Evaluating the Impact of QC/QA Programs on Asphalt Mixture Variability

by

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ABSTRACT

This report describes a study conducted at the University of Wyoming by Dr. Khaled Ksaibati, Associate Professor of Civil Engineering, and Nathan Butts, graduate student of Civil Engineering. In this study, the researchers evaluated the effectiveness of quality control/quality assurance (QC/QA) specifications in decreasing hot mix asphalt (HMA) variability. A questionnaire was written to gather general information about the QC/QA specification programs that are being used in the United States, and an evaluation of the effectiveness of the QC/QA specification being used by the Wyoming Department of Transportation (WYDOT) in decreasing HMA variability was conducted as a case study.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background

In recent years, many of the state highway agencies (SHAs) have implemented the use of a quality control/quality assurance (QC/QA) specification for construction of asphalt pavements. The Wyoming Department of Transportation (WYDOT) implemented their QC/QA specification in 1997. The implementation of this specification is part of an effort to improve roadways in a cost efficient manner. QC/QA specifications are expected to increase the quality of asphalt pavements being constructed in both the performance and the life of the pavement. This is accomplished with constant sampling and testing throughout the production and placement of the hot mix asphalt (HMA). The idea is that constant monitoring throughout production and placement of the HMA will allow for quick detection and response to HMA that is out of specification. This testing is part of quality control, which is the responsibility of the contractor. With QC/QA, the contractor is responsible for the quality of the HMA being produced. The SHA is responsible for quality assurance and acceptance of the product being produced. This is the result of a shift in responsibility for quality that occurs with the implementation of a QC/QA specification. Before the use of QC/QA specifications, materials and methods specifications were commonly used. With this type of specification, the SHA was fully responsible for the quality of the pavements being produced as long as the contractor followed the specification.

1.2 Problem Statement

The promise of using a QC/QA specification is that a less variable HMA will be produced with constant control throughout production and placement operations. This reduction in variability decreases the cost of the pavement over time through better performance and longer service life. Implementing a QC/QA specification, also increases cost. This cost is associated with the increased amount of testing required by the contractor. Due to the recent implementation, the benefits of using QC/QA specification have yet to be fully determined. It is important to determine the impacts that QC/QA specifications are having on the asphalts pavements being constructed.

1.3 Objectives of Research

Improved performance and longer pavement life are the expected long-term results of using a QC/QA specification, the direct result of decreased variability about the mixture design of the HMA that is produced and placed. The main objective of this research is to evaluate the effectiveness of the QC/QA specification in decreasing HMA variability in an effort to measure the impact of using QC/QA specifications. WYDOT's QC/QA specification will be used as a case study.

A QC/QA specification is a small part of a quality assurance program. Also, a QC/QA specification in itself is a very general concept. As a result, there is a lot of room for variations within the quality assurance program, and within the specification itself that could drastically affect the performance of a QC/QA specification. Hence, it is necessary to have at least a basic understanding of all the QC/QA specifications that are being used. A questionnaire was written and distributed to the 50 different states to gather the appropriate information. The gathering of this information is a secondary objective of this research.

1.4 Report Organization

Chapter 2 of this report reviews the literature associated with QC/QA specifications. This chapter includes a definition of QC/QA specification, a review of HMA characterization, a summary of WYDOT's QC/QA specification, and a discussion of previous studies that have been conducted to evaluate QC/QA specifications. Chapter 3 discusses in detail the QC/QA asphalt pavement questionnaire distributed to the 50 states. A summary of the results of this questionnaire and a more detailed description of the Region 8 SHAs is presented. Chapter 4 describes the data collection process and the consistency of the set of data collected from WYDOT to evaluate the effectiveness of WYDOT's QC/QA specification in decreasing HMA variability. Chapter 5 consists of the statistical analysis that was performed on the data set collected from WYDOT. Chapter 6 summarizes the tasks and conclusions of this study, and presents recommendations for future research.

2. LITERATURE REVIEW

2.1 Introduction

Construction of quality pavements in a cost-effective manner has always been the goal of the SHAs. In an effort to improve construction of asphalt pavements, many SHAs have recently adopted the use of statistically based QC/QA specifications, which are also known as quality assurance specifications (TRB, 1999). A QC/QA specification is meant to promote the construction of better performing and longer lasting roadways by decreasing HMA variability throughout the production and placement operations.

Quality assurance specifications are specifications that combine elements of end-result specifications and material-and-methods specifications (TRB, 1999). Patel, et al. (1997) write, "As with end-result specifications, the Contractor is responsible for quality control and the highway agency is responsible for acceptance of the product" (p. 66). Before the use of QC/QA specifications, materials and methods specification was common practice among the many SHAs. With materials and methods specifications, the SHA was fully responsible for the final quality of the pavement produced as long as the contractor fulfilled the requirements of the specification. The use of materials and methods specifications was very successful for many years, but changes in the pavement construction industry demanded improvement. The QC/QA specification accommodated these changes by shifting the responsibility for quality control from the SHA to the contractor. QC/QA specifications improve contractor-state relations, stimulate contractor innovation and competition, and most of all improve the quality of pavements constructed under its use.

This chapter is meant to provide a wide understanding of QC/QA specifications. To begin, QC/QA specifications are defined and contrasted with other types of construction specifications. Next, HMA characteristics are reviewed. This is followed by a summary of quality assurance program components and an examination of their effects on the performance of a QC/QA specification. WYDOT's QC/QA specification program is then outlined. The chapter ends with a presentation of evaluations that were previously performed on QC/QA specification programs, and a discussion of the conclusions of those evaluations.

2.2 Asphalt Pavement Construction Specifications

2.2.1 Overview

Transportation Research Board Committee A2F03 (1999) classifies construction specifications in the following manner: "Highway construction specifications may be classified according to (I) who is responsible for the quality of construction, (II) the type of sampling employed, and (III) the relationship between quality criteria and constructed product performance" (p. 14). Materials and methods, QC/QA, and end result specifications are the three types of specification commonly described when discussing who is responsible for the quality of construction. QC/QA may describe who is responsible for the quality of construction, but it does not describe how the quality is to be controlled, or how the quality of the final product is to be measured and weighed. Therefore, all QC/QA specification programs may have the same basic elements, but there are many variations in supporting specifications, creating many different QC/QA specification programs. Statistical, performance-related, performance-based, and performance specifications are the some of the supporting specifications that are bound to vary drastically among the different SHA programs. The type of sampling that is to be done and the relation to performance classifies these specifications (TRB, 1999). Patel et al. (1997) write, "Specification development is by nature an evolutionary process" (p. 66). All SHAs are unique and require a unique specification that will fit their situation at a given time. The changes that do occur in specification are usually slow and are motivated by the desire to achieve a high quality result at reasonable costs (Solaimanian, Kennedy, and Elmore, 1997).

2.2.2 Materials and Methods Specifications

TRB (1999) writes, "Materials and methods specifications, also called method specifications, recipe specifications, or prescriptive specifications are specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material" (p. 13). In the way of responsibility for the quality of construction, materials and methods specifications has zero-percent Contractor responsibility and 100 percent SHA responsibility. This type of specification has been used for many years by SHAs to control quality (Benson, 1995). However, changes in the pavement construction industry demanded a move away from this type of specification. There are many changes, but there are three in particular. First, the burden for quality control and inspection, both labor-intensive activities, was in the hand of the SHA (FHWA, 2001). The full-time presence of experienced field personnel was required to properly enforce a materials and methods specification (Benson, 1995). This proved to be no problem when there was a large, experienced staff, but SHAs are losing manpower at an unprecedented rate and are finding it harder to meet this demand (FHWA, 2001; Patel *et al.*, 1997). Second, materials and methods specifications require a representative of the highway agency to direct each step. The SHA tended to be obligated to accept the completed work regardless of quality (TRB, 1999; Willenbrock and Marcin, 1978). Method specifications do not stand up well to legal challenges when projects fail and the parties involved cannot resolve their differences (Willenbrock and Marcin, 1978). The FHWA (2001) writes, "The Contractors invariably win in court when they assert the method specification was followed and the materials still failed." Third, the growing public demand for better-quality roadways indicates that alternative methods for effectively constructing and maintaining state roads need to be considered (Patel *et al*, 1997).

