No. 1 TECH BRIEF December 2024

Advancing Concrete Pavement Technology Solutions

QUALITY ASSURANCE, QUALITY CONTROL, AND QUALITY CONTROL PLANS IN PRACTICE FOR CONCRETE PAVING

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SPONSOR

Federal Highway Administration

Part of Cooperative Agreement 693JJ31950004, Advancing Concrete Pavement Technology Solutions

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Summary and Disclaimers

The purpose of this tech brief is to provide an overview of agency quality assurance (QA) programs and their benefits, an overview of contractor quality control (QC) and its benefits, and the use of QC plans for concrete paving projects. The document is intended for highway agency and contractor engineers.

Introduction

Quality control (QC) by contractors, concrete suppliers, and materials suppliers is an integral component of a transportation agency's quality assurance (QA) program and supports the construction of quality concrete infrastructure. Recently, the Federal Highway Administration (FHWA) sponsored the development and publication of *Quality Control for Concrete Paving: A Tool for Agency and Industry* (Cavalline et al. 2021a), which provides an overview of QA and QC for concrete paving and aims to help both contractors and agencies improve or enhance their existing quality programs. Based upon the material presented in *Quality Control for Concrete Paving: A Tool for Agency and Industry*, this tech brief summarizes the characteristics and benefits of QA and QC and provides an overview of QA and QC programs and QC plans.

Characteristics and Benefits of Quality Assurance and Quality Control

Quality construction is central to the mission of FHWA and other agencies and is achieved in part through the QA and QC efforts of agencies, contractors, and materials suppliers.

Quality Assurance

The *Glossary of Transportation Construction Quality Assurance Terms* (TRB 2018) defines QA as follows:

> (1) All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service; or (2) making sure the quality of a product is what it should be. QA addresses the overall process of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible.

In a QA program, agencies are primarily responsible for acceptance of the work performed by contractors.

To support the acceptance process, agency personnel are responsible for monitoring the contractor's QC activities to ensure that they meet the agency's (minimum) requirements, measuring and evaluating the quality of the final product, and determining the final payment value of the completed work (Fick et al. 2012). The benefits of a QA program to an agency include the construction of infrastructure that performs as intended, with lower costs incurred over the facility's service life.

Federal regulation 23 C.F.R. § 637 requires state highway agencies to have a QA program. Although agencies are permitted to develop, and have developed, QA programs that meet their specific needs and risk tolerances, all QA programs are required to have six core elements (Dvorak 2019). These six core elements—contractor QC, agency acceptance, personnel qualification and certification, laboratory qualification, independent assurance, and dispute resolution for materials testing—are shown in Figure 1.

All six elements of a QA program work together to support the construction of quality projects. Each entity within a QA program has certain roles and responsibilities that support the success of the program, although interdependencies among these six elements require collaboration among the agency, contractors, suppliers, and other industry stakeholders on a regular basis.

Adapted from an image provided by Dennis Dvorak, FHWA, used with permission

Figure 1. Core elements of a quality assurance program

The following resources provide a more comprehensive overview of agency QA programs:

- Regulation 23 C.F.R. § 637
- *TechBrief: Independent Assurance Programs* (FHWA 2012)

Quality Control

The *Glossary of Transportation Construction Quality Assurance Terms* (TRB 2018) defines QC as follows:

> The process specified by the agency for a contractor to monitor, assess, and adjust their production or placement processes to ensure that the final product will meet the specified level of quality. QC includes sampling, testing, inspection, and corrective action (where required) to maintain continuous control of a production or placement process.

