Chapter 3
Construction Quality Assurance Long-Range Plan

Overview

The following sections lay out a potential long-range plan for changes to the Caltrans Construction Quality Assurance Program. The objectives are in order of highest priority and include the following: establish a construction quality assurance database; adopt a system-based acceptance process; implement performance specifications; and adopt risk-based acceptance criteria.

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Section 1
Long-Range Objective—
Integrated Construction Quality Assurance Database

Construction quality assurance databases are a key element of any construction quality assurance program because they enable highway departments to make sound, data-based decisions that lead to cost-effective construction. These databases improve data processing efficiency, minimize errors, unify data administration, and provide data security. They also provide the data source for a variety of analyses, such as construction quality monitoring, developing pay adjustments, and detailed statistical analyses.

A quality assurance database facilitates assessing the quality of materials production and placement and establishing pay factors, as defined by specifications. It also enables detailed analyses of quality, performance, and cost data that can help guide future improvements to standards and specifications (such as materials, techniques, and design strategies to use; quality characteristics and levels to use in acceptance; incentive/disincentive plan).

While most highway departments have established and maintained construction–related databases for many years, only within the last decade have they realized the need for more integrated systems to accommodate the requirements of new quality assurance programs.

Caltrans has a number of database and software systems that serve specific quality assurance functions for different groups. However, these individual databases are not integrated. They were established with different architecture, purpose, and data collection and access procedures, leaving limited means to match all the collected data. While Caltrans may be able to calculate pay factors and make acceptance decisions from one database, data from that database cannot easily be linked to other databases to monitor effectiveness of specifications, correlate construction quality to field performance, or to perform life-cycle cost analysis. The result is that by continuing to focus primarily on entering data and not necessarily on retrieving data to draw valuable conclusions, Caltrans may become “data rich and information poor.”

While individual databases may address current needs of the multiple functional groups, a more efficient, comprehensive, user-friendly database system is needed that can link existing individual databases. Such a system would allow the more efficient analysis required to develop or refine system-based and risk-based acceptance processes, performance specifications, warranty specifications, and innovative contracting procedures.

3.1.1 Construction Quality Assurance Database Requirements

Caltrans’ existing databases and software systems need to be integrated and updated to a web-based construction quality assurance database with client/server architecture having the following features and capabilities:

- User-friendly interface and configuration.
- Access by multiple users and functional groups (such as materials testing lab, construction engineers, field inspectors, designers, management, contractors, subcontractors, material suppliers and producers, and researchers) who most likely operate from different locations.
- Different levels of access security and operational privileges (such as viewing, entering, modifying, and analyzing data and generating output) depending on role in the department or project (inspector versus contractor).
- Ability to make "user group" assignments; users can belong to multiple groups.
- Audit and tracking information to trace users and their activities.
- Offline use of input modules or linkage to wireless hand-held devices to aid in timely data entry and subsequent uploading to the server.
- System for logging and tracking of material samples, related tests, and results.
- Capability to store construction details and contractor activities for each lot, including portland cement concrete (PCC) curing practices, thickness of hot mix asphalt lift in each paving operation, and traffic opening time.
- Aid in decision-making for quality assurance, performance-related, and warranty projects.
- Ability to perform fundamental and routine analysis for quality assurance operations, including pay factor calculations.
- Ability to generate system outputs and ad hoc or standardized reports that can be electronically distributed or published online.
- Ability to interface/link with other agency systems such as the pavement management system (PaveM) database and financial/cost accounting system.
- Capability to perform advanced analysis to correlate construction and material test data with performance (pavement management) and cost (bids, maintenance) databases.
- Common referencing across other key databases to perform analyses.
- Flexibility to customize the analysis for specific cases when required.
- Overall system stability (such as, backups and disaster recovery) and security (such as, firewall protection on machines accessing central database).

3.1.2 Potential Benefits of Construction Quality Assurance Database

A construction quality assurance database with well-integrated components (or individual databases) that can be linked with each other using a common reference system has benefits ranging across technical, administrative, and legislative levels for improving the quality of construction and enhancing Caltrans' operations overall. The more data contained in this database, the more potential there is to use and analyze the data and thereby benefit from it. A well-developed construction quality assurance database offers the following potential benefits:

- Automates data entry across various Caltrans functional units having to do with materials, construction, and specifications in the Division of Engineering Services and the Division of Construction.

