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Sources of Cost Saving Opportunities in Highway Construction Quality Assurance Practices

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Abstract: US transportation agencies are dealing with shrinking budgets, limited work forces, and deteriorating infrastructure. In order to cope with funding uncertainty, state highway agencies are now looking into their own organizations and identifying programs, practices, and processes that have potential for cost saving. A quality assurance (QA) program is an integral part of highway construction and ensures a project's contracted level of quality. The cost of quality (conforming and nonconforming) can constitute a sizable part of total construction cost. As the quality assurance programs evolved, various practices and processes were developed over time and later adopted by state highway agencies. These practices and processes include different QA standards and specifications, varying testing methods, central testing lab vs. on site testing, performance based vs. prescribed quality assurance practices, implementation of innovative quality assurance practices, etc. Therefore, there is an opportunity to assess different QA strategies and recommend those practices that are effective and cost efficient. A national survey was conducted by the authors, which provided a detailed mapping of various QA practices and processes used as part of QA programs and identified areas where agencies can focus on for cost savings. The survey found that QA sampling and testing plans, optimization of sampling plans, optimization of QA standards and specifications, and implementation of innovative test methods and processes are the main areas the agencies should focus to lean the current QA programs.

Keywords: Quality Assurance, Highway Construction, Cost of Quality, Cost Saving QA Practices

I. INTRODUCTION

The estimated value of U.S. transportation infrastructure in 2010 was over $7.0 trillion [1]. Having built that system and continuing to keep it efficient, state highway agencies (SHA) biggest challenge in the 21st century is to preserve the quality of our nation's top investment. State and federal departments of transportation realize the importance of quality assurance (QA) and implement methods and procedures for ensuring the best quality. However, these practices differ significantly. Examples of varying QA practices are different standards and specifications, varying test methods to determine properties of a finished construction which vary in accuracy and costs, destructive vs. non-destructive tests, central testing labs vs. on-site testing, performance based vs. prescribed quality assurance practices, implementation of innovative quality assurance practices, etc. Federal Highway Administration's Materials Quality Assurance provide detail descriptions of each of these practices including their strengths and limitations [2, 3, 4, 5]. However, cost of these practices are often overlooked. The variety of approaches taken by individual states offers an opportunity to assess the cost-effectiveness of different strategies and recommend those practices that are most successful.

There is a mismatch between revenue and spending in highway trust fund, and every year, most SHAs are facing funding shortfalls or asked to do more with little [6]. However, cost of quality activities such as cost of equipment, testing, inspection, training, etc. are significant. Numerous studies examining the cost of quality (conformance and nonconformance) have identified their costs as ranging from 5% to 20% of a project's contract value [7, 8, 9, 10, 11]. Therefore, there is real value in identifying, sharing, and implementing cost effective quality assurance practices and procedures among SHAs.

SHAs have implemented various quality assurance practices to ensure a high quality finished project [12, 13, 14]. Quality assurance (QA) is defined as "All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service" [15]. The implementation of QA has come from the experience that failure to conform to either material or construction specifications can result in the premature failure of highway components. Construction QA programs are intended to ensure that the quality of the materials and construction incorporated in highway products is satisfactory [16, 17]. Transportation agencies have made major changes to the systems used to monitor and enforce materials and construction acceptance. Traditionally, a SHA was responsible for performing inspections, conducting quality control tests, and making related acceptance decisions. Today, many agencies use the services of consultants or construction contractors for inspection and testing on projects. This shift in project oversight creates new opportunities in quality assurance practices and opens new avenues for innovative materials and construction acceptance

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procedures [18]. As a result, a wide variety of quality assurance practices and procedures have been developed and implemented by SHAs, consultants, and contactors over the year. However, little has been done to compile QA best practices, which are cost effective as well. Cost of Quality consist of cost of prevention, cost of appraisal and cost of failure [19]. Drilling down to these costs can vary widely as SHAs cost estimates vary based on location, availability of material, labor, technology, etc. [20, 21, 22]. It will be rather beneficial to identify various areas in existing QA practices where SHAs can further investigate with cost saving in mind. Therefore, the purpose of this study is to identify and share cost effective QA practices within SHAs' QA programs related to acceptance sampling and testing, optimization of QA standards and specifications, QA sampling plan optimization practices, usage of quality measures, etc. The study also identifies innovative and technology based QA testing methods and processes that are rapid, more accurate, but cost effective.