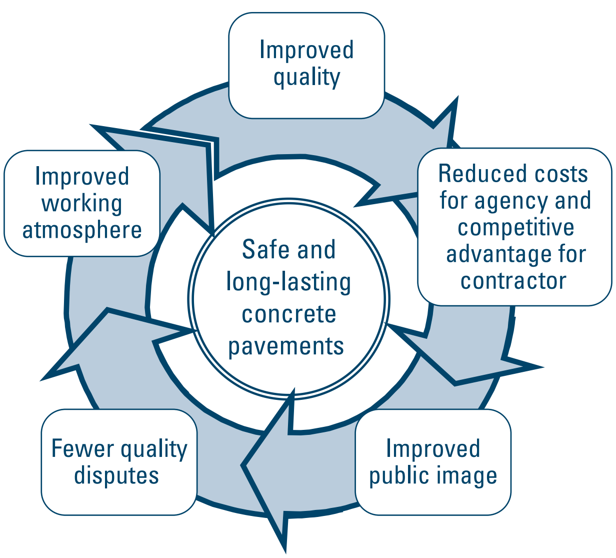
Central to QC are organizational-level quality management programs and project-level QC plans. Jointly, these activities and processes ensure that the appropriate elements of QC are implemented to meet the quality requirements or standards for the product(s) produced and work performed. For the purposes of this tech brief, "contractor" generally refers to a party preparing any QC plan or component of a QC plan. In instances where specific parties are intended, more specific terms (such as prime contractor, subcontractor, materials supplier) are used.

A robust contractor QC program and the implementation of a comprehensive QC plan provide confidence to agencies and other stakeholders that when the plan is followed, specification provisions will be met. Agencies benefit from QC in other ways as well. Within an agency's QA program, for example, acceptance sampling and testing, also referred to as verification sampling and testing, verify the quality of the contractor's work and the reliability of the contractor's QC. The acceptance sampling and testing performed by an agency (or agency's representative) is separate from the contractor's QC testing and typically aims to confirm the contractor's QC test results using fewer or less frequent tests. Due to resource limitations and other reasons, however, some agencies incorporate validated QC data from the contractor into the acceptance process, relying upon the contractor's QC data to help provide confidence that the work is in conformance with project plans and specifications and will ultimately meet acceptance criteria. The contractor's QC testing may be included in the agency's acceptance decision if the agency has independently validated the QC testing. This approach is important when statistical acceptance procedures, such as percent within limits (PWL), are used by an agency. Use of the contractor's QC data to support the acceptance decision is an important benefit of QC to the agency, though using more data in the acceptance decision reduces risk for both the agency and contractor.

The benefits of a QC plan are not limited to agencies, however. Nonconforming work is detrimental to contractors due to the costs of correction, the impacts of rework on scheduling, the impacts on other work due to the need to allocate resources to the nonconforming project, and reputational damage. Ultimately, substandard performance due to poor quality control can lead to an agency's reluctance to use a particular product or material, retain a certain contractor, or select a particular material type for its roadway network. A well-implemented QC plan, in contrast, provides many benefits to contractors, including increased profitability, reduced rework, greater pay factors, improved public image and customer satisfaction, and, in some cases, improved safety (Figure 2). Contractors can achieve these benefits through incorporating appropriate provisions into their operations and QC plans.

The establishment of an organizational-level quality management program can similarly provide many benefits to contractors, but doing so requires resources. Nonetheless, most organizations find that the benefits of investing in their quality management program far outweigh the costs. In many studies, the costs incurred to prevent failures have been shown to be significantly lower than the costs associated with correcting failures after the fact. Even a small investment in preventing quality issues will pay large returns due to reductions in the cost of failures (Juran and Godfrey 1999).

An example of such benefits was relayed to FHWA by the QC manager for a concrete supply company. The company partnered with other concrete supply businesses to seek a group insurance policy. During the audit required to apply for the insurance policy, the company identified that 80% of its workplace injuries occurred during rework (work performed to correct quality issues). The company decided to invest in improving its QC, which significantly reduced the number of workplace injuries. Consequently, money was saved on the company's insurance premium, in addition to the likely benefits of improved worker safety (in terms of a reduction in injury claims and lost-time incidents), reduced costs associated with rework, and increased productivity.



