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Cost Effective Quality Assurance Practices in Highway Construction

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A thesis

presented to

the faculty of the Department of Business and Technology

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Master of Science in Technology with a concentration in Engineering Technology

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by

James Matthew Newland

August 2015

Dr. Moin Uddin, Chair

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Mr. Mark Jee

Keywords: Quality Assurance, highway construction, cost effectiveness

ABSTRACT

Cost Effective Quality Assurance Practices in Highway Construction

by

James Matthew Newland

The estimated value of the U.S. transportation infrastructure is over $7.0 trillion. The challenge is preserving the quality of the investment. State and federal departments of transportation have methods and procedures for best quality, but vary significantly. With the variations comes opportunity to assess the cost-effectiveness of different strategies and make recommendation on practices that are most successful.

A survey was created and sent to all 50 states and the District of Columbia. The survey was aimed to capture information on construction finished product testing methods, optimized/reduced sampling techniques, innovative QA practices that measure multiple performance criteria and QA processes that are rapid and cost effective.

There are many testing methods and procedures being used throughout the U.S. This thesis will allow state and federal transportation agencies to look at the findings and possibly implement them into their own agency with hopes of saving time and money for future projects.

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CHAPTER 1

INTRODUCTION

Highway quality is all about achieving the shared goal of building, preserving, and maintaining better roadways. As we move forward into the future, we are faced with many challenges such as traffic growth with increased congestion on the roadways, freight management, and environmental concerns. Along with these concerns, transportation agencies are dealing with shrinking budgets and limited work forces as well as a highway system with a failing infrastructure. Because of these factors, the attention to quality is very important. All of these issues will require significant attention to ensure that we get the highest performance possible from our future highway projects (US DOT, 2007).

Quality cannot be achieved in one step, but it is a process that includes everything from planning to the final product. Quality does not always mean the same to everyone. We may see quality as an approved design or construction standard while the public see it as less congestion and safer roadways. The quality is the end result that adds value to everything else.

Transportation infrastructure plays a critical part in supporting the nation's economy and the construction industry plays a key role in building, maintaining, and improving the system. Highway construction is a huge infrastructure development and improvement effort by state and federal government where nearly $160 billion dollars is spent annually nationwide (US DOT, 2012). With the business being so big, it is important to stay innovative. The important benefits of quality assurance can result in significant savings in time and cost while making the roads safer and more user friendly. The industry is undergoing several changes to improve the process from concept to finished product. All of these changes cost a significant amount of money up front, but have the potential for big savings in the future. Many of these changes began in the 1980's. Prior to that, contractors were not held to a standard that they are today. In the 1980's, the Federal Highway Administration starting requiring contractor to add a warranty to their work. The upfront bids were higher, but the end result saved money by making them accountable for the work performed. There have also been changes in the bid process. Many projects are completed using the Design-Build method. This has proven to save time and money in the long run. There are also other measures to determine if the contractor is appropriate to complete the job. Many departments of transportations require pre-requisites before the contract will be awarded to them (Hancher, 2014).New innovations in highway construction are continuing to be implemented and used across the country. There will continue to be a demand for enhanced technologies in equipment, materials, and designs. These new innovations will be supported by the departments of transportation in hopes to improve the overall process in the future

Quality and safety are two of the most important topics to a project manager. Defects and failures can result in the cost and timeline of a project to be negatively affected. In the worst case, failures can cause personal injuries or even deaths. This can cause the cost of the project to increase tremendously. A good project manager ensures the job is done right the first time and done safely. Safety is often influenced by the design of the project. Some designs may increase the risk of injury while others may decrease the risk. It is also important to ensure the workers are alert and aware of their surroundings at all times while working in highway construction. While eliminating accidents is the ultimate goal, it will never be obtained. The job site is constantly changing as the work progresses, and the workers are not always at the same work stations. However, safety will always be a priority in highway construction and does affect the overall cost of a project (pmbook.ce.cmu, n.d.).

Quality Assurance Specifications and Practices

Traditionally, contractors are responsible for their quality control, and state departments (DOTs) are responsible for acceptance and independent assurance. With changes in federal regulations, the roles of the two are somewhat unclear. Under the new rules, the contractor can perform their own quality tests. Issues may arise when this is the case. Many times, the DOT will perform a test and compare it to the contractors to determine if the results are within the acceptance limit.

According to a study by Harrigan, many tests were ran and compared between the contractor's results and the state highway agency results. The results found that the contractor's quality tests were much stricter than that of the DOT. While there is no real push to use contractor quality tests at this time, it may be an opportunity for DOTs to save time and money on the overall construction project (Harrigan, 2007).

So, why do we need quality? Quality is a perceptual, conditional, and somewhat subjective attribute and may be understood differently by different people. We as consumers tend to focus on the quality of a product or service or how it compares to its competitor in the marketplace. In construction, we measure the conformance quality or degree to which the product or service was produced correctly. A quality item or product has the ability to perform satisfactorily in service and is suitable for its intended purpose.

In highway construction quality is very important. It is fundamental in meeting the federal highway administrations objectives. Quality highway construction improves system performance, reduces congestion on the highways, improves safety, and improves economic efficiency of our highway investments. For the final product to be of quality, it should meet all the scope and commitment requirements. It must be delivered on time and within budget, and it must be done in a safe manner.

There are many dilemmas that jeopardize a quality product in highway construction. The number one problem is the lack of funding from state agencies. State budgets have been cut in recent years, leaving roads not being maintained at a level necessary to keep them in quality condition. With budgets being cut, full time employees have also been cut. This has decreased the work force leaving them shorthanded and not being able to perform the work they once did. There is also a lot more congestion on the highways causing them to wear faster than expected. With the congestion comes a frustrated public that use the roads daily. Because of all of these issues, completing a quality product is more important than ever. With advancements in technology in machinery and processes, the highway agencies are starting to produce more quality highways. While all the problems exist, the highway administration is still responsible in making sure the product is of high quality (FHWA, 2013).

Problem Statement: How Do We Identify Quality in Highway Construction?

Quality can be identified in highway construction in a number of different ways. There are several tests and measurements used by both the highway agency and the contractors that ensure the product is of quality and meet the specifications of the project. One of the best methods to identify quality in highway construction is the use of quality assurance specifications. Quality assurance specifications require contractor quality control and agency acceptance activities throughout production and placement of the product. Final acceptance of the product is usually based on statistical sampling of the measured quality level. Quality assurance specifications clearly lay out responsibilities for both the contractor and the receiving agency.

The specifications include: variability of the materials, assign quality control sampling, testing, and inspection to the contractor, include acceptance sampling, testing, and inspection by the agency, identify the specific items to be measured, and provide price adjustments related to the quality level of the product.

Quality assurance specifications are practical and realistic because they both provide a rational means for achieving the highest overall quality of the material or construction. The contactor is responsible for quality control while the agency is responsible for accepting the product. This puts more responsible on the contractor to produce a quality job (FHWA, Construction, 2013).

Highway construction is very important to our society. The highways give us a way to connect throughout the country. The highways are traveled daily by millions of Americans. Many of the highways have been in place for many years and are beginning to fail. They are failing not because of poor quality per say, but due to their age and lack of maintenance. An increase in the use and lack of highway workers are somewhat of the problems. Highways are being repaired and reconstructed daily across the country to keep up with the growing use they receive. Because of this, it is more important than ever to make certain that the new work is of a high quality.

Objectives of the Study

The objective of this thesis is to identify the current state of testing methods and to determine if there are more cost effective methods available. There are four main objectives associated with this thesis: (1) to identify and share construction finished product testing methods (preferably nondestructive) that are more accurate but cost effective; (2) identify and share optimized or reduced sampling techniques; (3) identify and share innovative quality assurance practices that measure multiple performance criteria of the finished product; and (4) identify and share quality assurance processes that are rapid and cost effective.

Thesis Organization

The thesis is divided into four chapters. Chapter one contains the introduction, problem statement, and objective of the study. Chapter two is a literature review and includes theories of non-normal distribution. The literature review draws upon national and local studies conducted by the Federal Highway Administration, state highway agencies, and other research organizations. Chapter three contains a detail of the results of the survey that depicts potential cost savings in highway construction. Chapter four concludes the thesis with detail research outcomes, the expected contributions to the research and industry, and recommendations for future research. Appendix A contains the survey that was created and sent to the SHA's.

CHAPTER 2

LITERATURE REVIEW AND METHODS

State highway agencies are faced with challenging and expensive projects. Because of this, it is very important that the work is completed per the specifications laid out by the agencies, completed in a timely manner, and within budget. This can be achieved under the watch of the state highway agencies through various testing methods. This thesis aims to identify any cost saving opportunities through quality assurance practices.

Literature Review

Safe and efficient transportation infrastructure is a major part of economic growth. There are many factors that indicate that the current highway network is not meeting America's current and future needs. The U.S. is at a disadvantage when considering the importance of infrastructure in transporting goods and people in the economy. State highway agencies are facing budget shortfalls every year and are asked to do more with less. Because of these factors, it is more important now than ever to ensure quality assurance programs are designed and utilized to ensure better quality highway infrastructures with limited resources.

According to the World Economic Forum, the U.S. ranks 18th in road quality, and 19th in overall infrastructure quality. In 1956, The Highway Trust Fund was established as a means to provide funding for highway construction. The majority of funding for projects comes from state and local agencies for highway projects, but he Highway Trust Fund is a major player in that they provide grants and other direct contributions for projects. The Trust Fund also provides credit assistance which allows the state to finance the project on better terms. However, the Trust Fund is facing a shortfall due to the imbalance of revenues and spending. Over the last 10 years, the Trust Fund has spent $52 billion more than they collected. Lawmakers have neglected to address the shortfall and have opted to transfer money from other governmental departments. These reallocations do not fix the problem, they only worsen it. The Trust Fund receives about 87% of its money from fuel surcharges or “gas tax”. This tax has not been increased since 1993. Taxes on heavy trucks make up the rest of the funding. Regardless of the funding source, safe and efficient highway infrastructures are a driver of economic growth. In order to create long term stability for the Trust Fund, lawmakers must reduce spending, increase revenue, or a combination of both (Foundation, 2015).