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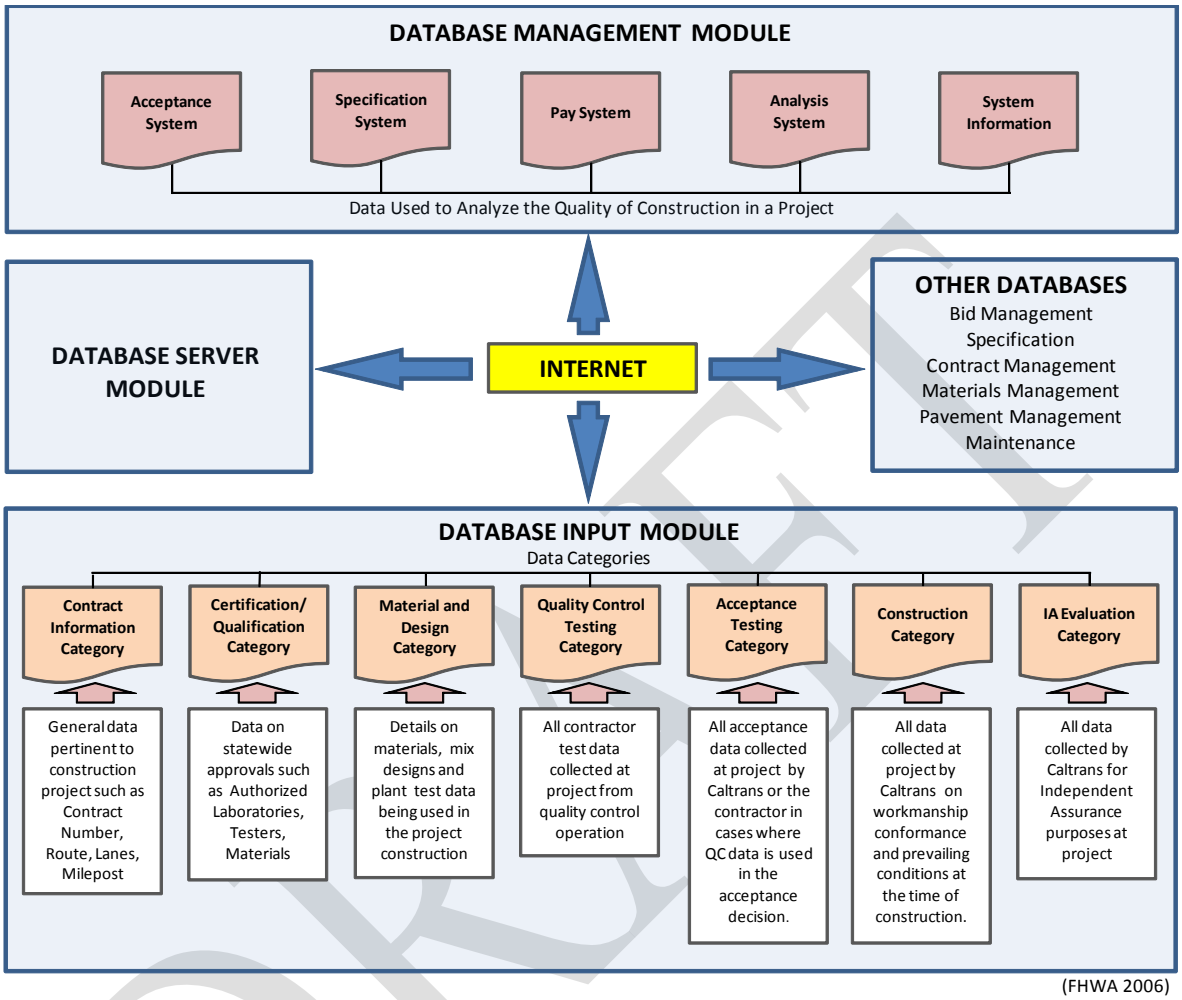
- Provides entry and storage of testing data and contract documents in an electronic format that is easily accessible by headquarters, region or district offices, project field offices, and other department personnel.
- Provides possibility for hierarchical data access.
- Provides ability to securely upload or import quality control test data and independent assurance data from external sources (such as, vendors, contractors, consultants).
- Provides electronic approvals.
- Automates calculating pay factors and make acceptance decisions.
- Provides ability to highlight specification non-conformance in real-time (such as during construction) and the opportunity to take timely remedial actions.
- Aids in developing performance measures for the overall quality assurance program.
- Generates ad-hoc and standardized reports in a manner that can be easily incorporated into documents. Reports that could be generated for a specific project or on a program-wide basis include:
  1. Measuring turnaround time between material testing and availability of the test results.
  2. Assessing compliance with minimum acceptance testing requirements.
  3. Monitoring conformance with Certificate of Compliance submittal requirements.
- Provides ability to perform various engineering analyses including:
  1. Rating asphalt and concrete plants based on quality they produce, which would be assessed from quality control records in the database.
  2. Pre-qualifying material suppliers and producers resulting in cost savings in quality assurance programs.
  3. Testing the effectiveness of current specifications or quality assurance processes and revising them as necessary based on performance or cost analysis.
  4. Assessing contractor performance.
  5. Tracking overall system performance and the performance of new and innovative materials, construction, and testing technologies.
  6. Forensic evaluation of pavements using lot specific materials, construction, and climatic data.
  7. Aiding in improving pavement design and pavement management processes.
  8. Aiding in the development of pavement performance models.
  9. Establishes basis for materials and performance warranties and performance specifications.

