

TRANSPORTATION RESEARCH
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**Key Elements
of Construction
Quality Assurance
for Implementation**

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Key Elements of Construction Quality Assurance for Implementation

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Introduction

QUALITY ASSURANCE: THERE'S VALUE IN THE BASICS

Lectern Session 604 on *Quality Assurance: There's Value in the Basics*, was held at the 2018 Annual Meeting of the Transportation Research Board (TRB). In this session, four speakers with a range of perspectives—the Federal Highway Administration (FHWA), state transportation agencies, and a contractor—presented on key elements and best practices for implementation of an effective quality assurance program. The details of implementing quality assurance can get complex depending on an agency's needs and practices. However, there are some basics, core elements, and best practices that can and should be followed to keep the focus on the ultimate goal of producing, delivering, and accepting quality products for infrastructure construction.

Following a brief introduction by the session moderator, Shreenath Rao, the first speaker, Dennis Dvorak of the FHWA, presented an overview of a quality assurance program. In his presentation, Dennis Dvorak covered the six core elements of a quality assurance program and talked about different approaches, important findings, best practices, and lesson learned from implementation of quality assurance programs across the United States. This was followed by a presentation by Rick Bradbury of the Maine Department of Transportation. Rick Bradbury provided an agency perspective and presented on independent assurance on a system basis as opposed to a project basis. He discussed dispute resolution and sample security as part of his presentation. The contractor's perspective was provided by Adam Hand, an associate professor at the University of Nevada, Reno, who worked for a contractor, Granite Construction, prior to his position at the university. Adam Hand discussed a systems approach to quality and provided many best practices examples for a contractor to control quality. The final presentation of the session was by Rick Kreider of the Kansas Department of Transportation. He presented Kansas Department of Transportation's perspective on specification changes and the lessons learned during the implementation of the specification changes.

This e-circular provides a synopsis of the session by including the slides along with notes from the speakers for each of the four presentations. The material included in this e-circular provides a valuable reference and a reminder that there is value in basics of quality assurance.

PUBLISHER'S NOTE

The views expressed in this publication are those of the authors and do not necessarily reflect the views of the Transportation Research Board or the National Academies of Sciences, Engineering, and Medicine. This publication has not been subjected to the formal TRB peer review process.

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Overview of a Quality Assurance Program

DENNIS DVORAK

Federal Highway Administration

The Federal Highway Administration (FHWA) updated Title 23 Code of Federal Regulations Part 637 Subpart B – Quality Assurance Procedures for Construction (23 CFR 637) on June 29, 1995 to allow state Department of Transportations to include the contractor's tests in the acceptance decision for Federal-aid projects.

http://www.access.gpo.gov/nara/cfr/waisidx_03/23cfr637_03.html

CORE ELEMENTS

A good quality assurance (QA) program seeks to balance the cost of testing and inspection for a project with the materials quality and performance risk to maximize the benefit to the traveling public. 23 CFR 637 includes six core elements of a QA program:

- Agency acceptance
- Contractor quality control (QC)
- Independent assurance (IA) sampling and testing
- Personnel qualification and certification
- Laboratory accreditation and qualification
- Materials testing dispute resolution

Starting in the 1960s, QA programs have attempted to reduce variability and increase long-term project performance. Figure 1 shows how the variability observed during quality assurance is a composite of separate sources of variability in different parts of the construction process.

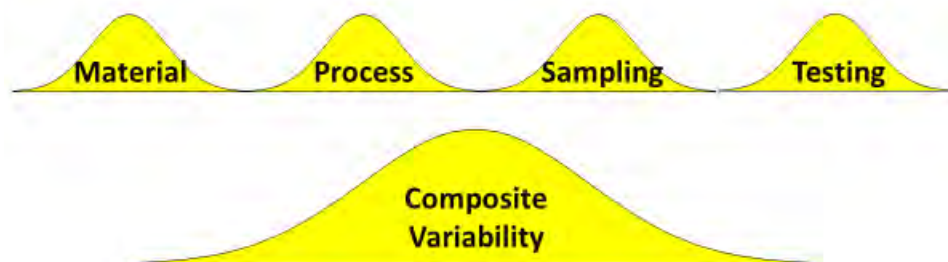


FIGURE 1 Illustration of how individual variabilities combine for a larger, composite variability.

Four of the core elements all assist in reducing variability: IA sampling and testing, personnel qualification and certification, laboratory accreditation and qualification, and materials testing dispute resolution.

CONTRACTOR QUALITY CONTROL

Owners are encouraged to require contractors to perform QC sampling and testing so that they learn more about their processes, which can reduce variability and increase long-term performance. If contractor's QC test results are part of the acceptance decision they must be taken independently of the agency verification sampling, conducted by qualified or certified technicians in qualified or accredited laboratories, and QC testers must have been evaluated by independent assurance sampling and testing. FHWA recommends using separate random numbers to determine the locations of QC and verification samples to ensure that they are taken independently. There's a need for additional checks and balances within a QA program when contractor's tests are included in the acceptance decision since a small portion of contractors have taken advantage of weaknesses in state QA programs to increase their profit by reducing their costs and/or increasing pay adjustments using falsified test results.

ACCEPTANCE BY THE AGENCY WITH VALID CONTRACTOR DATA

Agency test results should be used for acceptance and they can be supplemented by contractor QC test results if the quality of the material has been validated by the verification sampling and testing (23 CFR 627.207 (a)(1)(ii)(B)). When comparing two data sets such as from a contractor and an agency, it is important to compare both the mean and the variances. The F-test compares the variances and the t-test compares the means of the agency and contractor test results to determine if they came from the same population. The American Association of State Highway and Transportation Officials (AASHTO) and FHWA have recommended using F-tests and t-tests since the 1990's. Examples include FHWA-RD-02-095 "Optimal Procedures for Quality Assurance Specifications" (<http://www.tfhrc.gov/pavement/pccp/pubs/02095/>) and AASHTO Quality Assurance Implementation Manual. If the comparison validates the two data sets then contractor tests results may be used.

FHWA has developed a tool to evaluate the effectiveness of state QA programs to ensure that states receive high quality materials, make appropriate payment for the quality provided and minimize the potential for fraud and abuse. This tool is called the Quality Assurance (QA) Assessment. The initial assessment was conducted in 2008 with updates in 2010, 2012, and 2014. An update is currently underway in 2018. The responses for the QA Assessment are based on the standard practices used by a state DOT on a majority of work on federal-aid projects that are let by the state DOT. If contractor's tests are used in the acceptance decision, the criteria for validation of contractor's test results required that the state DOT use F- and t-tests with a minimum of five state tests in the comparison. Nine states met the criteria in the 2014 update while 22 did not meet the criteria as shown in Figure 2.

Validation of Contractors Test Results

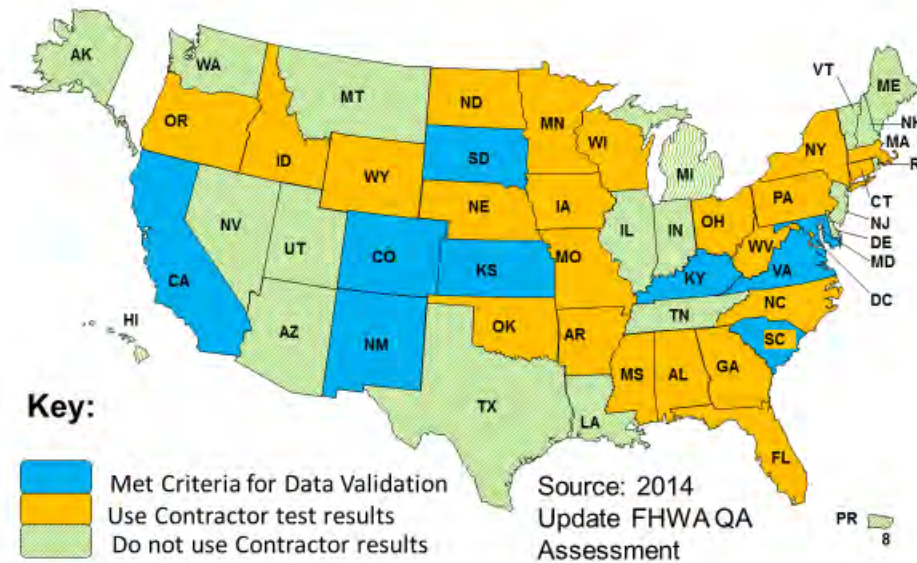


FIGURE 2 Use of contractor test results in quality assurance programs in the U.S.

INDEPENDENT ASSURANCE PROGRAMS

23 CFR 627.207 (a)(2) requires that the IA program shall evaluate the qualified sampling and testing personnel and the testing equipment. The program shall cover sampling procedures, testing procedures, and testing equipment. The following is a summary of the elements of the IA program:

1. Establish IA sampling and testing frequencies.
2. Evaluate testing equipment by using one or more of the following: calibration checks, split samples, or proficiency samples.
3. Evaluate testing personnel by observations and results from testing split samples or proficiency samples.
4. Prompt comparison and documentation of test results obtained by the tester being evaluated and the IA tester.
5. Develop guidelines including tolerance limits for the comparison of test results.
6. Provide an annual report to the FHWA when the system approach is used.

Each IA program shall include a schedule of frequency for IA evaluation. The schedule may be established based on either an individual construction project basis or a system basis. Several states use a hybrid approach where the project approach is used for some materials or portions of the state and the system approach is used for other materials or in other portions of the state. A total of 31 states used the system approach and 16 states used the project approach based on data from the 2014 update for the QA Assessment as shown in Figure 3.

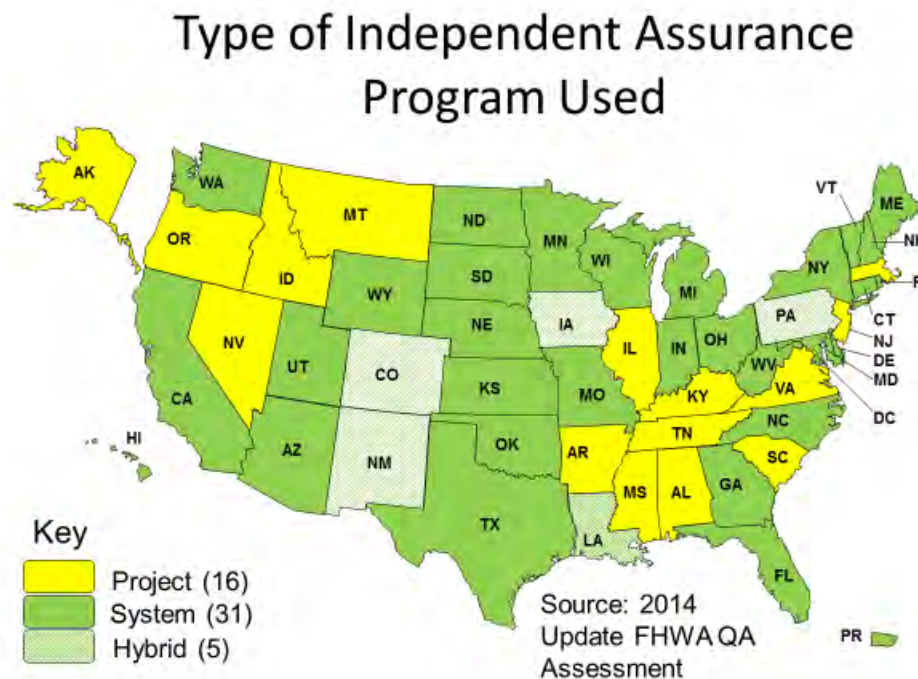


FIGURE 3 Types of independent assurance programs used.

A project approach checks each individual construction project at a frequency of 10% of the verification and QC testing used in the acceptance decision. A system approach evaluates verification and QC personnel across all active construction projects at a frequency of once or twice per year. A goal of checking 90% of the active testers has been established as part of the FHWA QA Assessment. A state using a materials management system can identify active testing personnel. States without a materials management system have found it difficult to use a system approach since they are unable to identify active testers.

TECHNICIAN AND LABORATORY QUALIFICATION

23 CFR 637.207 (a)(1)(ii)(A) requires that the sampling and testing used in the acceptance decision has been performed by qualified laboratories and qualified sampling and testing personnel. Many states use the American Concrete Institute (ACI) certification for field concrete testing and concrete strength testing. Two regional technician certification programs have been developed by the Northeast Transportation Training and Certification Program (NETTCP) including seven states and the Western Alliance for Quality Transportation Construction (WAQTC) including nine states. All other states have state programs for technician qualification and certification. AASHTO R25-18, Standard Practice for Technician Training and Certification Programs, notes that the terms technician qualification and technician certification are considered to be equivalent.

FHWA, on July 17, 1998, issued a Memorandum on Technician Qualification (<https://www.fhwa.dot.gov/pavement/materials/matqa.cfm#techqual>). The Memorandum included the following elements for a technician qualification program:

- Formal training of personnel including all sampling and testing procedures with instructions on the importance of proper procedures and the significance of test results,
- Hands-on training to demonstrate proficiency of all sampling and testing to be performed,
- A period of on-the-job training with a qualified individual to assure familiarity with state DOT procedures,
- A written examination and the demonstration of the various sampling and testing methods,
- Requalification at two to three year intervals (data from the Independent Assurance program can be used as one element of requalification), and
- The qualification program should have a documented process for removing personnel that perform the sampling and testing procedures incorrectly.

23 CFR 637.209 requires that all contractor, vendor, and state DOT testing used in the acceptance decision shall be performed by qualified laboratories. Each state DOT shall have its central laboratory accredited by the AASHTO Accreditation Program or a comparable laboratory accreditation program approved by the FHWA. Any non-state DOT designated laboratory that performs IA sampling and testing shall be accredited in the testing to be performed by the AASHTO Accreditation Program or a comparable laboratory accreditation program approved by the FHWA. Any non-state DOT laboratory that is used in dispute resolution sampling and testing shall be accredited in the testing to be performed by the AASHTO Accreditation Program or a comparable laboratory accreditation program approved by the FHWA.