2.2.3 End Result Specifications

End result specifications are the opposite of methods and materials specifications in many ways. End result specifications are based on properties indicative of potential pavement performance, which place the responsibility for the quality of construction on the contractor (Emery, 1995). The SHA's responsibility is to accept or reject the final product or to apply a penalty system that accounts for the degree of noncompliance with the specifications (TRB, 1999; Willenbrock and Marcin, 1978). Willenbrock and Marcin (1978) write, "This type of specification places no restrictions on the materials to be used or the methods of incorporating them into the completed product" (p. 8). Unlike materials and methods specifications, end result specifications involve the contracting community more directly in the control of the product quality by making contractors responsible for achieving quality and letting them decide how to do it (Benson, 1999; Benson, 1995). Benson (1995) writes, "Using this type of specification makes sense from economic as well as contractual standpoints. Contractors are in a better position to manage the day-to-day quality of their product because of their direct involvement with suppliers and subcontractors and their direct control over construction activities" (p. 3). He (1995) also writes, "This type of specification allows the contractor to experiment with new construction methods and will do so if it offers the possibility of a competitive advantage. The overall result is, theoretically, a high-quality product that meets design expectations" (p. 3).

2.2.4 QC/QA Specifications

Also called a quality assurance specification, a QC/QA specification is a combination of end result specifications and materials and methods specifications (TRB, 1999). The contractor is fully responsible for controlling the quality of the work, and the state's responsibility is to ensure that the quality achieved is adequate to meet the specification bid (Benson, 1999). Benson (1999) writes, "The promise of QC/QA is that better quality can be achieved by allowing the contractor more direct control over his or her operation. In theory, control of work is more efficient when the control function is fully integrated into the contractor's operation" (p. 89). Through constant testing and monitoring, feedback is instantaneous and adjustments can be made quickly. This decreases variability throughout the production and placement of the HMA. This inherently will increase the quality of the product by increasing adherence to the project's mixture design. The mixture design describes the most durable and best performing HMA for the project. Also, like end result specifications, QC/QA specifications free the contractor to innovate, increasing competitiveness, and create more opportunities for efficiencies (Benson, 1999). Benson (1999) writes, "The expected result is that either the quality of work continues to meet specifications at a lower cost, or the quality improves at the same or increased cost. If increases occur, they should be more than offset by the cost savings realized through extended project life" (p. 89).

2.3 HMA Components Review

2.3.1 Overview

When controlling the quality of a product it is important to know the properties and characteristics that describe a quality product, and to understand the effects that small variations on those properties may have. HMA consists of only three components apart from additives. These are aggregate, asphalt cement, and air voids. Only when the proper amounts of each of these exist within HMA will a quality pavement exist. Much of this knowledge goes into the mixture design procedures. Though the properties considered vary from one mix design procedure to the next, all mix designs are based on the fundamental concepts that have been found to create the highest performing pavement for a given situation. HMA mix designs should be developed with the following objectives in mind: resistance to permanent deformation, fatigue resistance, resistance to low temperature cracking, durability, resistance to moisture induced damage, skid resistance, and workability (Roberts, Kandhal, Brown, Lee, and Kennedy, 1996). The three types of mixture design methods presently used in the United States are the Marshall, Hveem, and the Superpave mix design procedures.

2.3.2 Aggregate Gradation

Roberts et al. (1996) write, "There are several aggregate properties that are important, but routine testing during construction is usually limited to gradation only" (p. 399). This gradation is determined from a sieve analysis. Robert et al. (1996) also write, "For QC/QA testing, aggregate samples are typically taken from the stockpile, cold feeder belt, hot bins (if applicable), and extracted asphalt mixture" (p 399). The aggregate that is extracted from a sample of HMA is the only sample of aggregate that is representative of the final product. This sample is usually collected from the road's surface after being placed by the paver and before compaction.

An aggregate gradation that deviates from the job mix formula (JMF) will affect the quality of the HMA in many ways. It affects the stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage (Roberts et al. 1996). An aggregate gradation must provide for a dense mat, while at the same time leaving adequate room for the liquid asphalt. If the gradation for HMA is one that gives the densest particle packing, bleeding and rutting will occur. If the gradation allows for too many voids, the quality of the pavement will decrease with increased exposure to air and water within the mix.

2.3.3 Asphalt Content

The optimum asphalt content in HMA is determined through the mixture design methods from the compaction and volumetric data. It is important to control the asphalt content of a mixture to ensure satisfactory performance (Roberts et al. 1996). The asphalt content is measured using extraction methods, ignition, with a nuclear gauge, or measured with metering devices before it is mixed with the aggregate. The extraction method is the same as is used for aggregate extraction. The asphalt is separated from the aggregate using a solvent that dissolves the asphalt cement. The advantage of using extraction methods, ignition, or nuclear gauging is that the asphalt content being measured is representative of the final product. Asphalt content measured with metering devices is not necessarily representative of the actual amount but rather is only an average amount in the HMA that was metered. The amount of HMA that is metered is usually very large. Typically, one meter reading would represent the production of an entire day.

It is important to monitor the actual asphalt content, because it directly affects mixture properties such as asphalt film thickness, voids, stability (Hveem or Marshall), and Marshall flow (Roberts et al. 1996). Insufficient asphalt causes inadequate coating, low film thickness, difficult compaction, raveling, stripping, segregation, and shearing when cool (WYDOT, 2000). Excess asphalt causes flushing, bleeding, tenderness, low skid resistance, rutting, shoving, and shearing when hot. The asphalt cement is only meant to bind the aggregate together. The aggregate alone provides the structural strength of the pavement. HMA with high asphalt content depends more on the strength of the asphalt cement and less on the aggregate. With high asphalt content the pavement is not stable. Mix design procedures consider all the effects of asphalt content, and directs the asphalt content of the JMF accordingly. This value needs to be controlled through quality control so that the HMA that is being produced adheres as closely as possible to the mix design value.

2.3.4 Volumetric Properties

The control of the asphalt content and the aggregate gradation dictates control of the volumetric properties of the HMA. The volumetric properties of HMA include the voids in mineral aggregate (VMA) and the voids in the total mix (VTM) (Roberts et al. 1996). The amount of voids in a HMA mixture is probably the single most important factor that affects performance of the mixture throughout the life of the pavement (Roberts *et al*, 1996).

VMA is the total amount of voids within the compacted aggregate. VMA significantly affects the performance of a mixture. The amount of VMA must first be adequate to contain the required asphalt content, as mentioned earlier in the discussion of aggregate gradation. If the VMA is too low the mix will have low film thickness will result in a dry mix, and will have low durability. If the VMA is too high the mix will have high film thickness, and high durability (WYDOT, 2000). However, if the VMA is too high the mix may show stability problems and be uneconomical to produce (Roberts et al. 1996). VMA is a good performance measure in the quality control of the aggregate, because it considers the control of all sieve sizes.