II. QA PROCEDURES

Once a construction project is awarded, the contractor in consultation with the SHA prepare a QA plan for the project based on construction standards and specifications. A QA plan is formally defined as "A project-specific document prepared by the contractor which identifies all QA personnel and procedures that will be used to maintain all production and placement processes "in control" and meet the agency specification requirements"[23]. The QA plan typically includes 1) Identification of quality characteristics (such as asphalt content, compressive strength, gradation, moisture content, etc,), 2) Sampling plan for quality control (QC) and acceptance, 3) Certification requirements of labs and lab technicians, 4) Inspections and tests including independent assurance (IA), 5) Data analysis and pay decision and 6) control of nonconformance [24]. Most agencies require contractor QC for the majority of materials used in the construction. Many agencies retain the entire acceptance function; however, the number of agencies using contractor test results in the acceptance decision is increasing. Since objective of QC and acceptance testing are different, it is desirable to separate these functions. This separation is often not clear. The third QA function, IA, is being conducted by all agencies in compliance with 23 CFR 637; however, the manner in which IA is organized within an agency varies greatly, as does the level of staffing and agency budgets. When using contractor test results in the acceptance decision, 23 CFR 637 requires that verification testing be done by the agency [25]. The type of verification currently being used varies greatly from agency to agency. Some agencies use a stronger statistical verification system such as F&t test and percent within limit (PWL) whereas some agencies use a weaker verification system that is less sensitive to differences between agency and contractor test results [26].

III. DESIGN AND METHOD

This study utilizes an online survey and interviews with STAs' quality assurance managers to collect cost effective quality assurance practices widely used by STAs. The authors developed a database of the contact information of quality assurance managers of all 50 states' transportation agencies. Online survey software "Surveymonkey" was used to develop and distribute the survey [27]. The survey was intended to capture the following information:

1. Typical acceptance QA tests used by STAs and failure percentages for:
   - i. Hot Mix Asphalt
   - ii. Portland Cement Concrete Pavement
   - iii. Structural Concrete
   - iv. Subgrade/Embankment
   - v. Aggregate Base/Subbase
2. Sampling techniques and whether they are optimized for cost, importance, and risk
3. Whether or not the SHAs are currently using or exploring an innovative testing method (such as intelligent compaction) that significantly reduces the cost, saves time, or produces more accurate results
4. QA processes which are rapid and cost effective, such as sampling frequency, standards and specifications, onsite vs. central labs, etc.

Once collected, the best practices of QA programs were complied, analyzed, and grouped together based on construction materials, e.g. Hot Mix Asphalt, Portland Cement Concrete Pavement, and Highway Subgrade/Embankment, Structural Concrete, and Aggregate Base/Subbase.

IV. DATA ANALYSIS AND RESULTS

The survey was sent out to all 50 states. A total of 19 state highway agencies completed the survey with a response rate of 38% (Figure I). The participants range from Quality Assurance Managers to State Materials Engineers. The results of the survey are elaborated below.

A. *State Highway Agencies' Focus of Quality Assurance Practices*

SHAs were asked how they measure construction quality performance. About 90% of the SHAs measure

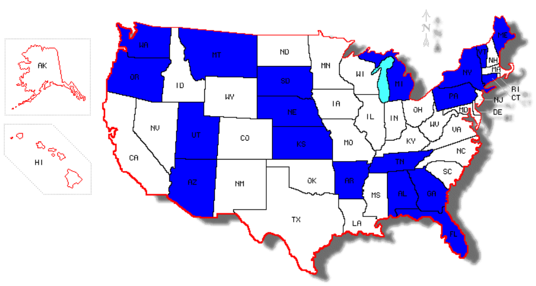


FIGURE I
SURVEY PARTICIPATING STATES (highlighted in blue).

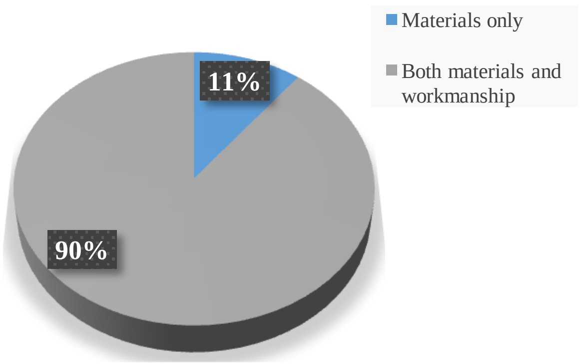


FIGURE II
SHA METHOD OF PERFORMANCE MEASUREMENT

both performance of workmanship and materials (Figure II). About 10% of the agencies measure the performance of materials only.