DISPUTE RESOLUTION

23 CFR 637.207 (a)(1)(iii) requires that if the results from the QC sampling and testing are used in the acceptance program, the state DOT shall establish a dispute resolution system. The dispute resolution system shall address the resolution of discrepancies occurring between the verification sampling and testing and the quality control sampling and testing. The dispute resolution system may be administered entirely within the state DOT. A material testing dispute resolution system is designed to address significant differences in test results that impact payment to reduce contractor risk that could increase bid prices. The dispute resolution system can be performed by the state DOT or else by an accredited third-party laboratory. Dispute resolution testing should not be performed in the same laboratory, personnel or equipment that conducted the original testing.

CONSULTANTS AND OVERSIGHT

Many state DOTs have increased their use of consultants as they reduced staffing. 3 CFR 627.209 requires that in order to avoid an appearance of a conflict of interest, any qualified non-state DOT laboratory shall perform only one of the following types of testing on the same project:

- Verification testing,
- Quality control testing,

- IA testing,
- Dispute resolution testing.

23 CFR 637.205 requires that each state DOT shall develop a QA program which will assure that the materials and workmanship incorporated into each federal-aid highway construction project on the National Highway System (NHS) (https://www.fhwa.dot.gov/planning/national_highway_system/) are in conformity with the requirements of the approved plans and specifications, including approved changes. The program must meet the criteria in § 637.207 and be approved by the FHWA. As part of FHWA Division Office oversight norms, the Division Office reviews QA program documents and approves them on a periodic basis. FHWA Division Office oversight also includes managing state DOT QA program flexibility and evaluating overall material quality assurance risks.

More than 45 states use the same QA processes and procedures for all state administered projects including design-build and other alternative contracting methods to minimize confusion by district/region and project staff.

GUIDANCE AND TRAINING

FHWA guidance includes Tech Briefs on:

- Independent Assurance Programs (FHWA-HIF-12-001)
https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=730
- Construction Quality Assurance for Design-Build Highway Projects (FHWA-HRT-12-039) https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=809
- Acceptance of Non-Structural Precast Elements TechBrief (FHWA-HIF-13-045)
https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=870

The National Highway Institute (NHI) has a course NHI 134064, Transportation Construction Quality Assurance, that covers the fundamentals of QA as well as the mathematical terms and principles used in QA sampling, testing, and decision-making quality assurance. Additional QA resources can be found in the FHWA Policy and Guidance Center for Pavement and Materials with documents under the categories of Regulations, Policy, Guidance, and Information at: <https://www.fhwa.dot.gov/pgc/index.cfm?ddisc=52>

Case Study of Agency Best Practices

Maine Department of Transportation's QA Journey

RICK BRADBURY

Maine Department of Transportation

The Maine Department of Transportation (Maine DOT) implemented a quality assurance (QA) program for hot mix asphalt (HMA) and Portland cement concrete (PCC) in the 1990s. This was accomplished through a cooperative effort including Maine DOT, FHWA, and representatives from several Maine HMA and PCC suppliers. The implementation process included numerous pilot projects to gain experience and acceptance, as well as a consultant review of Maine's QA specifications to identify opportunities for improvement. QA specifications were implemented on all HMA and PCC projects in 1998, and have undergone continuous review and refinement since then.

Many researchers associate QA with statistical acceptance plans and pay adjustments; however, a QA program includes much more. The six core elements of a QA program are: Contractor Quality Control (QC), Agency Acceptance, Independent Assurance (IA), Dispute Resolution, Laboratory Accreditation/Qualification, and Personnel Certification/Qualification. Each of these elements must be in place to have a properly functioning QA program.

MAINE DOT INDEPENDENT ASSURANCE

Independent Assurance is defined as “an unbiased and independent evaluation of all the sampling and testing (or inspection) procedures used in the QA program.” The goal of IA is to ensure that all sampling and testing activities used in the acceptance decision are conducted correctly by well-trained, competent technicians using properly calibrated and functioning equipment. The results of IA tests are not used as a basis of acceptance. IA activities include evaluation of equipment through calibration checks and testing of split samples. Personnel evaluation may include observation of procedures and split sample testing. Split samples are used in IA to exclude sampling variability from the analysis—sampling technique is evaluated through observation. Some agencies use lab-prepared proficiency samples in place of project split samples.

There are two approaches to IA: project basis and system basis. Under the project basis, the frequency of IA activities is tied to the acceptance sampling and testing, typically at a rate of 1 IA test/10 acceptance tests. The project basis can lead to inefficient use of IA resources—large, high-production projects may require frequent IA inspections, reducing the ability of the IA team to conduct IA on small projects with infrequent sampling/testing. This can lead to situations where some acceptance technicians receive numerous IA evaluations each month, while technicians on small projects may not be evaluated at all.

The system approach to IA overcomes many of the challenges associated with the project basis. IA activities are focused on personnel, not projects. The frequency of IA activities is based on time. For example, the goal of a system-based IA program may be to complete IA inspection of at least 90 percent of technicians conducting acceptance sampling and testing over a six-

month period. This allows for increased flexibility, since IA may be conducted on whichever project the technician is working on for a given day.

Scheduling of IA activities is made possible by tracking all acceptance sampling and testing through the Department's Testing Information Management System (TIMS). Also, since IA is not tied to project production rates, it is easier to capture technicians who are assigned to smaller projects, as the IA team is not conducting multiple inspections on acceptance technicians assigned to large projects. Use of the system basis allows Maine DOT to conduct IA with a team of one part-time and two full-time technicians.

The TIMS system allows the IA team to manage their time efficiently, and provides the information necessary for Maine DOT to produce an annual IA report (example in Table 1) for FHWA to ensure that program goals are being met.

TABLE 1 Maine DOT Example of Annual IA Report from Testing Information Management System

2016 IA INSPECTION OF FIELD TESTERS BOTH PERIODS

Acceptance Tester			Grad. Sample (30)		Soils In-Place (30)		Thin Layer (30)		HMA Mix (30)		Concrete Field (30)		
			ACC	IA	ACC	IA	ACC	IA	ACC	IA	ACC	IA	
Period 1 Totals													
Possible Inspections (>3 samples taken)			5		18		5		61		33		
Obtained Inspections				5		18		5		60		32	
Possible Inspections (>3 samples taken), %			100.0%		100.0%		100.0%		98.4%		97.0%		
Total Inspections				5		18		5		61		36	
All Possible Inspections (>3 samples taken)		122	Obtained IA Inspections		120	All Percent Obtained (>3 samples taken)			98.4%				

Period 2 Totals													
Possible Inspections (>3 samples taken)			6		19		5		90		24		
Obtained Inspections				6		19		4		84		24	
Possible Inspections (>3 samples taken), %			100.0%		100.0%		80.0%		93.3%		100.0%		
Total Inspections				6		19		5		85		29	
All Possible Inspections (>3 samples taken)		144	Obtained IA Inspections		137	All Percent Obtained (>3 samples taken)			95.1%				

Grand Total													
Possible Inspections (>3 samples taken)			11		37		10		151		57		
Obtained Inspections				11		37		9		144		56	
Possible Inspections (>3 samples taken), %			100.0%		100.0%		90.0%		95.4%		98.2%		
Total Inspections				11		37		10		146		65	
All Possible Inspections (>3 samples taken)		266	Obtained IA Inspections		257	All Percent Obtained (>3 samples taken)			96.6%				

Table 2, Table 3, and Table 4 provide examples of Maine DOT's inspection observation procedure, comparison testing process, and IA inspection report. While some agencies conduct field tests at field or district laboratories with IA tests at a central laboratory, Maine conducts all acceptance at one of two accredited laboratories with an IA comparison conducted monthly. IA technicians must be well trained and considered experts. Their equipment must be well maintained and should undergo frequent calibration checks. The IA technicians must be diplomatic in their approach—the IA technicians should not have a “gotcha” mentality.

TABLE 2 Maine DOT Example of Observation Procedures**Air Content (AASHTO T 152)**

Was meter calibrated within the past 12 months?	YES
Calibration Date 4/6/2015	
Was bowl dampened?	YES
Was bucket filled in 3 equal layers?	YES
Was each layer rodded 25 times?	YES
Was bucket tapped w/hammer 10-15 times per layer?	YES
Was concrete struck off so bowl was level full?	YES
Was all air removed from meter?	YES
Was initial pressure set correctly with petcocks open?	YES
Was valve depressed, bowl struck w/hammer, and gauge tapped before reading?	YES

Concrete Cylinder (AASHTO T 23)

Was cylinder filled with the required equal layers?	YES
Was each layer rodded 25 times?	YES
Was each layer consolidated by tapping 10-15 times?	YES
Was cylinder finished to an even surface and capped?	YES

TABLE 3 Maine DOT Example of Comparison Testing

AIR CONTENT	
IA Result, %	7.0
Acceptance Result, %	6.2
Difference, %	0.8
Allowable Tolerance, %	± 0.5
Outcome	OUTSIDE TOLERANCE
TEMPERATURE	
IA Result, °F	61
Acceptance Result, °F	60
Difference, °F	1
Allowable Tolerance, °F	± 2
Outcome	WITHIN TOLERANCE

TABLE 4 Example Maine DOT IA Inspection Results

INSPECTION RESULTS																																																																																																																																						
Procedure Observation/Equipment Inspection (AASHTO T 2, T 11, T 27)		Comparison of Tests																																																																																																																																				
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MAINE DOT DISPUTE RESOLUTION

Dispute Resolution is another important QA program element. Dispute Resolution is defined as “an agreed-upon procedure to resolve conflicts resulting from discrepancies, between agency and contractor results, of sufficient magnitude to have an impact on payment.” Dispute Resolution is required when contractor test data is used in the acceptance decision, but it is recommended for any QA program. Dispute resolution may involve retesting retained split samples by third-party laboratories.

It is important that the dispute resolution program is unbiased, and operates under well-defined business rules. MaineDOT’s dispute process for HMA evolved over several years and is shown in Figure 4. Originally, acceptance test results were compared to QC test results, not split samples. Contractors could dispute a DOT result based on independent QC results. This was changed to require disputes to be based on split sample testing. Split sampling of hot mix asphalt is illustrated in Figure 5. The dispute process was further refined to require contractors to

submit their split sample results prior to release of the department's acceptance test results. Prior to this, Maine DOT reported their results, and contractors could then test the split sample and possibly submit a dispute request, if the split sample results met the dispute criteria. This created an opportunity for potential manipulation of the split sample test results by QC technicians to trigger a dispute. By requiring submission of the split sample results first, this potential was eliminated.

Currently, dispute resolution follows this basic process:

- To have the ability to dispute a DOT test, contractor must obtain a split sample.
- Results of split sample are submitted to DOT prior to release of DOT test results.
- Contractors compare their results to DOT results. If the results on pay-related properties exceed a specified tolerance, the results may be disputed. Tolerances are based on d2s values.
- DOT's QA Engineer determines validity of dispute. If valid, a retained split of the original DOT sample is sent to alternate DOT lab.
- When completed, result of DOT dispute test is compared to the initial DOT test result and the contractors result.
- If the dispute result is closer to the initial DOT result, the initial DOT result stands; if the dispute result is closer to the contractor's result, the DOT dispute result replaces the initial DOT result in the acceptance decision.

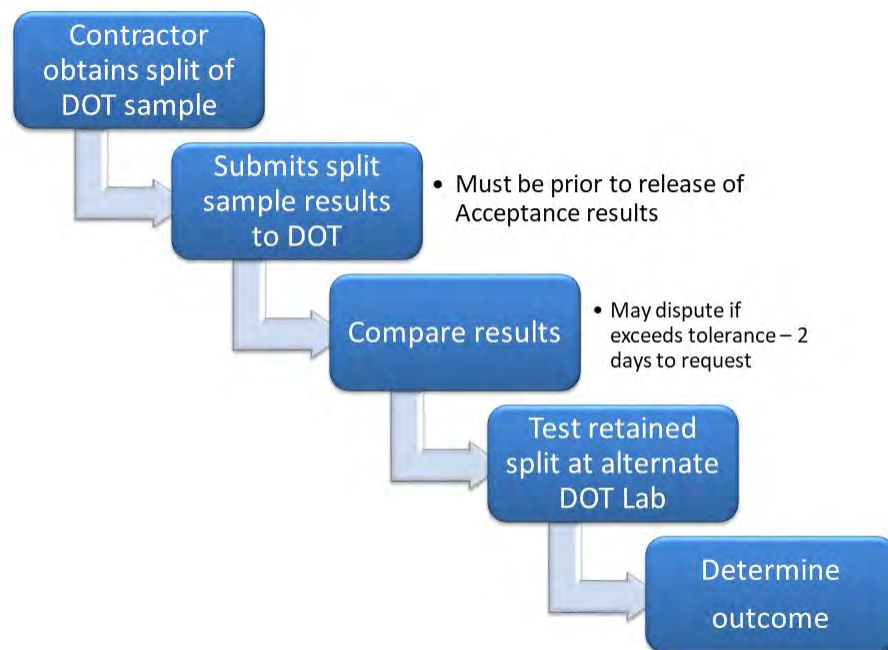


FIGURE 4 Schematic of Maine DOT dispute resolution process.



FIGURE 5 Sampling and splitting illustration for dispute resolution.

The dispute retesting may yield several outcomes as illustrated in Figure 6 with some hypothetical air void content data. The acceptance will be based on original DOT test results when the dispute retest is closer to the initial DOT test than to the contractor split sample results. When the dispute retest data are closer to the contractor's test results then the acceptance will be based on the retest. An example of a report is seen in Figure 7 that demonstrates a case in which the initial DOT test result for binder content is overturned by the dispute resolution process. The report displays the initial acceptance test result (5.9%), the retest result determined at the alternate DOT laboratory (5.5%), and the contractor's split sample result that triggered the dispute (5.4%). Since the DOT retest was closer to the contractor's result, the initial test result is replaced, and the retest binder content is used in all related calculations such as voids in mineral aggregate, voids filled with binder, and fines/effective binder ratio. The retest result for binder content will also be used to determine contractor payment.