VTM is related to both the gradation of the aggregate in the HMA and the asphalt content. It is the voids that remain after the aggregate and asphalt cement have been combined and compacted. VTM is a good performance measure in quality control of the HMA as a whole, because it is based on the quality and content of both the aggregate and the asphalt. The optimum VTM is determined through mix design procedures. Roberts et al. (1996) write, "The VTM in the compacted dense-graded HMA specimen at optimum asphalt content is suggested by most SHAs to lie between 3 and 5 percent" (p. 215). This air void content is only for samples compacted in the laboratory. In the field, this air void content should be acquired through compaction effort and not by adding more asphalt cement to the mix. Roberts et al. (1996) write, "Low air void contents minimize the aging of the asphalt cement films within the aggregate mass and also minimize the possibility that water can get into the mix, penetrate the thin asphalt film, and strip the asphalt cement off the aggregates" (pp. 215-216).

2.4 Quality Assurance Program Components

2.4.1 Overview

The Transportation Research Board (1999) defines quality assurance as, "All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. Quality assurance addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible" (p. 11). It is the responsibility of the SHA to have a program that fulfills these premises. One criterion is that all quality assurance programs must meet the requirements set by FHWA for Federal-aid highway construction projects on the National Highway System (FHWA, 1995). Many SHAs have implemented a QC/QA specification as part of their quality assurance program, but a QC/QA specification is only one part of a quality assurance program. QC/QA specifications only address who is responsible for the quality of construction and in a way are very vague. As a result of the vagueness, there are many variations of quality assurance programs among the many SHAs utilizing a QC/QA specification. These variations usually come in the form of how the quality is to be controlled and how the quality of the final product is to be measured and weighted. Each SHA that uses a QC/QA specification will use different methods for controlling quality and measuring the quality of the final product. The program that is used by a SHA is uniquely tailored for that particular SHA. A quality assurance program that utilizes a QC/QA specification emphasizes two distinct elements, quality control and quality acceptance. Both are essential parts of quality assurance. A close look at quality control and quality acceptance will reveal the many variations that could possibly exist with the use of a QC/QA specification.

2.4.2 Control Measures

Before discussing quality control and quality acceptance, it is necessary to first discuss the HMA properties used to measure quality. Sampling and testing the HMA during production and placement is essential to ensure that a satisfactory pavement is obtained. For the construction of HMA pavements, several properties may be considered. Parker, Jr., and Hossain (1994) state, "Asphalt content, air voids, aggregate gradation, and mat density are commonly used control properties" (p. 9). VMA, VFA, Marshall stability, retained tensile strength, temperature, mixture properties of laboratory samples, theoretical maximum density, and smoothness are some other properties that may also be considered. The properties that are measured and controlled throughout the production and placement of HMA may differ from one SHA to another. They may even differ within a single program between quality control and quality assurance. In a pure end-result specification, the contractor would be left with the decision of which HMA characteristics they felt should be controlled (Willenbrock and Marcin, 1978). With a QC/QA specification the SHA usually specifies which HMA properties are to be controlled at a minimum to ensure quality. The properties selected are chosen because they are deemed by the individual SHA to be the most necessary. The HMA properties that are considered for contractor quality control are in most cases equal in number or more numerous than those considered for quality assurance. These properties are then tested at or above the frequencies set by the SHA.

2.4.3 Quality Control

2.4.3.1 Quality Control Plan

CALTRANS (1996) writes, "The need for and use of a Quality Control Plan (QC plan) cannot be overemphasized. Quality cannot be tested or inspected into a product. It must be "built-in." It is imperative that the contractor has a functional, responsive QC plan" (p. 3). A QC plan must address actions needed, including the frequency of testing, to keep the process in control, quickly determine when the process has gone out of control, and to respond adequately to correct the situation(s) and bring the process back into control (CALTRANS, 1996; Cominsky, et al., 1998). A QC plan is usually required of the contractor by the SHA. It is intended that the minimum requirements included in the QC plan will be a starting point for all contractors and will ensure the SHA a minimum level of quality control of the materials being produced and placed into the project (CALTRANS, 1996). The elements of this plan vary from one SHA to another. Some of these elements are testing frequency, sampling, personnel, and corrective action.

2.4.3.2 Tolerances

Each process associated with the production and placement of asphalt concrete pavement has an inherent variability that is due to variations in material, equipment, and procedures (Markey, Mahoney, and Gietz, 1997; Patel *et al*, 1997). The highest quality HMA would fully adhere to the JMF, but because of the inherent variability in all construction processes this is impossible. However, through good quality control this inherent variability can be reduced. Once the HMA properties to be tested have been established, tolerance limits are set on these properties to ensure that the product is of acceptable quality. TRB (1999) defines tolerance limits as, "Limits that define the conformance boundaries for a manufacturing or service operation" (p. 21). These tolerance limits are of the general form JMF-value ± tolerance. These tolerance ranges are used for quality control through process control, and may vary from one SHA to another.

2.4.3.3 Process Control

Process control consists of statistically monitoring the quality of a product through production with frequent testing and control charts. Patel et al. (1997) write, "Timely reaction to the control charts can prevent the production of nonconforming material" (p. 67). The party responsible for taking corrective action when processes go out of control varies. The contractor may be responsible for taking such action, or the SHA may assume that responsibility. The programs that allow the contractor to take the necessary corrective action result in a quicker response and better control. Tunnicliff and the Warren Brothers Company (1978) write, "Timely, minor adjustments can eliminate problems before they become serious" (p. 26).

2.4.3.4 QC Sampling and Testing

Cominsky *et al* (1998) write, “The objective of sampling and testing associated with this QC plan is to ensure conformance of the mean properties of the ‘plant-produced’ mix with the ‘target’ mix and to minimize variability in the HMA” (p. 6). The target mix is represented by the HMA properties that were selected for measures of control. Cominsky *et al* (1998) write, “The Contractor’s QC plan shall be based on random sampling and testing of the HMA at its point of production” (p. 6). A QC plan shall include a statistically sound, randomized sampling plan to provide samples representative of the entire HMA production (Cominsky *et al*, 1998). The frequency of the testing is usually specified by the SHA. The frequency of quality control testing should be at or exceeding the minimums specified by the SHA. These minimums are set based on statistical representation and vary from one SHA to the next. Depending on the type of project, there may be varying requirements as to which HMA properties are to be measured, and how often they are measured. More frequent testing will provide for better control through more information. However, this more frequent sampling will increase cost. Conversely, infrequent testing will provide for poorer control due to possibly lacking information. Fewer tests would, however, cost less. The frequency is set at a level that is deemed appropriate by the individual SHAs.

2.4.3.5 QC Personnel Qualification

CALTRANS (1996) writes, “To ensure that sampling and testing are done correctly, personnel that perform sampling or testing for contract acceptance should be trained, qualified, and have relevant experience” (p. 15). For many SHAs this is a requirement. For others, it is not. This lack of qualification may have serious repercussions for obvious reasons. If the individual doing the testing or the sampling is doing so improperly or inconsistently the process may be deemed out of control and unnecessary corrections will be made. This may ultimately cost the contractor for a poor quality product, but it will also leave the SHA with a less than satisfactory pavement. Many of the SHA have very good training and certification programs for QC personnel to contend with this problem, but there are a few that do not.

2.4.3.6 Mix Design

Under a QC/QA specification, many SHAs require that the contractor design the HMA. This gives the contractor more flexibility with regards to controlling the quality of the final product. This is a true end result specification attribute. Tunnicliff and the Warren Brothers Company (1978) write, “Contractor mix designs are often more economical and easier to produce than agency mix designs because the Contractor’s knowledge of materials is different from the agency’s knowledge of the same materials. If other customers can use the same mixture, significant cost reductions are possible” (p. 26). These mix designs are often limited by aggregate gradation wide band limits, and confirmation and acceptance from the SHA.