B. State Highway Agencies' Typical Acceptance Testing

To ensure quality, SHAs conduct different types of tests for materials and finished products. These tests again vary based on construction type and also from state to state. The study identifies five different types of materials and construction and the typical tests performed for acceptance of the work. They are:

1. Hot Mix Asphalt
2. Portland Cement Concrete Pavement
3. Structural Concrete
4. Subgrade/Embankment
5. Aggregate Bases and Subbases

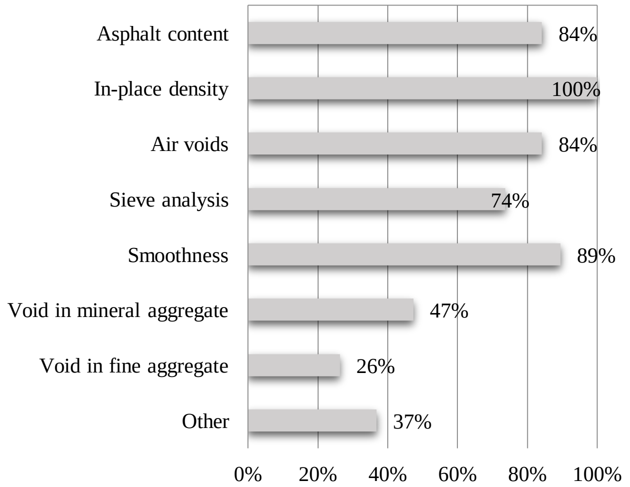
The following section summarizes typical acceptance tests conducted by SHAs for the above mentioned types of materials and construction.

1. Hot Mix Asphalt (HMA)

The survey requested the state highway agencies to respond about typical acceptance tests performed to measure the condition of placed HMA relative to acceptable standards/specifications. The survey found that SHAs use a wide variety of tests for acceptance. As shown in Figure III, the in-place density test is conducted by all SHAs. About 89% of SHAs test the finished surface of HMA for smoothness. Asphalt content and air void testing are also frequently used QA tests for HMA. Other QA tests for HMA are void in mineral aggregate and void in fine aggregate, sieve analysis, and binder content.

2. Portland Cement Concrete Pavement (PCCP)

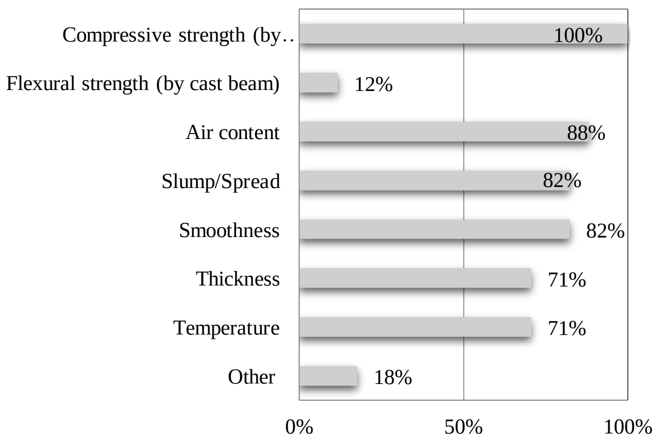
The SHAs were also asked about typical acceptance tests regarding PCCP. All SHAs use the compressive strength by cylinder test for acceptance, 88% utilize the air content test, and 82% utilize slump/spread and Smoothness



Other Tests
Aggregate Durability, Tensile Strength Ratio, Moisture Content, RAP, Joint Compaction, Dust/Asphalt Ratio, Hamburg and indirect tensile testing, #200 Sieve Material Content, AC and Density for Pay

FIGURE III
TYPICAL ACCEPTANCE TESTS CONDUCTED BY SHA FOR HOT MIX ASPHALT

tests (Figure IV). About 71% utilize thickness and temperature tests, and only 12% utilize the flexural strength (by cast beam) test.



