
Standard Practice for Acceptance Sampling Plans for Highway Construction

AASHTO Designation: R 9-05 (2022)

Technically Revised: 2005

Reviewed but Not Updated: 2022

Tech Subcommittee: 5c, Quality Assurance and Environmental



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1. SCOPE

- 1.1. *Definition of 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 (*Transportation Research Circular Number E-C037*, 2002).
- 1.2. *Purpose of Acceptance Plan*—This standard practice provides guidelines in the preparation of statistically based acceptance plans using statistical and quality assurance (QA) principles. The acceptance plans must be realistic, fair to both the contractor and agency, and statistically accurate. This standard practice includes the basic criteria for the most common AASHTO applications. It uses the broad definition of acceptance plan to include the separate functions of both quality control (QC) and acceptance. Other aspects are provided where deemed important, but should not be interpreted to define a complete QA program. References are given for more advanced criteria and special applications.
- 1.3. *Target Audience*—It is assumed that the user is a mid-level materials engineer and has an understanding of statistics, including the calculation of the mean and standard deviation, the development of histograms, and the use of continuous probability density functions or distributions.
- 1.4. *Background Sources*—Preparatory knowledge of acceptance plans is included in the course entitled *Materials Control and Acceptance—Quality Assurance* (2000); in the manual *Optimal Procedures for Quality Assurance Specifications* (2003); and in most basic statistics textbooks.

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
 - [R 10](#), Definition of Terms Related to Quality and Statistics as Used in Highway Construction
 - [R 25](#), Technician Training and Certification Programs
 - [R 38](#), Quality Assurance of Standard Manufactured Materials
- 2.2. *ASTM Standards:*
 - [D3665](#), Standard Practice for Random Sampling of Construction Materials
 - [E29](#), Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
 - [E178](#), Standard Practice for Dealing with Outlying Observations

- MNL7, *Manual on Presentation of Data and Control Chart Analysis*, 8th edition, 2010, Committee E-11 on Quality and Statistics

2.3. *FHWA Standard:*

- FHWA-RD-02-095, *Optimal Procedures for Quality Assurance Specifications*, 2003

3. TERMINOLOGY

3.1. *The following definitions are provided in this standard practice to help the reader become acclimated to general QA terms:*

3.1.1. *population (lot)*—A specific quantity of similar material, construction, or units of product subject to either an acceptance or a process control decision. This can range from all of the history of a material to a single lot (*Transportation Research Circular Number E-C037*, 2002).

3.1.2. *sample*—A small part of a population (lot) that represents the whole (R 10). This implies a statistical sample. Thus, the use of the term sample size, n , denotes the number of test values used to make a decision. (This should not be confused with size of sample that indicates a quantity of material.)

3.1.3. *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 (R 10). The results are best used to estimate a population. This is true for both QC and acceptance functions. To estimate a population, two measures are needed; one is the center of the estimated population and the other is a measure of its variability.

3.1.4. *types of acceptance plans*—A statistical acceptance plan is one based on an analysis of either variables or attributes. This standard practice focuses on analysis of variables for acceptance. Analysis by attributes is based on noting the presence or absence of some characteristic or attribute. Attribute analysis is most often used in visual inspections or when an item can only be classified as either acceptable, not acceptable, or pass/fail. Attribute plans are sometimes used with “screening tests” in which the material is tested before it is incorporated in the construction. Variables analysis is applicable to materials and construction in which quality is evaluated by measuring the numerical magnitude of a quality characteristic. A quality characteristic is a characteristic of a unit or product that is actually measured for acceptance purposes (*Transportation Research Circular Number E-C037*, 2002).

3.1.5. *variability known acceptance plans*—Acceptance plans that assume a known and constant variability. These types of acceptance plans measure only the average and are not appropriate for highway materials and construction.

3.1.6. *variability unknown acceptance plans*—Acceptance plans that measure both the product average and variability as estimates of a population. This is the type of acceptance plan discussed in this standard practice.

3.2. *For those definitions that are not described within, two useful reference sources are:*

3.2.1. Definition of Terms for Specifications and Procedures (R 10).

3.2.2. Glossary of Highway Quality Assurance Terms (*Transportation Research Circular Number E-C037*, 2002).

4. DEVELOPMENT AND REVISION OF ACCEPTANCE PLANS

- 4.1. The development and the revision of acceptance plans is a design process that should continuously evolve and improve as new processes, test methods, etc., are found. The development steps outlined below provide a rational development procedure and will be useful to those embarking on an initial statistical acceptance plan. The procedure assumes that some users may want to know how to initiate, proceed through the development, and eventually implement the plan. For those revising an existing plan, some steps may not be needed. However, in both cases it is important that the plan be analyzed to ensure it produces the desired results. The user may enter the steps at any point of interest.
- Initiation and Planning
 - Acceptance Plan Development Steps
 - Develop QC Procedures
 - Develop Acceptance Procedures
 - Risks and Risk Analysis
 - Pay Factors
 - Implementation Steps

5. INITIATION AND PLANNING

- 5.1. It is important to identify and establish the needs for a new or modified acceptance plan. Some possible reasons for doing this are:
- The present quality levels are substandard.
 - Premature failures have occurred that are related to the current acceptance plan.
 - A new or different quality measure, e.g., standard deviation, percent within limits, etc., is needed.
 - A new quality characteristic, e.g., permeability, resilient modulus, thickness, smoothness, etc., upon which to base acceptance has been identified.
 - The risks between contractor and agency are not properly balanced or are too high for one or both.
 - A more rigorous acceptance procedure is needed.
- 5.2. Define the goals and expectations of the acceptance plan. The primary goal is to identify potential benefits to the agency and to the industry. To achieve this goal, determine the criteria to be used to judge success. Examples of these criteria may be improved quality, a more knowledgeable industry, shared responsibility with industry, and/or faster completion times.
- 5.3. At this point, seek industry acceptance of and participation in the development of the acceptance plan. This is necessary to aid in industry cooperation and eventual positive reception.