3.1.3 Construction Quality Assurance Database Architecture

The recommended database is a web-based system with client/server architecture that permits the use of a standalone machine or a hand-held device for field data collection and subsequent

uploading to the server. As illustrated in Figure 3.1.1, the recommended database consists of three main modules:



(FHWA 2006)

Figure 3.1.1. Construction Quality Assurance Database Architecture

- Database server module—is the core of the architecture storing all system data information and is the module that all client machines connect to through the internet.
- Database input module—provides the framework and format to make data inputs in several categories including general contract information, materials and design, quality control testing, acceptance testing, construction records, and independent assurance testing.
- Database management module—provides necessary specification information for each material for comparison with quality-of-construction data (from database input module) to calculate pay factors, establish acceptance or rejection decisions, generate reports, and perform quality data queries and engineering analyses. This module also provides the required communication links and tools to permit the interchange of data between the construction quality database and other Caltrans databases.

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3.1.4 Construction Quality Assurance Database Input Software

The recommended software application for providing the interface to input construction quality-related data is known as AASHTOWare Project Construction & Materials.

The American Association of State Highway and Transportation Officials (AASHTO) is a nonprofit, nonpartisan association whose primary goal is to foster the development, operation, and maintenance of an integrated national transportation system. AASHTO was established in 1914 and now serves highway and transportation departments in the 50 states, the District of Columbia, and Puerto Rico. An increasingly important part of this service is to provide a construction contract management solution known as AASHTOWare Project™ (Project™).

Project™ is a modular approach to software that encompasses the lifecycle of construction contract management prevalent in transportation agencies throughout the United States. Currently, more than 48 state transportation agencies, several hundred cities and counties, several hundred engineering consulting firms, and several thousand highway-contracting firms now use at least one Project™ module. Applications include a range of functions, from project estimation, to contract proposal preparation, to electronic bidding, to pre-award analysis, and construction contract management.

The Project™ module categories include: estimation, projects & proposals, bid lettings, and construction. estimation, projects & proposals, and bid lettings categories are preconstruction functions and are distinguished from post-award or construction functions. The Project™ module with construction and materials functionality, known as AASHTOWare Project Construction & Materials, is currently in development with production release scheduled for late in calendar year 2014.

The web-based AASHTOWare Project Construction & Materials software is designed to be a comprehensive construction management tool providing:

- Capabilities for electronic data entry, tracking, reporting, and analysis of contract data from contract award through finalization eliminating the need for paper records and duplication of efforts in entering field test data.
- Capabilities for recording, tracking, and reporting of material samples and test results from job sites, plants, and test labs.
- Multi-tier web architecture allowing for easy integration and data exchange with other databases.
- Access by all levels of construction and materials personnel, such as field inspectors, technicians, project managers, clerks, auditors, lab personnel, management, producers, suppliers, contractors, and the FHWA.

By adopting software that has been proven in multiple transportation agencies and is supported through shared investment, Caltrans can avoid risk that is often associated with custom software development and implementation. Additionally, since on-going maintenance costs for a custom solution typically run 17 to 20 percent of the initial system cost, this financial burden will be significantly reduced by sharing these expenses with the other AASHTO software licensees. Also

of importance, all base software upgrades and standard customer support are included in the AASHTOWare licensing fees.