Adapted from Fick et al. 2012

Figure 2. Benefits of improved quality for transportation facilities

Moreover, contractors that have instituted robust QC programs throughout their organizations will be better prepared for an upcoming shift in the highway construction industry. In recent years, some agencies have begun moving toward performance specifications and performance-engineered concrete mixtures (PEMs) as part of FHWA's PEM initiative. In contrast to mixtures based on prescriptive specifications, PEMs allow contractors and suppliers to use their knowledge to produce better quality concrete. As agencies implement performance-type specification provisions, contractor QC programs and plans will become an increasingly important component of project QA. During the transition to performance specifications, many of the prescriptive contractual requirements and responsibilities related to quality will be transferred to the contractor, along with some of the performance risks.

In addition to contractors and agencies, materials suppliers benefit from good QC as well. One cement supplier indicated that it could provide many examples in which data from its QC program prevented it from becoming involved in construction lawsuits. The supplier representative stated, "Facts are stubborn things, as they do not change. As such, facts (data) from your quality program can save a lot of potential issues and grief."

Overview of Quality Control

QC encompasses the personnel, equipment, practices, and processes required to control the quality of the product(s) being produced and work being performed, as well as the implementation of improvements to practices and processes. "What gets measured gets managed" is a common adage in quality management, and it follows that at the core of every QC program is the monitoring of key quality characteristics and a process for the continuous improvement of both those characteristics and the QC process itself. Effective QC does not rely upon the agency to notice quality issues or defective work; rather, issues are identified by the contractor through process control and self-inspection so that adjustments and corrections can be made prior to the agency's acceptance activities.