6. ACCEPTANCE PLAN DEVELOPMENT STEPS

- 6.1. Develop the initial acceptance plan for one material and/or construction area, as opposed to several simultaneously. This is recommended to simplify the development process.
- 6.2. Determine if outside expertise is required. The agency may not have sufficient knowledge in such areas as statistical analysis or new areas such as nondestructive testing.
- 6.3. Look for other agencies or sources that have developed practices to provide guidance on how to proceed with selection of quality characteristics, the use of pay equations, composite pay factors,

etc. Contact and interview those agencies and keep in mind industry associations that may have practices that can be used. Learning from the mistakes that others have made can save time and effort. Conduct a thorough literature search to identify current practices. Recent Transportation Research Board and National Cooperative Highway Research Program publications can provide guidance.

- 6.4. *Develop an outline for the acceptance plan. This includes such items as:*
 - 6.4.1. QC requirements,
 - 6.4.2. Acceptance requirements,
 - 6.4.3. Independent assurance (IA) requirements,
 - 6.4.4. Agency validation (if contractor's tests are used in the acceptance decision),
 - 6.4.5. Conflict resolution, and
 - 6.4.6. Determination of pay factors, both individual and combined.
- 6.5. Develop the acceptance plan introductory information. A fundamental concept in statistical acceptance plans is the separation of the QC and acceptance functions. The contractor is *always* responsible for QC and the agency is responsible for acceptance. Maintaining the separation of the functions for QC and acceptance is very important. Additionally, address the needs and requirements for both technician and laboratory qualification in the introductory information ([R 25](#)).
- 6.6. A very important point that must be understood is the relationship between sample statistics and population parameters for both QC and acceptance procedures. The sample result is always an estimate of the population. The larger the sample size, the better the estimate of the population.
- 6.7. *Random Sampling*—Random sampling is a sampling procedure whereby any individual measurement in the population is as likely to be included as any other (*Materials Control and Acceptance—Quality Assurance*, 2000).
- 6.8. A basic assumption in a sampling plan is the necessity of taking samples in a random manner (*Materials Control and Acceptance—Quality Assurance*, 2000). Random sampling is achieved most commonly through the use of random number tables or random number generators on calculators or computers ([ASTM D 3665](#)). Random sampling always removes the selection of the sample tonnage, location, time, etc., from the decision of the sampler. Intuitively selecting a “random” sample is not random. Random sampling is a necessary requirement for all acceptance and IA sampling. Under some circumstances it is required for QC sampling.
- 6.9. Describe and discuss the need for the IA function and how it will be implemented in the acceptance plan. Independent assurance is a management tool that requires a third party, not directly responsible for QC or acceptance, to provide an independent evaluation of the testing process.
 - 6.9.1. The IA program is an independent evaluation of testing procedures and equipment and inspection procedures and is designed to provide continuity to the acceptance plan. It may involve a separate and distinct schedule of sampling, testing, and observation.
 - 6.9.2. It is very important that an IA program compare results and detect deficiencies, when they exist, in a timely manner. This improves the reliability of testing results. The timely comparison of data

may be restricted by agency resources, including personnel, facilities, and geographical constraints. These resource needs must be considered in the IA program.

- 6.9.3. It is very important that qualified personnel conduct IA tests and use different sampling and testing equipment than the equipment used for QC or acceptance.

7. DEVELOP QUALITY CONTROL (QC) PROCEDURES

- 7.1. *Quality Control (QC)*—Also called “process control.” Those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality of the end product (*Transportation Research Circular Number E-C037*, 2002).
- 7.2. *Purpose of QC*—The purpose of a QC plan is to measure quality characteristics and inspect activities that impact production at a time when corrective action can be taken to prevent nonconforming material from being incorporated in the project. (See *AASHTO Implementation Manual for Quality Assurance (1995)* for examples of QC plans for hot mix asphalt (HMA) concrete and both structural and paving portland cement concrete (PCC)).
- 7.3. A QC plan can be either contractor-specific or generic. Ideally, the plan should be contractor- and operation-specific. However, some agencies choose to develop a generic plan to be used by all contractors or suppliers. In either case, the contractor should develop control limits based on the production capabilities of the specific operation.
- 7.4. A very important part of a QC plan is the requirement that those persons performing the tests be qualified. This can be accomplished several ways, but some agencies require certification to determine qualification. (See [R 25](#) and [R 38](#) for more detailed information.)
- 7.5. The QC function is the responsibility of the contractor and is a separate function from acceptance. This means that control limits used for QC control charts must be developed separately from the specification limits.
- 7.6. Measure the quality characteristics chosen for QC early in the production activity to assess the quality as quickly as practical. Therefore, the QC tests should be relatively rapid tests.
- 7.7. Examples of QC tests for hot mix asphalt (HMA) are aggregate quality tests, binder physical properties, gradation of critical sieves, degree of aggregate coating, plant and discharge temperatures, moisture content of the fine aggregate and of the finished mix, and the use of a density gauge for field compaction control.
- 7.8. Examples of QC tests for portland cement concrete (PCC) are aggregate quality tests, gradation of critical sieves, air content, water–cement content, mix temperature, and slump.
- 7.9. The use of control charts is an important part of the QC function. Statistical control charts are the most effective control charts to use. This tool provides, in real time, the contractor and agency a visual estimate of the population of the quality characteristic being produced.
- 7.10. Because estimating the population being produced is the purpose of QC, the use of the most appropriate procedures is recommended. The most effective and simplest pair of statistical control charts is the joint use of:
- 7.10.1. An average chart ($\bar{X}$ chart) to measure the center.
- 7.10.2. A range chart (R chart) to measure the variability. The range is recommended because it is simple to calculate and record.