According to a report by the United State Department of Transportation, The U.S. transportation system is the largest in the world. It has more airports, miles of roadways and railways than any other country and is 4^{th} in the world for navigable waterways. These means of transportation connect the U.S. and provide economic growth both locally and globally. The estimated value of the U.S. transportation system in 2010 was just over $7.0 trillion (US DOT, 2012). Because the transportation infrastructure is such an enormous value to the U.S., it is more important now than ever to provide quality projects moving forward.

According to the Federal Highway Administration, quality assurance can be achieved through performance specifications. Performance specifications improve the performance of highways through better translation of design intent and requirements into construction specifications. The performance specifications can be used as a contract for highway construction. By providing the performance specifications, it sets a road map for the contractor to use throughout the construction process in hopes of improving quality assurance. The performance specifications provide what good specifications should look like. State highway agencies must evaluate and describe exactly what they want in a project. Because of this, there is a need for innovation and creativity that must include the contractors and suppliers. The processes will continue to change moving forward and it is important for the performance specifications to make changes along the way. If all parties are aware of what is going on the process will go much smoother (FHWA, 2004).

According to an article from Curtin University Library, project rework is a significant cost factor in highway construction. For example, rework has contributed to 52% of projects over-run cost. The rework was found to not be determined by the cost of the project, so it can happen to any project (Peter E.D. Love, 2014). Rework is necessary when the material does not meet the specifications provided by the state highway agency. With state highway agencies faced with budget deficits, it is important to cut costs when possible. One place may be in rework. If better testing methods are developed and put to use, the amount of rework could be reduced significantly. This would in turn save the stage highway agencies time and costs on projects.

Methods

An online survey was developed using SurveyMonkey with the guidance of the thesis committee and professionals from the Tennessee DOT. The survey was sent to all 50 states as well as the District of Columbia. The data was collected for six months. The data was analyzed throughout the collection period and the final analysis was completed in March 2015. The results of the survey are described in Chapter 3.

CHAPTER 3

RESULTS

The survey was designed to analyze the different Quality Assurance practices and their effectiveness to the state highway agencies.

The survey was sent out to all 50 states and the District of Columbia. A total of 19 state highway agencies completed the survey. The participants range from Assistant Systems Administrators to State Materials Engineers. The results are listed in tables and figures below.

State Highway Agencies Focus of Quality Assurance Practices

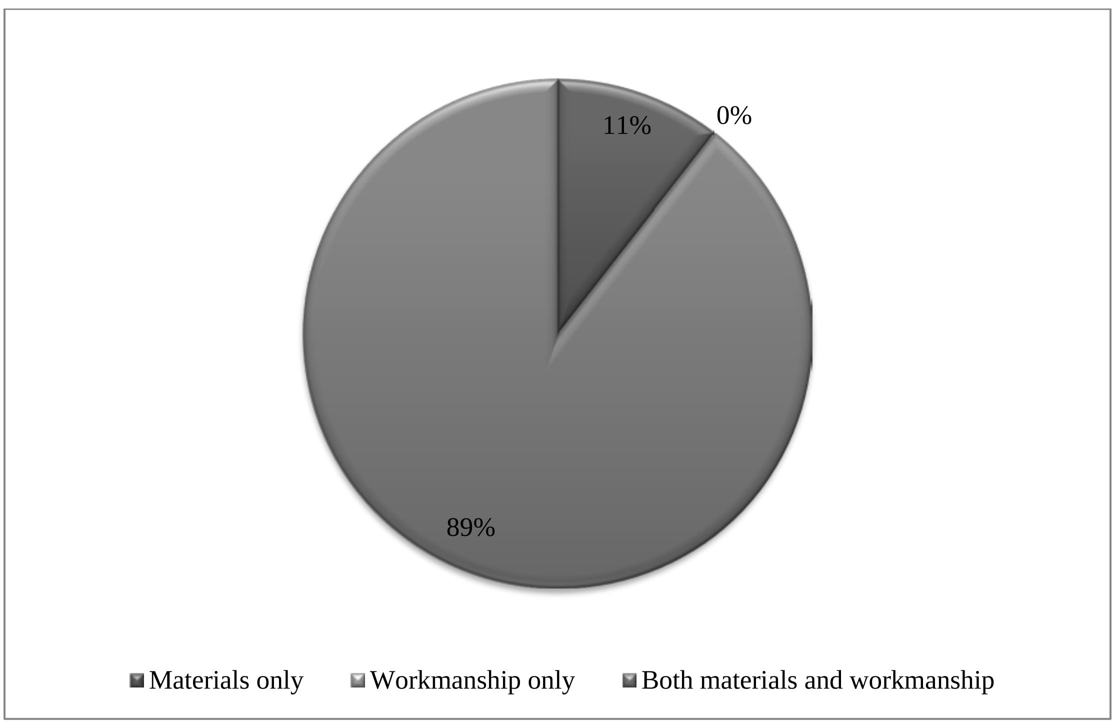


Figure 1: SHA Measurements of Performance of Workmanship and Materials

The state highway agencies were asked how they measure performance. As shown is Figure 1, about 89% measures both performance of workmanship and materials. About 11% of the agencies measure the performance of materials only. None of the responding agencies only measure the performance of workmanship.

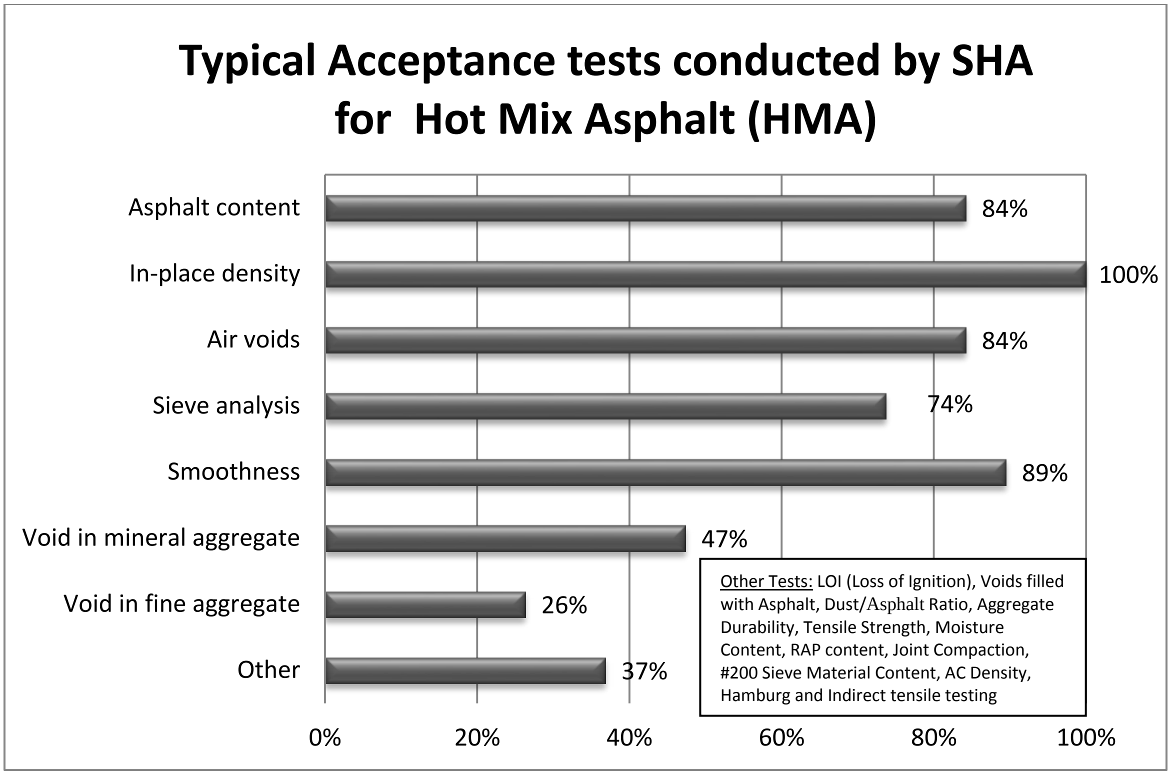


Figure 2: Typical Acceptance Tests Conducted by SHA for Hot Mix Asphalt

The survey requested the state highway agencies respond about typical acceptance tests that are conducted for hot mix asphalt. According to Figure 2, in-place density test is completed 100% of the time. Smoothness testing is completed 89% of the time. Asphalt content and air void testing is completed 84% of the time. Void in mineral aggregate and void in fine aggregate tests are used about half as much as the tests like asphalt content, in-place density, air voids, sieve analysis, and smoothness. The survey found that state highway agencies use a wide variety of tests to ensure the quality of HMA.