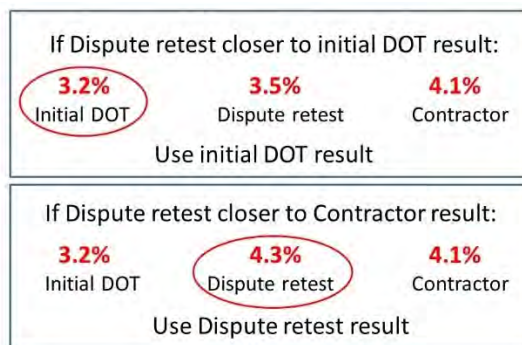


FIGURE 6 Example of different dispute retest outcomes.

Updated Test Report

Test Name		Initial	Dispute	Contractor
Asphalt Content (T 308), Method A	Temp, °C	538	538	
	Furnace	BGR-NCAT3.1	FRPT-NCAT1.1	
	Loss, %	6.32	6.14	
	Less C.F.	0.43	0.68	
	Binder, %	5.9	5.5	5.4
Air Voids (TP 4), %		5.1	5.1	
VMA (TP 4), %		17.2	16.8	
Avg. Gmb (T 166), Method A		2.394		
Avg. Gmm (T 209), Bowl Method		2.522		
Passing 12.5 mm Sieve, %		100		
Passing 2.36 mm sieve, %		44		
Passing 0.30 mm sieve, %		10		
Passing 0.075 mm sieve, %		3.7		

FINAL TEST REPORT

Note: Results or properties which have been changed by Dispute testing are highlighted.

PAYFACTOR ITEMS (bold)	Results	Specification	Meets?
Binder, %	5.5	5.5 ±0.4%	YES
Air Voids, %	5.1	2.5% to 5.5%	YES
VMA, %	16.8	15.0%, min.	YES
VFB, %	70	65% to 84%	YES
Fbe Ratio	0.7	0.6 to 1.2	YES
½ in. [12.5 mm]	100	See Sieve Analysis table on right for acceptability of test(s).	
No. 8 [2.36 mm]	44		
No. 50 [0.300 mm]	10		
No. 200 [0.075 mm]	3.7		
Avg. Gmb	2.394		N/A
Avg. Absorp., %	0.3		N/A
Avg. Gmm	2.522	2.515 ±0.030	YES

FIGURE 7 Maine DOT example dispute test report.

Using this process, disputes are resolved relatively quickly. The dispute process is based on the expected difference between two labs—arbitrary retests are not allowed. All parties understand the clearly defined business process. DOT has also worked proactively with industry to reduce disputes through improved consistency of testing practices, resulting in reduced rates

of disputed test results over time as seen in the reduction of reported disputed samples in Figure 8 and Figure 9 .

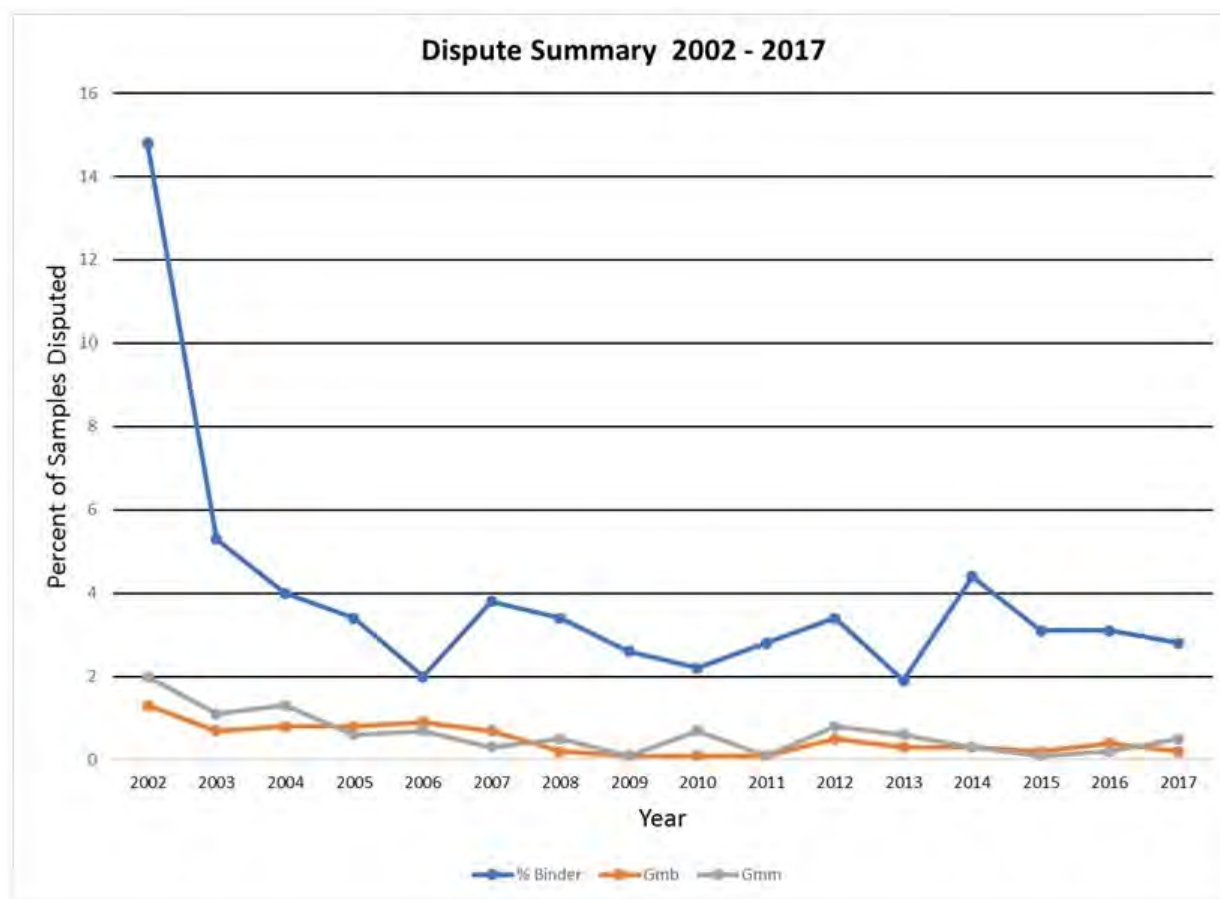


FIGURE 8 Dispute summary 2002 to 2017 for percent asphalt binder, bulk specific gravity (Gmb) and maximum specific gravity (Gmm).

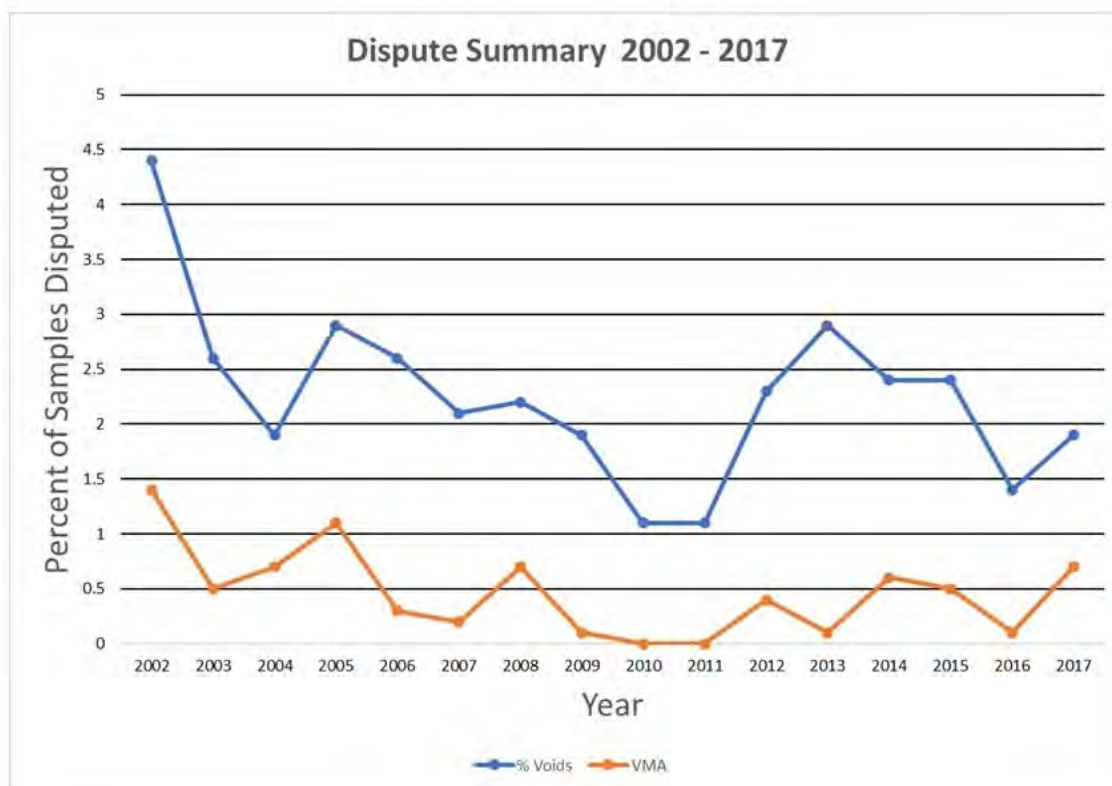


FIGURE 9 Dispute summary 2002 to 2017 for percent air voids and voids in mineral aggregate (VMA).

MAINE DOT SAMPLE SECURITY

Another important practice that supports a QA program is sample security.

FHWA requires agencies to control the acceptance sampling process to reduce opportunities for fraud and abuse. Traditionally, this has required that the DOT technician take immediate possession of all acceptance samples, and either deliver them to the appropriate DOT laboratory, or have them delivered by another DOT employee, to avoid possible tampering with the sample. However, Maine is a rural state and often has projects in remote locations, leading to situations where acceptance samples were not delivered to the DOT lab for several days. It should be noted that all acceptance testing for Maine DOT is completed at one of two AASHTO-accredited DOT laboratories. Contractors and material suppliers desired quicker turnaround of acceptance test results, so Maine DOT began using private courier services on remote projects to provide daily delivery of samples. Industry expressed concern that this manner of sample transport may result in mishandling of samples, and offered to deliver samples themselves.

Maine DOT worked with FHWA and industry, and developed a system using tamper-evident devices to guard against tampering with samples. This system, shown in Figure 10, Figure 11 and 12, has allowed contractors to deliver acceptance samples to the DOT labs daily, providing quicker turnaround of results while maintaining the integrity of the sampling program.



FIGURE 10 Security tape used for asphalt mix samples.



FIGURE 11 Demonstration of tamper resistant security tape.

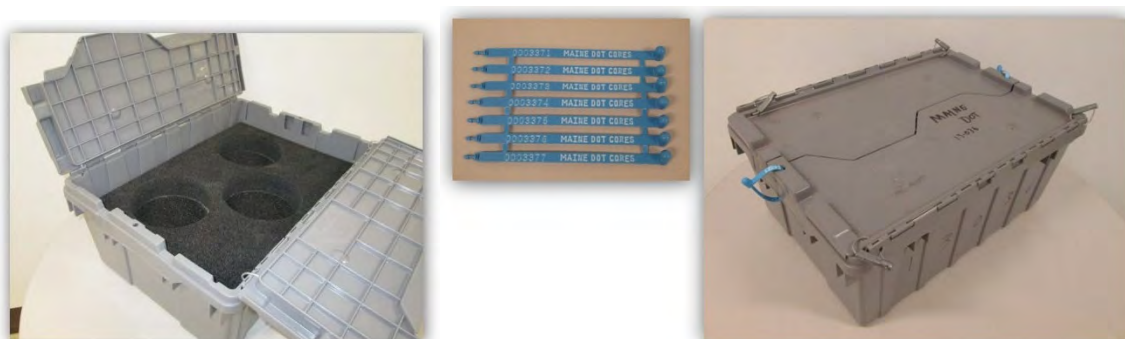


FIGURE 12 Tamper resistant security seal for asphalt pavement core sample cases.

SUMMARY

Quality assurance is not simply about sample size, operating characteristic curves and pay factors. All six core elements must be in place, and must be supported by effective business practices, and participation by all in order to provide our customers with a high quality transportation system.

Example Contractor Best Practices in Construction Quality

ADAM HAND

University of Nevada, Reno

KEY ELEMENTS AND REQUIREMENTS

Implementation of a quality assurance program at the project level places quality control responsibilities on contractors, which actually goes well beyond a specific project. To consistently deliver quality construction materials and projects, successful contractors are systematic in development and implementation of best practices. Depending on the complexity of work, some go as far as to implement formal management system practices, processes and tools.

For a contractor there are both internal and external key elements and related best practices for implementation of an effective quality program. The most important external element is an in depth knowledge of project specific requirements, so they can be successfully fulfilled. This level of knowledge can even, under the right conditions, lead to innovation and improved performance. A key contractor internal element is that the company senior management must be committed to delivering quality and place that expectation on the organization, then provide the resources (people, facilities, equipment, etc.) necessary to deliver it. It must be demonstrated. A good example of senior management support for quality is having the quality manager's report to senior managers, independent of operations, with not just the responsibility to, but rather the *expectation* that they stop work if quality is being compromised. Perception is reality and senior management must walk-the-talk. Stating that quality is important, but not investing in it or not holding those accountable for compromised quality, simply leads to deterioration of the effectiveness of quality management efforts.