DES-Office Engineers currently license AASHTOWare Project Expedite (the de facto national standard electronic bidding system) and BAMS/DSS (a client/server historical database and bid analysis software). Caltrans is also in the Feasibility Study Report (FSR) phase to procure AASHTOWare Preconstruction (web-based software for proposals and bid letting) and AASHTOWare Civil Rights & Labor.

Additional information about AASHTOWare software is available in the AASHTOWare catalog available for download at:

http://www.aashtoware.org/Pages/default.aspx

3.1.5 Implementation of Construction Quality Assurance Database

The first step in implementing a construction quality assurance database has already been accomplished with the approval of an Information Technology (IT) Concept Statement Form on June 26, 2009 (see Appendix E). The next step would be to develop an FSR. It is anticipated that FSR development and approval would take 12 months with an additional 4 to 6 months to obtain consultant services should Caltrans outsource FSR preparation. Caltrans would also need to prepare and approve a budget change proposal for costs and staffing necessary for the project.

The time and costs for implementing the database can vary depending on whether available software is purchased and modified or new Caltrans-specific software is to be developed (not recommended).

System acquisition could take 2 to 5 years after FSR approval. After system acquisition, collecting data, developing the needed correlations between as-built and design life, and verifying those correlations could take 2 to 10 years. Reallocation of staff would be required for implementation. For example, engineers would be relocated from field-testing to perform data analysis and evaluation to develop the needed correlations.

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Section 2
Long-Range Objective—System-Based Acceptance Process

Caltrans needs a system-based materials management system that monitors material quality on a statewide basis to facilitate more efficient use of testing and sampling resources.

System-based acceptance is the process by which a department of transportation performs tests and inspections on a system-wide basis, rather than on a project-specific basis. For example, in a system-based process only one verification sample would be tested for a particular heat of steel, whereas on a project-based system, several samples might be taken and tested for steel from the same heat delivered to multiple projects. System-based acceptance is most beneficial for off-site produced items, but can be advantageous for on-site produced materials on a more limited basis.

The advantages of a system-based acceptance process include improved quality because problem areas can be more readily identified and corrected, and more efficient resource use due to eliminating duplicate tests and inspections.

The following subsections discuss the system-based acceptance process.

3.2.1 Pre-Approved Source

Certain material sources consistently demonstrate the ability to supply acceptable products. Caltrans would periodically sample and test products from selected material sources and, if acceptable, would designate the source as approved and certified. Materials from such sources would be accepted for use upon delivery to the project site with proper documentation and no further sampling or testing would be required.

Pre-approved sources would be shown on a Caltrans approved list of sources for a specific time until a renewed approval was established by Division of Engineering Services – Materials Engineering and Testing Services/Office of Structural Materials (OSM). The current list would be available online.

3.2.2 Unapproved Source

If a source listed on the Contractor's Form CEM-3101, "Notice of Materials to Be Used," was not pre-approved by Caltrans, OSM would contact the source and arrange for source approval or for the testing of a specific "lot" of material. A "lot" generally refers to an isolated quantity of specified material from a single source. The variability of the material to be supplied would become the determining factor for source approval. Lot approval would only apply to the defined quantity of material. Source and lot approvals for unapproved sources are as follows:

- Lot Approval—Sampling of a specific lot would be arranged and, in most instances, would be submitted with a sampling report to Caltrans laboratories for testing and approval. The sampling report is essential, since it would be used to enter necessary information into the construction quality assurance database (QAD) for project-level documentation and to support the project materials certification when the pay item is completed.

- Source Approval—Source approval would work like lot approval except the data used for approval would often include manufacturer quality control data and site inspection results by Caltrans materials personnel. A report for source approval would be issued similarly to the report issued for the sampling of a specific lot. Lot and source approval reports would be essential to the QAD because they initiate tracking of the material approval process through project implementation and project materials certification.