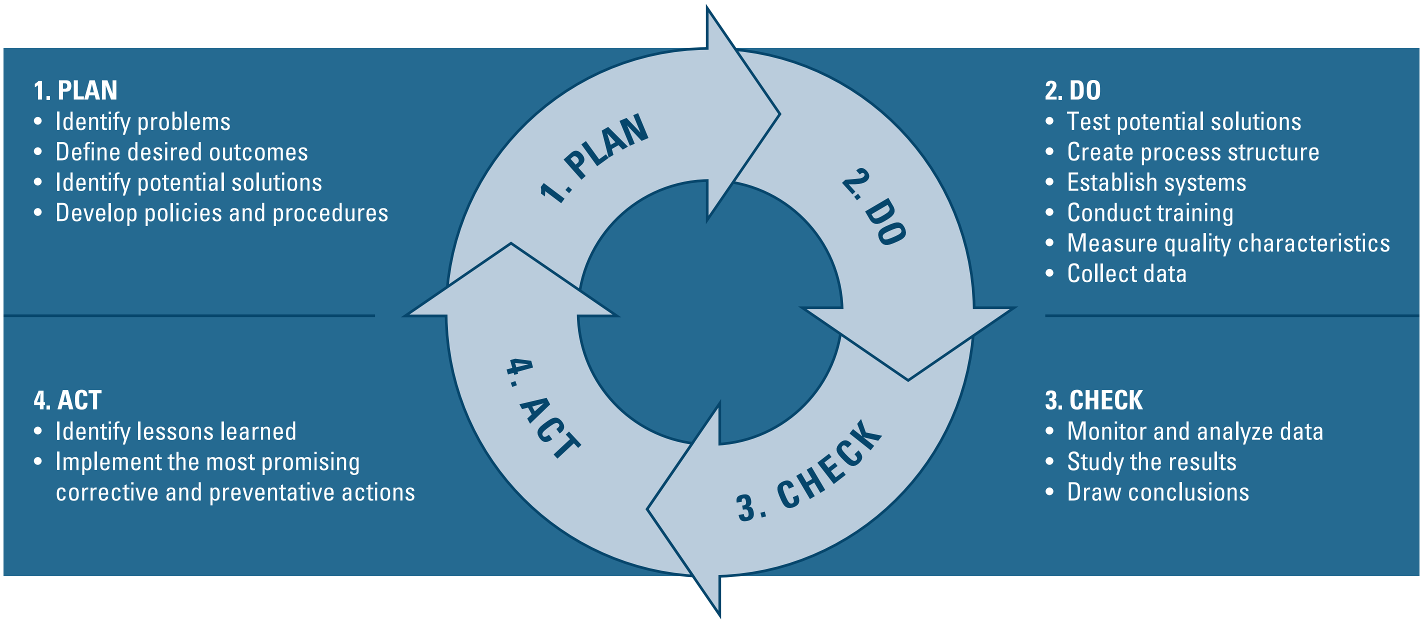


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Figure 3. Plan-do-check-act cycle

The Deming cycle, or the plan-do-check-act cycle (shown in Figure 3), is an important quality management approach describing a continuous improvement cycle. This approach originated almost a century ago and helped drive quality improvements in the manufacturing sector throughout the 20th century (Deming 1994), but it is still applicable today and is used in many manufacturing QC settings. This approach can be readily applied to the construction sector and incorporated by contractors into both organizational-level QC programs and project-level QC plans.

The quality improvement process begins with a plan (Step 1 in the cycle) that identifies goals such as achieving a higher production rate, reducing nonconforming material, lowering costs, or accomplishing other outcomes. Once specific goals are identified, policies and procedures that support the achievement of these goals are developed and implemented (Step 2 in the cycle).

Over time, as these policies and procedures become established, training and improvement continue and data are monitored and collected to check on key measures linked to the desired goals (Step 3 in the cycle). Data are analyzed using appropriate methods and presented using tools that enable the quality team to draw conclusions about the reliability of the processes and the quality of the outputs. Upon review of the data, areas for improvement and opportunities for growth or other benefits are identified. Ultimately, the quality team acts on these ideas, implementing corrective actions and continuing the cycle of improvement (Step 4 in the cycle).

Due to the unique nature of highway construction, the measures that need to be taken to ensure quality differ for each project. Contract documents (including plans, specifications, and special provisions) define the quality standards that an agency expects. However, it is up to contractors to specify the means and methods necessary to provide confidence that quality is attained by their own personnel, equipment, and processes.

Organizational-Level Quality Control Programs

Agency requirements for QC are typically established on a project basis and generally only necessitate minimum levels of personnel qualification/certification, sampling and testing, documentation, and reporting. For contractors to both meet project-level QC requirements and support continuous improvement throughout their operations, an organizational-level QC program that supports the long-term goal of providing high-quality materials and construction on all projects is essential.

Additionally, many quality management activities are not tied to specific projects but instead occur continuously “in the background” to support QC efforts across projects and within the company. In this way, a company’s broader quality management program, which includes QC efforts as well as more general matters such as human resources and staffing, integrates the various activities and processes within a company to support continuous improvement of the quality of work and to promote a culture of quality within the company. Ultimately, the contractor’s QC program should serve as the foundation for the QC efforts for every project the contractor is engaged in, and the practices included in the program should transfer to and support the QC plan prepared for each project.

> Contractors' QC programs include procedures and practices that occur continuously within the organization and that support the QC plans and process control required for each project. QC programs also establish leadership roles and authority and assign responsibilities to personnel to support quality-related activities and initiatives.

For contractors, agencies, and other organizations involved in concrete construction, an effective quality management program should "enable mechanisms of change" (Swift et al. 1997) with provisions that include training and education, communication, assignment of responsibilities, standardization of best practices, and other means to support excellence and improvement. The program should be customer-focused and established and supported by management and should engage stakeholders from across the organization: executives, project managers, technicians, field personnel, purchasing personnel, human resources personnel, and safety personnel, among others.

Personnel in all roles within the organization should be empowered and encouraged to identify areas for improvement and have ownership in the improvement process. Employee buy-in to the organization-wide charge of continuous quality improvement will support the success of initiatives and can improve morale and retention.

