

Keys to a Quality Culture

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Abstract

This paper looks at the elements that are needed to implement an effective quality assurance program for a concrete paving operation. In this paper, the authors argue that the benefit of a good quality assurance program far outweighs the costs associated with it for both the agency and the contractor. New technologies are described that can provide information that allow monitoring of the properties critical to pavement longevity. Many are nondestructive and thereby reduce quality control costs compared to traditional monitoring tests. The intent of this paper is to show how a good quality assurance program could benefit both the contractor and the agency without adding significant cost.

Introduction

The topic of Quality Assurance can be intimidating, and it is easy for experts to get into the weeds of statistics and jargon. But we all make quality based judgements in our lives every day: for instance choosing one brand of food over another by balancing our budget with the taste and (hopefully) the health benefits.

This paper aims to outline the bones of effective quality for concrete pavements using new technologies.

First: Commitment. Quality at any organization is a top down philosophy. Do we build with high quality or do we make it cheap? The real key is to understand that the owner can actually save money by making it with high quality because they don't have to replace it so often, and replacing a pavement is not trivial. The contractor can also win that low bid because they don't have to budget for replacing mistakes.

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There is the, likely apocryphal, story of a worker at a Rolls Royce factory being fired because he announced that a part he had made was “good enough”. At that organization “good enough” was not good enough, and that is how they maintained their reputation.

If the corporate philosophy, whether at the agency, contractor or materials supplier, is that quality is not negotiable, then it is a lot easier to implement an effective program that delivers “quality” transportation infrastructure to the tax-paying public, cost effectively.

Second: Tests, limits and specifications. The challenge we face is defining how good is good enough? How do we know we got it? If not, how bad is it and what is it worth or should it be replaced? Is there a bonus if it is better than good enough? Are we measuring the right things?

Third – Motivation. What’s in it for me? Does it save money? Will the pavement last longer? Will we need a lawyer or a party planner at the end of the contract? Will I keep my job?

Construction of concrete pavements is complex and the service life is dependent on a many factors. The process of building a concrete pavement is as critical as the materials that went into it. We therefore have to measure the right properties at the right time, and maybe often, as well as watch the process to be assured that the quality is indeed “good enough”.

It is tempting to not bother with quality and to save that inspector’s salary, but mistakes happen and the low bid system incentivizes cutting corners. Errors may only become apparent long after the final payments are made, potentially leaving the owner with a very expensive repair bill or a far shorter life than originally planned for.

Implementing quality does increase initial costs, but failure is more expensive by several orders of magnitude.

This paper looks at quality from the point of view of both the agency and the contractor while talking about “How do we do it to get the most out of it?”

The Agency

A simple definition of quality is “Making sure the quality of a product is what it should be” or as stated in TRB Circular E-C037 “All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service.”

Federal regulations require each state highway agency to have a QA system in place to assess the quality of items produced. The aim is to ensure that the public’s dollar is spent wisely.

Every Agency should be committed to paying for quality products, and therefore be prepared to invest in the cost of developing and enforcing appropriate policies.

The reason for having a systematic approach to quality is to consistently assess and pay for items provided on construction projects. The primary components are the owner/agency acceptance process, and contractor quality control. The other items discussed below serve as supporting elements to support these.

Owner/Agency Acceptance. It is the responsibility of the owner/agency to establish how it will accept and pay for work done under a construction contract.

A statistically based QA specification should identify what properties of the pavement will be tested and/or inspected, and how the results of those efforts will be used to determine payment. The acceptance process should focus only on factors that are directly related to the ultimate performance of the product. Payment may include bonuses for better than required product, and or penalties for product that is substandard, normally based on a statistical Percent-Within-Limits (PWL) method

Rigorous inspection is a key part of the acceptance process. A concrete mixture can yield good lab test results yet be unacceptable if the construction workmanship are poor.

The agency should also insist that the contractor implement an effective Quality Control plan as discussed below.