SYSTEMS APPROACH

Some of the larger materials production and construction companies performing transportation construction works in the U.S. have successfully implemented a *Systems Approach* to managing quality based on the ISO 9001 Quality Management Standard. It does not have to be complex, but it must be communicated and supported and therefore it takes time.

This international standard provides guidance and tools for companies that want to be sure the products and services they produce/provide consistently fulfill their customer's requirements. It relies on the Plan-Do-Check-Act (PDCA) model shown in Figure 13 in which what is going to be done is stated (Plan), the plan is executed (Do), the outcome of the execution is evaluated for success (Check), and the findings are used to improve the process the next time it is used (Act). The next time might be the next shift, next day, next project, etc.



FIGURE 13 Plan-Do-Act model for quality management (Dennis, A., Wixom, B.H., and Roth, R.M. (2015) System Analysis and Design. 6th Edition, John Wiley, New York).

This model can easily be applied at the company, project, element of work, and even at a single construction material level. Some of these same companies have on-going continuous improvement efforts that rely on Six Sigma (reduce defects) and Lean (reduce waste) principles. Figure 14 illustrates the effectiveness of integrating these principles in a quality management system showing the impact on material submittal approval cycle time. This shows the time from initial submission through the review and approval time in calendar days. Note that total cycle time was reduced from about 80 days to 30 days based on one effort, then 30 days to 10

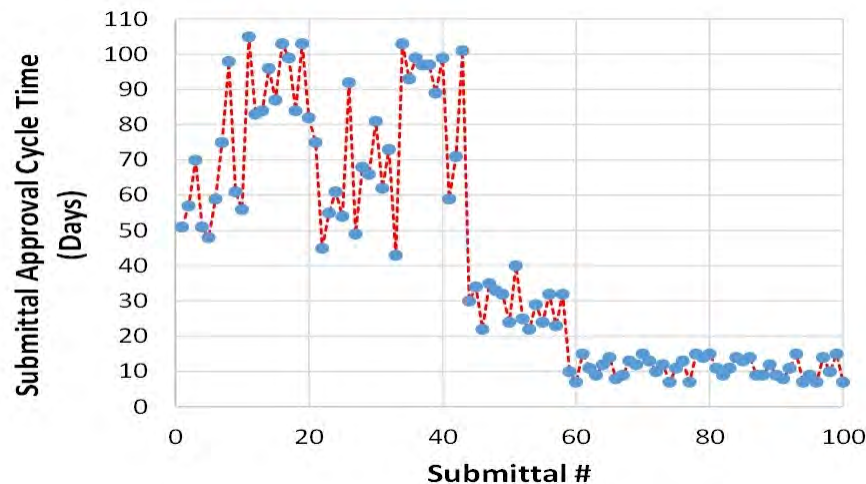


FIGURE 14 Improvements in submittal approval cycle times using Lean Six Sigma (LSS) approach.

Interestingly, regardless of whether ISO, Six Sigma, Lean or other principals are formally followed, companies that consistently deliver quality make expectations clear. Expectations include the activity and who has responsibility for fulfilling the activity. This leads to consistent use of processes that assure quality is delivered. Some call them policies, while others call them standard operating procedures, quality control procedures, or even best practices. Regardless of the name, the outcome is delivering quality materials and products fulfilling customer's requirements.

PEOPLE, ORGANIZATION, AND BEST PRACTICES

Projects with different sizes and complexities can follow the same system of managing the expected outcomes. For example, a highway-widening project with a 10,000-ton asphalt overlay can have a simpler quality control plan than a more complex dam project shown in Figure 15. On the paving project the quality control team may be composed of as few as four people. The dam project will require quality control specialists associated with each element of work (e.g. geotechnical, concrete, electrical, gates, etc.).

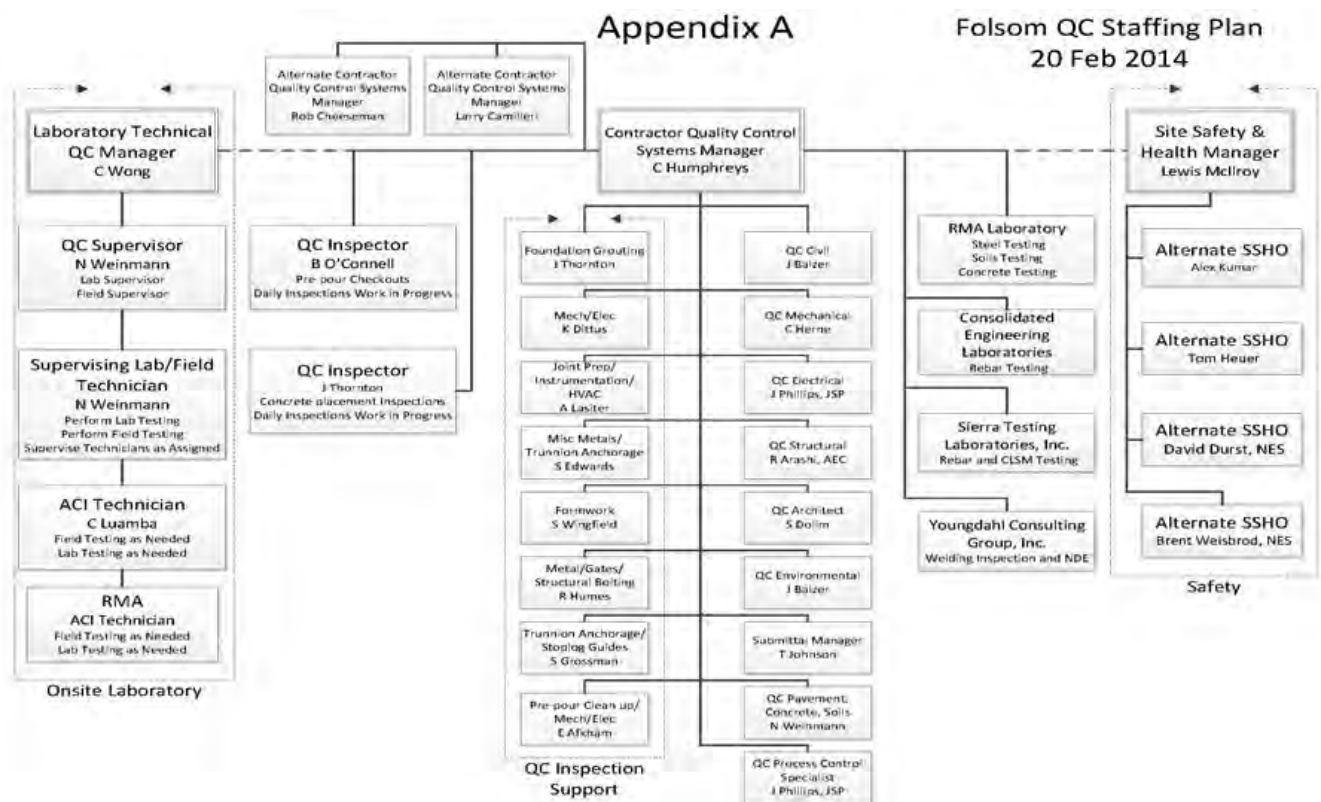


FIGURE 15 Example of quality control structure for an organization constructing Folsom Dam Auxiliary Spillway.

Regardless of the staffing or quality requirements and expected outcomes, the key is to understand and manage risks and the impacts on safety, cost, schedule, quality. One question that often arises is “Who controls quality?” Responsible staff who are all part of the construction process can be the quality manager, quality control manager, inspector, technician, quality assurance representative and the owner. However, the quality conversation can be changed from “Who controls quality?” to “Who actually makes the material or product?”. This can include the superintendent, foreman, equipment operator, and so forth.

Only those making a product can ultimately control the quality of that product. With this change in conversation within a company or at a project, the quality management department/staff becomes the facilitators and supporters of production operations that are sought after, rather than complained about getting in the way of operations. This also requires that companies hire and retain technically competent quality department staff with the right attitude, and then continually invest in training and development of them for success. It also leads to partnering in the company and with customers that is beneficial to both. Some agencies require formal partnering on projects. An example is the California Department of Transportation and its requirements are outlined in its *Field Guide to Partnering* (2013). This is a good example and resource for structuring partnering activities, regardless of whether or not they are required by contract.

Best practices do not make companies successfully deliver quality, only people armed with best practices can. Understanding who controls quality and fulfilling project requirements are important, but the best practices are knowing what is explicitly NOT required by contract that is needed and doing it. It is equally important for contractors to assign responsibility for quality to the people that actually produce materials and products. For example, the quality control manager at a ready mix concrete plant should not be responsible for the quality of concrete produced at the plant. The plant manager or superintendent should be because they actually make the operational decisions and direct the operational staff that make the concrete. The quality control manager's responsibility should be to inform them of the product quality and arm them with technical information they can use to make better operational decisions that will positively impact the concrete quality. A construction example would be a quality control inspector repeatedly identifying honeycombing and voids requiring sacking on concrete sound wall panels. The quality control department does not make the wall panels or perform sacking repairs on them. It identifies the voids and honeycombing, informs the construction manager and superintendent of the issues, and provides information on solutions to the poor quality being observed. In this example solutions would include doing a better job of cleaning the forms between pours, changing vibrating practices and potentially a ready mix concrete material (admixture) change.

PROCESS CONTROL AND QUALITY ASSURANCE

Process control (PC) is a method for keeping a process within boundaries and/or the act of minimizing the variation of a process. It is a voluntary part of the quality assurance program that could include sampling, testing, inspection, etc. It is the responsibility of the contractor. Quality assurance includes quality control (QC) and acceptance. The contractor has QC responsibilities while the owner has acceptance responsibilities. Contractor QC requirements are typically

dictated by the owner (e.g. sampling, testing, inspection, reporting and corrective action). Contractors also often perform Process PC activities that are equally or more important to delivering quality though they are not dictated by the owner. An effective PC activity is one that is simple and rapid, while at the same time identifies process or product change early enough to address issues. PC activities may routinely take place that are not documented, but are extremely effective at impacting quality.

A simple example, seen in Figure 16, is inspection of aggregate feed belts at a rock production, hot mix asphalt, or Portland cement concrete plant. An aggregate color change on a belt can be instantly identified by a well-trained eye and lead to stopping production to address the change. This is far more effective (timely) than taking a sample from the belt and performing a gradation test that takes several hours during which hundreds, if not thousands, of tons of production would take place that could all be out of specification.

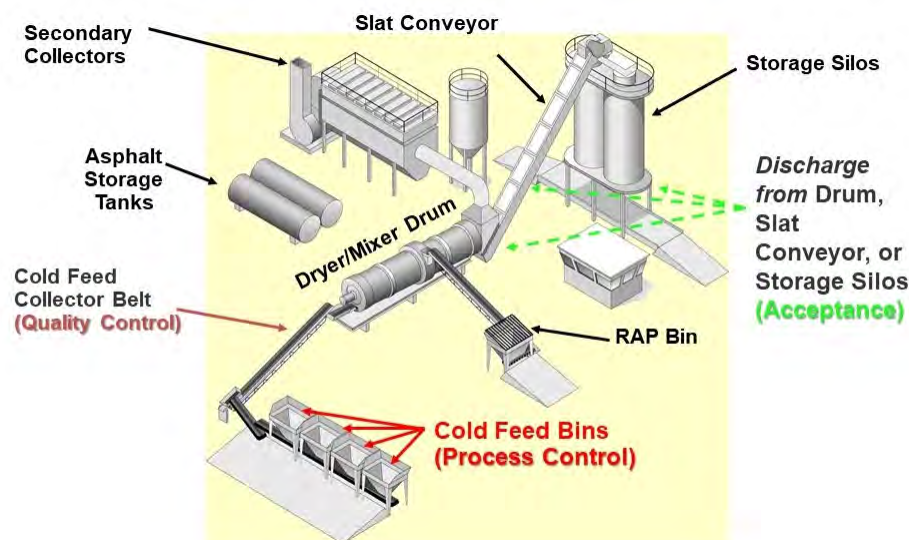


FIGURE 16 Illustration where Process Control (PC), Quality Control (QC) and Acceptance can be focused at different parts of a construction materials plant.

Process controls and best practices may or may not be the same, but they are both opportunities to improve quality. Figure 17 illustrates the locations where aggregate gradation could be measured for acceptance, quality control and process control purposes. In this example contractually the contractor has to sample and test material from the cold feed collector belt (QC testing), while the agency samples and tests hot mix asphalt on plant discharge or loadout (Acceptance testing of gradation after ignition oven asphalt content determination). The contractor is performing gradation tests on the individual aggregate stockpile materials as they are being fed to the cold feed bins (PC) to assure that the QC and Acceptance samples will be in specification. The PC testing is not required by contract, but rather a contractor best practice implemented to manage risk.

Figure 18 is an example of an inspection and test plan (ITP) for aggregates produced at a quarry. This ITP is not a project contractual QC requirement. It is part of a contractor plant quality management system that identifies what testing and inspection will be performed on each aggregate produced by the plant at a quarry. It shows the products, frequency of sampling and

testing, and standard test methods employed. Use of ITPs, not required by contract, for monitoring and controlling product quality is a best practice and it provides the information needed to monitor, control and improve material quality.

HMA Aggregates																
Product	Sieve Analysis (CTM 202)		Sand Equivalent (CTM 217)		Durability Index (CTM 229)		Specific Gravity, Absorp Coarse Aggregates (CTM 206)		Specific Gravity, Absorp Fine Aggregates (CTM 207)		Specific Gravity, Absorp Fine Aggregates (CTM 208)		Fractured Faces (CTM 205)		LA Abrasion (CTM 211)	Sodium Soundness (CTM 214)
	Stockpile	Loadout	Stockpile	Loadout	Stockpile	Loadout	Stockpile	Loadout	Stockpile	Loadout	Stockpile	Loadout	Stockpile	Loadout	Stockpile	Stockpile
19.0mm PMA	12/day	1/week	N/A	N/A	N/A	N/A	2/month	1/3 months					1/month	1/6 months	1/6 months	1/6 months
12.5mm PMA	3/day	1/week	N/A	N/A	N/A	N/A	2/month	1/3 months					1/month	1/6 months	1/6 months	1/6 months
9.5mm PMA	3/day	1/week	N/A	N/A	N/A	N/A	2/month	1/3 months					1/month	1/6 months	1/6 months	1/6 months
Dust	3/day	1/week	1/day	1/week	1/day	1/week			2/month	1/3 months	2/month	1/3 months				1/6 months

FIGURE 17 Aggregate plant inspection and test plan (ITP) example.