2.4.4 Quality Acceptance

2.4.4.1 QA Sampling and Testing

Quality assurance testing is done to either get a good representation of the final product to measure specification compliance or to check the accuracy of quality control testing. The second is especially true when quality control testing is used for acceptance. Patel et al. (1997) write, “A relatively high frequency of SHA sampling and testing is required if acceptance is to be based solely on agency testing and inspection activities" (p. 70). This, however, requires a large number of SHA personnel, and because of the increasing unavailability of qualified personnel some SHAs are unable to do the necessary testing for acceptance. As a result, some SHAs are relying on the results of the contractor's quality control testing, provided that adequate checks and balances are in place to ensure the accuracy and reliability of the contractor test results (Patel et al. 1997). The amount of testing required of the SHA in this case is greatly reduced. The frequencies and methods used for the verification of the quality control test results vary greatly among the SHAs. Slit-sample testing and independent assurance testing are two common ways of verifying the accuracy of quality control testing.

2.4.4.2 Specification Limits

Quality assurance through acceptance of a product is the responsibility of the SHA. The SHA may accept or reject the product produced by the contractor, or place a pay adjustment on the contract bid in accordance with the level of specification compliance attained. Most SHAs are opting to use a statistically based specification in addition to a QC/QA specification to measure the relationship between the quality criteria and constructed product performance. Parker, Jr. and Hossain (1994) write, "A statistical QC/QA procedure is implemented by setting limiting acceptance criteria to ensure desired product quality" (p. 9). These acceptance criteria are referred to as specification limits. TRB (1999) defines these as, "The limiting values established, preferably by statistical analysis, for evaluating material or construction acceptability within the specification requirements. The term refers to either an upper specification limit (USL) or a lower specification limit (LSL), called a single specification limit; or to both USL and LSL, called a double specification limit" (p. 20). These specification limits vary between the different SHAs. Parker, Jr. and Hossain (1994) write, "To develop realistic and valid quality requirements, acceptance limits should be based on a statistical analysis of variations in materials, processes, sampling, and testing" (p. 9). These controls should be adequate to control the quality of the HMA, but it is essential that these limits are achievable. Yoder and Witczak (1975) write, "It does no good to specify statistically orientated specifications so strict that contractor compliance is impossible" (p. 439). Patel et al. (1997) write, "Specifications that are unnecessarily restrictive tend to raise costs and strain relations with Contractors. Conversely, excessively wide specifications may lead to wide variations in quality" (p. 66).

2.4.4.3 Pay Adjustments

After a representative measurement of the final product through random sampling and testing, the level of specification compliance is to be determined. Most of the SHAs use a price adjustment system that would adjust the payment for the final product according to specification compliance. The product would then be accepted above a certain acceptance limit with a pay deduction. The acceptance limits vary among the SHAs. These acceptance limits may be expressed as a quality index, a percent within limits or percent defective, a mean, an absolute average deviation, or some other measure of quality (TRB, 1999). Most of the SHAs use a deduction or disincentive system, and some even use incentives. Incentives are used to reward a contractor for exceeding the specification in areas where additional value is provided in terms of performance of the finished product. Wegman (1996) writes, "Disincentives or penalties are applied when a contractor does not meet specifications on work already incorporated into the project that does not warrant removal and replacement" (p. 10).

Within many of the SHAs, the final pay factor is a weighted composite of individual pay factors, where the composite pay factor equals the sum of the individual quality characteristic pay factors multiplied by the weighting factor placed on the individual quality characteristic (Benson, 1999). This is a general form of a pay factor equation. Different SHAs will use different quality characteristics for pay determination, different weights on those characteristics, and sometimes even different equation forms.

2.5 WYDOT's Quality Assurance Program

2.5.1 Non-QC/QA Specification Transition

In 1997, WYDOT implemented the use of an asphalt pavement QC/QA specification. They used this specification in constructing a select few projects in 1997. Full implementation was nearly realized by 2000. The seeming four-year implementation was caused by budgeting restraints. The budget for projects is usually drawn up ten years in advance of actual project construction. Since costs for projects constructed under a QC/QA specification differ from costs for those constructed under a non-QC/QA specification, changing the budget was an unrealistic option. During this four-year period, minor changes were made in this specification. The biggest changes occurred with the inclusion of provisions for recycled asphalt pavement (RAP), and later Superpave.

2.5.2 Non-QC/QA Specification

Before using a QC/QA specification, WYDOT used a method and materials specification. WYDOT took full responsibility for the final HMA produced and paid all costs involved with assuring that the quality of the final product was acceptable. The following is a quote from the Wyoming Department of Transportation's 1996 Edition of their Standard Specifications for Road and Bridge Construction. It helps sum up the involvement of both the SHA and the contractor prior to the use of a QC/QA specification.

> **106.04 Samples, Tests, Cited Specifications.** All material will be inspected, tested, and accepted before incorporation into the work. Any work in which untested and unaccepted materials are used without approval or written permission shall be performed at the Contractor's risk and will not be paid for.
>
> All tests will be made by and at the expense of the Department in accordance with the most recent cited standard or interim methods of AASHTO or ASTM, as adopted or modified by the Department, which are current on the date of advertisement for bids. All materials being used are subject to inspection, test, and either acceptance or rejection at any time prior to incorporation into the work. If requested copies of all test reports will be furnished to the Contractor. Test methods are listed in the Wyoming Field Testing Manual and specified sections of the Standard Specifications (p. 45).

2.5.3 WYDOT's QC/QA Specification

2.5.3.1 Overview

The following description of WYDOT's quality assurance program fully references the Wyoming Department of Transportation's Supplemental Specification for Plant Mix Pavements, which was last revised January 3, 2001. This is not an officially published document at this time. It is available only through the Wyoming Department of Transportation. This document is very long and detailed. The following description of WYDOT's QC/QA specification for plant mix pavements is only a brief summary of details.

WYDOT's QC/QA specification applies only to bituminous pavement. Depending on the success of this specification, however, QC/QA specifications may be used for other types of construction. This specification is fairly typical. It is described as being an integral part of quality assurance. Quality control is the responsibility of the contractor. The contractor shall provide and maintain a quality control system. The contractor shall be responsible for all bituminous pavement materials and constructed pavements whether produced and constructed by the contractor or procured from subcontractors or vendors. WYDOT is responsible for the quality assurance and acceptance of the product. WYDOT has selected a list of specific HMA properties to be controlled through quality control and quality assurance. They have set limits on these properties, and have established appropriate testing frequencies. In addition, WYDOT has a list of requirements for personnel, and for quality control plans as part of their QC/QA specification.

2.5.3.2 JMF and Mix Design

Before construction begins, a suitable JMF and a mix design must be performed. The Marshall mix design procedure is most commonly used in Wyoming. However, the Superpave mix design procedure is used on occasion. WYDOT's QC/QA specification requires that the Contractor perform both the JMF and the mix design. These are then subject to the approval of the WYDOT Materials Program before construction begins. The JMF shall include a single percentage of virgin aggregate passing each required sieve size, a target RAP percentage when used, a single target asphalt content, and the single mixing and compaction temperature. "The JMF along with the allowable tolerances shall be within the wide band specified." The Marshall wide band requirements and the tolerances can be found in Tables 2.1 and 2.2. Also, the Marshall mix design must adhere to a list of mixture property requirements. It should be noted that Superpave has some additional requirements, especially for the aggregate. WYDOT has four classes of property requirements that are dependant on traffic loading. These required mixture properties can be found in Table 2.3. Before the use of a QC/QA specification, the Contractor only developed a JMF for aggregate gradation, and WYDOT would approve the JMF and use it to develop a mix design.