Quality Control. QC activities are performed by the contractor on both constituent materials and the final product.

QC is the act of monitoring the final product. What the contractor is really doing is looking for change during production. Production processes are changed if the desired quality is not being produced.

Process control is the work of monitoring the constituent materials and construction process to be assured that the final product will reach the desired targets. Tests such as aggregate gradation and moisture at a concrete plant are examples of process control.

The QA specification should mandate a minimum level of quality control and process control. Experience has shown that better contractors will often exceed these minima because an effective QC program will enhance productivity and reduce the risk of failed materials. The QC Plan should detail the QC and PC activities to be performed. Once the Plan is approved, the agency is in a position to monitor whether it is being followed and to enforce compliance.

Personnel Qualifications. Individuals performing sampling, testing, and inspection, for all QA activities must be suitably trained, qualified, and ethical. This is because their findings have direct implications on pay. The specification should establish what qualifications are required and which individuals should have them.

Laboratory Qualifications. Laboratory qualification is part of a QA system for the same reason as personnel qualification. State highway agency's central lab should be accredited through the AASHTO Accreditation Program, or equivalent, with other labs being qualified under state procedures.

Independent Assurance. Independent Assurance (IA) refers to the periodic checking done on the individuals and equipment performing sampling and testing activities. The IA process assures that they continue to provide accurate results. Two concepts are important:

1. IA is conducted using split samples; this allows for all material and construction-related variability to be eliminated. The only variability will be that of the sampling and testing process. The technician being evaluated performs a given test using their testing apparatus. The results are then compared for accuracy. Witnessing the test allows the IA technician to verify that proper test procedures were followed.

2. The IA results care only about the accuracy of the test result, not the actual result itself. For example, if a test sample fails to meet the specification limit, yet the two results are within the allowable tolerance for that test, the tester “passes” their IA evaluation.

Dispute Resolution. Dispute resolution refers to the “referee” process used when the test results from the owner/agency qualified lab do not agree with results from the contractor or lab being used in the QC/PC process. The QA Program will establish how these disputes are handled. Typically, an independent, qualified, laboratory not involved in the original testing will be used as the referee.

The Contractor

Like the Agency, the effective contractor is committed from the top down to delivering a product that is acceptable to their clients. Unlike the Agency, the contractor must consider all aspect of the construction process.

Corporate Culture. To implement a quality culture within a company, there must be support for that effort starting at the very top of the organization through every employee. Each employee must understand that they, along with their fellow employees, are critical to producing a quality product. Top management must understand and support this effort by bringing qualified people into the organization and adequately support them.

Emphasis should be placed on using the quality system to teach and encourage good practices at all levels. Failures should become teaching opportunities rather than tools to punish individuals.

Internal policies are needed to guide every aspect of a project. From the mixture design that complies with targets, through quality control during production, the tests and action limits should be spelled out. These should include the actions that will be taken when control limits are approached or exceeded. The guidelines should include:

- The plant calibration steps and responsibilities
- The tools used to evaluate the properties of the aggregates
- The cementitious materials handling, testing and monitoring
- Testing frequency and tolerances
- Degree of overdesign

The technical staff must be given the authority to initiate changes when corrective actions are required, even if they are costly. This must include shutting down the paving operation if control is being lost; while undesirable in the short-term, this type of response demonstrates management’s commitment to quality and helps show project staff what the company perspective on “good enough” is.

Trained and Experienced Managerial Technical Staff. A well trained and experienced managerial technical staff is a key to reducing risk. There is a cost to having this level of expertise but the value they add to a project greatly exceeds the cost to the company. They are able to optimize the concrete design mixture and often reduce the cost of materials, as well as improve the constructability of the concrete. These personnel are able to monitor test results, analyze the test data and then initiate changes during construction when needed.