- 7.11. An example of an average and range control chart is shown in Figure 1.
- 7.11.1. The mean of the $\bar{X}$ chart is the center of production. This may or may not be the center of the specification limits. In fact, there may not be a specification requirement for this QC measure.
- 7.11.2. Control limits, also called “action limits,” are boundaries established by statistical analysis for material production control using the control chart technique. When values of the process fall within these limits, the process is “under control” (R 10). The limits are set at the equivalent of $\pm 3\sigma_{\bar{X}}$ from the mean of the $\bar{X}$ chart. Both an upper control limit (UCL) and a lower control limit (LCL) are used.
- 7.11.3. Because an estimate of variability is desired, the sample size used to plot statistical control charts must be at least two, i.e., $n \geq 2$.
- 7.11.4. Warning limits are boundaries established on control charts within the UCL and LCL to warn the producer of possible problems in the production process that may lead to the process going “out of control” (R 10). These limits are often set at $\pm 2\sigma_{\bar{X}}$. When values fall outside these limits, there is approximately a 5 percent chance the process is out of control. (For the purpose of clarity, these are not shown on Figure 1.)
- 7.11.5. The center of the R chart is the mean range and the control limits are typically set at $\pm 3\sigma_R$. In this case, σ_R is the standard deviation of the ranges. However, the LCL for the R chart is zero for most practical sample sizes.
- 7.12. Control limits are intended to show when a process is out of control. The chance of a point being more than $\pm 3\sigma_{\bar{X}}$ away from the average is only 0.3 percent. So, a value outside the action limit is an indication that the process has changed.
- 7.12.1. In the case that a point is more than $\pm 3\sigma_{\bar{X}}$ from the average, the contractor may decide to quickly take another test in an attempt to confirm that the process has, in fact, changed before altering production. If the second test result is close to the first, this provides an indication that the process may have changed. (If a check test is made, include both test results in the QC documentation.) Although the check sample would not have been obtained in a random manner, it is a permissible course of action. This is one good example of why QC and acceptance must be maintained as separate functions.
- 7.13. The calculation and use of control chart limits are beyond the scope of this standard practice. (See ASTM MNL7A for more information on control charts.)

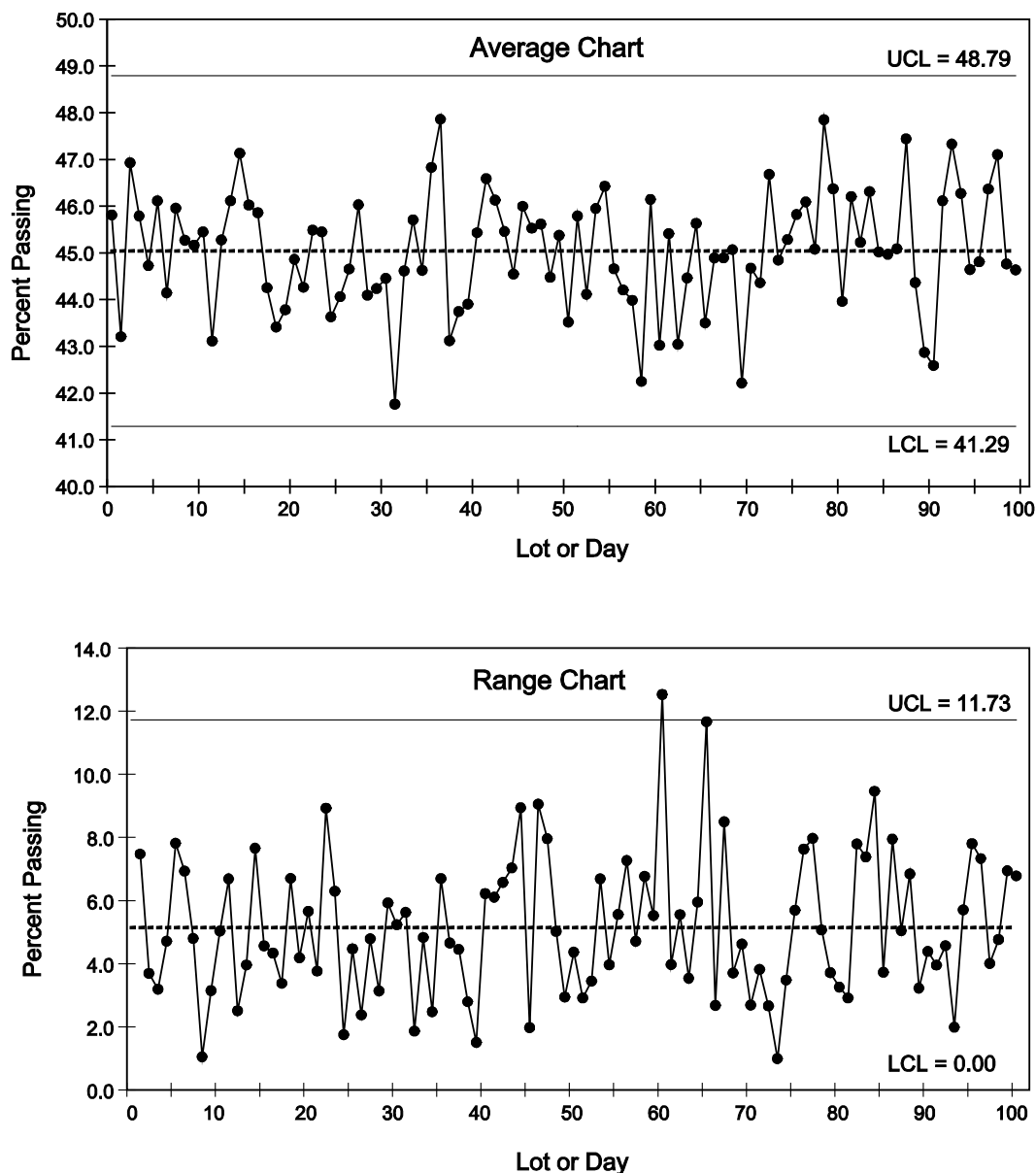


Figure 1—Examples of Average and Range Charts for the 2.36-mm Sieve

8. DEVELOP ACCEPTANCE PROCEDURES

- 8.1. *Acceptance*—Sampling and testing, or inspection, to determine the degree of compliance with contract requirements (*Transportation Research Circular Number E-C037*, 2002).
- 8.2. *Purpose of Acceptance Procedures*—These procedures are intended to accept adequate quality level product and reject inadequate quality level product as often as is feasible.
- 8.3. Most previous work in acceptance plans has been in terms of percent within limits (PWL) and some work has been done using percent defective (PD). Percent within limits and PD are complementary and add up to 100 percent. One can be converted to the other by Equation 1:

$$PD + PWL = 100\%$$

(1)

This relationship is shown graphically in Figure 2. The PWL is sometimes called the “percent conforming”; also, the “percent nonconforming” may be a more appropriate term than percent defective. The PWL approach is preferred by some agencies over PD because it is a positive expression. Also, in terms of the theory of acceptance sampling plans, the material outside of the limits may not be strictly defective but of lesser quality than material within the limits.