The framework, mechanisms, and processes used in quality management programs differ among organizations depending on the scope of work, operational structure, needs, and preferences of each. The establishment of a quality management program often includes the following (Thorpe and Sumner 2004, Cavalline et al. 2021b):

- Defining the organization's structure and operations
- Identifying key processes, interfaces, and outputs
- Identifying personnel roles, responsibilities, and authority
- Developing formal guidance for procedures and practices so they can be implemented in a way that reflects the organization's best practices at that moment in time

The most important part of an organization's quality management program is the establishment of procedures and practices at the core of operations. Regardless of the organization's structure or, for contractors, specialization, these formal procedures and practices should support the following (Taylor et al. 2019):

- Personnel training
- Laboratory certification
- Standardization of processes and best practices
- Procurement of products and services
- Preliminary material testing
- Equipment and process monitoring
- Communication and information flow
- Documentation and recordkeeping
- Control of documents

Each procedure and practice should include means to take corrective action and support the continuous quality improvement cycle. If continuous quality improvement is fostered, best practices will become more readily adopted throughout the organization and will change and improve over time. For contractors especially, growth, market adaptation, and technology advancements will also require changes to an organization's procedures and practices. Formal guidance should be updated accordingly, and quality management documents should essentially be "living" documents.

> Quality must be a mindset embraced by all personnel within a company because all individuals engaged in a project play a role in the quality of the work performed.

Fostering a culture of quality from the top down is critical to ensuring the buy-in of personnel working directly for the contractor as well as for subcontractors, materials suppliers, and external personnel performing QC activities. As part of this culture, transparency and communication between all individuals, from managers to laboratory technicians to field crews, are critical to ensuring that opportunities to improve quality are identified and improvement measures are implemented and monitored. Quality management requires continuous improvements such as these, and the lessons learned on each project should be incorporated into future QC activities, processes, and plans. In addition to open communication within a company, open communication with agency personnel and their representatives helps improve the quality of a given project and reduces the potential for conflict. Organizational charts should establish reporting authority as well as designate the individuals responsible for quality. It is also important for an organization to embrace the philosophy that quality should not be secondary to production.

Project-Level Quality Control Plans

All parties that contribute in some way to a given project, including the prime contractor, subcontractor, materials suppliers, and fabricators, contribute to QC. However, it is the responsibility of the prime contractor to lead and oversee the QC activities and to ensure that personnel from all entities are engaged and focused on contributing to quality work. Central to this effort at the project level is a QC plan. The FHWA defines a QC plan as "a project-specific document prepared by the contractor which identifies all QC personnel and procedures that will be used to maintain all production and placement process 'in control' and meet the agency specification requirements" (FHWA 2008).

In the past, agencies controlled quality through the use of method specifications and by closely directing the work performed by contractors. As agencies have transitioned to the use of QA specifications, the QC responsibilities previously assumed by the agency have been transferred to the contractor, and the QC plan has become a tool that the agency can use to ensure that the contractor is competent, capable, and prepared to assume responsibility for quality. Whether required by an agency or not, a QC plan is a beneficial tool that provides written guidance on the procedures and activities required to support the delivery of a quality project.

A QC plan is often submitted to an owner, such as an agency or other entity, or an owner's representative, prior to the start of the work. The QC plan can be a standard plan used internally by the contractor (modified as necessary to meet project requirements) or can be developed specifically to meet an agency/owner's requirements for a project. Either way, the QC plan should fit the scope of work for that project. While an agency may establish the minimum required components of a plan and the level of detail required, to successfully complete most projects contractors must include more in their QC programs and plans. The contractor has the freedom to develop and implement a QC plan that best suits both the project's requirements and the contractor's processes, personnel, and risk tolerance.

In short, a QC plan is not a one-size-fits-all document. "Boilerplate" QC plans that have not been modified to meet project-specific needs and requirements and/or do not contain the information necessary to effectively support process control provide no assurance that a quality project will be delivered.