QC Managers are responsible for using Process Control to ensure that the product will be accepted by the agency. During production, the process is always subject to change and some tweaking of the mixture may be required. A skilled QC Manager knows when to act, and equally important when not to act. The result is improved control of the mixture and a lower standard deviation in the test data. This allows the contractor to bid and produce mixtures with less overdesign that are more economical but still meet the requirements of the contract.

Testing consultants can perform specified tests. But, in general they do not possess the long term experience and knowledge of the materials, concrete mixtures, and performance characteristics that optimize the compatibility with the concrete mixtures and the company equipment and production style. These skills are what translate the test results into quality pavement.

The technical managers should manage the testing staff to insure procedural consistency, testing equipment calibration, and timely reporting of test results. These people are available to assist construction personnel with needed changes when issues are identified. They assist them in setting a testing plan and the scheduling of the tests.

All of these functions will lead to better control thereby insuring maximum return of incentive payments and minimizing costly corrective actions.

New Technologies. Utilizing new technologies to gather better data, sooner, can reduce risk and improve the finished product. As discussed below, there are many new and often nondestructive test that can provide information instantly and aid a contractor in monitoring the process to assure it is under control.

Materials Selection. Materials selection is critical to the development of a concrete mixture so it will not only meet the project requirements but also will positively affect the construction process. Running mixture trials and evaluating products prior to the bid letting is very important to ensuring that the cost of the project is known and surprises will not pop up. This work should be the responsibility of those with quality management responsibilities.

As the mixture is developed, all aspects of the paving operation must be considered:

- The haul distance must be considered when evaluating the dormancy period of the cementitious material. This will change with weather and thereby the season when paving will occur.
- Admixtures affect the concrete mixture. Therefore the selection of what ones should be used should not be considered merely on the initial cost but within the context of the whole paving operation.

- How will the stockpile be managed? The underlying challenge is to maintain a consistent moisture and gradation of the coarse aggregate. In many cases, watering the stock pile needs to be an intentional and carefully watched activity.
- Concrete delivery will need to be considered in terms of delivery time. The availability of trucks and batching rate will go hand in hand. The equipment used on the paving operation will need to be coordinated with the production and delivery capabilities.
- Also important will be the opening to traffic needs of the project. The ability to use supplementary cementitious materials will be affected by those restrictions, particularly with early spring or late fall paving.

It is important for QC Management personnel to understand that the process of materials selection is much greater than just the contract testing requirements. Some examples include: cost/benefit considerations, plant type, specific performance of the alternative materials sources, plant location, water source, haul distances, truck delivery method, placement equipment, project specific needs, intended use for the concrete.

It must be remembered during the mixture design process and evaluation that a mixture made in the laboratory acts differently in the field. First the small laboratory mixer is different from at large drum mixer used in mainline paving. Also the weather is normally not 72°F in the field as it was in the laboratory. Humidity, sunshine, and night conditions all affect the properties and behavior of the concrete.

Test Methods for Everyone

Inherent in an effective QA program is the ability to measure the parameters that matter, quickly, cost effectively and reliably. Traditionally the only tests available that met these criteria were strength, slump, air content and thickness. These tests have been the backbone for specifications for decades, despite their poor correlation with long term performance in modern systems. The lack of more effective tests has been a significant barrier to implementation of performance specifications.

However, the last 10 years have seen some major advances in the concrete testing arena. Several new tests are now available that are more practical, faster, economical, field implementable and measure properties that are related to actual concrete and pavement quality. Many of these tests could be incorporated in quality assurance programs not only because they offer cost savings but they also measure properties that actually matter. Some of these tests can be used for quality control (contractors), some of them can be used for both acceptance and quality control, some during mixture design stage and some during production/construction stage.

The following section briefly describes new technologies/tests that should be routinely used in quality assurance programs. These tests/technologies are described here from a value added standpoint. Detailed information on these tests is available in the references provided. Figure 1 shows the testing devices or outputs.

Further tests are continually being developed, all with the aim of improving data collection for the truly critical parameters.