3.2.3 Laboratory Testing

Material samples for projects throughout the state would be routinely routed to the Transportation Laboratory, district/region, or field laboratories. The laboratory would assign a number for tracking purposes, and enter basic information from the sample report into the QAD, including source identification, material identification, and, if applicable, project identification. As each laboratory completes the required testing, the results of the test data would be entered, cross-referenced, and tracked using the QAD. QAD data would be available to all Caltrans district/regions and their respective project personnel, who would track the material sample from the time it was received at a laboratory until the time project materials certification was needed for the item. The QAD would also track the approval of components for such items as PCC. For a PCC item, the QAD would maintain data on components (for example, cement, aggregates, admixtures, water) as well as the resulting PCC. If the resident engineer, contractor, producer, or manufacturer requested test status on a particular sample, Caltrans personnel could quickly access and provide the information.

3.2.4 Material Approval and Delivery

After materials were tested at a Caltrans laboratory, Caltrans personnel would evaluate the results in accordance with contract or standard specifications. If the material source or lot were approved, OSM would notify the manufacturer or producer. Upon delivery, the manufacturer or producer would be required to provide shipping documents as minimum evidence of inspection to demonstrate delivered materials are from an approved lot or approved source. The resident engineer would verify that a copy of the shipping document is forwarded to the district/region materials engineer. Upon receipt, the district/region would enter the source identification, destination identification, material type, lot identification (the lot number at the time of approval), and the quantity delivered into the QAD. The QAD would allow Caltrans to verify the status of each shipment and the remaining balance in an approved lot of material.

3.2.5 Field Release of Manufactured Items

The QAD would also identify and track manufactured items that OSM had released from a facility to be field inspected for acceptance. Field staff would be able to identify from the QAD the items required to be inspected at site.

3.2.6 Project-Level Documentation

With few exceptions, all off-site materials used in Caltrans construction would be pre-inspected (tested and approved to meet the contract specifications) before they were delivered to the project. The resident engineer would ensure project materials were delivered to the site with the proper shipping documents, which include the laboratory number as evidence of inspection. In addition,

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some materials would have additional inspection requirements and additional indicators for evidence of inspection.

OSM should develop and maintain an "Evidence of Inspection Documentation," listing the minimum evidence of inspection documentation required for the acceptance of all applicable materials at the project site. OSM should also distribute a copy of this list to the contractor, resident engineer, and assistant resident engineer at each pre-construction meeting. Material without evidence of inspection would not be incorporated into the work.

The resident engineer has the final opportunity to observe project materials to detect any problems before they are incorporated in the project. If evidence of inspection were lacking or less than minimum or if there were any doubt as to a material's acceptability, the district/region materials engineer would be immediately contacted before the material was accepted. When materials were shipped to projects from intermediate suppliers, the supplier's shipping document would be required to reference the laboratory number and the original manufacturer's shipping document number. The original manufacturer (point of sampling) would be required to submit the proper documentation to OSM. The resident engineer would forward a copy of all shipping documents to the district/region materials engineer.

The assistant resident engineer or office engineer would be responsible for recording, on the Daily Report, the quantity of material delivered and placed and the acceptability of the material. If a manufacturer or producer delivered material to the site, the assistant resident engineer or office engineer would again be required to verify the shipping document referenced the appropriate laboratory numbers. Caltrans project personnel would enter the laboratory number and additional information from the shipping document into the QAD and request verification of acceptability. The QAD would assign the request a tracking number and the data would be uploaded from the computerized project record system to the QAD, which, in turn, would verify the data entered against the data previously entered by OSM on the status of the approved lot of material. The QAD would verify the lot identification, delivery date, project identification, and quantity. At the time the data were uploaded, the QAD would immediately notify project-level personnel of any deviations in acceptance criteria. All deviations would require resolution prior to OSM performing the final review and audit; otherwise, acceptance criteria would be met and the QAD would document completion and acceptance of the pay item.

All data entered at the project level would be required to match the data in the QAD for that particular material. If the data matches, the QAD would generate a verification report for the resident engineer documenting the quantity shipped from the approved lot. As part of the tracking and auditing system, the QAD would then adjust the balance of the quantity remaining in the approved lot.

3.2.7 Final Materials Certification

The primary objective of the QAD is to track and document materials certification for all project pay items during project construction. The QAD would use project level materials data from the computerized project record system and from Caltrans laboratories to document the acceptability of pay items (that is, validity of samples and test results comply with specifications, lot and source approvals properly documented, shipments properly documented and traceable to source). If

material discrepancies were encountered during the project, the QAD would immediately alert Caltrans personnel to resolve the issue. The system would also be tied to the project pay system and would calculate pay adjustments as indicated by test results. Project materials certification, in essence, would occur as the project was being constructed. At the time project materials certification was required for project finalization, the QAD would provide Caltrans personnel with an efficient and relatively routine method of validating project pay items. After project completion, Caltrans would generate the materials certification for the project. The resident engineer would use the QAD to generate a report documenting the acceptability of each pay item in the project. The final report would be signed and dated by the resident engineer, and the project records of the QAD would be locked to protect against unauthorized modification.