Control charts showing how production changes with time, such as the examples shown in Figure 18, are very valuable because they are objective and data-driven and can correlate to other properties used for acceptance. Development and implementation of an ITP leads to the information needed to plot control charts for monitoring quality and communicating with both plant operational and management staff on performance.

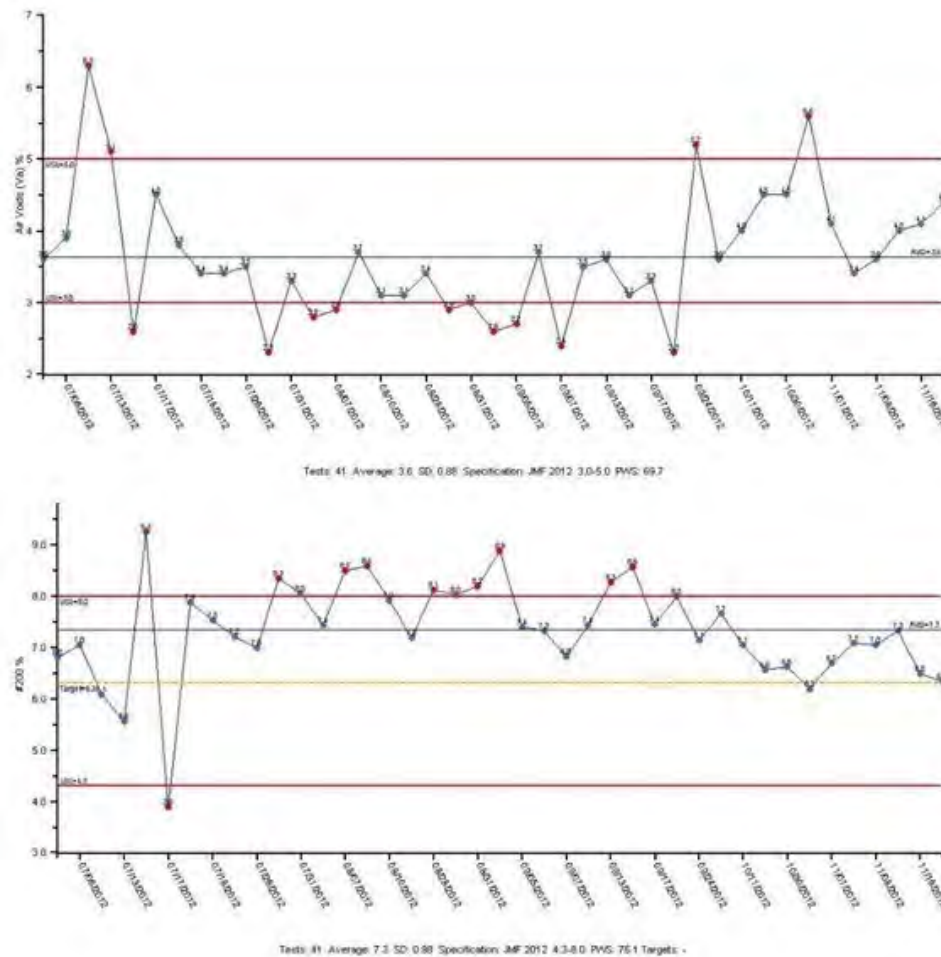


FIGURE 18 Generalized Control Chart showing change of material properties with time.

The ideal process control should identify changes early enough in the production to address and make adjustments and they should be simple and rapid. They do not necessarily have to be documented but they must be conducted. More frequent visual inspection than testing can be very useful. For example, simply inspecting stockpiles on a daily basis can reveal color change, which is a red flag for product quality change that can be investigated immediately.

Quality conscious operators are constantly conducting PC activities by self-inspection. Examples of PC activities an asphalt plant operator would do include constantly watching a moisture measurement system (MMS) on a material feed belt, exhaust gas temperature, mix temperature on discharge, amperage meters on motors drive belts and the slat conveyor, variable frequency drive (VFD) on a dust control system, and bin limit indicators for change (see Figure 19). These are all best practices regardless of what they are termed and the fact that they are not required QC activities.

- Continuous MMS on Collector Belt
- Continuous temp
 - Ever Seen One?
- Gas discharge temp
- Slat Amperage
- Dust & VFDs



FIGURE 19 Examples of plant process control traceability.

TRACEABILITY BEST PRACTICE

Traceability can be defined as ability to verify the location, application or history of an item by means of documented recorded identification. It is really the ability to discover information about where and how a product was made. This is extremely important for proving to a customer that the product they specified was actually delivered to them.

As an example consider asphalt binder. When purchasing binder traceability involves the specification, purchase order (PO), bill of lading, certificate of compliance and submittals. Once a contractor takes possession of binder traceability involves labeling/tagging, proper handling and storage, chain of custody forms, QC testing, providing assurance testing samples, plant inventory reports, plant production records, plant control settings, truck tickets and mix design. POs are a commercial document and first official offer issued by a buyer to a seller, indicating types, quantities, and agreed prices for products or services. It is used to control the purchasing of products and services from external suppliers. Always reference a specification when issuing a PO; “Asphalt binder shall comply with Section ...”. Bills of Lading are used to document materials exchanged from the supplier to the customer. A signature on the BOL is required to acknowledge receipt of the materials. Certificates of compliance are used for the supplier to illustrate materials meet requirements specified in the PO with test result values reported and a signature from a responsible individual. Quality control or assurance testing are still required; certificates of compliance do not eliminate the need for these elements.

Samples of materials in control of the contractor should follow best practices for labeling and storage. An example of a clean, printed, and readable labeling scheme is shown in Figure 20 where the sides of the container are labeled. Lids should never be labeled. Poorly labeled samples are shown in Figure 21. Consider indoor and covered storage as well as the ambient temperature of the storage location and how long sample remain in storage are important. Some of the most common compromises of traceability include lack of sample labeling detail and sample labeling integrity issues due to poor storage practices. Computer-based logging system

with consistent labeling of the samples can be used (Figure 22) and managing the storage of samples with chain of custody (Figure 23) improve an organization's traceability. True quality best practices assure traceability for contractor success and customer confidence.



FIGURE 20 Properly labeled samples for traceability.



FIGURE 21 Improperly labeled samples are not traceable.

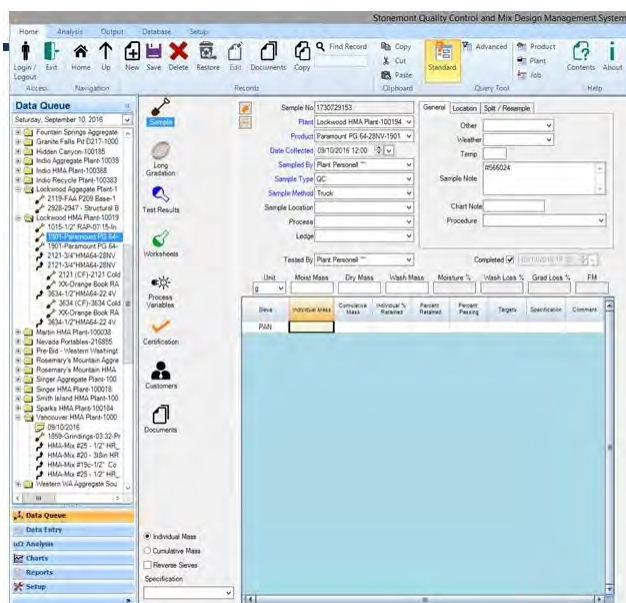


FIGURE 22 Example of computer-based logging software for traceability.

CHAIN OF CUSTODY FORM

Your Logo Here
Your Address Here

[Agency Name] Case #:

Item #	Date/Time Removed	Reason for Removal of Evidence	Signature

FIGURE 23 Example of Chain of Custody form for traceability.

LEVERAGING TECHNOLOGY, REPORTING WORK AND PERFORMANCE

Three valuable best practices available to contractors that are not commonly implemented by contractors include leveraging technology, reporting performance, and reporting rework. Examples of leveraging technology include hardware at plants, in labs, on equipment, tools, cameras, drones, and software that all provide real-time feedback to operations that can be used to monitor and improve quality. Silo loadout cameras, intelligent compaction equipment, inspection with drones and instant out-of-specification software notifications to smart phones and computers are a few specific examples. Electronic data rather than handwritten forms (Figure 24) minimizes calculated errors, is more efficient with time spent, and can provide

real-time feedback of a Key Performance Indicator such as with email notifications and automatic reporting to production staff.

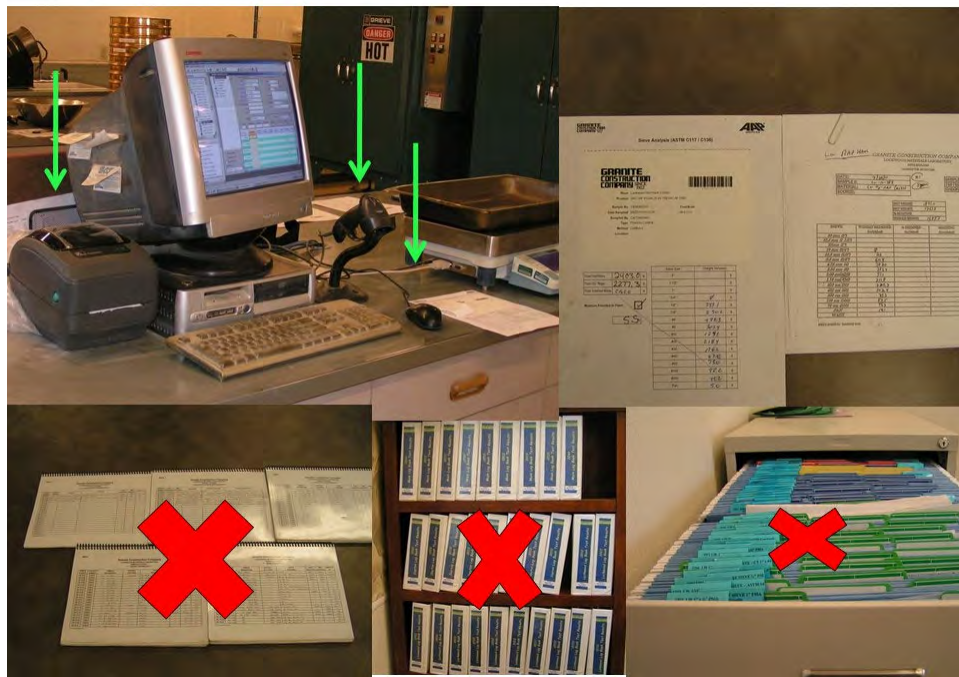


FIGURE 24 Electronic data have advantages over hand written methods.

Reporting performance (Figure 25) such as percent conformance to specifications or incentive/disincentive payment earnings at the project and production facility to various levels within the company will breed competition that spurs improvement. Reporting rework allows for it to be understood, prevented from that point in time forward on a project and communicated to other projects/parts of a company so the same rework doesn't occur in the future. This results in saving the company money and allowing it to truly understand its costs for future bidding purposes.

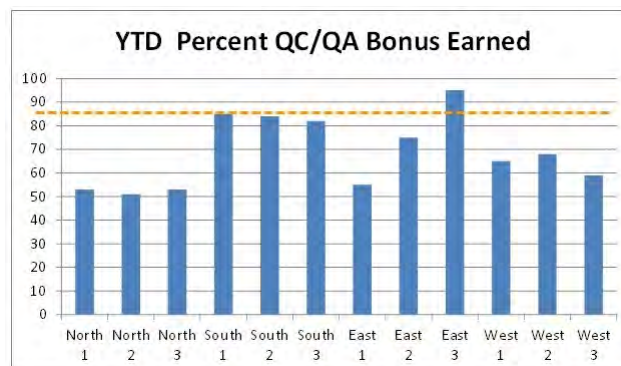


FIGURE 25 Example of reviewing reported performance.

SUMMARY

The manufacturing industry has been successfully implementing the systems approach of quality management for decades. With it management provides the resources necessary and makes sure responsibilities and expectations are clear. This leads to consistent processes that are routinely being reviewed for improvement and customer satisfaction. Regardless of the terminology used to describe the processes or whether or not they are documented, or if they have even organically grown to simply be part of a company culture, they are examples of opportunities for the construction industry. There are many best practices opportunities that can improve quality and company performance when the right people with the right technical and interpersonal skills are allowed to implement them and supported in the process. In the end the customer and the company win. The construction industry could learn much more about this from manufacturing.

Using Contractor's Quality Control Data in the Acceptance Decision

Case Study of a Successful Specification and Implementation

RICHARD E. KREIDER, JR.
Kansas Department of Transportation

INTRODUCTION

Lessons learned from the development and implementation of the Kansas Department of Transportation's (KDOT) Quality Assurance (QA) Specifications are presented. It is not intended to reflect poorly on agency or contractor, merely to help those that read the information to better prepare themselves when making specification decisions or performing forensic investigations.

It's easy to talk about the strengths of a given process or product. However, this can be only half of the story. Not knowing the weaknesses can dramatically decrease the quality of a project, to the point of failure. Therefore, it is imperative to take the time and effort to discover the weaknesses. Discover where this process or product has previously been used and talk with individuals that were directly involved with using it. The challenges of not knowing weaknesses within the QA processes adopted by KDOT are presented with lessons learned during the 20+ years use of the QA specifications to help others discover what weaknesses may exist in their process/product prior to moving forward.