Box Test – Workability (Mixture Design Phase). The Box Test is a simple and economical test method to evaluate if a concrete mixture is suitable for slip formed concrete paving, unlike tests available to date (Cook, 2014). It measures the response of the concrete to vibration and the ability of the concrete to hold an edge

Slipformed concrete is unique because it must be fluid enough to allow proper placement and consolidation, but still stiff enough to stand without edge forms. The test comprises partially filling a 305 mm (1 ft) cubic form up to a height of 241 mm (9.5 inches) and inserting a 25 mm (1 in) stinger vibrator for 6 seconds. The forms are immediately removed and the concrete is assessed for consolidation and edge slump. A mixture can then be modified until it achieves both of these desired properties.

The test can be completed in the laboratory or the field in a few minutes and could be a supplement or substitute for the slump test for concrete pavements.

The Box Test is a Quality Control (Contractor) Test.

VKelly – Workability (Mixture Design Phase). The VKelly is a tool that also assesses the response of a mixture to vibration (Taylor, 2015). Ideally a mixture should flow readily under vibration, yet avoid slumping at the edges after the paving machine has moved on. This property is known as thixotropy. The principle of the approach is relatively simple. A Kelly Ball is a device used in the 1940's that reported the slump of dry mixtures. It comprises a 13.6 k (30 lb) hemispherical ball, 203 mm (8 in) in diameter that is placed on the surface of unconsolidated concrete and allowed to sink under its own weight. The depth that it sinks is directly correlated to the slump of the concrete. It was an ASTM method until it was dropped, although CA DOT still uses it. It can be used to assess the workability of a mix in the back of a dump truck before it is unloaded. The VKelly approach is to attach a vibrator to a Kelly Ball, and to monitor the rate at which the ball sinks with the vibrator running. A good correlation has been observed between the so-called VKelly index and the Box test. Development work is continuing, in both the lab and field, to fine tune and validate the method and equipment.

Like the Box Test, the VKelly can be used to guide the design of slip formed concrete mixtures and to assess any changes during construction due to changes in source materials or the environment.

The VKelly Test is a Quality Control (Contractor) Test.

Semiadiabatic Calorimetry - Chemistry Consistency (Mixture Design and Production Phase). Hydration of cementitious materials is exothermic, meaning that the progress of the chemical reactions can be monitored by measuring the total heat liberated over time using a semiadiabatic calorimeter (ASTM C1753). The shape of the power curve obtained through calorimetry is an indicator of relative performance of cementitious mixes. The amount of heat liberated by cement hydration over time strongly depends on the chemical and physical properties of the cementitious materials and admixtures used in the concrete mixture. This test allows regular monitoring of the mixture for any changes in the cementitious materials, both quality and quantity. It also will identify a change in admixture dosage or chemistry.

A 102 X 203mm (4 X 8 in) cylinder can be cast at the job site and immediately placed in the calorimeter. Heat data are collected for the first 20-24 hours and can be compared with heat signature curves from previously generated curves from the same mixture. Significant differences will flag a potential problem, although some expertise may be required to infer the type or cause of the problem. The test is cost effective, and not operator sensitive. It can be conducted on the grade, or in a field lab.

This is a Quality Control (Contractor) test and cannot be used as an acceptance test.

Surface Resistivity – Permeability / Durability (Mixture Design Phase – Production Phase). Permeability is an indicator of concrete durability because most damage mechanisms involve the presence of water. Mixtures that limit the transportation of fluids through the pore system will tend to be longer lasting. Permeability is influenced by w/cm, cementitious system and degree of hydration.

There are no good tests to measure permeability directly but resistivity does provide an indirect measure (Rupnow, 2012). The premise behind the test conducted on saturated samples is that electricity is more readily conducted through fluids than through solids. The higher the resistivity, the lower the fluid (i.e. voids) content, and thus the lower the permeability. Measurements from this test have shown a good correlation with other electrical indication tests, such as the Rapid Chloride Permeability Test, AASHTO T 358-15.