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Section 3
Long-Range Objective—Performance Specifications

Performance specifications reflect the values for materials characteristics or engineering properties used in the design process to predict the design performance life of a facility. The as-built values of those properties are used to predict the as-built performance life. Comparing the as-built performance life to design life is used to calculate the change in life-cycle cost (LCC). The LCC analysis is used to adjust the payment to the contractor. When the as-built life exceeds the design life, the payment would be increased by the decrease in LCC. Conversely, the payment would be decreased by the increase in LCC, when the expected life is less than the design. The advantage to using performance specifications is that the compensation paid to the contractor is adjusted based upon any additional calculated cost or savings to the owner. These types of specifications provide the opportunity for maximum fairness by sharing either savings or cost due to respective good or poor performance.

Performance specifications are either performance-related (calculations of performance life are related to materials quality characteristics) or performance-based (calculations of performance life are based on engineering properties).

Implementing performance specifications would be most feasible in coordination with development of a new construction quality database system, such as that described in Section 1 of this chapter, in which to collect and analyze data to correlate performance with selected materials characteristics or engineering properties.

Examples of needed data include:

- As-constructed values for the designated material characteristics or engineering properties.
- Type, magnitude, and time of observed distresses.
- Correlation between as-built and design life.
- Costs associated with correcting the distresses (LCC).

3.3.1 Performance-Related Specifications

Performance-related specifications (PRS) are "specifications that use quantified quality characteristics and life-cycle cost analysis (LCCA) relationships that are correlated to product performance." (AASHTO Highway Subcommittee on Construction Quality Construction Task Force, Major Types of Transportation Construction Specifications, draft of August 2003).

PRS identifies and quantifies the particular technical factors that influence product performance. It uses empirical data, engineering judgment, mechanistic modeling, and life-cycle costing as the basis for determining the potential for performance. Like quality assurance specifications, PRS only specifies quality characteristics that lend themselves to acceptance testing at the time of construction. It does not specify the desired long-term product performance.

PRS uses mathematical models to predict future performance, maintenance requirements, and life-cycle costs. Construction quality characteristics, such as initial smoothness, slab thickness, air voids

in asphaltic pavements, and strength of concrete cores, have been found to correlate with fundamental engineering properties that can predict performance. Conceptually, designs are developed based on these models to achieve predetermined service lives for specific conditions of load and environment. Because they are based on data, PRS models present a clear and realistic picture of what influences a constructed product's performance. These models are also the means through which enhanced or diminished life is estimated from results of acceptance tests and, when combined with appropriate economic principles, how rational payment factors are determined. Implementation of PRS depends on the development and validation of such models. Correctly applied, PRS could enable identifying the level of quality that provides the best balance between cost and performance and assure the attaining that level in the constructed work. Refer to Appendix F, "Features of Performance-Related Specifications," for more detailed information about PRS.

3.3.1.a Advantages and Requirements of Performance-Related Specifications

The advantages of using PRS include:

- Design relates performance to quality characteristics.
- Testing and inspections measure characteristics that directly influence performance.
- Payment to the contractor is based upon performance determined from the measured as-built quality characteristics.

PRS includes specifications for key materials and construction quality characteristics that have been demonstrated to correlate significantly with long-term performance of the finished work. These specifications are based on quantified relationships between such characteristics measured at the time of construction and subsequent performance. They include sampling and testing procedures, quality levels and tolerances, and acceptance (or rejection) criteria. Typically, PRS also includes payment schedules with positive and/or negative adjustments that are directly related through the performance models to changes anticipated in worth of the finished work as a result of departure from the quality level defined as acceptable.

Performance-related specifications require:

- A design method that can predict performance based upon material characteristics.
- An information system to register the values of the material characteristics of the constructed facility.
- An information system to register performance data of the constructed facility.
- A system for correlating the as-designed to the as-built of the constructed facility.