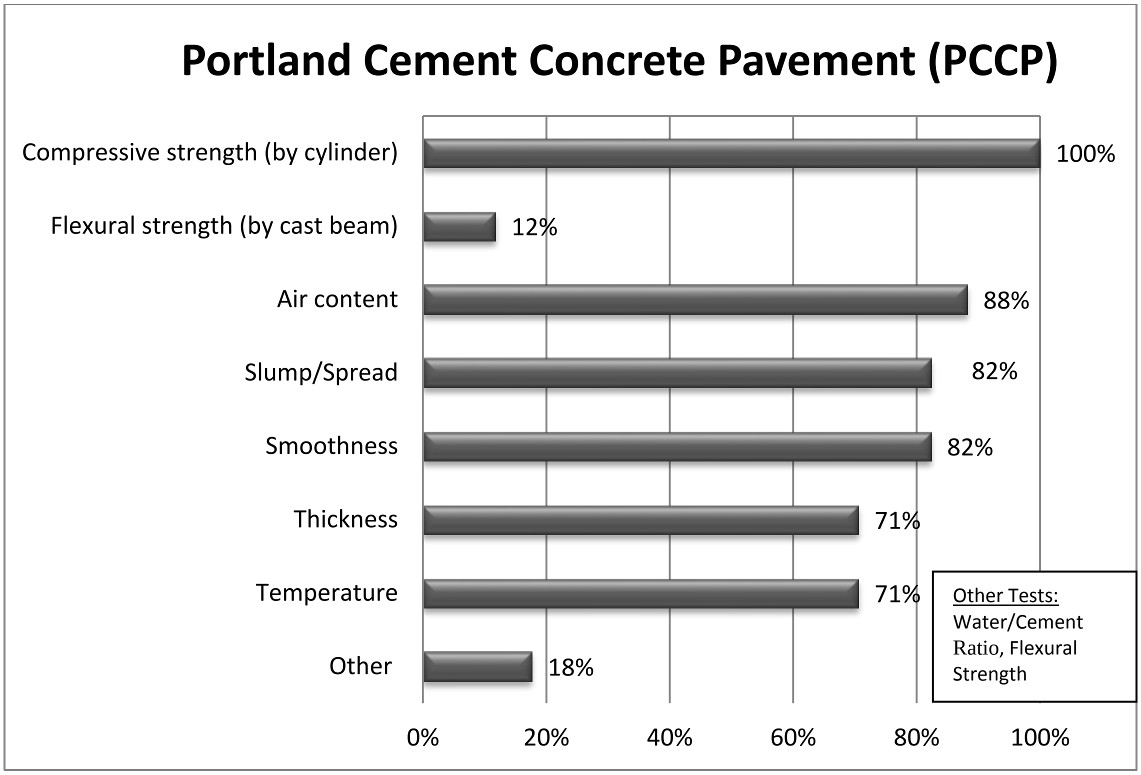


Figure 3: Typical Acceptance Tests Conducted by SHA for Portland Cement Concrete Pavement

The state highway agencies were also asked about typical acceptance tests regarding Portland cement concrete pavement (PCCP). As shown in Figure 3, 100% use the compressive strength by cylinder test for acceptance, 88% utilize the Air Content test, 82% utilize Slump/Spread and Smoothness tests.71% utilize Thickness and Temperature tests and only 12% utilize the flexural strength (by cast beam) test.

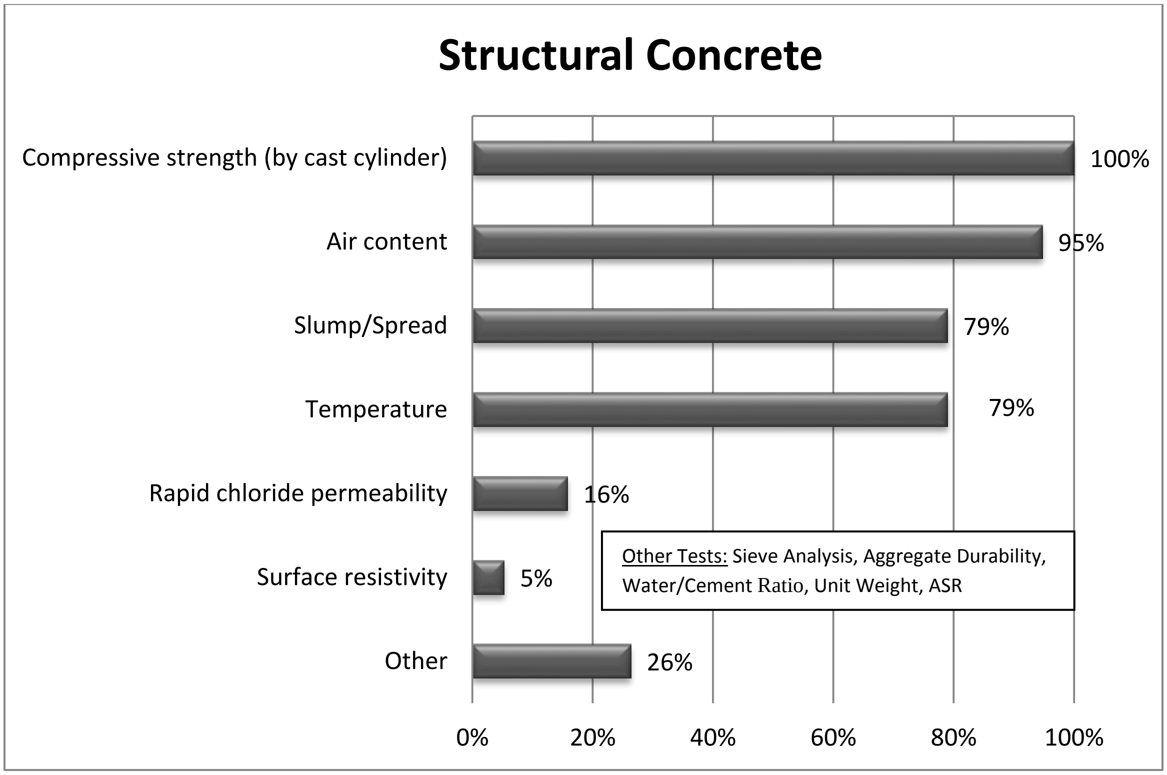


Figure 4: Typical Acceptance Tests Conducted by SHA for Structural Concrete

There are several acceptance tests that are used by the state highway agencies for structural concrete. As shown in Figure 4, like PCCP, the compressive strength test by cylinder is used 100% of the time. Air content test is utilized 95% of the time, slump / spread test, and temperature tests are utilized 79% of the time. These tests are utilized frequently for quality acceptance. However, the rapid chloride permeability test is only utilized 16% of the time and the surface resistivity test 5% of the time.

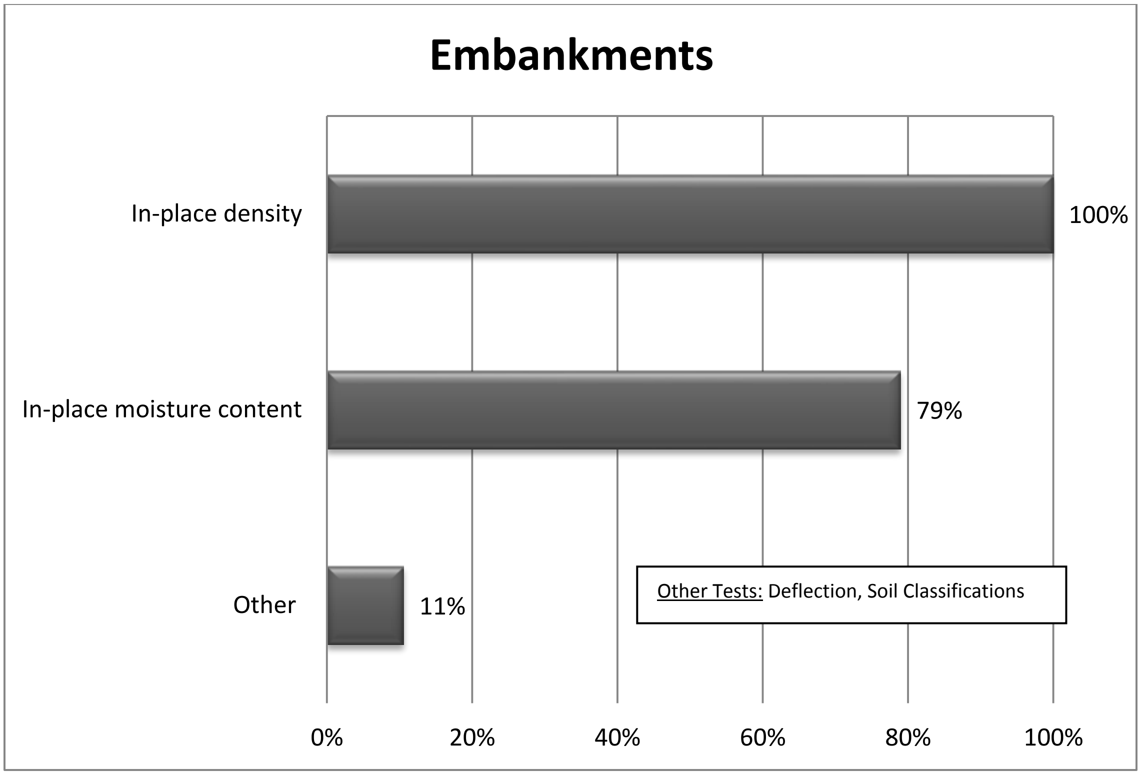


Figure 5: Typical Acceptance Tests Conducted by SHA for Embankments

The state agencies were asked about typical acceptance tests associated with embankments. According to Figure 5, In-place density testing is conducted 100% of the time. 79% utilize the in-place moisture content test. 11% responded “other” which included deflection testing and soil classifications.