Other Tests
Water/Cement Ratio Flexural Strength

FIGURE IV
TYPICAL ACCEPTANCE TESTS CONDUCTED BY SHA FOR PORTLAND CEMENT CONCRETE PAVEMENT

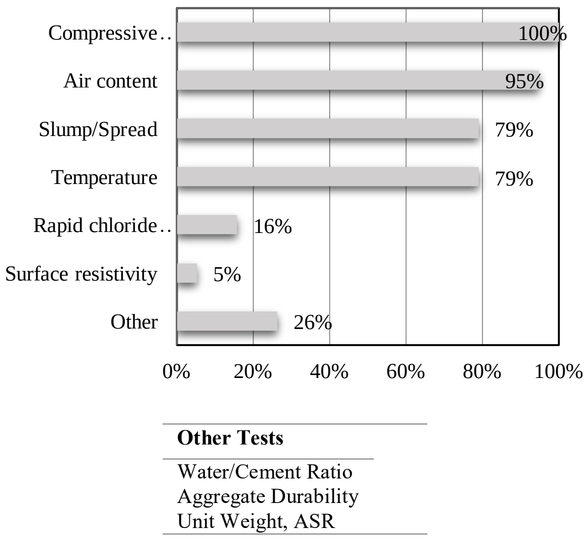


FIGURE V
TYPICAL ACCEPTANCE TESTS CONDUCTED BY SHA FOR STRUCTURAL CONCRETE

3. Structural Concrete

There are several acceptance tests that are used by the SHAs for structural concrete. As shown in Figure V, like PCCP, the compressive strength test by cylinder is used by all SHAs. About 95% of SHAs utilize the air content test, and 79% utilize the slump/spread test and the temperature test. The rapid chloride permeability test (16%) and the surface resistivity test (5%) are used less frequently to ensure quality of structural concrete.

4. Subgrade/Embankment

The SHAs were asked about typical acceptance tests associated with subgrade/embankments. As shown in Figure VI, the in-place density testing is conducted by100% of all SHAs. About 79% utilize the in-place moisture content test. 11% responded “other,” which included deflection testing and soil classifications.

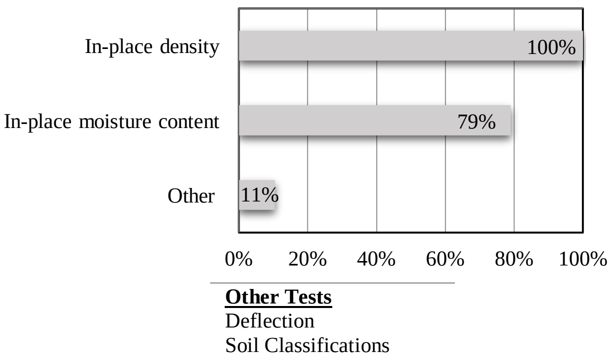


FIGURE VI
TYPICAL ACCEPTANCE TESTS CONDUCTED BY SHA FOR SUBGRADE/EMBANKMENT

5. Aggregate Base and Subbase

Typical acceptance tests conducted by SHAs for aggregate base/subbase include gradation (100%), in-place density (95%), and in-place moisture content (68%) (Figure VII). About 11% of SHAs conduct other tests that include deflection, durability test, and the LA abrasion test.

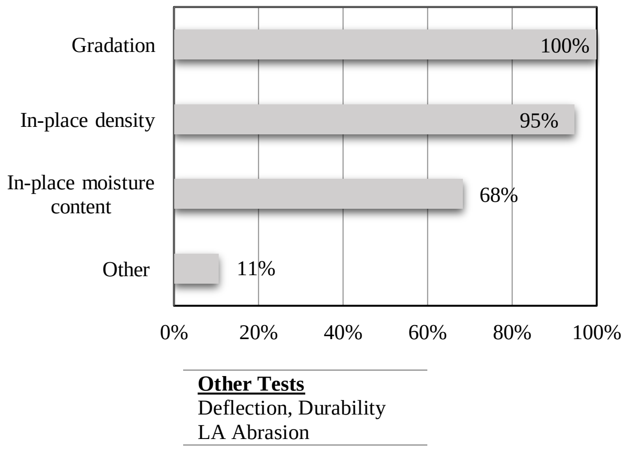


FIGURE VII
TYPICAL ACCEPTANCE TESTS CONDUCTED BY SHA FOR AGGREGATE BASE/SUBBASE

As evident, SHAs use different acceptance testing to ensure appropriate quality of the finished construction material. Testing cost of these quality characteristics comprise bulk of the cost of quality and as such provide an area of opportunity for cost saving.

C. Failure Statistics in Acceptance Test Results

A failure in acceptance test for highway construction is determined when the test results do not meet the specification limit for the test. For example, if a job mix formula requires an asphalt content of 4%±1% (Lower Limit = 3% and Upper Limit = 5%), but tests show less than 3% or more than 5% asphalt content, then it will constitute a failure according to the acceptance test, and re-working of the material related to the test is warranted until a pass is achieved. The following section summarizes failure statistics for acceptance tests for the previously mentioned five different types of materials and construction.

1. Hot Mix Asphalt (HMA)

The SHAs were asked to record the estimated percentage of acceptance tests failing to meet the specifications for HMA. As shown in Table I, for the asphalt content, 80% responded that failures occurred only 1%-2% of the time; 20% responded the failures occurred 2% - 10% of the time. Most states responded that in place density and air voids tests most frequently fail to meet the specifications (>2% failure frequencies), while remaining tests have less frequent failure rates (0 to 2%).