Table 2.1 Tolerances for Aggregate Gradations

HMA Parameter	Non-QC/QA Tolerances	Marshall QC/QA Tolerances
1-inch Sieve	± 7%	± 7%
3/4-inch Sieve	± 7%	± 7%
1/2-inch Sieve	± 7%	± 7%
3/8-inch Sieve	± 7%	± 7%
No.4 Sieve	± 7%	± 7%
No. 8 Sieve	± 5%	± 5%
No.30 Sieve	± 5%	± 5%
No. 200 Sieve	± 3%	± 2%

Table 2.2 Aggregate Gradation Wide Band Requirements for WYDOT's QC/QA Specification

Sieve Designation	Grading A	Grading C	Grading E	Grading G
1 ¼ inch			100	
1 inch	100		90-100	
3/4 inch	90-100	100	65-90	
1/2 inch	55-90	90-100	50-85	100
3/8 inch	45-85	55-90	40-75	90-100
No. 4	30-65	35-70	30-60	45-85
No. 8	20-50	20-55	20-45	30-65
No. 30	5-30	5-35	5-25	10-40
No.200	2-7	2-7	2-7	2-7

2.5.3.3 Control

WYDOT's QC/QA specification is based on levels of control. These levels of control are a function of traffic, type of construction, type of facility, type of funding, and quantity of material. There are four such levels. For each of these levels of control, the requirements for the mix design, quality control, and quality assurance differ. The requirements of these levels decrease as the levels themselves increase. The requirements for the different levels of control can be seen in Table 2.5. These requirements were used for the construction of asphalt pavements through the 2001 construction season.

Table 2.3 Required Mixture Properties Used for WYDOT's QC/QA Specification

	CLASS I	CLASS II	CLASS III	CLASS IV
Los Angeles Abrasion	35 Max.	35 Max.	40 Max.	40 Max.
Number of Marshall Blows	75	75	50	50
Marshall Stability (minimum), N (lbs)	11000 (2500)	11000 (2500)	9000 (2000)	9000 (2000)
Marshall Flow, 0.25 mm (0.01 in)	8-16 (8-16)	8-16 (8-16)	8-16 (8-16)	8-16 (8-16)
% Voids in Laboratory Mix % Voids in Production Mix	4.0-6.0 3.0-5.0	3.0-5.0 2.5-4.5	3.0-5.0 2.5-4.5	2.5-4.5 2.0-4.0
Dust/ Effective Asphalt	0.8-1.4	0.8-1.4	0.8-1.4	0.8-1.4
Minimum % Asphalt	4.5	4.5	4.5	4.5
Minimum Tensile Strength Retained, %	75	75	75	75
Film Thickness, μm	6-12	6-12	6-12	6-12
% Voids in Mineral Aggregate	Table 2.4	Table 2.4	Table 2.4	Table 2.4

Table 2.4 VMA Requirements for WYDOT's QC/QA Specification

	Grading A	Grading C	Grading E	Grading G
CLASS I	13.0-16.0	14.0-17.0	12.0-15.0	14.0-17.0
CLASS II	12.0-15.0	13.0-16.0	11.0-14.0	13.0-16.0
CLASS III	12.0-15.0	13.0-16.0	11.0-14.0	13.0-16.0
CLASS IV	11.0-14.0	12.0-15.0		12.0-15.0

For quality control there are tests required by WYDOT for both virgin aggregate production and mix production and placement. For virgin aggregate production, it was required at a minimum that the gradation, and liquid limit (LL), and plasticity index (PI) be measured as the aggregate is produced and stockpiled. These were to be tested at or above the minimum frequencies set by WYDOT. All of the testing frequency requirements are shown in Table 2.5, with their corresponding level of control. For mix production, the contractor performed quality control testing during production and placement. The testing program included, but was not necessarily be limited to, tests for the control of aggregate gradation, reclaimed material, LL, PI, coarse aggregate angularity, fine aggregate angularity, sand equivalent, moisture content of the aggregate, asphalt content, moisture content of mixture, mix temperatures, and field compaction. All samples were to be selected randomly using WYDOT sampling procedures.

For quality assurance, the virgin gradation, in-place density, and asphalt content were to be measured at a specified frequency. These frequencies can be found in Table 2.5. The frequencies for quality assurance testing, when performing tests similar were equal in number. This can also be seen in Table 2.5. A lot is defined as the quantity of produced bituminous pavement, represented by five tests with a tonnage as shown for the level of control for aggregate gradation, and is represented by seven tests for in-place density.

2.5.3.4 Quality Control Plan

WYDOT requires the contractor to submit a QC plan prior to the pre-construction conference. This QC plan must be accepted and approved by the engineer and the Materials Program prior to the production of materials. The QC plan shall be adhered to at all times. The QC plan shall contain twelve items of information at a minimum. Descriptive information and calibration records for the production facilities shall be included. Personnel and responsibilities shall be included with an organizational chart indicating lines of authority for quality control for all aspects of the bituminous pavement construction. The plan shall include the sampling procedures and techniques to be used, which will consist of how sample times and locations shall be determined, how samples should be collected for testing, how the calibration shall be accomplished for sampling devices, and how mix design samples shall be collected.

Information about the mix design process that the contractor plans to follow shall be included. A description of the quality control laboratory and testing equipment shall be included. The QC plan shall include a schedule of testing for each aggregate produced prior to mix production. Test methods and frequency of testing to be used for the control of the bituminous mixture shall be shown in the QC plan. These tests shall be more than the minimum required by WYDOT. As part of the QC plan, the contractor shall note records of field observations, inspections, and measurements as they occur. All of these records shall be made available to the engineer upon request. Also, control charts are a required part of the QC plan. They shall be maintained and displayed at the field laboratory.

Table 2.5 Testing Requirements by Levels of Control Used by WYDOT as Part of QC/QA Specification Prior to 2002

	Level I	**Level II**	**Level III**	**Level IV**
Mix Design	New Design Required	Reference design allowed 5000 tons or less Voidless Unit Weight Required	Reference design allowed 5000 tons or less Voidless Unit Weight Required	Reference design allowed 5000 tons or less Reference of Voidless Unit Weight allowed
QUALITY CONTROL	Required	Required	Required	Required
VIRGIN AGGREGATE PRODUCTION				
Gradation each stockpile	1/1000 t min.	1/1000 t min.	1/1000 t min.	2 test min.
L.L. & P.I. on Virgin Material	1/1000 t min.	1/1000 t min.	1/1000 t min.	2 test min.
MIX PRODUCTION				
Virgin Aggregate Gradation	1/1000 t min.	1/1000 t min.	1/1000 t min.	Not Required
L.L. & P.I. on Virgin Material	1/1000 t min.	1/1000 t min.	1/1000 t min.	Not Required
Moisture Content of Virgin Aggregate/Hydrated Lime	1/day min.	1/day min.	1/day min.	Not Required
Mix Verification	** as per Subsection 7.0107	Not Required	Not Required	Not Required
Moisture Content of Mixture	1/day min.	1/day min.	1/day min.	Not Required
Test Strip	Required	Required	Required	Not Required
In-Place Density	1/200 t	1/200 t	1/200 t	1/200 t 5 min.
QUALITY ASSURANCE				
Virgin Gradation	1 lot/5000 t	1 lot/5000 t	*As per Section 8.0	*As per Section 8.0
In-Place Density	1 lot/1500 t	1 lot/1500 t	*As per Section 8.0	*As per Section 8.0
Asphalt Content	1/day	1/day	*As per Section 8.0	*As per Section 8.0
Quality Acceptance Field Lab	Required	Required	*As per Section 8.0	*As per Section 8.0

* References the WYDOT specification, which is not included in this paper.
** The mix verification for the Recycled Bituminous Pavement shall be performed daily until no adjustments are required to the mix to ensure that all design criteria are within control limits. Once this is determined, then the mix verification frequency will become a minimum of 1 test per 6000 t.