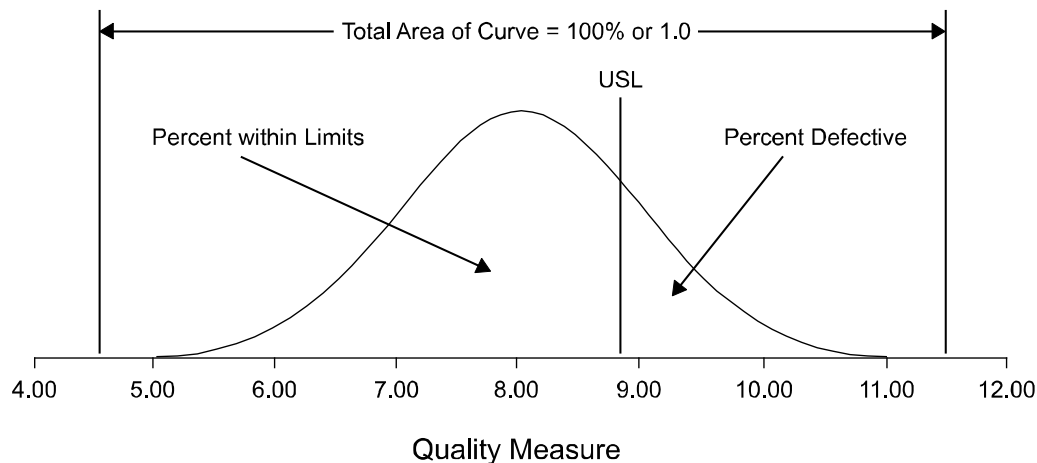


Figure 2—Complementary Relationship between Percent within Limits and Percent Defective

- 8.4. The PWL procedure produces an estimate of the population. Conceptually, as the sample size, n , increases, the estimate of the population improves. The PWL concept is one of small sample sizes and the distribution used is the noncentral t distribution. This distribution converges with the normal distribution when n approaches infinity. Because PWL is an estimate of a population, it must use an estimate of both the central tendency and the variability.
- 8.5. *Specification and Acceptance Limits*—In the development of an acceptance plan, specification and acceptance limits must be determined, and the acceptable quality level (AQL) and rejectable quality level (RQL) must be selected. The AQL, RQL, specification limits, and acceptance limits are intimately related, and the decisions regarding these are typically made concurrently.
- 8.6. *Specification Limits*—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 upper specification limit (USL) or lower specification limit (LSL), called a “single specification limit”; or to USL and LSL together, called “double specification limits” (*Transportation Research Circular Number E-C037*, 2002). As discussed below, specification and acceptance limits are different and serve different purposes.
- 8.7. Specification limits are based on engineering requirements and are expressed in the same units as those used for the quality characteristic of concern (e.g., percent, millimeters, kilograms per square millimeter, etc.). The acceptance limits are the limiting values placed on a quality measure that will permit acceptance of the lot. In PWL acceptance plans they are expressed in statistical units (PWL).
- 8.8. *Establishing the Specification Limits*—Establishing specification limits requires determining what constitutes acceptable (AQL) and unacceptable (RQL) material. The determination of both AQL and RQL are engineering decisions. The AQL decision defines acceptable material or construction, and addresses the product that will provide satisfactory service at an affordable cost when used for the intended purpose. Acceptable material is often determined based on what has performed well in the past. However, if performance data are available, it is preferable to quantify

performance. Statistics has been a valuable tool in defining the parameters (mean and standard deviation) for acceptable material. Caution should be exercised if a lower variability is chosen for the specification than has been shown to be readily achievable. Arbitrarily “tightening the specs” can increase the cost of the product above what is considered cost-effective.

- 8.8.1. *Acceptable Quality Level (AQL)*—That minimum level of actual quality at which the material or construction can be considered fully acceptable (for that quality characteristic). 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 (*Transportation Research Circular Number E-C037*, 2002). Acceptance plans should be designed so that AQL material will receive an average pay over the long run of 100 percent.
- 8.8.2. *Rejectable Quality Level (RQL)*—That maximum level of actual quality at which the material or construction can be considered unacceptable (rejectable) (*Transportation Research Circular Number E-C037*, 2002). For example, when quality is based on PWL, the RQL is that actual (not estimated) PWL 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.]
- 8.8.3. Setting specification limits is slightly more complicated for double specification limits as compared to a single specification limit. For a quality characteristic with a single specification limit, the limit can be set at the appropriate number of standard deviations (process variability) above the minimum desired value to obtain the necessary PWL. But for a specification with double limits, there may be concern that in addition to the number of standard deviations (process variability) used to set the limits, a “target miss” may be warranted.
- 8.8.4. *Target Miss*—The failure of a contractor to center the process exactly on the target value. (For more detailed information on target miss, see *Optimal Procedures for Quality Assurance Specifications*, 2003.)
- 8.8.5. The proper way to address the issue of “target miss” is to determine how variable the actual process means are about the target value. This variability regarding where the process will be centered, called “target miss variability,” can then be combined with the typical process variability to obtain the correct standard deviation value for use in establishing specification limits. The “target miss variability” and the “process variability” can be combined simply by adding their associated variances, *not* their standard deviations (see Equations 2 and 3). This assumes that the amount of process variability is independent of where the process is centered. (The example in Appendix X1 includes a calculation of “target miss” variability.)

$$\hat{\sigma}_{\text{combined}}^2 = \hat{\sigma}_{\text{target - miss}}^2 + \hat{\sigma}_{\text{process}}^2 \quad (2)$$

$$\hat{\sigma}_{\text{combined}} = \sqrt{\hat{\sigma}_{\text{combined}}^2} \quad (3)$$

where:

$\hat{\sigma}_{\text{combined}}^2$ = estimated combined target miss and process variance,

$\hat{\sigma}_{\text{target - miss}}^2$ = estimated target miss variance,

$\hat{\sigma}_{\text{process}}^2$ = estimated process variance, and

$\hat{\sigma}_{\text{combined}}$ = estimated combined standard deviation.

