertainty that an individual or organization is willing to accept. The inverse of a person's risk aversion is sometimes called his or her risk tolerance.

Risk neutral. An adjective that describes a behavior that is in between risk averse and risk seeking. [If offered either $50 or a 50% chance of $100, a risk-averse person will take the $50, a risk seeking person will take the 50% chance of $100, and a risk neutral person would have no preference between the two options. As the magnitude of the payoff increases or decreases, it is possible (probably likely) that the person's risk behavior will change.]

Abbreviations and Symbols

AAD	average absolute deviation
A + B	cost plus time
AC	asphalt concrete
AQC	acceptance quality characteristic
AQL	acceptable quality level
α	significance level; probability Type I hypothesis testing error; confidence coefficient; seller's risk
α_{pf}	seller's risk in acceptance plan with pay adjustments
$1 - \alpha$	confidence level
β	probability of Type II hypothesis testing error; buyer's risk
β_{pf}	buyer's risk in acceptance plan with pay adjustments
$1 - \beta$	power
c	acceptance number
CI	conformal index
CMGC	construction manager–general contractor
CMR	construction manager at risk
DB	design–build
DBB	design–bid–build
EP	expected pay
GMP	guaranteed maximum price
g_1	sample skewness coefficient
g_2	sample kurtosis coefficient
γ_1	population skewness coefficient
γ_2	population kurtosis coefficient
H_0	null hypothesis
H_a	alternative hypothesis
k	acceptance constant
I/D	incentive–disincentive
LSL	lower specification limit
μ	population mean
M&C	materials and construction
n	number of samples
OC	operating characteristic
PCC	portland cement concrete
PD	percent defective
PF	pay factor
P3	public–private partnership
PRS	performance-related specifications
PWL	percent within limits
QA	quality assurance
QC	quality control
QLA	quality-level analysis
Q	quality index

Q_L	lower quality index
QU	upper quality index
r	correlation coefficient
r^2	coefficient of determination
RMS	root mean square deviation
$(\text{RMS})^2$	root mean square variance
RQL	rejectable quality level
s	sample standard deviation
s^2	sample variance
σ	population standard deviation
σ2	population variance
SEE	standard error of estimate
T	target value
USL	upper specification limit
X	independent variable
$\overline{X}$	sample mean
Y	dependent (response) variable
$\hat{Y}_x$	linear regression estimate of Y at point x

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