Different agencies have different requirements regarding the components of a project for which a QC plan must be prepared and the items that must be included in a QC plan. Often, agencies require a QC plan for some components of a project but not others. Therefore, the entity (or entities) preparing and submitting the QC plan(s) may differ depending on the following:

- The components of the project for which the agency requires a QC plan
- The components of the project for which the prime contractor or subcontractors deem a QC plan to be necessary or desirable
- Relationships between the prime contractor, subcontractor, and materials suppliers
- The project delivery method

A comprehensive QC plan for a concrete paving project is often prepared by the prime contractor, although parts of the plan can be prepared by others based on agency requirements and project responsibilities. For example, agencies often require QC plans from materials suppliers as part of certified producer programs, and these QC plans may or may not need to be included in a project-level QC plan. Subcontractors performing work in areas such as grading, utilities, or other specialties may provide their own QC plans to the agency or may instead contribute to the QC plan submitted by the prime contractor. For projects that include bridge components, a QC plan from a bridge contractor may be required as part of the paving contractor's plan if the latter is the prime contractor. Conversely, if the bridge is the key component of the project, the paving contractor's QC plan may be included as a component of the QC plan prepared by the bridge contractor.

> Regardless of whether a QC plan is tried and true or developed specifically for a unique project, the objective of a QC plan remains the same: To establish a framework of activities and actions that, when implemented over the course of a project, enable a contractor to reduce the risk of out-of-specification work and associated delays, costs, and impacts to reputation.

Over time, experience will allow the contractor to improve and refine the QC processes used and the QC plans prepared for subsequent projects. As such, the contractor should view a QC plan as a highly beneficial tool that supports the company's goals of profitability and risk mitigation, not as an undesirable addition to the list of agency requirements.

Components of a Quality Control Plan

The provisions included in a QC plan should provide a proactive approach to ensuring that quality standards are met during construction. The plan should describe specific measures, including process control activities such as self-inspection, sampling, and testing, to ensure that issues are identified while adjustments can still be made (in real-time, when possible) instead of after work is completed and corrective actions are required. The plan should also clearly designate roles, responsibilities, and authorities and the person(s) ultimately responsible for quality. The QC plan should give the owner confidence that the project will reliably meet specifications.

A QC plan typically includes the following elements:

- A description of the relationships between the parties involved in the project or in the portion of work covered in the QC plan. Communication between the contractor's QC personnel and the contractor's production personnel and between the agency's personnel and the contractor's QC personnel is critical to maintaining a workflow and resolving potential problems. For this reason, contact information for key personnel in the project's communication chain should be provided.
- A list of personnel involved in the project or in the portion of work covered in the QC plan, including their certifications and relevant experience. The personnel listed should include managers, superintendents, foremen, technicians, and others.
- The role and responsibilities of each person involved in the QC process and a hierarchy or line of responsibility that includes information on decision-making authority.
- Documentation required for the materials and manufactured products used in the project.
- Reference to the appropriate specification provision(s) for each material or component included in the project. The tests to be performed and test methods used, a sampling plan, testing frequency, and other relevant information supporting the testing program should be adequately described.
- A description of monitoring activities, including frequency and other relevant information.
- A procedure for evaluating data, including analysis methods and tools. This procedure should include both limits for action, indicating when corrective action should be taken or processes should be adjusted, and limits for suspension, indicating when processes should be stopped and adjusted prior to continuing production.
- A description of the means for maintaining control of the portion of work covered in the QC plan, including methods (with corresponding channels of authority) to adapt processes or stop work until it complies with expectations.
- Corrective actions that should be taken to both address out-of-control processes and remedy deficient work. Levels of corrective action could be established for various items to address issues that (1) may simply need correction or adjustment, (2) may require suspension of the work, or (3) may require corrective work. For example, the contractor could propose that concrete production be suspended when the results of air content tests fall below a certain threshold for three lots. Along with corrective actions, provisions could be included that detail the means to proceed with limited operations when operations are suspended (including information on such items as production rate/speed, testing frequency, and desired results) until satisfactory test results are achieved.
- Information regarding documentation of the work supporting the QC plan and the dissemination and archiving of this documentation.