Performance-related specifications for pavement, as an example, require four major elements:

1. Pavement management system..
2. Mechanistic/empirical (M/E) design.
3. Life-cycle cost analysis.
4. Material management system.

Performance-related specifications for pavement rely upon inter-relationships among these major elements:

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- A pavement management system that tracks pavement performance.
- The M/E formulation for pavement design relates material quality characteristics to pavement performance.
- The pavement management system data is used to calibrate the M/E formulation for the local materials.
- Field measurement data entered in QAD, for material quality characteristics for each project, is compared to those used in the M/E design formulation.
- The differences between the material quality characteristics used in the M/E design formulation and those measured in the field are used in the life-cycle cost data to determine pay factors.
- Pay factors increase or decrease the payment to the contractor based upon predicted performance. (For example, M/E is used to develop the parameters for a 20-year pavement life, and the actual field production results show that the pavement would only have a life of 15 years, the LCCA would be used to calculate the cost for 5 years, and this would be the amount deducted from payment to the contractor.)

3.3.1.b Status of Performance-Related Specifications

Caltrans is already working to implement three of the four numbered elements listed above. In 2013, the Caltrans pavement management system (PaveM) became functional. The M/E design for flexible pavement was required for all designs beginning January 2014. Caltrans is conducting experimental work for rigid pavement M/E. LCCA has been performed since 2007. The QAD still needs to be planned and implemented.

3.3.2 Performance-Based Specifications

Performance-based specifications (PBS) are quality assurance specifications that describe the desired levels of the actual fundamental engineering properties (not the key quality characteristics) that are predictors of performance. The fundamental engineering properties in PBS (for example, resilient modulus, creep properties, and fatigue properties) are used in performance prediction relationships (mathematical models). In turn, these models can be used to predict stress, distress, or performance from combinations of predictors that represent traffic, environmental, and structural conditions. In the true sense, PBS is concerned with the performance of the final in-place product, not how it was built.

3.3.2.a Distinguishing Features of Performance-Based Specifications

- Acceptance based on measurement of the finished product's fundamental engineering properties that predict performance.
- Acceptance limits that are developed on a statistical basis.
- Mathematical models used to quantify the relationship between the fundamental engineering properties measured and product performance. Price adjustments that are based on the expected LCC of the constructed transportation facility.

3.3.2.b Status of Performance-Based Specifications

Complete performance-based specifications do not yet exist. Specifications, in *Superpave Performance Graded Asphalt Binder Specifications and Testing*, which were developed through the Strategic Highway Research Program, are an example of a partial performance-based specification. However, a performance-graded asphalt binder is only one component of the final product. All of a product's constituent materials and their related fundamental engineering properties must be included to have complete models to predict performance of that product. Other performance-based test methods have not been fully developed. Performance-based test methods have yet to be developed to a user-friendly level that would permit timely acceptance testing. Further development and validation of performance-based tests are currently underway through research programs.

In addition, true PBS will require good PaveM data to generate and validate the models required to determine price adjustments based on expected LCCA. As discussed previously, most agency management systems do not presently collect and evaluate all of the data necessary to develop the required performance and cost models. Accordingly, PBS has not yet emerged as a viable tool in highway construction.

3.3.3 Quality Assurance Program Changes

As performance specifications are implemented, it will be necessary to make changes to the QAP, primarily in the sampling and testing requirements, in the pavement specifications, and the *Construction Manual*. For example, if fatigue and stiffness are chosen as the performance measure for hot mix asphalt, testing requirements will need to be included in those documents.

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Section 4
Long-Range Objective—Risk-Based Acceptance Criteria

Caltrans should analyze the uniformity and quality of materials produced and, based on the results of those analyses, adjust the quality verification program accordingly.

Risk-based acceptance is a statistical method for establishing the level of risk to each party by calculating the likelihood of accepting materials that do not meet specification and, conversely, rejecting acceptable material. The benefit of using risk-based acceptance is that variances of materials and of testing and sampling are recognized and accounted for, which helps minimize the use of erroneous test results.

Risk-based acceptance criteria assume these governing specifications:

- Incorporate material quality characteristics that are consistent with design requirements.
- Include acceptance limits that consider the normal variability associated with products, sampling and testing processes, contractors, and producers.
- Acknowledge the inherent risk that measurements made to determine compliance with statistically based requirements may result in the acceptance of "bad" material or rejection of "good" material. Include specification limits based on historical data. (This data would be stored in the QAD. See Appendix F, Materials Management System Objective.)