Whenever a specification or test procedure is written or rewritten, it is imperative to consider what the end goal is and how the wording can be interpreted by both DOT representatives and contractors. In other words, one needs to be *shrewd* in how a specification is written so the completed project can match the desired outcome. The first three topics presented here involve hot mix asphalt (HMA), while the last involves concrete.

1. Gaining contractors acceptance
2. Lessons learned from the summer of 1999 construction season
3. G_{mm}/G_{mb} split sample comparisons
4. "No incentive" design-built project(s)

All information reflects real, field produced data; not theoretical or design-only data. It is noteworthy that KDOT implemented both QA and Superpave mix design at the same time.

GAINING CONTRACTOR'S ACCEPTANCE

This section is dedicated to understanding the initial challenges and the need to adapt as the QA program develops. It is highly recommended that continuous relationship exists between the agency and contractor industry group. Sustaining an open dialogue during specification development and to resolve "needed changes" will pay dividends as the process matures.

When KDOT implemented the QA specification, and several times since its inception, individuals have claimed KDOT could expect a significant increase in cost. Looking specifically

at HMA, shifting from Marshall to Superpave mix design took approximately four years (Figure 26). Figure 27 illustrates how that corresponded in price. While there was an increase in costs, within six years the Superpave prices were back to its original price. This occurred even though the contractor was now required to purchase core Superpave testing equipment, set up field laboratories and hire technicians.

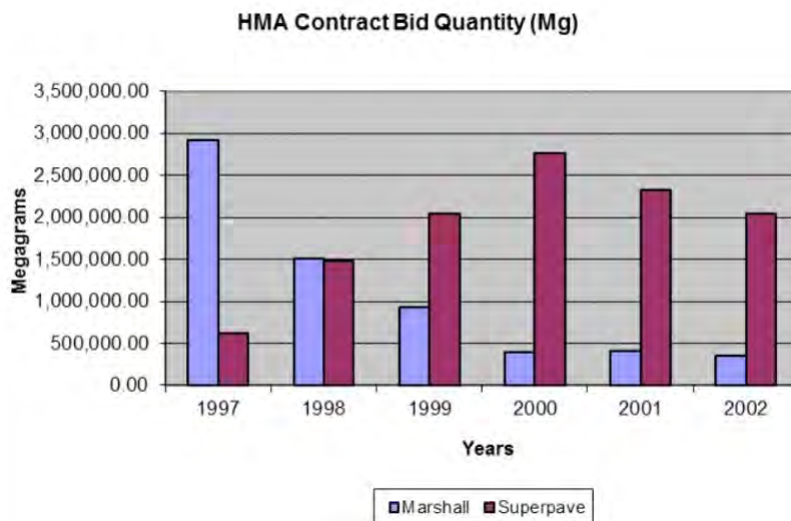


FIGURE 26 Quantities of KDOT Marshall and Superpave mix design hot mix asphalt.

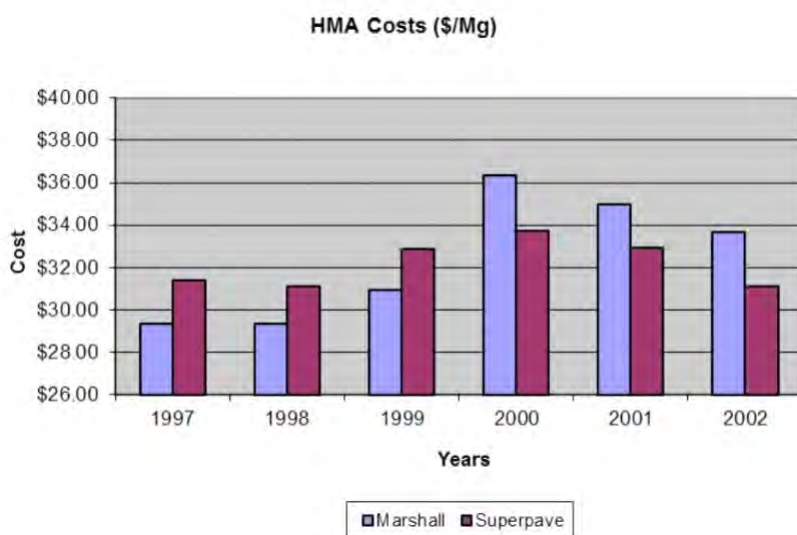


FIGURE 27 Price of hot mix asphalt.

Figure 28 and Figure 29 illustrate 10 years of materials and constructions specification changes KDOT implemented to improve the quality assurance program. One of the primary components of any quality program is continuous improvement. Certainly, KDOT exercised this component in a most aggressive fashion. Truthfully, part of the changes was brought about due to contractors interpreting the specification in an unanticipated manner. Despite what some may believe, keeping the communications flowing with the contractor industry averted many errors.

With their assistance, the specification continues to improve to this day; continuous improvement never stops.

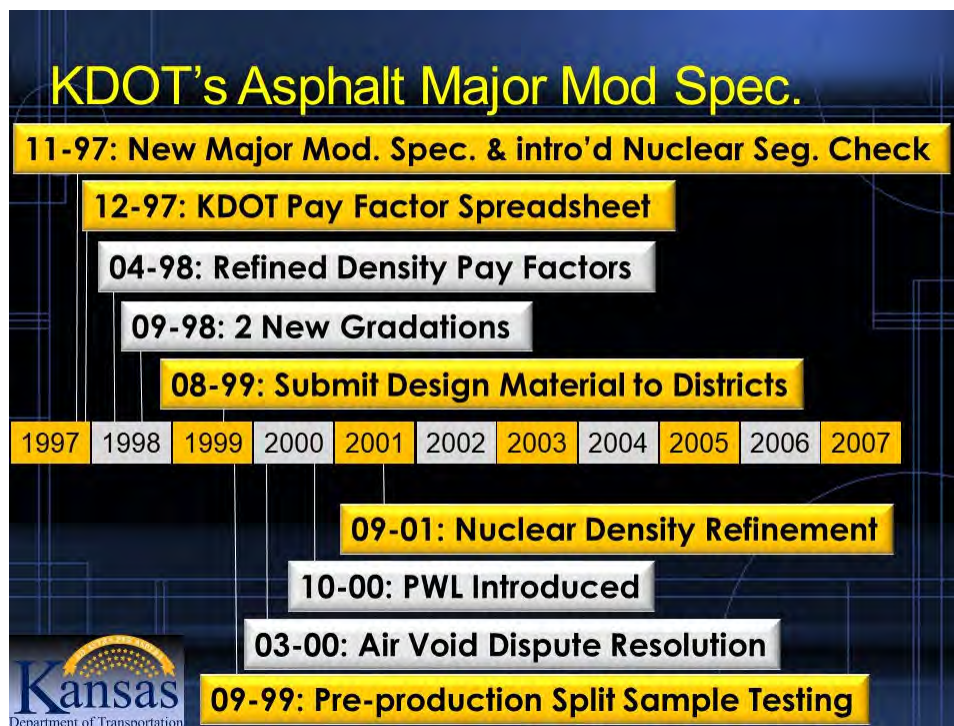


FIGURE 28 Timeline of KDOT Specification Improvements from 1997-2001.

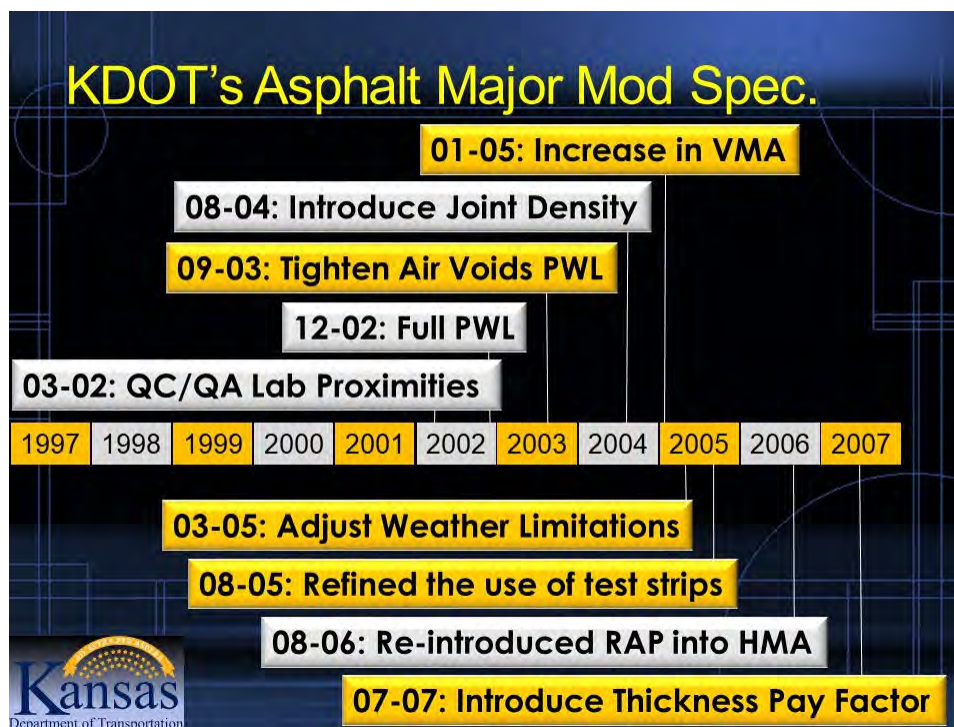


FIGURE 29 Timeline of KDOT Specification Improvements from 2002-2007.

LESSONS LEARNED FROM THE SUMMER OF 1999 CONSTRUCTION SEASON

This section demonstrates how specific quality assurance issues presented themselves and how they were resolved. Staff were optimistic two years into the fully implemented Superpave specification. KDOT pays incentive/disincentive on two HMA items: air voids and density. Figure 30 shows the air voids for 1998 and 1999. It basically tells two things; both contractor and KDOT field test data are increasing, but both are trending closer. However, both KDOT and contractor are dissatisfied with the quality assurance workflow.

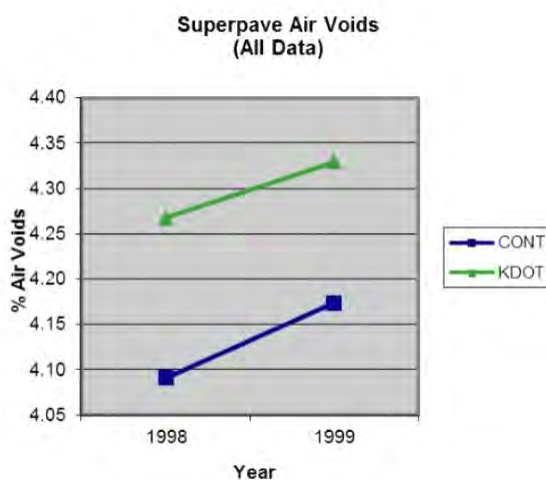


FIGURE 30 Contractor and KDOT test data.

Part of the reason for the dissatisfaction can be found in the specifications, which are shown in Figure 31. In 1999, KDOT's average air voids for the year was 4.33. When you subtract off 4.0 (target air void value), you get an *absolute* value of 0.33. This approaches the "less than maximum" pay factor. But it only approaches, which begs the question of what else could be contributing to the KDOT-contractor discrepancy.

$$\text{Deviation from target} = |4.0 - \text{test value}|$$

Air Voids Average Deviation	Pay Factor
$0.00 \leq D_4 \leq 0.35$	1.030
$0.36 \leq D_4 \leq 0.55$	$1.000 + 0.15 (0.55 - D)$
$0.56 \leq D_4 \leq 1.05$	1.000
$1.06 \leq D_4 \leq 1.40$	$1.000 - 0.44 (D - 1.05)$
$1.41 \leq D_4$	(a)

FIGURE 31 KDOT pay factor table and equation.

As seen in Figure 32, KDOT's field single standard deviation placed the agency's values to drop into the next lower pay bracket almost half the time. That explained the reason for the anger on the project sites, but it certainly didn't explain how to fix it. After scrutiny of both contractor and agency field technicians testing equipment and procedures, it became apparent that there was substantial latitude in how to conduct the test procedures. *Working with AASHTO Materials Reference Laboratory*, the HMA field test procedures were "tightened up" and redistributed for use the following construction season. Figure 33 shows how the new testing procedures improved the agreement of the data with time.

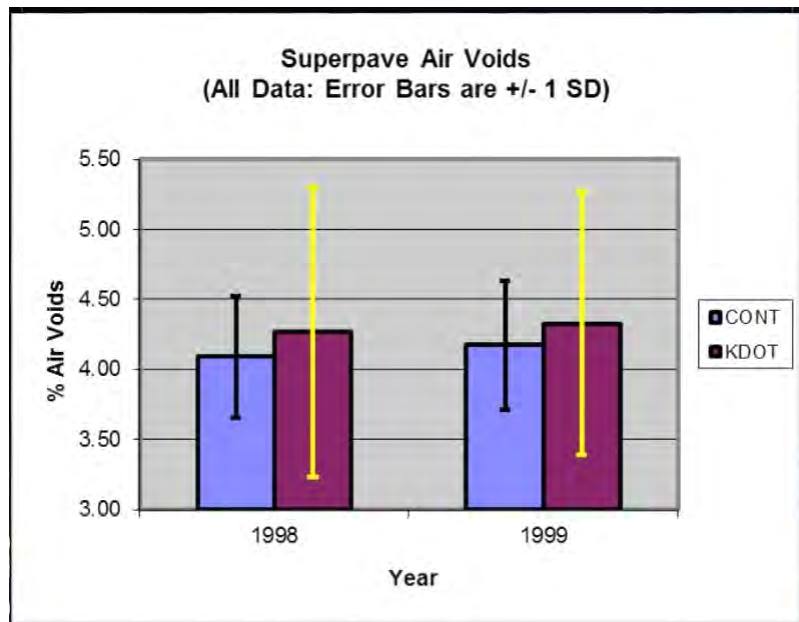


FIGURE 32 Average and variability of KDOT and Contractor air void data.