2. Portland Cement Concrete Pavement (PCCP)

Failure to meet specification limits also occurred in PCCP acceptance testing. About 64% of SHAs reported that the air content test failed more frequently (>2% failure frequencies). Acceptance tests that meet specification limits more frequently are compressive strength, flexural strength, slump, and temperature (Table I).

3. Structural Concrete

Structural concrete's acceptance tests show a similar pattern for failures to meet specification limits as PCCP. As shown in Table I, most SHAs reported that the air content test and the slump test more frequently fail to meet specifications (>2% failure frequencies), while remaining tests often meet specifications (0 to 2% failure rate).

4. Subgrade/Embankment

Failure to meet specification requirements are also found during testing for subgrade/embankment. Due to uncertainty in soil conditions, a high percent of SHAs reported frequent failure of acceptance tests related to subgrade/embankment. The in-place density and in-place moisture content test fail to meet specifications more frequently (i.e. >2% failure rates) as reported by 56% and 53% of SHAs respectively (Table I). About 17% of SHAs reported more than a 10% failure rate for dynamic/stiffness measurement.

5. Aggregate Base/Subbase

Just like subgrade/embankment, in-place density and in-place moisture content for aggregate base/subbase have high failure rates. About 53% and 50% of SHAs reported more than 2% failure rates for in-place density and in-place moisture content respectively (Table I). Other tests meet specifications more frequently.

Based on all the tests that are conducted as part of QA acceptance tests, on average, only 5% of SHAs reported that acceptance tests fail to meet specification limits more than 10% time. This implies that out of 10 tests performed, 9 tests meet specification limits. This means that SHAs' QA standards, specifications, and sampling plans are effective and stringent. The survey found that many tests have a significantly higher success rate (>98%). This offers SHAs an opportunity to optimize specifications and sampling plans for such tests with either limiting sampling frequencies or increasing lot size for acceptance testing.

TABLE I
SHA FAILURES OBSERVED IN TEST RESULTS FOR DIFFERENT CONSTRUCTION TYPES/ MATERIALS

Construction/ Material	**Quality Characteristics**	**Failure Frequencies**			
		Never	1% to 2%	More than 2% to 10%	More than 10%
HMA	Asphalt content	0%	80%	20%	0%
	In-place density	0%	38%	56%	6%
	Air voids	5%	44%	45%	6%
	Sieve analysis	6%	80%	7%	7%
	Smoothness	7%	50%	36%	7%
	Void in mineral aggregate	25%	42%	25%	8%
	Void in fine aggregate	30%	70%	0%	0%
PCCP	Compressive strength (by core)	20%	60%	13%	7%
	Flexural strength (by cast beam)	88%	12%	0%	0%
	Air content	6%	40%	47%	7%
	Slump/Spread	26%	47%	27%	0%
	Temperature	21%	71%	8%	0%
Structural Concrete	Compressive strength (by cast cylinder)	6%	67%	28%	0%
	Air content	0%	41%	53%	6%
	Slump/Spread	19%	38%	44%	0%
	Temperature	13%	75%	6%	6%
	Rapid chloride permeability	60%	30%	10%	0%
Embankments/ Subgrade	In-place density	11%	33%	39%	17%
	In-place moisture content	15%	31%	38%	15%
	Dynamic/Stiffness Measurement	67%	17%	0%	17%
Aggregate Base/Subbase	In-place density	12%	35%	35%	18%
	In-place moisture content	0%	50%	42%	8%
	Los Angeles abrasion loss	46%	38%	15%	0%
	Organic impurities (fine aggregate)	33%	58%	8%	0%
	Deleterious material	38%	62%	0%	0%

D. Optimization of Acceptance Sampling and Testing Plan

Most SHAs have developed QA sampling and testing plans for systematic and consistent testing of materials and finished products. SHAs consider many factors when deciding QA sampling and testing plans, however, three factors are typically considered by many SHAs. They are cost (cost of sampling and testing), risk (agency's and contractor's risk related to acceptance plan, also referred as α and β risk), and importance (effects on overall construction project). There are benefits of optimizing sampling and testing plans for cost, risk, and importance. For high importance jobs where safety is a bigger factor, such as bridges, importance is the dominant factor for optimization. However, in lower importance jobs, the agencies can look more at the cost and not as much at the risk. As shown in Figure VIII, 42% of the agencies responded that their sampling and testing plan is optimized for all of the factors: cost, risk, and importance. About 78% of the responding agencies considered either risk or importance for optimizing their sampling and testing plans. Surprisingly, cost was not as significant of a factor as importance and risk, since 42% responded that their sampling plans are optimized for cost, while 58% do not optimized their plans for cost (Figure VIII). It can be recommended that SHAs who have not optimized their sampling and testing plans for cost, risk, and importance should consider optimizing their sampling and testing plans. This would be an opportunity to reduce costs and improve efficiency in QA practices.