- 8.9. Select the specification limit(s) in concert with the quality measure, i.e., the measure that is used to quantify quality and the AQL and RQL. For instance, the AQL might be set at 90 PWL. This means that when the population has 90 percent of the product within specification limits, the

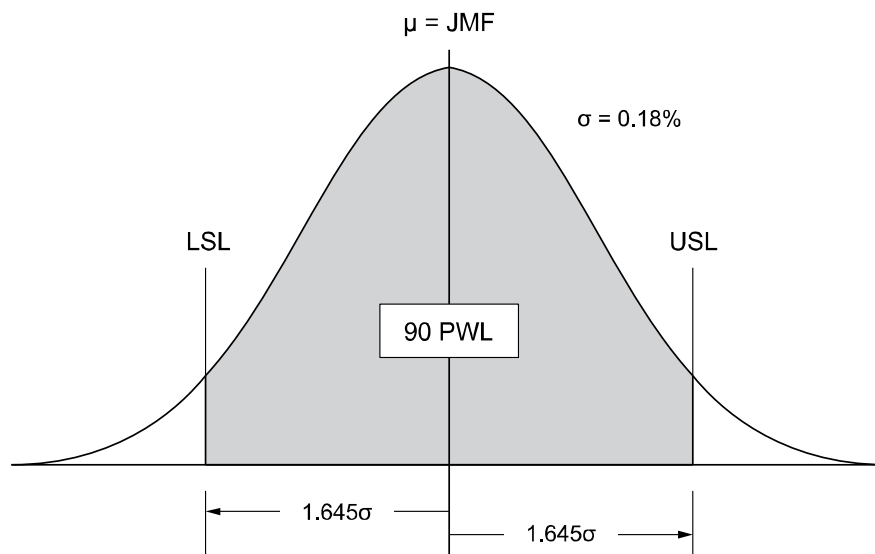
product is completely acceptable. However, the same product could be defined by an AQL of 85 PWL with more restrictive specification limits or by many other possible combinations of AQL and specification limits. Selecting lower values of AQL may give the perception that lower quality levels are acceptable. It is recommended that AQL values be set at 90 or 95 PWL unless there is an overriding reason to select another value.

- 8.9.1. It is important to distinguish between a population (e.g., $N = 4$) and a sample (e.g., $n = 4$), because different equations are used to determine a population's variability than are used to estimate a sample's variability. When working with a population, it is desirable to have a large number of data points. However, sample sizes upon which to base acceptance or process control decisions are typically small, e.g., from four to ten, depending on the lot size. Larger lot and sample sizes are suggested to offer the advantage of lowering the risks of making a wrong acceptance or rejection decision.
- 8.10. *Acceptance Limit*—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, in PWL acceptance plans, PWL refers to specification limits placed on the quality characteristic, and the minimum allowable PWL identifies the acceptance limit for the PWL quality measure.) (*Transportation Research Circular Number E-C037*, 2002)
- 8.11. *Acceptance Limits with Pay Adjustments*—For acceptance plans with pay adjustment provisions, additional acceptance limits, often expressed in the form of an equation or equations, are used to distinguish among the various possible pay levels.
- 8.12. *An Example of Specification and Acceptance Limits, AQL and RQL:*
- 8.12.1. An agency has decided, based on a large number of project data that it collected and analyzed, that a “typical” standard deviation for a lot defined in the acceptance plan for asphalt content for HMA is 0.18 percent. It has further been decided that PWL will be used as the quality measure. (See the example in Appendix X1 on how to properly select the “typical” standard deviation.)
- 8.12.2. *Determine AQL Material*—Because asphalt content has a stipulated target value, i.e., the job mix formula (JMF) asphalt content, the agency may choose to determine AQL material as a lot for which the average asphalt content is equal to the JMF target value and for which the standard deviation is equal to or less than the “typical” value of 0.18 percent. This defines AQL material in terms of the desired population mean and standard deviation, but the AQL definition must also be related to the required quality measure, which in this case is PWL.
- 8.12.3. *Set Specification Limits*—Because the specification limits and the AQL are related, the agency might decide to set the AQL as a value of 90 PWL. This selection of 90 PWL for the AQL is arbitrary but is a commonly used value and one suggested in the *AASHTO Quality Assurance Guide Specification* (1995). The AQL population defined from past projects in terms of mean and standard deviation should just meet this PWL definition for AQL. So, in this case, the specification limits would be set such that a population with a mean at the JMF and a standard deviation of 0.18 percent would have 90 percent of its area within the specification limits. These limits can be determined by finding the Z -value from a standard normal table that corresponds to an area of 0.90 within the mean $\pm Z$ standard deviations (i.e., $\mu \pm Z\sigma$). (This example assumes the contractor can hit the JMF consistently, and no target miss is necessary. See the example in Appendix X1 on the addition of a target miss value.)
- 8.12.4. Table 1 presents some typical $\pm Z$ regions within which selected areas of the normal distribution fall. From this table, it is seen that 0.90 (or 90 percent) of the normal distribution falls within ± 1.645 standard deviations from the population mean.

Table 1— $\mu \pm Z\sigma$ Regions for Selected Areas under the Normal Distribution

Area	0.99	0.95	0.90	0.85	0.80
$\pm Z$	2.576	1.960	1.645	1.439	1.282

- 8.12.5. Figure 3 shows the specifications set at the JMF asphalt content ± 1.645 times the typical standard deviation value, or $\text{JMF} \pm 1.645 (0.18 \text{ percent}) = \text{JMF} \pm 0.30 \text{ percent}$. In this case, the AQL is 90 PWL and the specification limits are $\text{JMF} \pm 0.30 \text{ percent}$.
- 8.12.6. Alternatively, using the same AQL population, the agency could decide to establish the AQL as 85 PWL. In this case, the specification limits would be set at the $\text{JMF} \pm 1.439$ times the typical standard deviation value (see Table 1), or $\text{JMF} \pm 1.439 (0.18 \text{ percent}) = \text{JMF} \pm 0.26 \text{ percent}$. The specification limits are different in this case because the definition for AQL in terms of PWL is different. However, although the same population is desired in both cases, the perception is that quality is not as important with an AQL of 85 compared to an AQL of 90.