Given the purpose of a QC plan, as well as the typical provisions required by many agencies, it is clear that an effective QC plan is not an empty, feel-good promise that a quality project will be delivered by the contractor. The plan should not simply restate the agency's specifications without providing details regarding how these specifications will be met and requirements achieved. Instead, it should provide an adequate level of detail and sufficient information as to "who, what, when, where, and how" to support efficient and successful implementation by contractor personnel.

Conversely, a QC plan is not useful if it is overly complicated, unorganized, or presented in a manner that cannot readily be followed by the personnel responsible for its implementation. For example, the QC plan should not require the collection of a certain type of data if the plan does not include provisions to use those data for improvement or other purposes. The QC plan should be written in clear language and should be structured in a manner that makes it straightforward for personnel to interpret and execute.

> The QC activities required to successfully complete each concrete paving project will differ, and each contractor approaches QC in a unique way. In all cases, however, the QC plan should be well structured, provide sufficient detail, and be straightforward for personnel to interpret and execute. A QC plan with the appropriate provisions will support the construction of a quality product and benefit all stakeholders.

Appendix C of *Quality Control for Concrete Paving: A Tool for Agency and Industry* (Cavalline et al. 2021a) presents an outline of a QC plan for concrete paving projects. The outline models the recommended structure for this type of document and provides a flexible framework that contractors can use to develop a new QC plan or enhance existing QC approaches. A condensed version of the outline that includes the main section headings is presented below. The reader is directed to Cavalline et al. (2021a) for the full outline as well as a model QC plan based on an approach recommended by the Northeast Transportation Training and Certification Program (NTTCP).

Other key resources to consult in developing a QC plan include the following:

- National Highway Institute (NHI) Course Number 131141, *Quality Assurance for Highway Construction Projects* (NHI 2020)
- *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual* (Taylor et al. 2019)
- *Field Reference Manual for Quality Concrete Pavements* (Fick et al. 2012)

Sections 1 and 2: General Quality Control Information and Applicable Specifications and Standards

Sections 1 and 2 are general in nature but should be tailored to each project in light of the applicable specifications and mixture design.

1.0 Quality Control Organization and Qualifications

- 1.1 Narrative describing the contractor's approach to QC
- 1.2 Organizational chart showing responsibility and authority
- 1.3 Project-specific information
- 1.4 Subcontractor roles and responsibilities
- 1.5 Communication protocols
- 1.6 Summary of staff experience and certifications
- 1.7 Listing of all QC resources
- 1.8 Listing of all concrete paving equipment

2.0 Applicable Specifications and Standards

- 2.1 Concrete material specifications
- 2.2 Concrete paving specifications
- 2.3 Specified acceptance criteria
- 2.4 Testing standards: AASHTO, ASTM, etc.
- 2.5 Approved mixture design with supporting test data

Sections 3 through 6: Concrete Mixture Production and Concrete Paving Process

Sections 3 through 6, as outlined below, should provide detailed information for every step of the concrete mixture production and concrete paving process. These details should be developed based on the best practices documented in the appropriate chapters of *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual* (Taylor et al. 2019) and *Field Reference Manual for Quality Concrete Pavements* (Fick et al. 2012) or other appropriate and widely accepted industry standards.