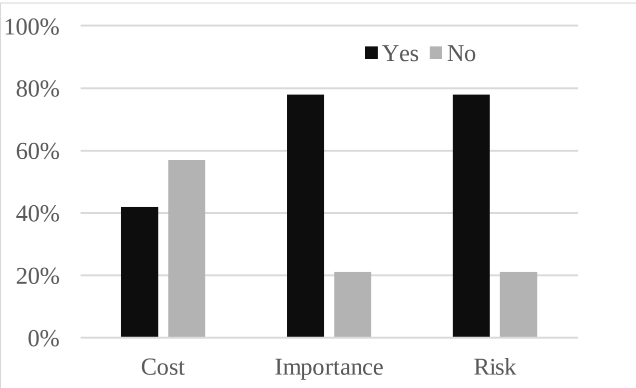
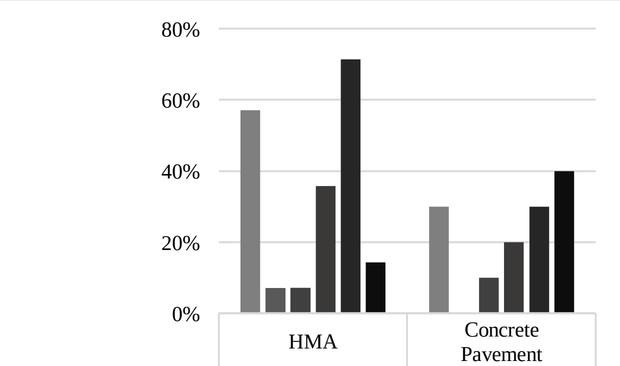


FIGURE VIII
OPTIMIZATION OF MATERIAL SAMPLING AND TESTING PLAN FOR COST, IMPORTANCE, AND RISK

E. Quality Assurance Measures for Acceptance Sampling and Testing

There are several quality assurance measures that are typically used by SHAs for material and construction acceptance. These include: percent within limit (PWL), average absolute deviation (AAD), mean, statistical F&T test, and split sample comparison. Even though FHWA recommends PWL as the quality measures to be used, other measures are still in use according to the survey. For HMA, 57% of SHAs use PWL, 36% use statistical F&T test to estimate that the SHAs' tests and the contractor's tests are from the same population and the variability and mean of the two data sets are equal, and 71% use split sampling, which provides a check on testing equipment and procedures (Figure IX). For concrete pavement, 30 % of SHAs utilize PWL, 20% use statistical F&T test, and 30% use split sampling. It needs to be mentioned that most SHAs use a combination of the above mentioned quality assurance measures for sampling and testing. However, few SHAs mentioned that they don't use any statistical method for verification test results with the contractor's test results. It is necessary to measure both the center and spread when characterizing lot material. PWL quality measure uses the mean and standard deviation to measure center and spread and then estimate the percentage of the lot that is within the specification limits. Other quality measures have limitations. For example, AAD often encourages the



	HMA	Concrete Pavement
PWL Quality Measure	57%	30%
AAD	7%	0%
Mean	7%	10%
Statistical F & T	36%	20%
Split sample test results compared	71%	30%
No statistical verification performed	14%	40%

FIGURE IX
FREQUENCY OF SHAS VERIFICATION OF CONTRACTOR PERFORMED QUALITY ASSURANCE TESTING FOR MATERIAL ACCEPTANCE SAMPLING AND TESTING.

contractor to manipulate its process during the production of a lot in order to get the average of the test results to be at or near the target value. Split samples estimate only testing variability and can be biased if not independently obtained by SHAs or a third party. Therefore, such measures may result in acceptance of poor quality construction which may deem costly in future maintenance and rehabilitation. Implementation of PWL is the recommended cost-effective practice.

F. Quality Assurance Verification Practices

There are several methods that are used by SHAs for QA verification. They are contractor quality control sampling & testing (verified by qualified testing personnel employed by the SHAs or its designated agent, excluding the contractor and vendor), independent assurance (IA) procedures (activities that are an unbiased and independent evaluation of all the sampling and testing procedures used in the acceptance program – all agencies are required to perform IA), testing certification practices, and regional, district or divisional lab practices, etc. As shown in Figure X, the survey found that, for HMA, 43% of SHAs responded the contractor and vendor), independent assurance (IA) procedures (activities that are an unbiased and independent evaluation of all the sampling and testing procedures used in the acceptance program – all agencies are required to perform IA), testing certification practices, and regional, district or divisional lab practices, etc. As shown in Figure X, the survey found that, for HMA, 43% of SHAs responded that they utilize regional, district, or divisional labs for verification testing; 14% utilize testing certification practices, 14% utilize IA procedures, and 29% utilize contractor quality control sampling and testing. For PCCP, 33% responded that they utilize regional, district, or divisional labs for verification testing, 17% utilize testing certification practices, 17% utilize IA procedures, and 33% utilize contractor quality control sampling and testing.