The following parameters shall be recorded on the control chart: gradation of the control sieves in the JMF, virgin asphalt content, total asphalt content, in-place density, VMA, and VTM. The control charts shall include the control limits, each individual quality control test result, and the moving average of the last four tests. The single and moving average control limits are set by WYDOT. The QC plan shall contain a set of rules that the contractor shall use to determine what actions will be taken when material's properties do not meet the control limits. This corrective action process shall adhere to the minimums required by WYDOT. A test strip shall be constructed to evaluate the rollers and the mix design and determine the compactive effort of the rolling patterns. The construction and evaluation of the test strip shall be addressed in the QC plan. The twelfth and final item to be included in the QC plan is notification of start-up. The engineer may suspend operations when any part of the QC plan is not adhered to.

2.5.3.5 Personnel Requirements

Under their QC/QA specification, WYDOT requires that many of the construction personnel be certified and qualified to perform a number of certain duties. For one, the contractor or consultant laboratories that perform mix designs shall be AASHTO accredited for a great number of procedures. The contractor shall provide a quality control supervisor. The quality control supervisor shall be the contact between all parties involved for all quality control and quality acceptance issues. The supervisor shall be capable of, but not limited to, interpreting, ensuring adherence and review of the QC plan, coordinating activities for mix design and quality control testing, reviewing and interpreting testing reports, and making recommendations for the control process. Qualified technicians shall perform all quality control and quality acceptance sampling and testing. The contractor shall have a qualified technician at the production site during aggregate production and production of bituminous pavement. Qualified technicians shall be certified through the Wyoming Certification Program, or be qualified through a qualification process. All test reports shall be reviewed and signed by a certified technician.

2.5.3.6 Pay Determination and Acceptance

Through the 2001 construction season, WYDOT performed independent quality assurance testing as required by and at a frequency specified for the level of control shown in the plans and in accordance with Table 2.5. The results of these were used for the quality acceptance and pay determination. WYDOT changed their QC/QA specification, so that now contractor quality control tests would be used for quality acceptance and pay determination. These quality control tests are verified with just a few tests performed by WYDOT. This change in QC/QA specification drastically changed the testing requirements of both the Contractor and WYDOT. The changes that were made can be seen with a comparison between Tables 2.5 and 2.6.

Through the 2001 construction season, quality acceptance included a quality analysis for aggregate gradation, in-place density, and asphalt content. These three items were accepted based on a quality analysis for individual lots of material. Each property was analyzed independently using independent lots of material. A pay factor was determined for aggregate gradation, in-place density, and asphalt content for Level I and II mixes only. WYDOT's test results will be used for these pay factor determinations. The contractor's test results were allowed for quality acceptance for Level III and IV control mixes.

WYDOT uses a pay adjustment system that utilizes bonuses and deductions. For virgin aggregate gradation and asphalt content, anything outside of the tolerance limits is considered to be a less than quality product, at which point the material is removed or accepted at a reduced price. The choice of removal or pay reduction is the contractor's. The material is only accepted, however, if the pay factor is greater than or equal to 0.75. The highest achievable pay factor for these two pay items is 1.05. The pay factor for aggregate gradation is calculated using a USL, an LSL, the average percent passing an individual sieve, and the standard deviation of the test results for the lot. The USL and the LSL are set at the JMF ± the sieve tolerances, which were seen in Table 2.1. The pay factor for the lot is based on the sieve size that resulted in the lowest pay factor. The tolerances for the #200 sieve size decreased with the implementation of a QC/QA specification. This decrease in tolerance makes it more difficult to achieve an acceptable HMA pavement. These changes can be seen in Table 2.1. The pay factor for the asphalt content is based on the quantity of bituminous pavement produced for a day's production. It is calculated using the variance of asphalt content from the design content. As with the aggregate, the material will only be accepted if the pay factor is greater or equal to 0.75. The material will be rejected if the variance from the design content is greater than 0.50 percent.

Payment for in-place density is based on lots and is calculated according to the testing done per lot. The pay factor for a lot of compacted pavement is calculated using the average relative density of the pavement and the sample standard deviation of the test results for that lot. Any average relative density greater than or equal to 92 percent is acceptable. Any pavement with an in-place density less than 92 percent is rejected. The pay adjustment for substandard compaction is figured using a quality index (QI). A high average relative density with a low standard deviation will result in the highest pay factor. The highest pay factor achievable is 1.01. The lowest allowable pay factor is equal to 0.50. Any material with a pay factor below 0.50 will be rejected.

2.6 Effectiveness of QC/QA Specifications

2.6.1 Overview

After implementing a new specification, it is essential to evaluate the effectiveness of the new specification. By allowing the contractor to control the quality of the final product through constant sampling, testing, and monitoring throughout the production and placement of the HMA, quality is sure to be enhanced through decreased variability. This is because constant monitoring of operations allows the contractor to quickly recognize any problems that may occur within the operations, and to react to these in a timely fashion. Decreased variability in the HMA itself will increase the life of the pavement, therefore decreasing life-cycle costs. Integrated control can also free the contractor to innovate, creating more opportunities for efficiencies, which may also decrease cost (Benson, 1999). There are, however, extra costs associated with the use of a QC/QA specification. Bid prices go up when the Contractor needs extra personnel to do the necessary quality control testing.

Table 2.6 Testing Requirements by Levels of Control Used by WYDOT as Part of QC/QA Specification Since 2002

	Level I	**Level II**	**Level III**	**Level IV**
Mix Design	New Design Required	Reference design allowed 5000 tons or less Voidless Unit Weight Required	Reference design allowed 5000 tons or less Voidless Unit Weight Required	Reference design allowed 5000 tons or less Reference of Voidless Unit Weight allowed
QUALITY CONTROL – VIRGIN AGGREGATE PRODUCTION				
Gradation each stockpile	1/1000 T min.	1/1000 T min.	1/1000 T min.	2 test min.
L.L. & P.I. on Virgin Material	1/1000 T min.	1/1000 T min.	1/1000 T min.	Not Required
QUALITY CONTROL – MIX PRODUCTION				
Virgin Aggregate Gradation	1/1000 T min.	1/1000 T min.	1/1000 T min.	Not Required
Asphalt Content	1/day	1/day	1/day	1/day
Test Strip	Required	Required if shown on plans	Required if shown on plans	Not Required
In-Place Density	1/200 T	1/200 T	1/200 T	1/200 T 5 min.
QUALITY ACCEPTANCE – MIX PRODUCTION				
Virgin Gradation	1 lot/5000 T	1 lot/5000 T	*Per Section 8.0	*Per Section 8.0
In-Place Density	1 lot /1500 T	1 lot /1500 T	*Per Section 8.0	*Per Section 8.0
Asphalt Content	1/day	1/day	*Per Section 8.0	*Per Section 8.0
Quality Acceptance Field Lab	Required	Required	*Per Section 8.0	*Per Section 8.0
L.L. & P.I. on Virgin Material	1/1000 T min.	1/1000 T min.	1/1000 T min.	Not Required
Moisture Content of Virgin Aggregate/Hydrated Lime, and Moisture Content of Mixture	1/day min.	1/day min.	1/day min.	Not Required
Mix Volumetrics	*Per Subsection 8.05 Acceptance – Mix Volumetrics	Not Required	Not Required	Not Required
VERIFICATION – MIX PRODUCTION				
Virgin Gradation	1/lot	1/lot	Not Required	Not Required
In-Place Density	1/lot	1/lot t	Not Required	Not Required
Asphalt Content	Not Required	Not Required	Not Required	Not Required
Mix Volumetrics	Split sample required, but no test frequency specifically	Not Required	Not Required	Not Required
Virgin – LL, PI. Virgin Material; Moisture Content Virgin Aggregate/Hydrated Lime; Moisture Content of Mix	Not Required	Not Required	Not Required	Not Required

* References the WYDOT specification, which is not included in this paper.