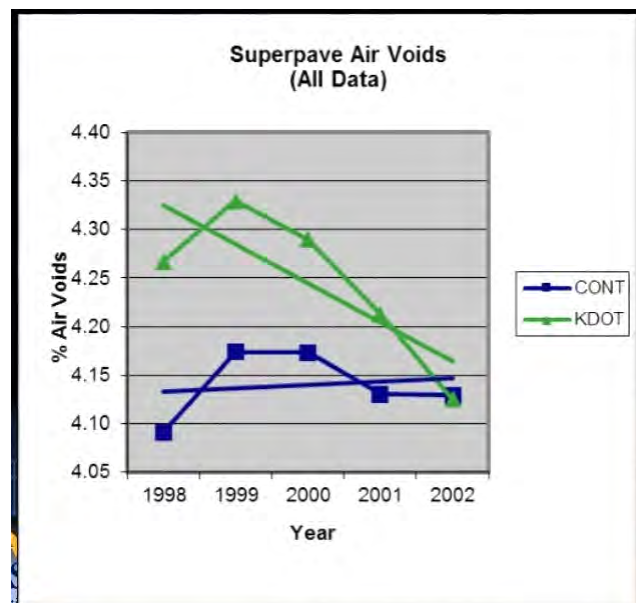


FIGURE 33 Improved agreement between Contractor and KDOT air void data.

Continuous improvement of a quality assurance specification would always push you towards perfection, but continuous improvement is all about the journey, not the destination. Notice the gap in 2004 air void data in Figure 34. This is another great lesson learned. Over the course of 20+ years in KDOT's QA program, there's been over five different individuals responsible for the QA database. During that time there's also been a major shift in how to consider storing the data. Between the various individuals and their unique approach to data management, some data has been lost. Consider placing strict rules and documentation requirements in place to minimize this happening with your data.

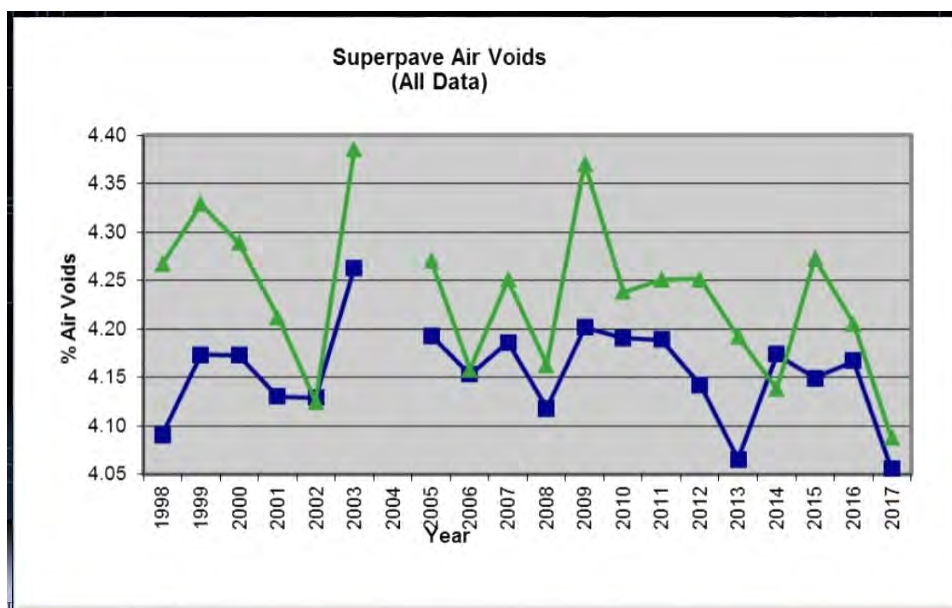


FIGURE 34 Air void content data through the years.

G_{MM}/G_{MB} SPLIT SAMPLE COMPARISONS

Within Superpave, air void content is calculated by using three test procedures: maximum specific gravity of the uncompacted mixture G_{mm} , gyratory compaction of a specimen, and testing the bulk specific gravity G_{mb} of the compacted specimen. Early on, KDOT learned it was beneficial to perform a three-way split at the beginning of the project shown in Figure 35 comparing the contractor's QC test to the KDOT field laboratory QA tests and again to the KDOT district laboratory verification tests. This helped to minimize the risk of test equipment/procedures being incorrect. NOTE: Split samples are a powerful forensics tool if you record and retain the raw test weights.

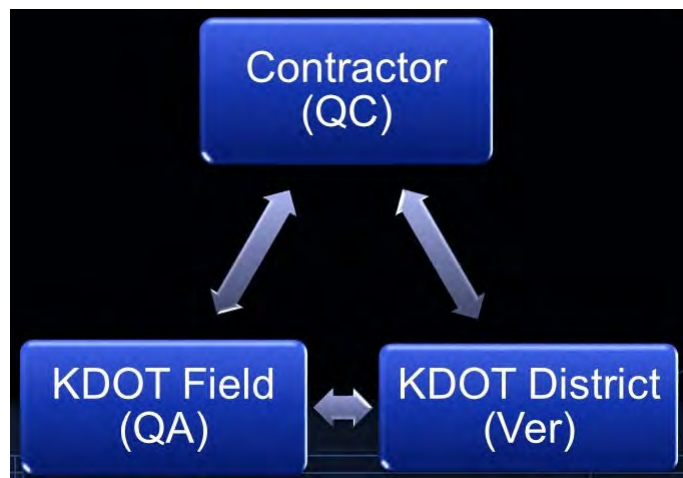


FIGURE 35 KDOT three-way split sampling and testing at beginning of a project.

In an effort to reduce the overall expense of Superpave implementation, KDOT decided that certain pieces of contractor equipment (gyratory compactor, drying ovens, ignition oven) would be made available to KDOT field technicians. This has been a successful endeavor, but does require split sampling with the District laboratory to verify these pieces of equipment are functioning properly.

%Gmm@Ndes is equal to “100 minus air voids” and 96% is the target value. Examine the ratios between agency and contractor during 2002 and 2006 in Figure 36. Even though the air voids improved, there’s a greater separation in 2006 with both Gmm and Gmb. It was impossible to see the problem by looking at just air voids data. There is a clear bias between agency and contractor test results. When this type of bias is discovered, it needs to be investigated.

Going back to Figure 34 illustrates how misleading the data can be for a single year. Sometimes it’s not what the data is telling you, it’s what the data isn’t telling you. Always be prepared to dig deeper, even if that requires analyzing the raw weight values. For this particular case, it was necessary to look at the actual test results that are used to calculate air voids before the cause for concern could be observed.

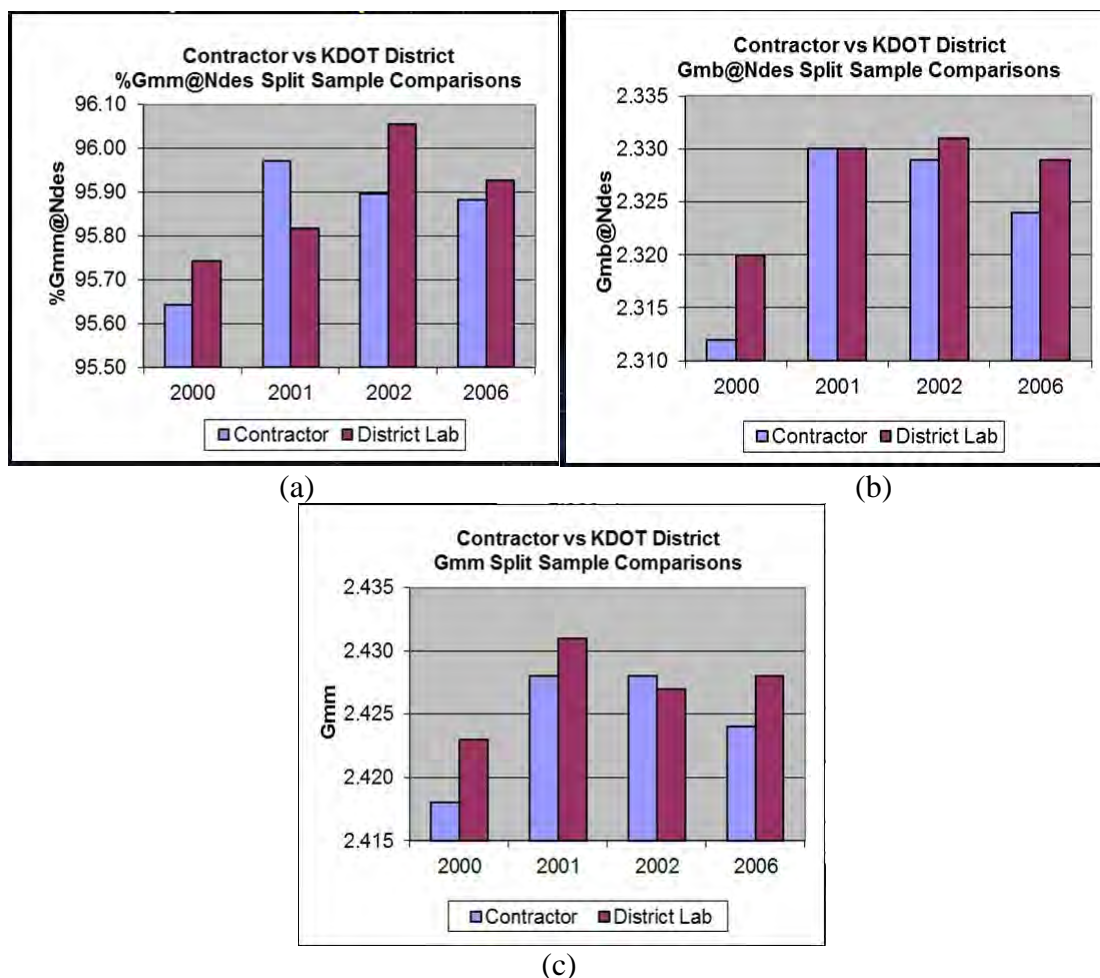


FIGURE 36 Comparison of Contractor and KDOT laboratory tests for (a) Air void content (b) Gmb (c) Gmb.

“NO INCENTIVE” DESIGN-BUILD PROJECT(S)

The Johnson County Gateway project (I-435, I-35, and K-10) is a unique project KDOT completed in December 2016 because it was KDOT’s first official design-build project and the first use of *non-incentivized* QA specifications. The Gateway Project shown in Figure 37 represents a total investment of approximately \$300 million. It represents about a third of the overall improvements required at this intersection, which was originally estimated to be about \$1 billion. The Gateway improvements are shown in orange. Because of the size, it represented an excellent opportunity to be a rich source of concrete pavement test data.



FIGURE 37 Overview of KDOT's Gateway Design-Build Project.

The pay adjustment of concrete strength was broken into three zones seen in Figure 38 that defined how much disincentive may be assessed at the end of the project. Figure 39 illustrates when compressive strengths fall into the 0% to 6% pay adjustment, then those funds could be used to offset any disincentive that fell within the 0% to -6% pay adjustment. Should the incentive portion not fully cover all of the 0% to -6% disincentive portion, then the contractor would receive less pay. The contractor would pay all disincentive that fell into the -6% to -24% pay adjustment, and would be required to remove and replace all sections falling below the -24% pay adjustment.

$$P = ((PWL_s + PWL_T - 100) \times 0.010) - 0.940$$

Pay Adjustment Factor	Disposition
Between -0.06 to +0.06, inclusive	Award incentives only as an offset to disincentives ¹
Between -0.24 to -0.06	Assessed disincentives are not eligible for offset by incentives
Below -0.24	Remove and Replace at the Design-Builder's Expense

¹ No net incentive for Portland Cement Concrete Pavement will be paid on the project.

FIGURE 38 Pay adjustment equation and table explanation of three.

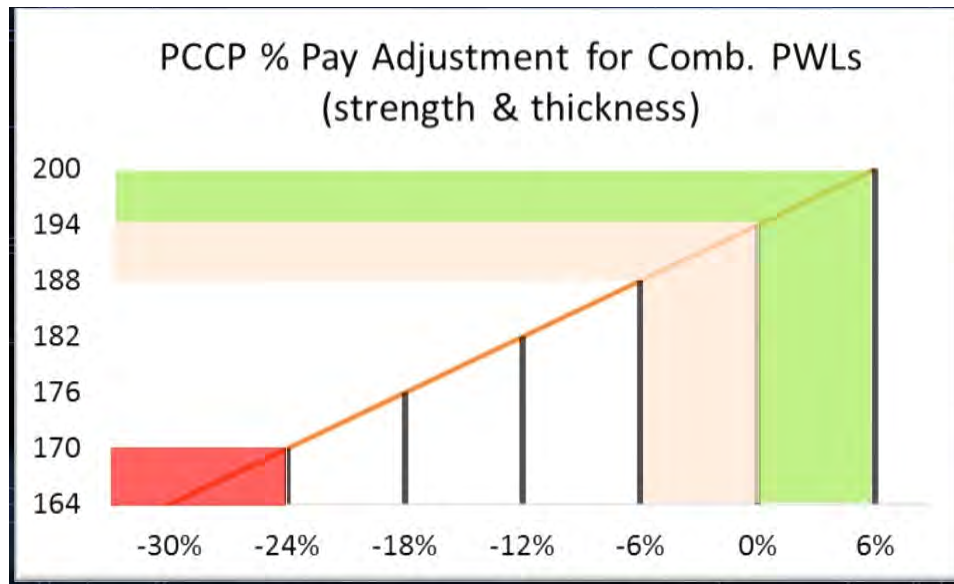


FIGURE 39 Pay adjustment for combined Percent Within Limits (PWL).