G. Use of Innovative Quality Assurance Test Methods

With advancements in technology come an opportunity for developing and implementing innovative quality assurance practices. In particular, quality assurance related tools and equipment are now more efficient and accurate as a result of technology improvement. As a result, many SHAs are currently using or exploring innovative testing methods (that are quick and nondestructive) that significantly reduce the cost, save time or produce more accurate results. About 58% of SHAs responded that they use innovative quality assurance test methods to reduce cost, save time, or produce more accurate results (Table II). Some of the innovate methods that SHAs are currently using or exploring for HMA are ignition oven for asphalt content, intelligent compaction, nuclear gauge and electric density gauge for in-place density, and line laser for smoothness. For PCCP, three agencies responded utilizing the maturity test for compressive strength for possible cost and time savings. For the air content test, the use of super air meters yield faster results and measures both the air void spacing and air content of fresh concrete in about 10 minutes. Air void spacing is a better indicator of concrete freeze-thaw durability than total air content. One agency is utilizing plastic air content and hardened air content to yield more accurate results (Table II).

H. Review of Quality Assurance Practices and Procedures

Quality assurance practices are evolving. Technological innovation, new tools and techniques, better knowledge about construction materials and finished materials, better means and methods of construction, more insight between quality assurance and construction performance, etc. are significantly impacting quality assurance practices and procedures. Only by continuously reviewing quality assurance practices, procedures, and manuals, SHAs can keep up with the latest trend which can open up new opportunities for cost and time savings. On average, 34% of SHAs responded that they annually review quality assurance practices and procedures for: sampling frequency, acceptance limits, workmanship standards, and prescriptive work practices (Figure XI). About 44% of SHAs review acceptance limits annually, while only 18% of SHAs review workmanship standards annually. Most SHAs (65%) responded that their review frequencies vary and are typically conducted on an as needed basis. Failure to review QA practices routinely can be deemed as a wasted opportunity as new technologies can be introduced which may conduct rapid data collection making old practice wasteful. It can be recommended to SHAs to review the QA practices and procedures at least annually. This would allow the state highway agencies to stay up to date with any new and innovative tools, testing methods and technology which may improve the effectiveness of QA practices and procedures.

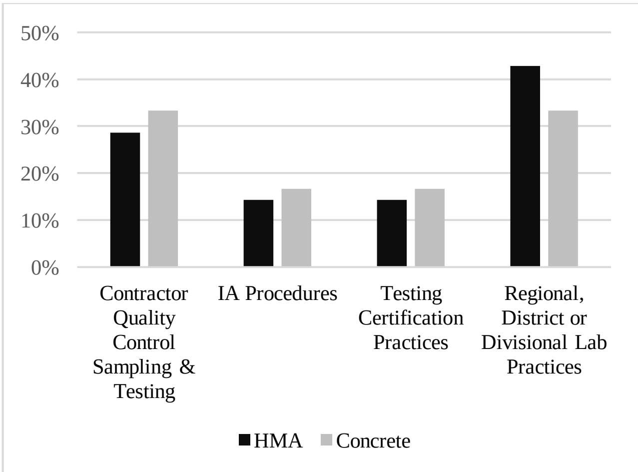


FIGURE X
QUALITY ASSURANCE VERIFICATION PRACTICES FOR HMA AND PCCP

TABLE II

SHAS' USE OR EXPLORATION OF INNOVATIVE TESTING METHODS THAT REDUCE COST, SAVE TIME, OR PRODUCE MORE ACCURATE RESULTS

HMA	PCCP
Asphalt Content: Ignition oven Using daily recordation of asphalt plants to verify AC	**Compressive strength (by core):** Maturity Test
In-Place Density: One point proctor, Intelligent compaction, Nuclear Gauge Ground penetrating radar Electric Density Gauge	**Flexural strength (by cast beam):** Use of maturing testing for opening to traffic time and concrete repair mixes
Smoothness: Line Laser Using IRI on John Deere Gators	**Air Content:** Super Air Meter (SAM) Plastic air content and Hardened Air Content