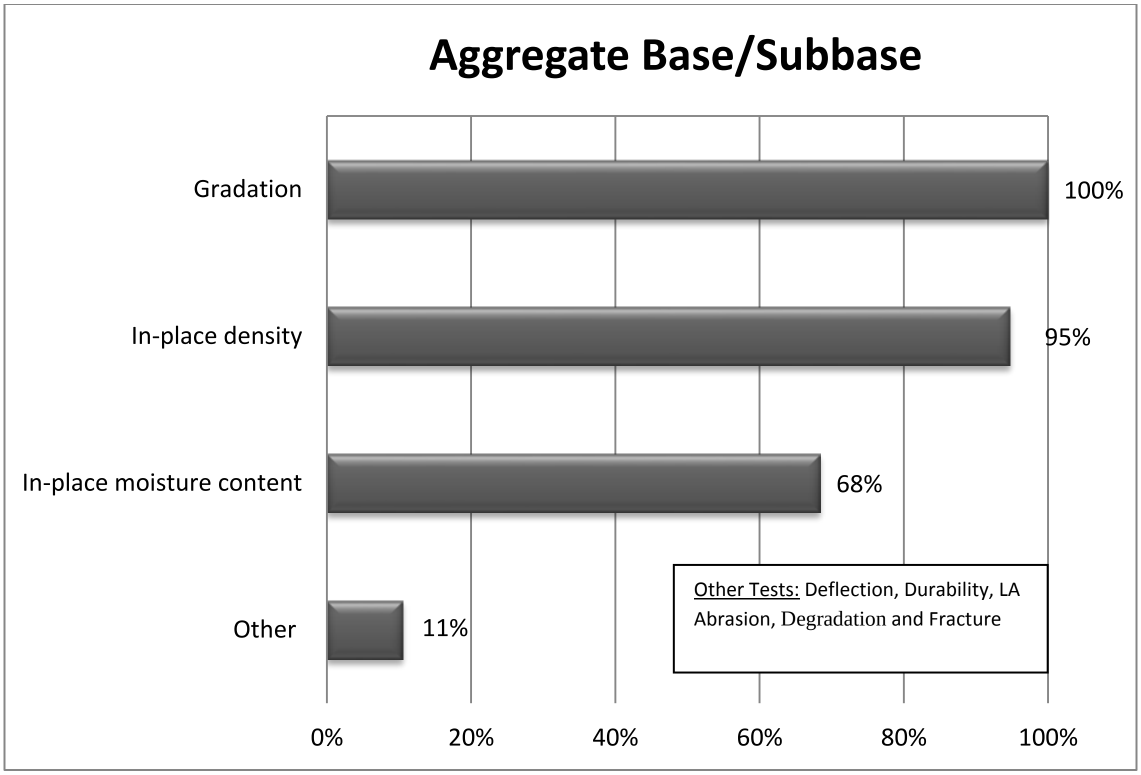


Figure 6: Typical Acceptance Tests Conducted by SHA for Aggregate Base/Sub base

Typical acceptance tests for aggregate base / sub base include gradation, in-place density, and in-place moisture content. The state highway agencies were asked which tests they typically utilize for acceptance of aggregate base / sub base. According to Figure 6, 100% utilize gradation acceptance test, 95% utilize in-place density, and 68% utilize in-place moisture content. 11% conduct other tests that include deflection, durability tests, and LA Abrasion tests.

Failure Statistics in Quality Assurance Test Results

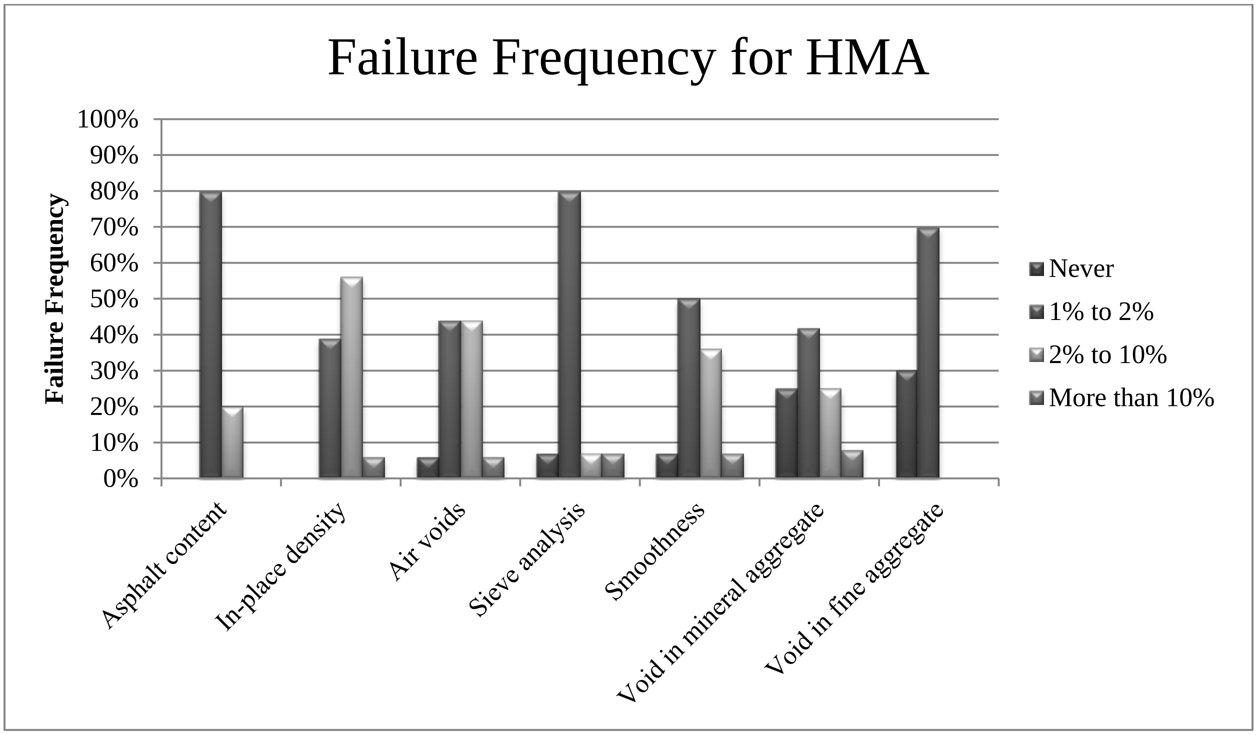


Figure 7: SHA Failures Observed in Test Results for Hot Mix Asphalt

A failure in QA for highway construction is determined when the test results do not meet the specification limit for the test. The state highway agencies were asked to record the percentage of the failures based on test results collected by the SHA for the different test methods used in hot mix asphalt. As shown in Figure 7, for the asphalt content test, 80% responded that failures occur 1%-2% of the time of use; 20% responded the failures occur 2% - 10% of the time of use. For the in-place density test, 39% responded the failures occur 1%-2% of the time of use; 56% responded failures occur 2%-10% of the time of use; and 6% responded failure occurs more than 10% of the time of use. For the air voids test, 6% responded they never have a failure; 44% responded failures occur 1%-2% of the time of use; 44% responded failures occur 2%-10% of the time of use; and 6% responded failures occur more than 10% of the time of use. For the sieve analysis test, 7% responded they never have a failure; 80% responded failures occur 1%-2% of the time of use; 7% responded failures occur 2%-10% of the time of use; and 7% responded failures occur more than 10% of the time of use. For the smoothness test, 7% responded they never have a failure; 50% responded failures occur 1%-2% of the time of use; 36% responded failures occur 2%-10% of the time of use; and 7% responded failures occur more than 10% of the time of use. For the void in mineral aggregate test, 25% responded they never have a failure; 42% responded failures occur 1%-2% of the time of use; 25% responded failures occur 2%-10% of the time of use; and 8% responded failure occur more than 10% of the time of use. For the void in fine aggregate test, 30% responded they never have a failure; and 70% responded failures occur 1%-2% of the time of use.

After carefully observing these results, it can be recommended to limit the amount of testing for void in mineral aggregate due to the low percentage of failures. It can also be recommended to eliminate the void in fine aggregate test due to low percentage of failures. By reducing and eliminating these two tests, the state highway agencies can save time and money.

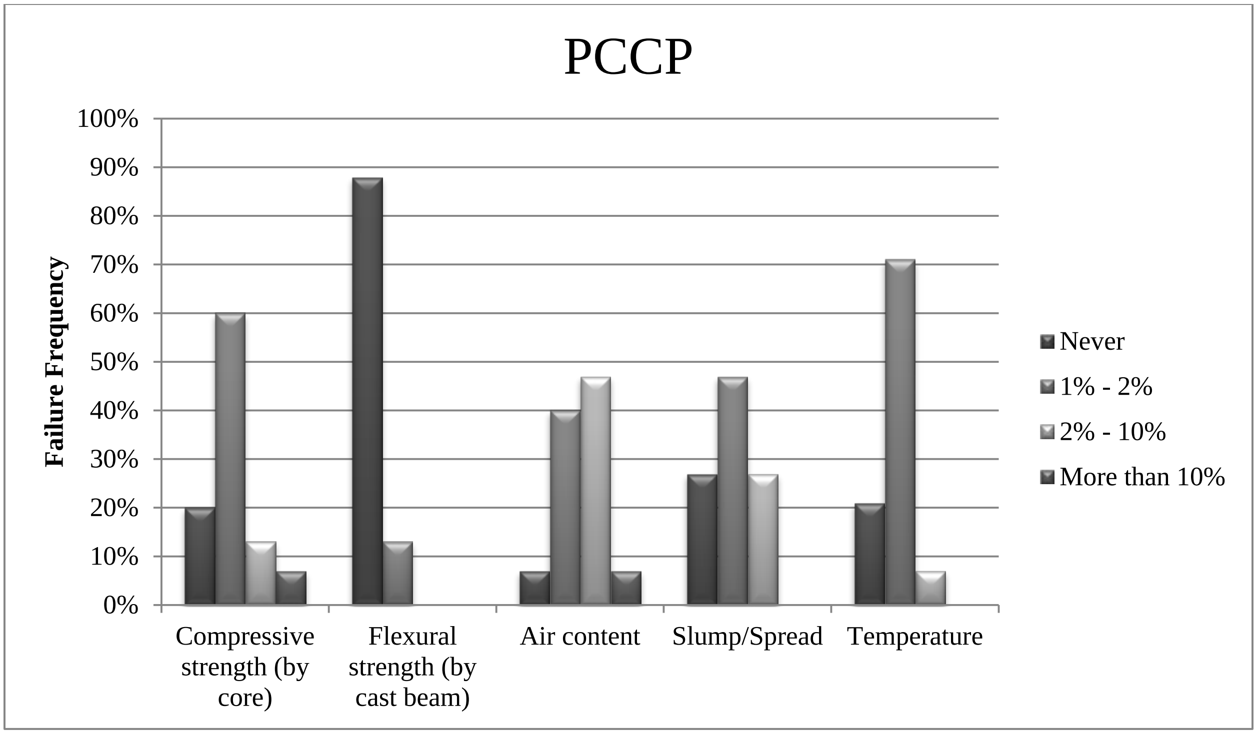


Figure 8: SHA Failures Observed in Test Results for PCCP

Failure to meet specification limit also occur in Portland cement concrete pavement testing. State highway agencies were asked about the frequency of these failures based the different tests. As shown in Figure 8, for the compressive strength test by core test, 20% responded they never have a failure; 60% responded a failure occurs 1%-2% of the time of use; 13% responded a failure occurs 2%-10% of the time of use; and 7% responded a failure occurs more than 10% of the time of use. For the flexural strength test by cast beam, 88% responded they never have a failure; and 13% responded a failure occurs 1%-2% of the time. For the air content test, 7% responded they never have a failure; 40% responded a failure occurs 1%-2% of the time of use; 47% responded a failure occurs 2%-10% of the time of use and 7% responded a failure occurs more than 10% of the time of use. For the slump/spread test, 27% responded they never have a failure; 47% responded a failure occurs 1 in 1%-2% of the time of use; 27% responded a failure occurs 2%-10% of the time of use; and no responses for more than 10%

failures. For the temperature test, 21% responded they never have a failure; 71% responded a failure occurs 1%-2% of the time of use, 7% responded a failure occurs 2%-10% of the time of use, and no responses for failures occurring more than 10% of the time.