A few of the SHAs that are using a QC/QA specification have evaluated their programs for effectiveness. Each SHA uses different methods to evaluate and looks at different things in these evaluations. The California Department of Transportation (CALTRANS) and the Texas Department of Transportation (TxDOT) are two of the SHAs that have conducted an official evaluation of their QC/QA specifications. Overall, the results of these types of evaluations are fairly positive. According to one survey conducted by Andrew Backus (1999), the QC/QA programs currently used are cost effectively increasing quality. Respondents to the survey typically reported noticeable to significant improvement in pavement quality at only a slight increase in cost.

2.6.2 CALTRANS

Benson (1999) writes, “CALTRANS implemented QC/QA in an effort to improve the quality of asphalt concrete pavements and involve the contracting community more directly in the control of product quality” (p. 88). The new asphalt concrete specifications were developed in 1995-1996 and were fully implemented in April 1996 without a pilot program (Douglas, et al., 1999). Nichols Consulting Engineers (NCE) was selected as a consultant in September 1996 to independently evaluate the new statistical quality assurance (SQA) program. Douglas *et al* (1999) write, “Seventeen construction projects using the new asphalt concrete QC/QA specification were selected for monitoring during the 1997 construction season” (p. 95). These projects were chosen to represent projects from all across the state and were of all sizes and types. A very in-depth study involving an analysis of interviews and physical property data revealed several positive findings with regards to bidability, goals, workability of specification, and increased quality. Apart from the NCE study, CALTRANS had also conducted a quality comparison between projects constructed under their QC/QA specification, their previously used end-result specification, and their old method specification. Benson (1999) writes, “The quality comparison was based on two specified properties: percent relative compaction and asphalt content” (p. 88). Cost analysis was also included. The results show progressively less material outside compaction specification limits for the method, end-result, and QC/QA approaches. This improved performance is achieved by increasing the average level of compaction, not by reducing variability (Benson, 1999). For asphalt content, there is a clear improvement in quality obtained under the QC/QA specification. Benson (1999) writes, “These improvements are attributable to reductions in variability, not closer adherence to the target value. If anything, the QC/QA jobs showed greater scatter about the design target values” (p. 90). The cost analysis showed an increase in cost, but it is assumed that reduced rehabilitation costs over the life of the projects would more than compensate.

2.6.3 TxDOT

TxDOT has been using a QC/QA specification since 1993. Questions regarding the quality and cost effectiveness of the QC/QA specification were raised within the first two years of use. To address these concerns, TxDOT sponsored and initiated a research project (Solaimanian *et al*, 1998). As part of this research project, attempts were made to address the existing problems by collecting technical information and performing numerical analyses, and by comparing projects built under the two sets of specifications. Solaimanian *et al* (1998) write, “The study indicates that, statistically, there is no significant difference between the uniformity of the control parameters (air voids, asphalt content, gradation) of the two specifications. However, simple and direct comparison of statistical parameters, without any hypothesis testing, indicates less uniformity in the method specification projects, as compared with the QC/QA projects” (p. ix).

2.7 Chapter Summary

The construction of quality pavements in an economical way has always been the goal of the SHAs. In recent years, QC/QA specifications have been implemented by many SHAs to improve the quality of asphalt pavements. QC/QA specifications also accommodate for many other changes that are presently occurring in the construction industry. Before the use of QC/QA specifications, methods and materials specifications were used. This type of specification placed all responsibility for achieving a quality pavement on the SHA. A QC/QA specification shifts some of this responsibility to the contractor. With QC/QA, the contractor is responsible for quality control, and the SHA is left with the responsibility of quality assurance and product acceptance. Fully integrating quality control into the construction operations allows the contractor to quickly detect problems that may occur, and to respond in a timely fashion. Continuous sampling, testing, and monitoring throughout the production and placement of the HMA allows for the production of a high quality pavement.

QC/QA specifications promise higher quality pavement, but there are additional costs associated with the use of this type of specification. Therefore, it is important to evaluate the impacts of the specification that is being used. Many different QC/QA specifications are being used, so a specification evaluation must be done on an individual basis. Evaluations that have already been conducted have had positive results. The increases associated with the use of QC/QA specifications, seem to be balanced or outweighed by the decreases in cost associated with increased pavement performance and life.

3. NATIONWIDE QC/QA QUESTIONNAIRE

3.1 Introduction

In recent years, many SHAs have adopted QC/QA specification programs for the construction of asphalt pavements. Introducing this new specification is meant to promote construction of better performing and longer lasting roadways by decreasing asphalt mixture variability throughout asphalt mixture production and placement. The use of QC/QA specifications is rapidly growing and gradually gaining wide acceptance within most SHAs (Solaimanian et al. 1998). With a QC/QA specification, the contractor is responsible for the quality of the pavement, while the highway agency is responsible for the acceptance, rejection and/or price adjustment of that product. This is a general definition of a QC/QA specification. Details of how the responsibilities for quality achievement are divided can vary greatly. Also, a QC/QA specification is only a part of a quality assurance program. A QC/QA specification only describes who is responsible for the final quality of the product. Anything outside of this may vary greatly among the SHAs. Therefore, in order to evaluate the effectiveness of QC/QA specification programs in decreasing the variability of HMA, a basic understanding of the status quo of QC/QA specification programs is essential.

A questionnaire consisting of about 40 questions was written and sent to the 50 SHAs in July 2001. The purpose of the questionnaire was to gather information and obtain an understanding of each of the SHA's asphalt pavement QC/QA specification programs. Although a full understanding and evaluation of every one of the State DOT's asphalt pavement QC/QA programs is outside the scope of this study, it is necessary to have at least a basic understanding of them all. This basic understanding of all the asphalt pavement QC/QA programs leads to future comparisons and evaluations of each of the individual QC/QA specification programs.

Information directly gathered by the questionnaire included: QC/QA program history, the distribution of quality control and quality assurance responsibilities between contractor and SHA, and the levels of control demonstrated by the QC/QA specification program. Also, because of the difficulty in generalizing asphalt pavement QC/QA across the different states, a request for specification summaries regarding the different aspects of QC/QA programs was included. A copy of the questionnaire that was sent can be found in Appendix A. The results of the survey are presented in this chapter.

3.2 Results of Survey

There were 44 full responses and one partial response to the questionnaire. All of the states except Arizona, Iowa, New Mexico, Tennessee, and Rhode Island responded to the questionnaire. The responses have been reduced and summarized in the sections that follow.

3.2.1 SHAs with a QC/QA Specification Program

Of the 45 SHAs responding to the survey, 40 or nearly 90 percent have implemented an asphalt pavement construction QC/QA specification program. Connecticut, Delaware, Hawaii, Massachusetts, and Montana were the only SHAs to indicate that they do not have such a program. Delaware and Massachusetts, however, are planning to implement such a program in the near future.

For the 40 SHAs that indicated having an asphalt pavement QC/QA program, the years that these programs were implemented range from 1968 (New Jersey) to present. Most of the programs, however, were implemented just recently. Twenty-nine or more than 80 percent of the 35 SHAs that provided a date of implementation started their programs after 1985.

3.2.2 Scope of QC/QA

Within any state, there are many classifications of roadways, and to maintain these roadways simple maintenance to full reconstruction projects are needed. Since QC/QA introduces complexity and cost, it seems logical that it would not be used for all projects on all classifications of roadways. This was found to be true in the survey.