The Louisiana Transportation Research Center performed a cost-benefit analysis that showed that implementation of the device will save the Department approximately \$101,000 in personnel costs in the first year. It is estimated that contractors will save about \$1.5 million (Rupnow, 2012).

This test could be used both as a Quality Control and as an Acceptance test.

Super Air Meter – Freeze-Thaw Durability (Mixture Design Stage – Production Stage). The presence of closely spaced air voids in concrete is recognized as the primary factor in improving the freeze-thaw durability of concrete. Normal tests performed on fresh concrete provide information on the total air content of the sample, but do not give any indication of the quality of the air void system. Petrographic methods (ASTM C 457) and freeze-thaw tests (ASTM C 666) are normally used to determine the air void distribution and freeze-thaw resistance of concrete respectively. However, these tests take many days and therefore are of little value in monitoring concrete during construction.

The Super Air Meter or SAM (Ley, 2014) is a field test that gives an indication of the distribution of air in concrete. The test takes just over 10 minutes to run and provides immediate information about the air void quality in the fresh concrete. This is especially useful to evaluate a concrete mixture before and after a paver.

The SAM is a modified ASTM C231 Type B Pressure Meter that provides the same information as a Type B meter. After completing the conventional testing, the pressure is increased in increments through two cycles. By understanding how the concrete responds to the series of high pressures, the meter can assess properties of

the air-void system beyond the total air content. The result is a measurement that has been shown to correlate well with the spacing factor measurement from ASTM C457 and freeze-thaw performance data such as ASTM C666. The SAM number is a value calculated from the pressure curves produced in the test.

This test could be used both as a Quality Control and as an Acceptance test.

MIT-Scan T2 – Pavement Thickness (Construction Stage). The service life of a concrete pavement is significantly influenced by the pavement thickness. However, coring to measure thickness is destructive, expensive, and time consuming. The MIT Scan T2 test is proposed as an alternative.

The MIT-Scan-T2 uses pulse induction technology to measure pavement thickness nondestructively using a metal target pre-placed on the top of the base prior to paving. The results are within 2 mm of core lengths. It works well over a wide range of concrete pavement thicknesses and base conditions (Grove, 2012).

Measurements can be taken as soon as the pavement can be walked upon. The technology offers the ability to measure a large number of locations inexpensively and thereby minimize risk of thin pavement. It can be used for both acceptance and QC. It allows the agency to randomly choose which targets to measure for acceptance, thereby maintaining random testing. Many highway agencies are currently evaluating this technology.

This test could be used both as a Quality Control and as an Acceptance test.

MIT - Scan 2 – Dowel Alignment (Construction Stage). Properly aligned dowel bars help provide load transfer between panels in jointed plain concrete pavements. Misaligned dowels may lead to joint locking which can cause slabs to crack. Insufficient embedment leads to a decrease in load transfer efficiency, which can result in faulting and other pavement distresses.

MIT Scan 2 is a nondestructive testing device for measuring the position of dowel bars embedded in concrete. The device helps in determining the horizontal alignment, vertical alignment, side shift and depth of the dowel bar from the top of the pavement (Rao, 2009).

An advantage of the MIT Scan 2 is that it can be used as soon as the pavement can be walked on. This allows the contractor to take corrective action immediately. Another advantage is the ability to measure the location of the entire bar for each bar across a joint, not just a small portion of one bar. Additional benefits of MIT Scan 2 include being nondestructive in nature, rapid and simple to operate.

This test could be used both as a Quality Control and as an Acceptance test.

HIPERPAV III – Construction Issues (Construction Stage). HIPERPAV is a software program, developed through research sponsored by FHWA, that can be used to predict early age development of concrete strength and internal slab stresses related to moisture and temperature changes within the pavement.

There are several factors that influence the cracking risk of concrete during the initial days including mixture design, pavement design, construction methods, and weather. HIPERPAV is a Windows based software package designed to assess the

influence of these factors on the early-age behavior of concrete pavements and indicates the likelihood of early age cracking (Rasmussen, 2001).