Based on these results, it can be recommended to limit all of these tests since most of the failures occur 1% - 10% of the time. By limiting the amount of testing, state highway agencies can save time and money.

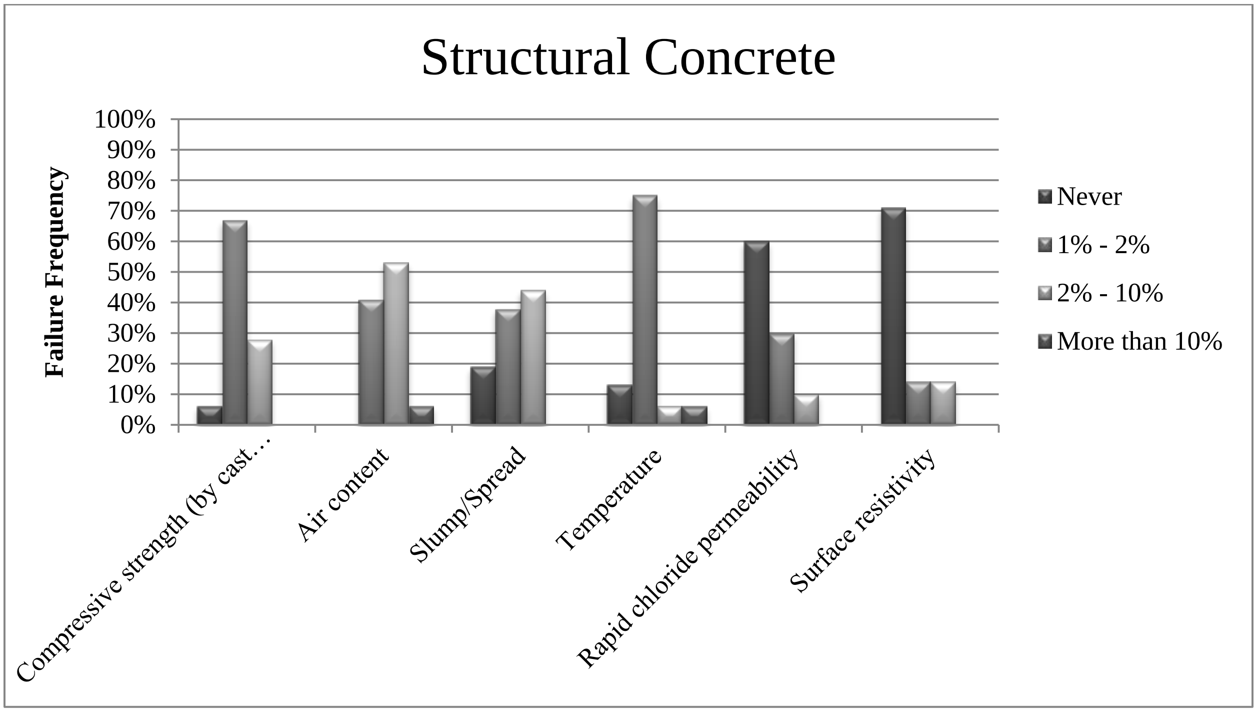


Figure 9: SHA Failures Observed in Test Results for Structural Concrete

Structural concrete is also tested for failures to meet specification limits for a project. There are several tests conducted to identify these failures by state highway agencies. As shown in Figure 9, the compressive strength by cast cylinder test, 6% responded they never have a failure; 67% responded a failure occurs 1%-2% of the time of use; 28% responded failures occur 2%-10% of the time of use; and no responses for failures for more than 10% of the time of use. For the air content test, no responses for never having a failure; 41% responded a failure occurs

1%-2% of the time of use; 53% responded failures occur 2%-10% of the time of use; and 6% responded a failure occurs more than 10% of the time of use. For the slump/spread test, 19% responded they never have a failure; 38% responded a failure occurs 1%-2% of the time of use; 44% responded a failure occurs 2%-10% of the time of use; and no responses for more than 10% of the time. For the temperature test, 13% responded they never have a failure; 75% responded a failure occurs 1%-2% of the time of use; 6% responded a failure occurs 2%-10% of the time of use; and 6% responded a failure occurs more than 10% of the time of use. For the rapid chloride permeability test, 60% responded they never have a failure; 30% responded a failure occurs 1%-2% of the time of use; 10% responded a failure occurs 2%-10% of the time of use; and no responses for failures occurring more than 10% of the time of use. For the surface resistivity test, 71% responded they never have a failure; 14% responded a failure occurs 1%-2% of the time of use; 14% responded a failure occurs 2%-10% of the time of use; and no responses for failures in more than 10% of the time.

Based on these test results, it can be recommended to limit the amount of tests since most of the failures occur 1% - 10% of the time. If the testing was less frequent, the state highway agencies would save time and reduce costs.

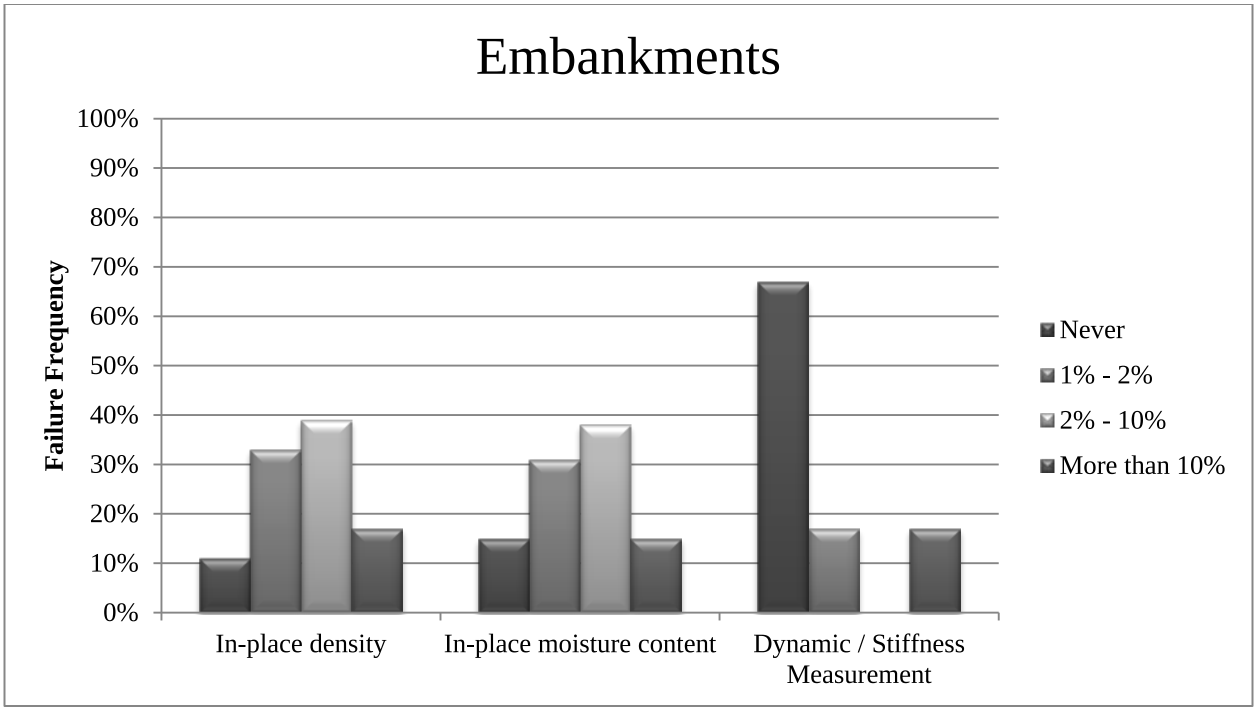


Figure 10: SHA Failures Observed in Test Results for Embankments

Failures to meet specification requirements are also found during testing for embankments. When performing the in-place density test for embankments, according to Figure 10, 11% responded they never have a failure; 33% responded a failure occurs 1%-2% of the time of use; 39% responded a failure occurs 2%-10% of the time of use; and 17% responded a failure occurs more than 10% of the time of use. For the in-place moisture content test, 15% responded a failure never occurs; 31% responded failures occur 1%-2% of the time of use; 38% responded failures occur 2%-10% of the time of use; and 15% responded failures occur more than 10% of the time of use. For the dynamic/stiffness measurement test, 67% responded they never have a failure; 17% responded a failure occurs 1%-2% of the time of use; no response for 2%-10%; and 17% responded a failure occurs more than 10% of the time of use.

Based on the responses, It can be recommended to reduce the amount of testing for embankment since most of the failures occur from 1% - 10% of the times. There were many responses that a failure never occurs, but I do not recommend eliminating the tests. By reducing the testing, state highway agencies can reduce costs and save time.