**Figure 3**—AQL Material for Example 8.12

- 8.12.7. *Determine RQL Material*—There is no single correct way to establish either the AQL or the RQL. Once the AQL and specification limits are established, the RQL can be determined in a number of ways. One way is to decide that the material should be rejected once a “large” percentage of material is outside the specification limits. Determining what constitutes a “large” percentage then needs to be decided. The agency may decide that the material is unacceptable once half of it is outside of the specification limits. In this case, the RQL would be established as a PWL value of 50. Any lot with an estimated PWL value of 50 or less would then be required to be removed and replaced or other penalty applied. Typical values for RQL are between 70 and 30 PWL.
- 8.12.8. Alternately, the agency might base the definition of RQL on the analysis of past project data. The agency might decide that past projects had performed inadequately when the average asphalt content was 0.25 percent above or below the JMF target value. In this case, the agency might decide to set the RQL based on the PWL value for a population with a mean 0.25 percent above or below the JMF target and with a standard deviation equal to the “typical” value of 0.18 percent. Figure 4 illustrates the case of the RQL population when the specification limits are $\text{JMF} \pm 0.30 \text{ percent}$. In this case, it can be seen that the PWL for the RQL population corresponds to the area

of the population that lies within the specification limits. In this case, the RQL might be defined as a lot with a PWL value of 60 (rounded from 61) as shown in Figure 4.

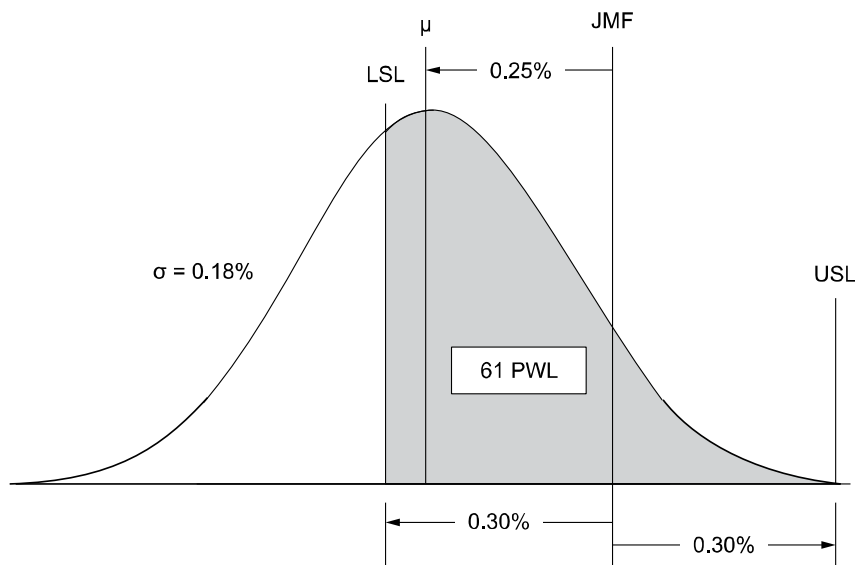


Figure 4—RQL Material for Example 8.12

- 8.12.9. The above approach to defining RQL material contains a number of simplifying assumptions. It looks only at how far the population mean departs from the target value and does not consider the population standard deviation. This assumes that the typical standard deviation value of 0.18 percent will be achieved on all projects. This approach also does not consider the interaction and effect of other quality characteristics, such as density, thickness, etc., on the performance of past projects.
- 8.13. *Application of PWL*—Determining the PWL is similar in concept to determining the area under the normal curve. The theory in the use of the PWL (or PD) method assumes that the population being sampled is normally distributed. In practice, it has been found that statistical estimates of quality are reasonably accurate provided the sampled population is at least approximately normal; i.e., reasonably bell shaped and not bimodal or highly skewed. This has been found to be true for most material and construction measures not associated with a physical constraint; e.g., because gradation cannot exceed 100 percent passing a top size sieve, a measure of this characteristic is often skewed and therefore not normally distributed.
- 8.13.1. When the average and standard deviation are known (or assumed known), the area under the normal curve can be calculated to determine the percentage of the population that is within certain limits. However, when the average and standard deviation are unknown—as in the case of determining the acceptance for a lot—the percentage of the lot that is within the specification limits can be estimated. In this latter case, instead of using the Z -value and the standard normal curve, the quality index, Q , is used to estimate PWL. The Q -value is used with a PWL table to determine the estimated PWL for the lot.
- 8.13.2. A sample table relating Q values with the appropriate PWL estimate is shown in Table 2 for a sample size of $n = 5$. A more complete set of PWL tables in this format, for sample sizes from $n = 3$ to $n = 30$, is available (*Quality Assurance Software for the Personal Computer*, 1996).