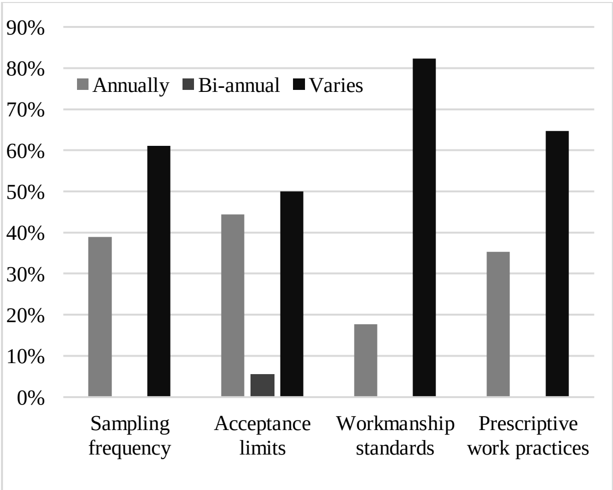


FIGURE XI
FREQUENCY OF REVIEWING SHAS' QA PRACTICES AND PROCEDURES

I. SHAs' Implementation of Innovative Quality acceptance Processes

Many industries are facing rising costs of doing business. In order to combat this problem, many organizations have implemented innovative processes, such as lean six sigma, just in time, etc. These streamlining processes have resulted in products or services that are completed faster and more efficiently with minimum waste and defects at no costs to quality. SHAs were requested to identify if there are any innovative QA acceptance processes they are utilizing that can reduce costs. As shown in Figure XII, most SHAs have not explored or implemented such processes. Only a few SHAs have implemented requirement verification, quality check points, intelligent compaction, and 3D design modeling processes for a limited number of projects.

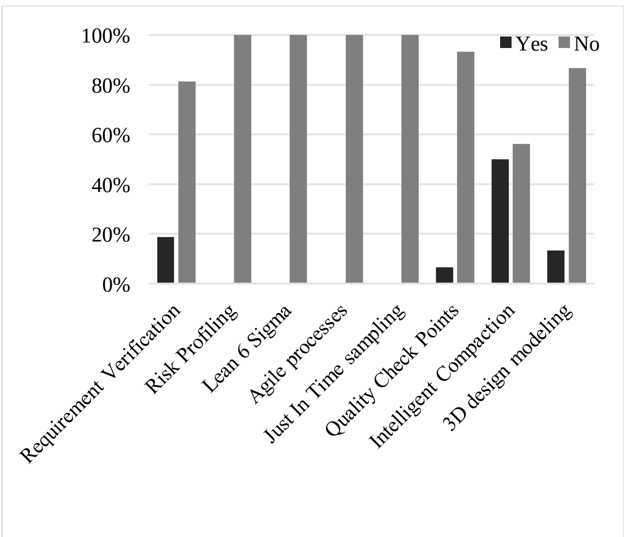


FIGURE XII
SHAS IMPLEMENTATION OF INNOVATIVE ACCEPTANCE APPROACHES.

V. CONCLUSIONS

The US highway system serves as the backbone of the country's economy. However, SHAs are constantly under pressure to do more work with less money. Because of the budget constraints, it is important to identify opportunities available within the agencies that could save costs. The cost of quality (both conforming and nonconforming) and quality related activities can be significant. There is a real value in identifying, sharing, and implementing cost effective QA best practices and procedures among SHAs. A national electronic survey collected data that provided a detail mapping of various QA practices and processes used as part of QA program and identified areas where agencies can focus for cost savings. The main findings of the survey are as follows:

- Measurement of the performance of both material and workmanship is the best practice for ensuring quality of the construction.
- The survey found that for many acceptance tests, more than 98% of tests meet specification limits. For such tests, there is an opportunity to optimize sampling and testing plans and related specifications and standards.
- Even though many SHAs reported that their QA sampling and testing plans are optimized for cost, risk or importance, only few SHAs considered all three factors. About 58% of SHAs reported that cost was not considered as a factor for optimization of sampling and testing plans. A sampling and testing plan that is optimized for cost, risk, and importance will not only be efficient but cost-effective as well.
- Percent Within Limit (PWL) is the recommended quality measure.
- Use of innovative test methods, such as intelligent compaction, electronic density gauge, line laser for HMA and maturity test and super air meter for concrete are rapid and cost effective.
- Implementation of quality acceptance processes such as lean six sigma, quality verification, and 3D design modeling can save cost and time.

There are several limitations to this study. Only 19 agencies responded the survey, and the results are based on this small sample size. The survey information provided by the SHAs are opinion-based and may not be data-driven. Therefore, future studies will focus on the SHAs' actual acceptance data analysis and implementation of cost effective measures and quantities analysis of their cost effectiveness.

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