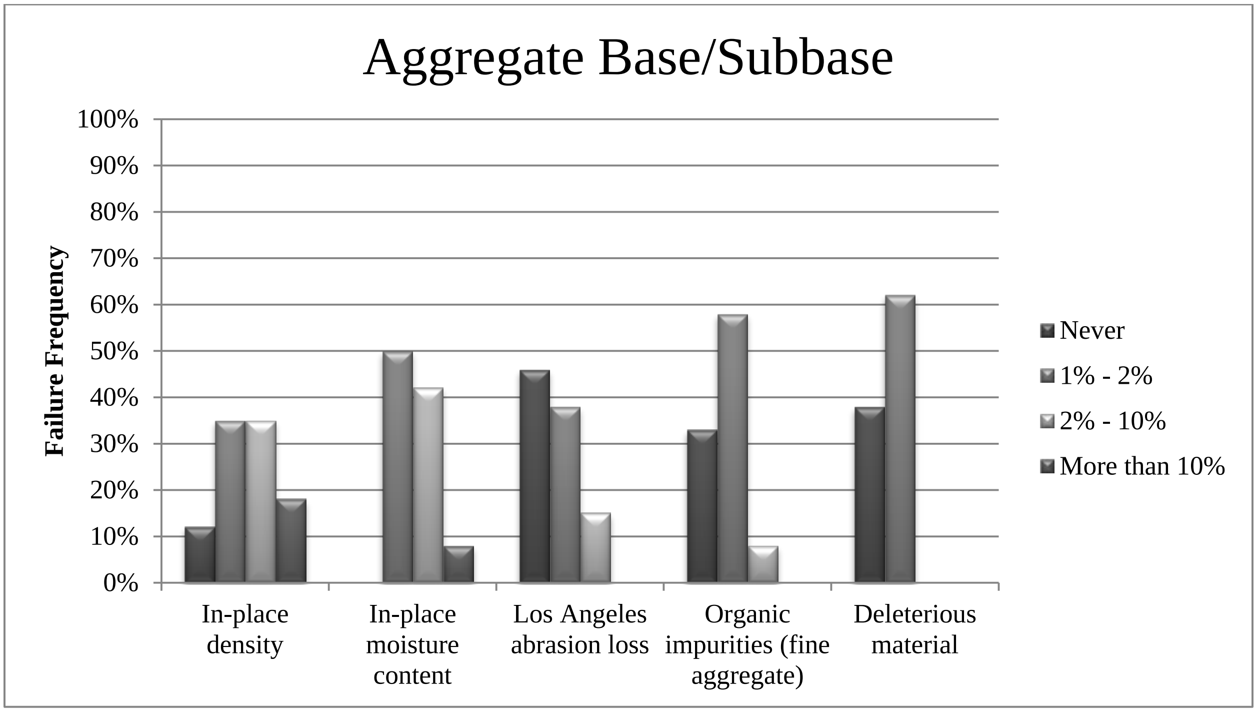


Figure 11: SHA Failures Observed in Test Results for Aggregate Base/Sub base

Testing is also conducted for aggregate base / sub base. Frequencies of failures that occur were recorded based on the different types of quality tests performed. As shown is Figure 11, the in-place density test, 10% responded they never have a failure; 31% responded a failure occurs 1%-2% of the time; 31% responded a failure occurs 2%-10% of the time; and 15% responded a failure occurs more than 10% of the time. For the in-place moisture content test, no responses for never having a failure; 31% responded failures occur 1%-2% of the time; 26% responded failures occur 2%-10% of the time; and 1% responded failures occur more than 10% of the time. For the Los Angeles abrasion loss test, 31% responded they never have a failure; 26% responded failures occur 1%-2% of the time, 10% responded failures occur 2%-10% of the time; and no responses for failures occurring more than 10% of the time. For the organic impurities in fine aggregate test, 21% responded they never have a failure; 36% responded failures occur 1%-2% of the time; 1% responded failures occur 2%-10% of the time; and no responses for failures occurring more than 10% of the time. For the deleterious material test, 26% responded they never have a failure, 42% a failure occurs 1%-2% of the time; no responses for 2%-10% of the time; and no responses for failures occurring more than 10% of the time.

Based on these results, it can be recommended to only conduct the in-place density test and in-place moisture tests. I would not recommend conducting the Los Angeles abrasion loss test of the deleterious material test due to the fact that many agencies responded they never have a failure based on these tests. By only conducting the in-place density and in-place moisture content tests, state highway agencies can save time and reduce costs.

Optimization of Material Sampling Plan

There are benefits of optimization for cost, importance, and risk. Like I mentioned before, on high importance jobs where safety is a bigger factor such as bridges, the cost of sampling will not be considered. By doing this, it allows the state agency to focus on the risk rather than the cost. In lower importance jobs, the agencies can look more at the cost and not as much of the risk. As shown in Figure 12; 42% of the agencies that responded to the survey base the sampling frequency on all of the factors: cost, importance, and risk. At least 78% of the responding agencies consider at least one of the factors for sampling frequency.

Sampling and testing frequencies will vary from state to state. States can reduce the frequency of testing for materials with a history of accurate, uniform testing results that consistently meet specification requirements. The frequency of testing should be greater on newly developed material sources, sources with questionable quality, sources that have a wide range of results, and sources with a history of failing test results. The frequency can also be increased when using contractor test results that do not meet the SHA test results. SHA can consider visual inspections and/or manufacture's certification for accepting small quantities of non-critical materials (Administration, 2006).

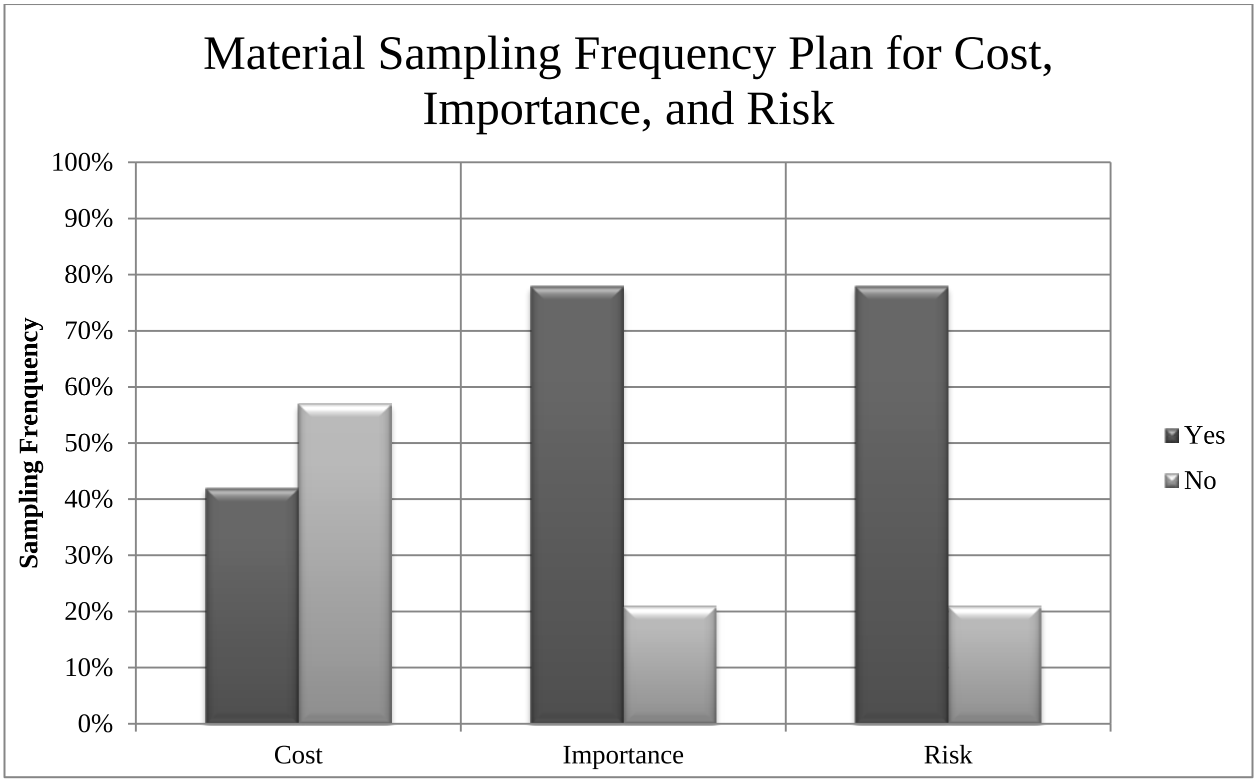


Figure 12: If Material Sampling Frequency Plan is Optimized for Cost, Importance, and Risk

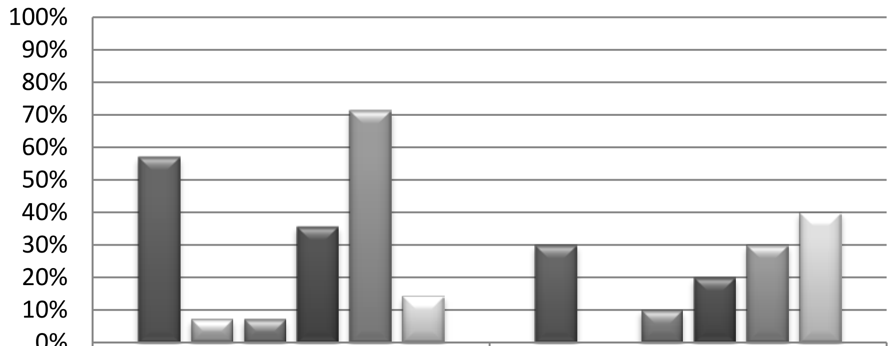
The state highway agencies were asked if the material sampling frequency plan was optimized for cost, importance, or risk. Surprisingly, the cost of the sampling was not as much of a major factor as importance and risk 42% responded sampling frequency is based on costs while 57% do not. 78% responded sampling frequency is based on importance while 21% do not. 78% responded sampling frequency is based on risk while 21% do not (Figure 12). Some of the comments indicate that the testing is completed for safety reasons for bridges, and structural slabs and that the cost is not a concern for items of such high importance. It can be recommended that SHA's should consider a plan that can reduce the amount of testing for other materials such as hot mix asphalt. This would be an opportunity to reduce costs but would have to be evaluated job to job.