Table 2—A PWL Estimation Table for Sample Size $n = 5$

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.36	50.71	51.07	51.42	51.78	52.13	52.49	52.85	53.20
0.1	53.56	53.91	54.27	54.62	54.98	55.33	55.69	56.04	56.39	56.75
0.2	57.10	57.46	57.81	58.16	58.52	58.87	59.22	59.57	59.92	60.28
0.3	60.63	60.98	61.33	61.68	62.03	62.38	62.72	63.07	63.42	63.77
0.4	64.12	64.46	64.81	65.15	65.50	65.84	66.19	66.53	66.87	67.22
0.5	67.56	67.90	68.24	68.58	68.92	69.26	69.60	69.94	70.27	70.61
0.6	70.95	71.28	71.61	71.95	72.28	72.61	72.94	73.27	73.60	73.93
0.7	74.26	74.59	74.91	75.24	75.56	75.89	76.21	76.53	76.85	77.17
0.8	77.49	77.81	78.13	78.44	78.76	79.07	79.38	79.69	80.00	80.31
0.9	80.62	80.93	81.23	81.54	81.84	82.14	82.45	82.74	83.04	83.34
1.0	83.64	83.93	84.22	84.52	84.81	85.09	85.38	85.67	85.95	86.24
1.1	86.52	86.80	87.07	87.35	87.63	87.90	88.17	88.44	88.71	88.98
1.2	89.24	89.50	89.77	90.03	90.28	90.54	90.79	91.04	91.29	91.54
1.3	91.79	92.03	92.27	92.51	92.75	92.98	93.21	93.44	93.67	93.90
1.4	94.12	94.34	94.56	94.77	94.98	95.19	95.40	95.61	95.81	96.01
1.5	96.20	96.39	96.58	96.77	96.95	97.13	97.31	97.48	97.65	97.81
1.6	97.97	98.13	98.28	98.43	98.58	98.72	98.85	98.98	99.11	99.23
1.7	99.34	99.45	99.55	99.64	99.73	99.81	99.88	99.94	99.98	100.00

Note: Values in the body of the table are estimates of PWL corresponding to specific values of $Q_L = (\bar{X} - LSL) / s$ or $Q_U = (USL - \bar{X}) / s$.
 For negative Q values, the table values must be subtracted from 100.

8.13.3. *Calculation and Rounding Procedures*—The calculation procedures and rounding rules can influence the estimated PWL value that is obtained. This can become a point of contention, particularly if the pay determination is based on the estimated PWL value. It is, therefore, important that the agency specify the exact calculation process, including number of decimal places to be carried in the calculations, as well as the exact manner in which the PWL table is to be used.

8.13.4. Conceptually, the Q -value performs identically the same function that the Z -value does for a normal distribution. Except now the reference points are the individual sample mean ($\bar{X}$) and standard deviation (s) instead of the population mean (μ) and standard deviation (σ), and the points of interest with regard to areas under the curve are the specification limits.

$$Q_L = \frac{\bar{X} - LSL}{s} \quad (4)$$

and

$$Q_U = \frac{USL - \bar{X}}{s} \quad (5)$$

where:

Q_L = quality index relative to the lower specification limit,

Q_U = quality index relative to the upper specification limit,

LSL = lower specification limit,

USL = upper specification limit,

$\bar{X}$ = sample mean for the lot, and

s = sample standard deviation for the lot.

8.13.5. The Q -value, therefore, represents the distance in sample standard deviation units that the sample mean is offset from the specification limit. A positive Q -value represents the number of sample standard deviation units that the sample mean falls inside the specification limit. Conversely, a negative Q -value represents the number of sample standard deviation units that the sample mean falls outside the specification limit. These cases are illustrated in Figure 5. Q_L is used when there is a one-sided lower specification limit, while Q_U is used when there is a one-sided USL. For two-sided specification limits, the PWL value is estimated as:

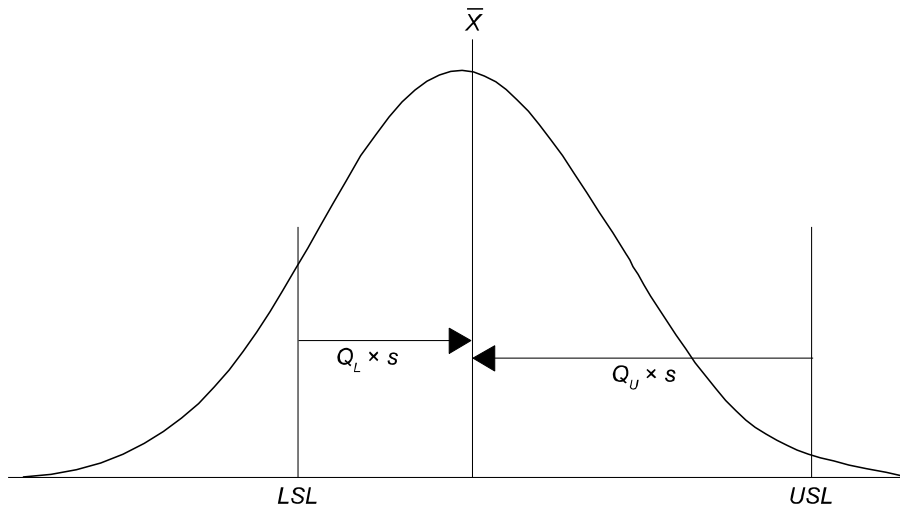
$$PWL_T = PWL_U + PWL_L - 100 \quad (6)$$

where:

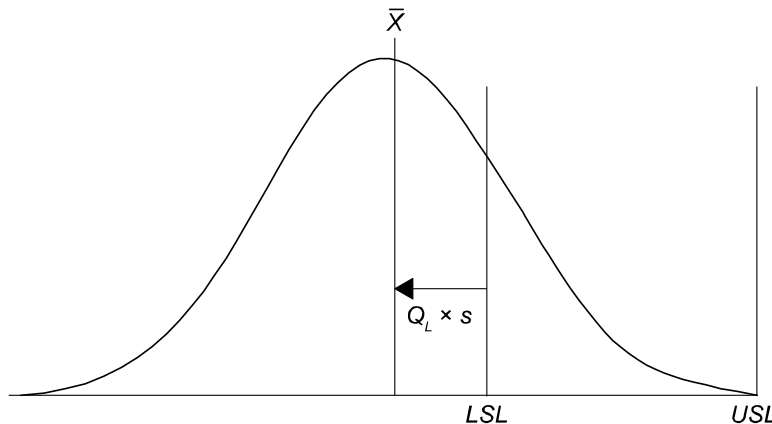
PWL_T = percent within the upper and lower specification limits.

PWL_U = percent below the upper specification limit (based on Q_U).

PWL_L = percent above the lower specification limit (based on Q_L).