3.4.1 Analysis Acceptance Limits

Overall product variability can be classified into two main categories:

- Material and construction variability that are mainly the sole responsibility of the contractor.
- Sampling, testing, and performance prediction error, plus any other error sources over which the contractor has no control.

If the specification limits of acceptance do not include reasonable allowances for material and construction variances, sampling variances, and testing variances that are all inherent in the construction process, specification conformity levels will always be low.

A classic example of this situation can occur in the measurement of slump to determine the consistency of plastic concrete. Research has shown that for a reasonably well-controlled process, the overall standard deviation can be expected to be about 1/2 inch. With specification tolerance limits of ±1/2 inch imposed, research has shown that, over a period of time, one could expect to have approximately 32 percent of the test results out of specification if the process is producing concrete with normal variability and the average slump is equal to the specified target value.

To allow for normal variability due to sampling, testing, and inherent materials variations, the tolerance limits in this example should be set at ±1 inch (equal to two standard deviations) when judging conformity on the basis of one test. With these tolerance limits, approximately 95 percent conformity can be expected over a period of time. This will avoid having changes made when the

process is really under control. Only when the precision of sampling and testing methods and normal production processes are improved would it be practical to tighten these tolerances.

The following are required to confirm statistically based limits of acceptance:

- The materials and construction quality levels from appropriate contractors and producers to determine representative inherent local variability for each quality characteristic.
- Data collected using multiple random field samples under controlled conditions that reflects the known variability of the materials produced for each quality characteristic.

If conformity with the specification limits of acceptance is consistently high and the specifications are deemed adequate to produce the performance desired, sampling frequencies specified in the quality verification program should be reduced on a project basis. Conversely, if the specification conformance is low, increased sampling frequencies should be considered to reduce the risk of accepting non-specification material.

3.4.2 Analysis to Confirm Acceptance Plan Risks

Establishing the limits to be used for acceptance is an important part of a quality assurance program. Making the limits too restrictive deprives the contractor of a reasonable opportunity to meet the specification. Making them not sufficiently restrictive makes them ineffective in controlling quality. Selection of the limits relates to the determination of risks. The two types of risk encountered are the seller's (or contractor's) risk, alpha, and the buyer's (or Caltrans') risk, beta.

The seller's risk is the probability that an acceptance plan will erroneously reject acceptable quality level material or construction with respect to a single acceptance quality characteristic. The contractor or producer takes the risk of having acceptable quality level material or construction rejected.

The buyer's risk is the probability that an acceptance plan will erroneously fully accept rejectable quality level material or construction with respect to a single acceptance quality characteristic. Caltrans takes the risk of having rejectable quality level material or construction fully accepted.

To evaluate how the acceptance plan will perform over a wide range of possible quality levels, it is necessary to construct an operating characteristic curve that is a graphic representation of an acceptance plan. This would show the relationship between the 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 pay levels (for acceptance plans that include pay adjustment provisions).

Acceptance plans must consider these risk in a manner that is fair to both the contractor and Caltrans. Too large a risk for either party undermines credibility; therefore, the risks should be both reasonably balanced and reasonably small.

The seller and buyer risk levels that may be appropriate vary, depending on the material or construction process involved. While setting the acceptance risk levels is a Caltrans decision, Section 9, "Risks and Risk Analysis," of AASHTO's Standard Practice for Acceptance Sampling Plans for Highway Construction (AASHTO R 9-05 [2009], page R9-19) presents the following guidance:

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> The appropriate risk level is a subjective decision that can vary from agency to agency. However, as an economic decision, typical practice limits risks to no more than five percent. The more critical the application, the lower should be the buyer's risk. But only under rare circumstances should the buyer's risk be lower than the seller's risk.

If the acceptance plan risks are considered acceptable in terms of being low and the specifications are deemed adequate to produce the performance desired, consideration should be given to reducing sampling frequencies set forth in the quality verification program on a project basis. However, if the risks are considered unacceptable in terms of being too high, a reassessment of the quality verification plan and possible increased sampling frequencies should be considered to reduce the risk of accepting non-specification material.

In summary, the opportunity exists for Caltrans to use existing quality verification program resources more effectively by including risk-based acceptance criteria provisions in the governing specifications.