Quality Assurance Measures for Acceptance Sampling and Testing

There are several measures that can be taken to for verification of Quality control testing for material acceptance. Some of these measures include:

- PWL Quality Measure – The Percent Within Limits measurement is the percentage of the lot falling above the lower specification limit, beneath the upper specification limit, or between the USL and LSL. This measure uses the sample mean and deviation to estimate the percentage of population that is within the specification limits.
- AAD – Average Absolute Deviation is the average of the absolute deviations from a central point and is a summary statistic. This verification method is not used often in highway construction.
- Mean – is the measure of the central tendency either of a probability distribution or of the random variable characterized by that distribution. This verification method is not used often in highway construction.
- Statistical F&T – this test is used to check for variances between two tests. This test provides a method of comparing two independent data sets of multiple test results to determine if the materials tested come from the same population.
- Split Sample test results comparison – a method where a sample is divided into random sub-samples which are treated differently. This is a common method to check for validity when contractor test results are used.

SHA Verification of Contractor Performed Quality Control Testing for Material Acceptance



	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 13: How SHA Verifies Measurements of Contractor Performed Quality Control Testing for Material Acceptance Sampling and Testing

During some projects, the state highway agencies may accept the test results performed by the contractor. In this case, the state highway agencies can compare the contractor test results with the acceptance values. As shown in Figure 13, for hot mix asphalt, 14% responded they perform no statistical verification; 71% responded they split sample test results and compare; 36% responded they utilize the statistical F&T, 7% responded they compare the mean; 7% responded they compare AAD; and 57% responded they compare PWL quality measures. For concrete, 40% responded they do not perform statistical comparisons; 30% responded they utilize split sample test results comparisons; 20% responded they utilize statistical F&T comparisons; 10% responded they compare the mean; no responses for AAD comparison; and 30% responded the utilize PWL quality measure for comparison.

As shown in Figure 13, using the PWL Quality Measure, Statistical F&T, and Split sample test results comparison verification methods can be advantageous to the state agency. The AAD and Mean verification methods are a disadvantage and can slow the process.

There were several agencies that commented that the state highway agency does not accept contractor test results for any job. If the agency does accept the contractor test results, I would recommend the state highway agencies verify all test results to ensure the agency is getting the quality product they have specified. Since most agencies do not accept contractor test results, the acceptance values will be revealed during testing whether it is in the lab or in the field.

Quality Assurance Verification Practices

There are several methods that can be used to identify cost effective sampling and testing methods. One is contractor quality control sampling and testing. For this method, the contractor is responsible for the quality of construction and materials incorporated into the project. The contractor performs all quality, sampling, and testing and is then verified by the state agency. The agency then in turn can accept or reject based on the results. Another method is IA procedures. Independent Assurance is required by the state agencies for verification of the contractor testing and sampling of materials. This will take any bias out of the testing results and is another verification process. Testing certification practices are also required in the construction process by the state agency as another check. In this process, the contractor will perform the tests, and the results are then certified by an independent testing agency. The results are then compared to the specifications supplied by the state agency. Regional, district, or divisional labs can also be required by the state agency. Depending on the project, the state highway agency will require the testing of materials to be conducted at specific labs. These may be done at the regional lab, district, or divisional labs. Each location will have similar specifications that are to be met, while others may be more stringent. The verification will be determined by the state agency.

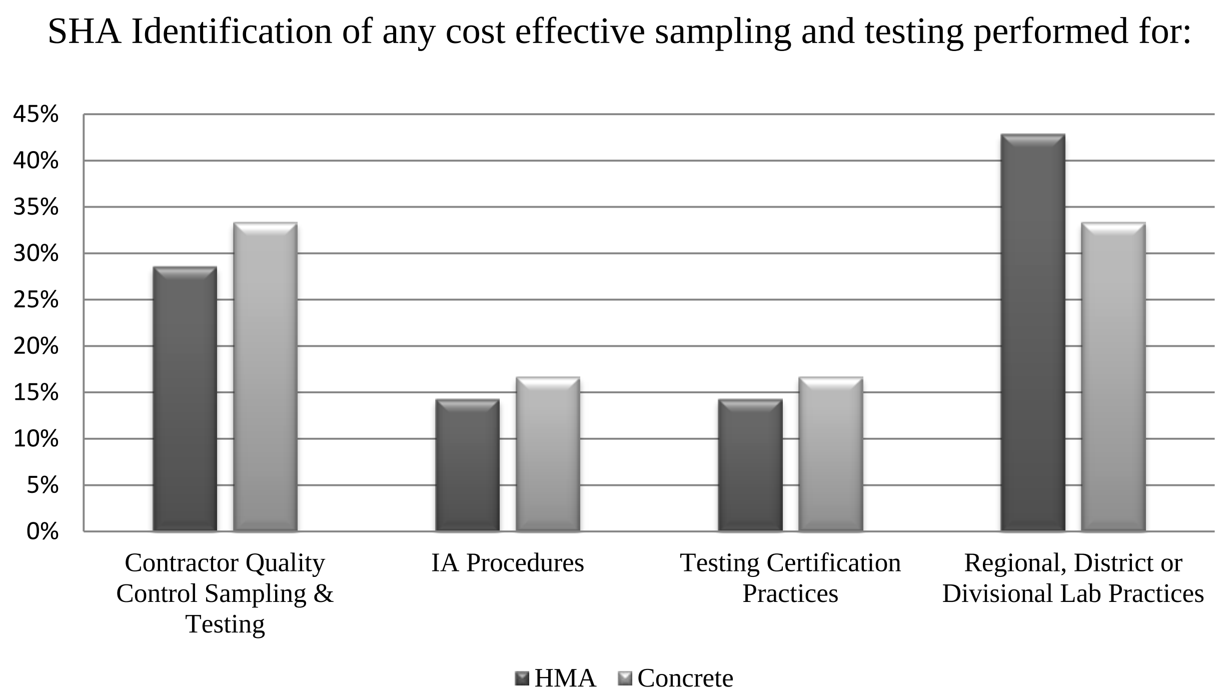


Figure 14: If SHA Identifies Any Cost Effective Sampling and Testing for HMA and PCCP

SHA's were requested to provide information on any cost effective sampling and testing performed for hot mix asphalt and concrete. For hot mix asphalt, 43% responded they utilize regional, district, or divisional labs for testing; 14% responded they utilize testing certification methods; 14% responded they utilize IA procedures for testing methods; and 29% responded they utilize contractor quality control sampling and testing. For concrete, 33% responded they utilize regional, district, or divisional labs for testing; 17% responded they utilize testing certification methods; 17% responded they utilize IA procedures for testing methods; and 33% responded they utilize contractor quality control sampling and testing (Figure 14).

Use of Innovative Quality Assurance Test Methods

With advancements in technology comes an opportunity for developing and implementing innovative quality assurance test methods. However, there was a mix response on this question. Some agencies did not identify any cost effective methods for sampling and testing while others do. One agency responded they rely on extensive feedback from industry contractor testing requirements because the industry standards are often more strict than the state agency requirements. Another agency uses a system approach. For some applications they utilize the state testing labs but for small quantity, low risk applications, they will accept the material tests on certification, with random verification tests. This may be the best option. It can be recommended the state agencies use a system approach and accept material testing from the contractor for the lower risk applications. This would save the agencies time and money.

Table 1: SHA Using or Exploring Innovative Testing Methods That Reduce Costs, Save Time, or Produce More Accurate Results for HMA

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

It was requested that SHA's provide information on if they are currently using or exploring an innovative test method such as quick and nondestructive that significantly reduces the cost, saves time, or produces more accurate results for hot mix asphalt. As shown in Table 1, one agency responded they are using the ignition oven to save time and money. One agency is using daily recordation of asphalt plants to verify the asphalt content. Another agency is exploring the Hamburg test for the asphalt content. For in-place density testing, one agency is utilizing the one point proctor test, and nuclear gauge; three agencies are utilizing ground penetrating radar and intelligent compaction; one agency is utilizing the electric density gauge; one agency is utilizing Core Dry; one agency is utilizing PQI or Pavement Quality Indicators. PQI is a non-destructive test that is quick and accurate for measuring asphalt density. For smoothness testing, there were two responses for cost saving test methods. These include using the line laser and IRI attached to John Deere Gators.

State highway agencies responded on methods to save time and money for Portland cement concrete pavement. According to Table 1, for the compressive strength test, 2 agencies responded utilizing the maturity test for possible cost and time savings. For the flexural strength test, one agency responded use of the maturity test will save time. For the air content test, the use of Super Air Meters will yield faster results in that it 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. There were no responses for the slump/spread test or the temperature test.