The use of HIPERPAV is mandated in states such as California, Wisconsin, Ohio and Delaware. HIPERPAV is a contractor's tool to reduce the risk of random cracking.

The current version of the software includes:

- The ability to model and compare different construction scenarios. Once the base file is created, it should take less than 10 minutes to input the various features from each paving day and run the analysis for pavement placed at different times during the day.
- Weather data can be automatically downloaded from the National Oceanic and Atmospheric Administration's website.

Cost. Table 1 shows the approximate cost of the equipment discussed above as well as the time required to run a single test. Please note that these time and cost numbers are very approximate and are only presented to give a general idea on how much would it cost to incorporate these new tests into a quality assurance program.

Table 1: Time and Costs Associated with the New Tests

Test / Technology	Cost of Equipment	Additional Costs	Technician Time to perform a single test including set up and cleaning etc. Minutes		Suggested Frequency of Testing	
					Mixture Design Phase	Production / Construction Phase
Box Test	\$250	\$0	15	Per Test	Iterative	1
Semi-Adiabatic Calorimeter	\$3,500	\$0	15	Per Test including data interpretation	1	Twice per day
Surface Resistivity	\$5,000	\$0	5	Per Test	Iterative	Twice per day
Super Air Meter	\$2,500	\$0	20	Per Test including cleaning	Iterative	Minimum 3 tests per day
MIT Scan T2	\$21,000	\$2 per Target	10	per location (placement and measurement)	NA	Project Requirement
MIT Scan 2	\$60,000	\$0	5	per joint	NA	At least 10% of the joints
HIPERPAV III	\$0	\$0	20	Per Run	1	1



Box Test



V-Kelly Test



Semi-Adiabatic Calorimeter



Surface Resistivity



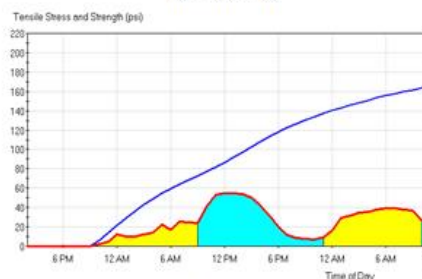
Super Air Meter



MIT Scan T2



MIT Scan 2



HIPERPAV

Figure 1: New Tests / Technologies Proposed for Inclusion in Quality Assurance Programs

Limits

Testing alone is of little value. Utilizing the test results are the heart of a quality effort. Control charts plot consecutive test results to provide a visual track of the trends of the production. Setting limits that trigger actions is the companion step.

The contractor will set action limits to mark the point when something must be changed if a limit is crossed. Specification limits are set by the agency to define acceptable work. Engineering limits are the final step beyond which, the product is unacceptable. Between the specification limits and the engineering limits, agencies normally set degrees of penalty to account for the deficiency of the work.

Summary

An effective Quality Assurance (QA) program is built upon a culture of quality for both the agency and the contractor from the beginning when the project is being scoped through the final acceptance. The program is a systematic approach that does not prevent all problems from occurring during concrete paving operations but greatly reduces the risk. The QA program includes agency acceptance based on testing for desired outcomes, contractor quality control spelled out in a Quality Control Plan, and the utilization of new technologies/techniques. The QC/Process Control aspect of the QA program provides the contractor the tools necessary to respond more quickly and recognize when there are potential problems on the horizon. The return on the investment in an effective quality assurance program far exceeds the costs associated with it for both agency and contractor.

In this paper, the authors argue that the benefit of a good quality assurance program far outweighs the costs associated with it for both agency and contractor. New technologies are described that can provide information that allow monitoring of the properties critical to pavement longevity. Many are nondestructive and thereby reduce quality control costs compared to traditional monitoring tests. The intent of this paper is to show how a good quality assurance program could benefit both the contractor and the agency without adding significant cost.

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