After completion of the project, all pay adjustments were compiled and shown in Figure 40. Based on this unique contract, the contractor appeared to maximize the incentive pay adjustment. Had this been a normal KDOT project, the contractor would have received approximately \$1.5 million in incentive payment. Looking at this data, one would consider this part of the contract a success. The data are explored deeper.

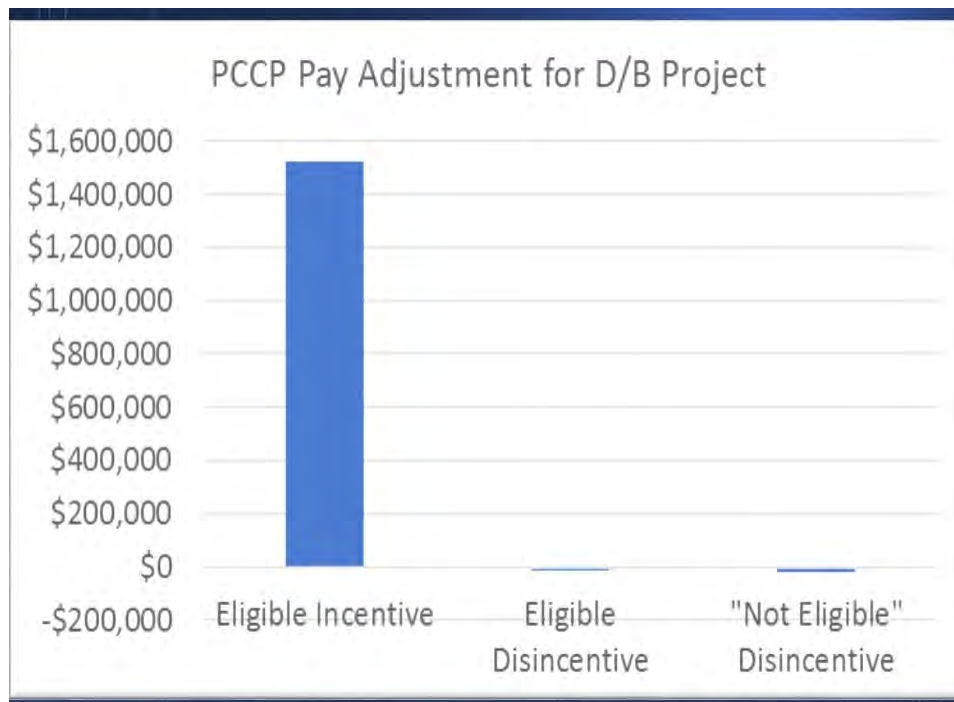


FIGURE 40 ELIGIBLE PAY ADJUSTMENT FACTORS COMPILED.

KDOT establishes the strength statistical lower specification limit for concrete compressive strength at 3900 psi (Figure 41). Compressive strengths on this project exceeded 8000 psi, with the mean exceeding 5700 psi. This far exceeds what is expected and brings into question what is desired. Clearly, there are opportunities for improvement.

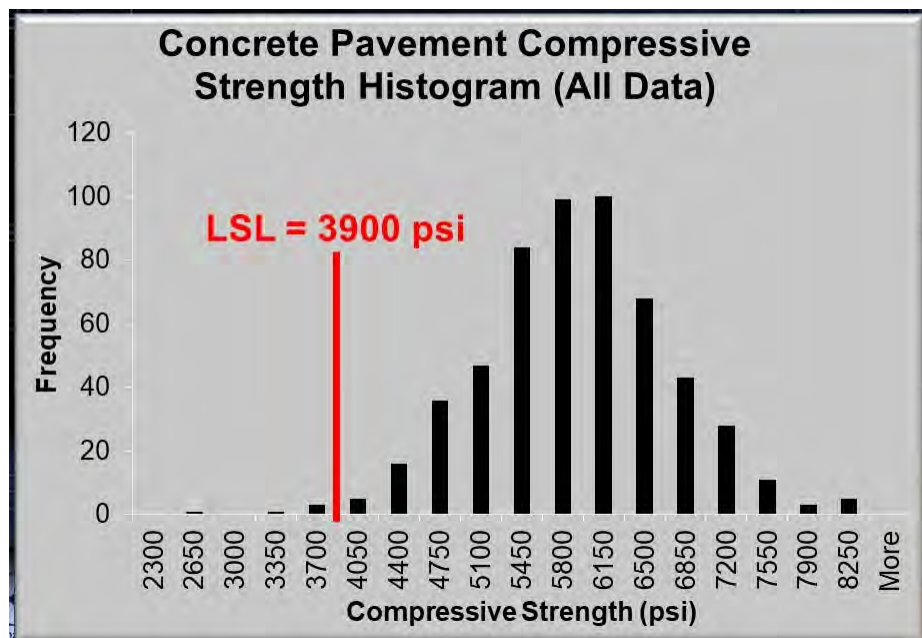


FIGURE 41 Histogram of all PCCP compressive strength samples.

Figure 42 displays the compressive strength data chronologically where the pattern increases then decreases for several cycles in a sinusoidal fashion. The concrete temperature (not ambient temperature) is shown in Figure 43 with a much better definition transitioning from summer to winter. The combined data are overlaid in Figure 44 showing contrasting flows between temperature and strength. The concrete temperature is fundamentally an inverse of the compressive strengths. When temperature increases the strengths decrease as seen in Figure 45. With a fixed mix design, contractor was producing a concrete that was excessively strong for parts of the year when the temperature was cooler, but would satisfy the materials requirements when conditions were not optimal.

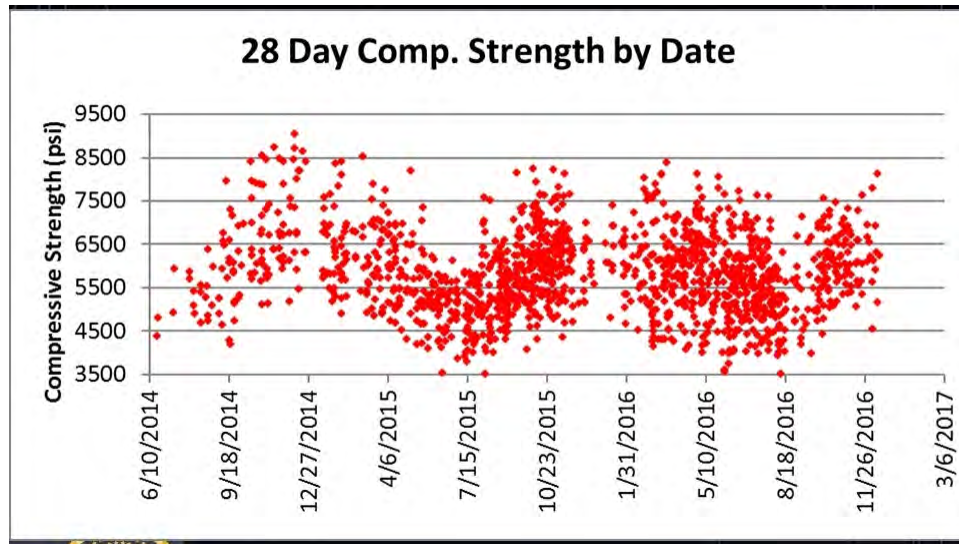


FIGURE 42 Trend of 28-day compressive strength tests with time.

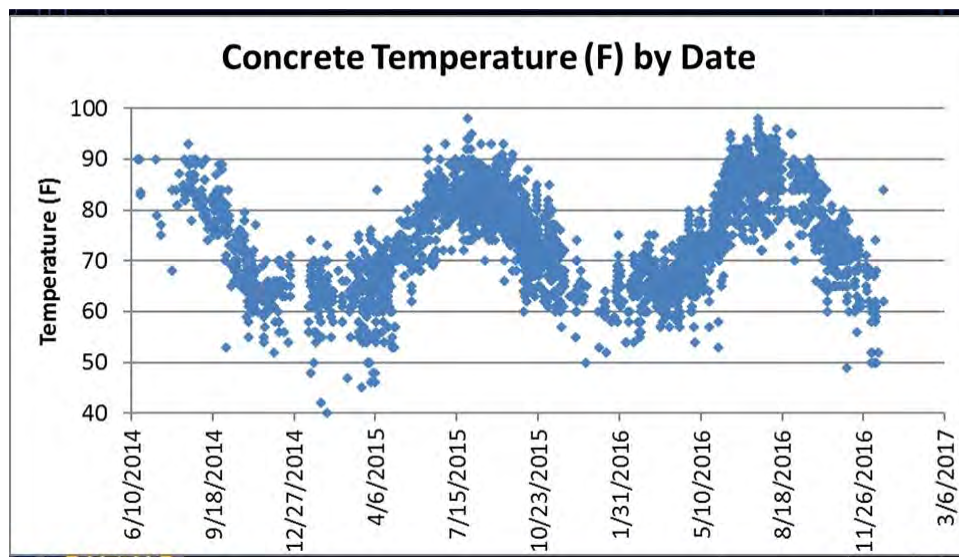


FIGURE 43 Trend of concrete temperature with time.

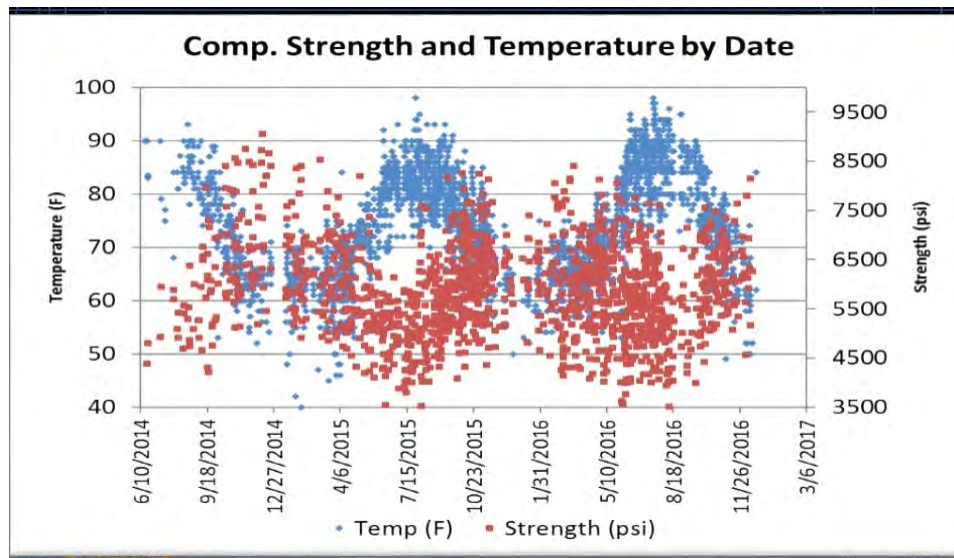


FIGURE 44 Strength and temperature data overlaid.

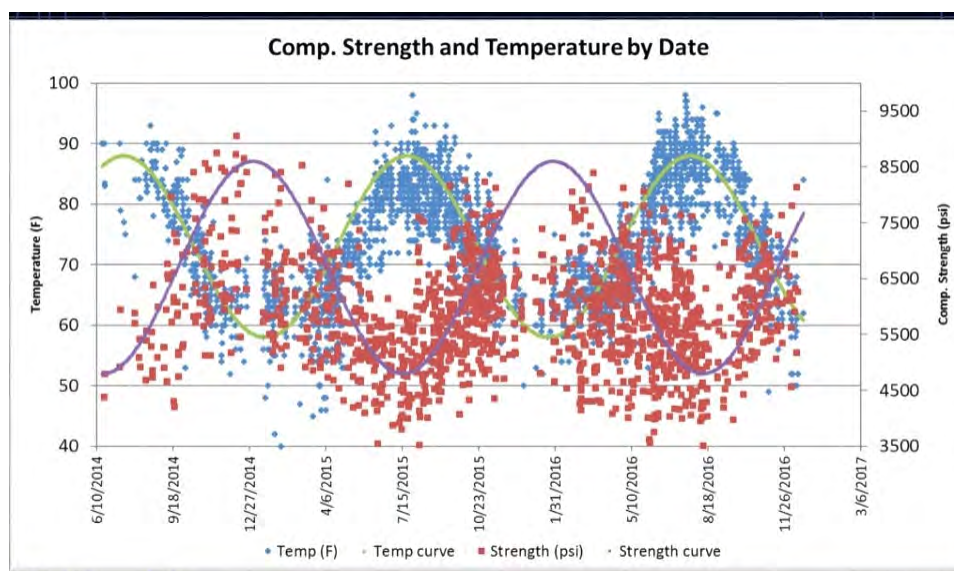


FIGURE 45 Sinusoidal models fit to strength and temperature data.

Obviously, it is not economical to dramatically modify the concrete temperature, but is there an opportunity to modify the concrete strengths? Currently, a mix design is established in a laboratory setting that does not take into account climatic conditions during curing. This creates a fixed environment to illustrate what can be expected out of the combined materials in a concrete mix design. Perhaps this concept is ready to take another step forward. Technology is available to monitor environmental conditions during the construction process. Monitoring processes could be combined with models that bridge the laboratory and environmental

conditions to automatically adjust the concrete plant to modify the final combination of materials to produce a concrete mix that can accommodate current conditions. This could provide a much more uniform concrete product throughout the year (within reason, of course).

SUMMARY

It is important to take the time to understand the strengths and weaknesses of specifications and test procedures when writing them. In addition, it is key to consider the quality assurance specifications and procedures from not just the agency's perspective. Whenever possible, it is best practice to obtain all relevant data, including the originally measured weights. Doing so would afford an excellent opportunity to perform a data forensic investigation. And finally, when limited with options, creatively plot the data in alternate formats and inspect for trends that may not be revealed by conventional analyses.

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