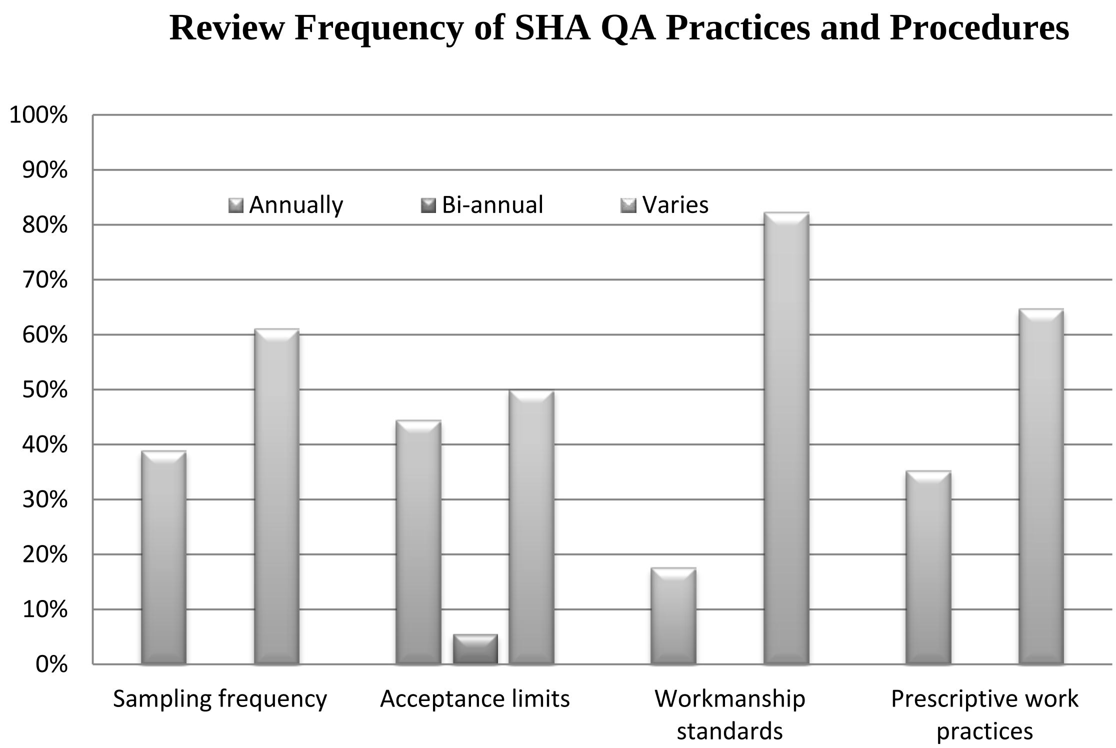


Figure 15: How Often SHA Review Their QA Practices and Procedures

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 opportunity for cost and time savings. On average 34% SHAs responded that they annually review quality assurance practices and procedures for: sampling frequency, acceptance limits, workmanship standards, and prescriptive work practices (Figure 15). About 44% SHAs review acceptance limits annually while only 18% SHAs review workmanship standards annually. Most SHAs (65%) responded that their review frequencies vary and typically conducted as needed basis.

It can be recommended to SHA's 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 testing methods that may improve the practices and procedures of the organization.

Table 2: SHA Implemented Innovative Acceptance Approaches

SHA Implemented Innovative Acceptance Approaches	Yes	No
Requirement Verification	15%	68%
Risk Profiling	0	78%
Lean 6 Sigma	0	78%
Agile processes	0	78%
Just In Time sampling	0	78%
Quality Check Points	1%	73%
Intelligent Compaction	42%	47%
3D design modeling	10%	68%

Used for what area?
Asphalt
There has been one HMAC project with Intelligent compaction this year and our construction offices are pursuing more for next year.
Asphalt pavement and base materials
Asphalt and Embankment
Some pilot work in intelligent compaction and 3D modeling but none have been used for acceptance yet.

SHA were requested to determine if there are any innovative acceptance approaches they are utilizing that can reduce costs. According to Table 2, there are not as many innovative acceptance approaches identified. Most of the innovative methods are for hot mix asphalt and include intelligent compaction and 3D modeling. I think this is an area for state highway agencies to pursue in the future as a means of reducing costs and saving time.

Table 3: Results of Any Other Cost Effective QA Practices SHA Has Implemented

Please explain any other cost effective QA practices that your SHA has implemented
Purchasing an impact echo device to evaluate non-destructive testing for bridge deck thickness
We are exploring a regional approach to verification of structural precast items, and utilize a regional approach with random verification tests for HDPE pipe.
Operational Reviews in conjunction with independent sampling - FHWA has identified as a best practice.

It was requested to the state highway agencies to explain any other cost effective QA practices the agency have implemented. Unfortunately, only three responses were collected (Table 3). However, these options can be explored by other agencies in hopes of reducing costs and saving time.

CHAPTER 4

CONCLUSIONS / FINDINGS

Highway construction is a very important asset to the U.S. State highway agencies are constantly under pressure to do more work with less money. Because of the budget constraints, it is important to identify opportunities available that could save costs. The cost of quality activities such as cost of equipment, testing, inspections, training, etc. are significant. There is a real value in identifying, sharing, and implementing cost effective quality assurance best practices and procedures among state transportation agencies. This research was able to identify specific cost effective implementations that are currently being used throughout the U.S. by various state transportation agencies. It has been determined that state transportation agencies utilize a wide variety of test methods to ensure quality for hot mix asphalt, Portland cement concrete construction, structural concrete, embankments, and aggregate base / sub base.

For hot mix asphalt, the preferred testing methods are in-place density, air voids, sieve analysis, and smoothness tests. For Portland cement concrete construction, the testing methods preferred by the responding agencies are compressive strength by cylinder, air content, slump/spread, thickness, and temperature. For structural concrete, the preferred testing methods are compressive strength by cylinder, air content, slump/spread, and temperature. For Embankments, the preferred testing methods are in-place density and in-place moisture content test. For aggregate base/ sub base, the preferred testing methods are gradation, in-place density, and in-place moisture content tests.

There are limitations to this research. One of the greatest limitations is the small sample size that was received. The survey was sent to all 50 states and the District of Columbia however, only 19 agencies responded.

It can be recommend reducing sampling overall or only perform testing on a case by case basis as an effort to reduce costs and save time. There are always opportunities for future research. I recommend the agencies take advantage of the technology that is available and use it to its full potential in an effort to reduce costs for the state highway agencies. For future testing, it can be recommended that a cost effectiveness analysis be completed to determine a monetary value of savings that can be obtained if these tests are reduced or eliminated.

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APPENDIX

Cost of Quality Assurance in Highway Construction Survey

Cost Effective QA Survey

Implementation of quality assurance program by different state highway agency (SHA) has taken many forms. The success or failure of these efforts has yet to be studied in a comprehensive and impartial manner. There are reports of improved quality, but also increased costs. 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. The purpose of this questionnaire survey is to identify cost-effective approaches for quality assurance program that are being used by different state highway agencies.

Your participation is voluntary and your responses are confidential. Your responses will not be reported in any manner which can be associated with any specific individual, organization, agency, program, or project.

If you have questions about this survey, you can contact Dr. Moin Uddin by phone or email at 423-439-4164 or at uddinm@etsu.edu. This survey information is requested by Tennessee DOT. The results will be publically accessible upon completion.

Please include your contact information

Please include your contact information Name:

State Highway Agency:

Title/Position:

Email Address:

Phone Number:

1. Does the SHA measure performance of workmanship and materials?

A. ☐ Materials only

B. ☐ Workmanship only

C. ☐ Both materials and workmanship

2. Typical Acceptance tests conducted by your SHA include:

A. Hot Mix Asphalt (HMA) Asphalt content

In-place density ☐

Air voids ☐

Sieve analysis ☐

Smoothness ☐

Void in mineral aggregate ☐

Void in fine aggregate ☐

Other (please specify)

B. Portland Cement Concrete Pavement (PCCP) Compressive strength (by cylinder) ☐

Flexural strength (by cast beam) ☐

Air content ☐

Slump/Spread ☐

Smoothness ☐

Thickness ☐

Temperature ☐

Other (please specify)

C. Structural Concrete: Compressive strength (by cast cylinder) ☐

Air content ☐

Slump/Spread ☐

Temperature ☐

Rapid chloride permeability ☐

Surface resistivity ☐

Other (please specify) ☐

D. Embankments

In-place density ☐

In-place moisture content ☐

Other (please specify)

E. Aggregate Base/Sub base

Gradation ☐

☐

In-place density

In-place moisture content ☐

Other (please specify)

3. Based on SHA collected test results, failures observed in test results:

HMA	More than 10%	2% to 10%	1% to 2%	Never
Asphalt content				
In-place density				
Air voids				
Sieve analysis				
Smoothness				
Void in mineral aggregate				
Void in fine aggregate				

PCCP	1 in 10	1 in 50	1 in 100	Never
Compressive strength (by core)				
Flexural strength (by cast beam)				
Air content				
Slump/Spread				
Temperature				

Structural Concrete	1 in 10	1 in 50	1 in 100	Never
Compressive strength (by cast cylinder)				
Air content				
Slump/Spread				
Temperature				
Rapid chloride permeability				
Surface resistivity				

Embankments	1 in 10	1 in 50	1 in 100	Never

In-place density				
In-place moisture content				
Dynamic / Stiffness Measurement				
Other (please specify)				

Aggregate Base/Sub base	1 in 10	1 in 50	1 in 100	Never
In-place density				
In-place moisture content				
Los Angeles abrasion loss				
Organic impurities (fine aggregate)				
Deleterious material				

4. Is the material sampling frequency plan optimized for cost, importance and risk?

	YES	NO
Cost		
Importance		
Risk		

If yes, please explain how does your SHA has optimized sampling and testing plan in terms of cost, importance and risk

5. If Contractor performs Quality Control testing for material Acceptance sampling and testing, how are the results verified by SHA?

	PWL Quality Measure	AAD	Mean	Statistical F & T	Split sample test results compared	No statistical verification performed
HMA						
Concrete						

Other (please explain)

6. Does SHA identify any cost effective sampling and testing performed for:

	Contractor Quality Control Sampling & Testing	IA Procedures	Testing Certification Practices	Regional, District or Divisional Lab Practices
HMA				
Concrete				

Other (please explain)

7. Is the SHA currently using or exploring an innovative testing method (such as quick and nondestructive) that significantly reduces the cost, saves time or produces more accurate results?

HMA	Cost	Time	Results
Asphalt content Approach			
In-place density Approach			
Air voids Approach			
Sieve analysis Approach			
Smoothness Approach			
Void in mineral aggregate Approach			
Void in fine aggregate Approach			

PCCP	Cost	Time	Results
Compressive strength (by core) Approach			

Flexural strength (by cast beam) **Approach**			
Air content **Approach**			
Slump/Spread **Approach**			
Temperature **Approach**			

8. How often does the SHA review their QA practices and procedures?

	Annually	Bi-annual	Varies	Never
Sampling frequency				
Acceptance limits				
Workmanship standards				
Prescriptive work practices				

Other (please explain)

9. Has the SHA implemented any innovative Acceptance approaches such as:

	YES	NO
Requirement Verification		
Risk Profiling		
Lean 6 Sigma		
Agile processes		
Just In Time sampling		
Quality Check Points		
Intelligent Compaction		
3D design modeling		

If yes, in what area? (Asphalt or Concrete)

10. Please explain any other cost effective QA practices that your SHA has implemented.

VITA

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