(a) Illustration of Positive Quality Index Values



(b) Illustration of a Negative Quality Index Value

Figure 5—Illustration of the Quality Index, Q

- 8.13.6. Intuitively, PWL is a good measure of quality because it is reasonable to assume that the more of the product that is within the specification limits, the better the quality of the product should be. (A detailed discussion and analysis of the PWL measure of quality is presented in *Optimal Procedures for Quality Assurance Specifications*, 2003.)
- 8.14. If the agency conducts the acceptance tests, sampling and testing must be performed in qualified laboratories and by qualified sampling and testing personnel. There are no additional requirements for verification other than the typical IA requirement.
- 8.15. However, if the contractor/third party conducts tests used in the acceptance decision, a validation procedure is necessary as required in FHWA 23 CFR 637 (1995). The requirements are:
- 8.15.1. The sampling and testing must be performed in qualified laboratories and by qualified sampling and testing personnel.
- 8.15.2. The quality of the material must be validated by verification sampling and testing. The verification sampling and testing is to be performed on samples that are taken independently from those used in the acceptance decision.
- 8.16. Statistically sound verification procedures must be developed and used. There are several forms of verification procedures, and some forms are more efficient than others. It is in the best interest of both parties to make the verification process as effective and efficient as practicable.
- 8.17. FHWA 23 CFR 637 states that the verification samples shall be taken independently. This requirement does not allow the direct comparison of split samples for validation. However, this does not prohibit the use of split-sample test results. For instance, the contractor may test 100 samples and the agency select the split portion of all 100 samples but test only 20 of the samples. Then the agency can compare its 20 tests results to the 80 contractor test results that are not paired with those of the agency, using the *F*-test and independent *t*-test.
- 8.17.1. There is a difference in the information provided by split and independent sampling procedures, and the difference is related to the concept of components of variability.
- 8.17.2. *Split Sample*—A 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 comprised solely of testing variability.) (*Transportation Research Circular Number E-C037*, 2002)
- 8.17.3. *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 (which often includes both the material and the process variabilities), sampling, and testing.] (*Transportation Research Circular Number E-C037*, 2002)
- 8.17.4. The five specimens shown in Figure 6(a) have been taken independently. The variability represented by them includes all sources of variability, i.e., material, process, sampling, and testing. Thus, if the total variability is to be evaluated, independent samples must be taken.
- 8.17.5. In Figure 6(b), four of the five specimens have been taken independently; however, the two on the far right are split samples from the same batch, i.e., they are two results that represent the same material. The variability represented by these two specimens includes only the component of testing variability. However, either of the two specimens on the far right can be combined with the other three to measure all sources of variability, but both cannot be used with the other three in an

analysis. Specimens tested by different laboratories may be combined, from a statistical standpoint, if found not to be statistically different. However, a higher variability is likely to result, and, thus, this is not recommended.

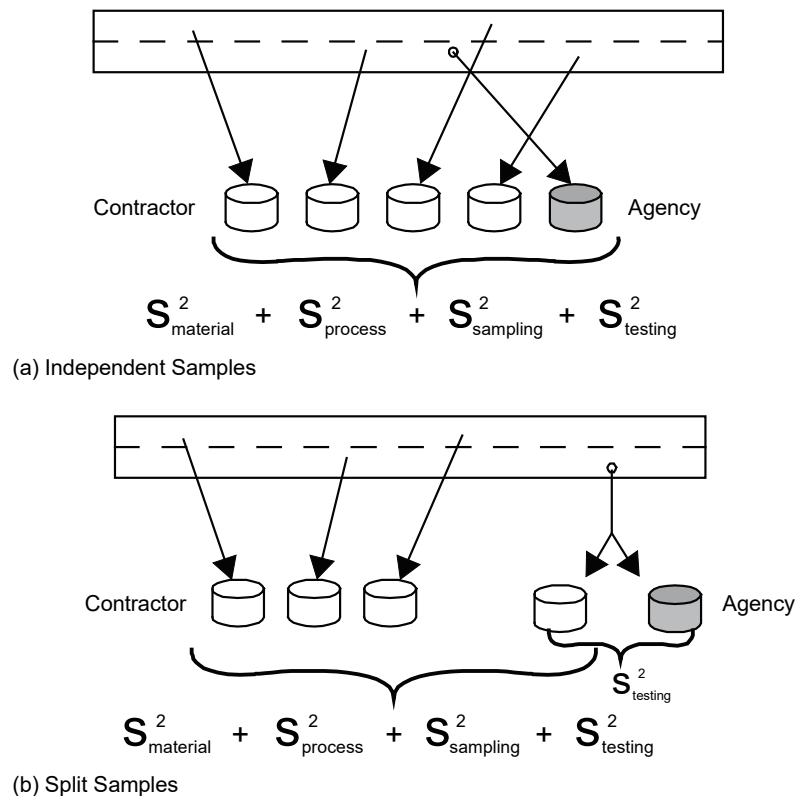


Figure 6—Components of Variance for: (a) Independent Samples and (b) Split Samples

8.17.6. The analysis of the variability for split samples will be a smaller value, $\sigma^2_{\text{testing}}$, than the variability for independent samples, $\sigma^2_{\text{overall}}$, because the latter includes all components of variability. But the decision of whether to use split or independent samples should not be made based on the magnitude of the variability but, instead, on the component(s) of variability that is (are) desired to be measured. So, the choice of whether to use split or independent samples is not an arbitrary decision.

8.18. *Definition of Verification*—The process of determining or testing the truth or accuracy of test results by examining the data and/or providing objective evidence. [Verification sampling and testing may be part of an IA program (to verify contractor QC testing or agency acceptance) or part of an acceptance program (to verify contractor testing used in the agency's acceptance decision)]. (*Transportation Research Circular Number E-C037*, 2002)

8.19. *Verification Procedures*—The ability of the comparison procedure to identify differences between two sets of test results depends on the number of tests from each set that are being compared. The greater the number of test results from each set, the greater the ability of the procedure to identify statistically valid differences. A rule of thumb is a minimum agency rate of 10 percent of the contractor's testing rate. It is preferred to conduct a risk analysis to determine whether a higher rate is warranted. It also must be decided whether the test method or the process is to be verified. This relates to the use of split or independent samples.