The typical content for each step outlined in Sections 3 through 6 should include the following:

- Narrative describing the construction process. In addition, photos and illustrations can be very effective at communicating and setting expectations of what the construction and QC processes will look like.
- QC measurements, including frequency, locations, action limits, and suspension limits
- Checklist items, including frequency and appropriate actions if deficiencies are noted
- Visual inspection items, including frequency and appropriate actions if deficiencies are noted
- Corrective actions for any item that is nonconforming to the QC plan

3.0 Prepaving Activities

- 3.1 Subgrade
- 3.2 Subbase

4.0 Mixture Production: For each subitem, fully describe the approach for producing a uniform mixture that conforms to the specifications; **provide details regarding QC measurements, checklists, visual inspections, action limits, suspension limits, and corrective actions for nonconformance.**

- 4.1 Material sources
- 4.2 QC plans from suppliers
- 4.3 Aggregate stockpile management
- 4.4 Plant calibration
- 4.5 Mixture designs by phase and/or season
- 4.6 Batching sequence
- 4.7 Mixing time
- 4.8 Verification of mixture proportions used by the batching control system
- 4.9 Moisture compensation for free water in the aggregates
- 4.10 Transportation of concrete

5.0 Concrete Paving: For each subitem, fully describe the approach for the construction of concrete pavement that conforms to the specifications; **provide details regarding QC measurements, checklists, visual inspections, action limits, suspension limits, and corrective actions for nonconformance.**

- 5.1 Paving schedule
- 5.2 QC plans from subcontractors
- 5.3 Fixed-form placement
- 5.4 Slipform placement

6.0 Weather Adjustments: Fully describe all precautions and adjustments that will be made for daily and seasonal changes in weather.

- 6.1 Hot weather concreting
- 6.2 Cold weather concreting
- 6.3 Imminent rain
- 6.4 Evaporation rates above 0.2 lb/yd^2/hr

Closing

QA programs provide assurance that an agency will receive the expected level of quality in the materials and work it pays for and that the constructed product will perform satisfactorily over its anticipated service life. Contractor QC is a critical component of an agency's QA program and will play an increasingly important role as agency resources become stretched and the shift toward performance specifications prompts agencies to consider transferring performance risks and responsibilities onto the contractor. QC is also important to the success of a contractor because it increases profitability, lowers risk, and improves reputation, and the money invested in QC activities regularly provides benefits far exceeding the amount invested. For both QA and QC, the trust and partnership fostered between the agency and the construction industry on quality-related initiatives provides benefits to all stakeholders.

QC requires both organizational-level quality management programs and project-level QC plans. Jointly, these activities and processes ensure that the appropriate elements of QC are implemented to meet the quality requirements or standards for the product(s) produced and work performed.

A successful QC program begins with activities that occur in the "background" of a company's day-to-day operations, regardless of the company's ongoing or upcoming projects. They include personnel training and certification, equipment maintenance, and other routine activities that support the improvement of talent as well as the fitness of equipment for use. A QC program should also include provisions for appropriate communication and recordkeeping, ensuring that a process is in place to support the flow of instructions and information.

More broadly, managing quality within an organization requires the establishment of a culture of quality, good communication, established and understood procedures, and a focus on the continuous improvement of processes and personnel capabilities. Quality must be a mindset embraced by all personnel within a company because all individuals engaged in a project play a role in the quality of the work performed. Fostering a culture of quality from the top down is critical to ensuring the buy-in of personnel working directly for the contractor as well as for subcontractors and materials suppliers.

Whether required by an agency or not, a QC plan is a beneficial tool that provides written guidance on the procedures and activities required to support the delivery of a quality project. QC plans should be tailored specifically to each project and should not be "one size fits all" or reused from previous projects. The QC activities required for each project differ, and approaches are unique to each contractor. The guidance provided in this tech brief as well as in *Quality Control for Concrete Paving: A Tool for Agency and Industry* (Cavalline et al. 2021a) supports the development of detailed, usable QC plans for concrete paving projects that are tailored to project needs, contractor preferences, and risk tolerance.

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About the National Concrete Pavement Technology Center

The mission of the National Concrete Pavement Technology Center (CP Tech Center) at Iowa State University is to unite key transportation stakeholders around the central goal of developing and implementing innovative technology and best practices for sustainable concrete pavement construction and maintenance.