All of the 40 SHAs use QC/QA specification on interstate and primary roadways and on projects larger than 5,000 tons of asphalt mixture. However, only 88 percent of them use a QC/QA specification for secondary roadways, and only 80 percent use it for projects smaller than 5,000 tons.

3.2.3 Quality Control Responsibilities

Of the 39 SHAs responding to the question and claiming to have an asphalt pavement QC/QA program, Colorado and Nevada were the only two to hold the SHA responsible for quality control testing. The other 37 hold the contractor responsible for quality control testing. The responsibility for evaluating the QC test results is more evenly split. Of the 39 responding SHAs, 26 of them hold the contractor responsible for the evaluation of quality control testing, nine accept the responsibility themselves, and 4 share the responsibility with the contractor. When quality control testing has been evaluated and corrective action is needed, three of the QC/QA programs are set up to have the SHA initiate corrective actions themselves, three of them share the responsibility for initiating corrective actions, and the remaining 33 hold the Contractor responsible for taking such actions.

Knowing which party is held responsible for all of the quality control activities helps to characterize the asphalt pavement QC/QA specification programs that are being used by the SHAs and the degree of the responsibility shift that has taken place toward the contractor. When the SHAs were asked if they were moving to change involvements with quality control in any way, Colorado, Delaware, Ohio, Wisconsin, and Wyoming stated that they were. Colorado, Delaware, and Wyoming stated that the change being made involves the acceptance of the contractor’s quality control test results for incentive and disincentive payment and quality acceptance. Ohio’s new program puts even more responsibility on the contractor, while Wisconsin is rewriting its program to conform to federal verification requirements.

3.2.4 Quality Assurance Responsibilities

All of the SHAs responding to the question and claiming to have an asphalt pavement QC/QA specification program perform quality assurance testing. South Carolina added a note stating, “The contractor does all quality control and quality assurance testing with the state doing quality assurance verification testing at a ratio of 1:10 of the quality assurance tests. Additionally, the state’s Independence Assurance personnel obtain comparison samples on Federal Aid projects.”

The number of quality assurance tests performed for a typical project varies significantly among the SHAs. The amount of quality assurance testing for most of the SHAs is based on lot size, occurs at a daily rate, or depends on the number of quality control tests performed. Typically, Arkansas does one quality assurance test for every 750 tons produced; Kentucky does one every 4000 tons; Minnesota does one per day; North Carolina does a minimum of 10 percent of the number required by the contractor; North Dakota does two per day; Oregon does one for every 10 contractor quality control tests performed; Utah does four quality assurance tests per lot per day; and Washington does one per 400 tons for density and one per 300 tons for gradations and asphalt content.

3.2.5 Quality Assurance Testing

The approximate ratio of the number of quality assurance tests to the number of quality control tests (QA:QC) ranges from 1:1 to as low as 1:10. For some of the SHAs, this ratio varies significantly and an approximate ratio is difficult to determine. The approximate ratios between the numbers of quality assurance and quality control tests performed among the SHAs are summarized in Table 3.1.

The QA tests that are performed by different SHAs are for a variety of purposes. Some of the SHAs use QA testing to verify QC test results. When the contractor is responsible for QC testing, QA tests are performed to verify that contractor testing is being done properly and precisely. Others use QA testing to adjust the final pay. QA testing is considered in this case to measure the quality of the product being placed. Initial correlation is another area where QA test results are utilized. At the beginning of the production of HMA, the SHA often performs QA tests mirrored by QC tests to make sure that all testing equipment is calibrated and that testing procedures are being followed. This will usually save the contractor time and money throughout construction. Of the 39 SHAs to respond to this question, 26 use QA tests for QC test result verification, 16 use QA test results for final pay adjustments, and six use QA test results for initial correlations. Most of the SHAs use QA test results for more than one purpose. QA test results are also used for determining acceptance by a number of SHAs, and for contractor's QA test verification in Michigan.

Florida, Indiana, Maryland, Michigan, Ohio, Wisconsin, and Wyoming are all making a move to change the contractor or state's involvement with quality assurance testing in some way. The agency in Florida will start verifying contractor quality control tests at a reduced rate. Indiana is going to start using contractor quality control tests for acceptance and payment under contractor acceptance specifications and acceptance by certification. Maryland is looking to use statistical evaluation from AASHTO R 4-97 and NCHRP 9-7. State inspectors in Michigan will start performing total quality assurance testing. Ohio's new 1056 program puts even more responsibility on the contractor. Wisconsin is adjusting its specification to meet federal requirements for verification testing. In Wyoming, the contractor will start doing acceptance testing at the frequency and location designated by the state, and the state will be responsible for pay factor calculations and acceptance decision.

3.2.6 Properties to be Tested for QC/QA

There are many tests to be run during the production and placement of HMA. These tests are used to compare the characteristics of the HMA being produced and placed to characteristics that are known to represent a good product. A high quality pavement can be produced with the control of a select few of these characteristics. Density, asphalt content and aggregate gradation are three of the most commonly controlled characteristics. The specifications for quality control testing, quality assurance testing, or a combination of the two intended to control the production of asphalt mixture and the proper placement of the mixture vary between the SHAs. Table 3.2 summarizes the mixture and mat characteristics controlled through the use of quality control and quality assurance testing of 39 different SHAs.

Table 3.1 Approximate Ratio of QA to QC Tests

SHA	Ratio
Alabama	1:2
Alaska	Varying
Arkansas	Varying
California	1:10
Colorado	1:10
Florida	1:1
Georgia	Varying
Idaho	1:10
Illinois	1:5
Indiana	1:3
Kansas	1:4 mix properties, 1:2 density
Kentucky	1:4
Maine	1:2
Maryland	1:6, varying
Michigan	Varying
Minnesota	1:4
Mississippi	1:10
Missouri	1:4
Nebraska	1:5
Nevada	Varying
New Hampshire	1:1
New Jersey	Varying
New York	Varying
North Carolina	1:10 min.
North Dakota	1:10
Ohio	1:4-6, depending on specifications and test types
Oklahoma	1:10
Oregon	1:10
Pennsylvania	Varying
South Carolina	1:10
South Dakota	1:5
Texas	1:4
Utah	1:1
Vermont	4:3
Virginia	1:4 mix, 1:1 density
Washington	Varying
West Virginia	1:10
Wisconsin	1:5
Wyoming	1:1

Table 3.2 Mixture and Mat Characteristics Controlled in QC/QA

SHA	Agg. Grad. (extract)	Agg. Grad.	Clay Content	Asphalt Content (extract)	Asphalt Content	VTM	VMA	Voidless Unit Weight	Dust-to-Asphalt Ratio	TSR	Mix Temp.	Mat Density	Smooth-ness
Alabama	QC/QA	QC	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA		QC/QA	QC/QA
Alaska		QA			QA							QA	
Arkansas					QC/QA	QC/QA	QC/QA	QC/QA				QC/QA	QC/QA
California	QC/QA	QC/QA	QC/QA	QC/QA	QC	QC/QA						QC/QA	
Colorado		QC/QA			QC/QA			QC/QA				QC/QA	
Florida	QC/QA	QC		QC/QA		QC/QA	QC	QC/QA	QC		QC/QA	QC/QA	QC/QA
Georgia	QC/QA	QC		QC/QA	QC/QA	QA		QC/QA			QC/QA	QA	QA
Idaho	QC	QC/QA		QC/QA	QC/QA	QA						QA	QC
Illinois	QC/QA	QC/QA			QC/QA	QC/QA		QC/QA				QC/QA	
Indiana	QC/QA	QC			QC/QA	QC/QA	QC/QA	QC/QA			QC/QA	QC/QA	QA
Kansas	QC/QA	QC/QA	QA	QC/QA		QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC
Kentucky		QC			QC/QA	QC/QA	QC/QA				QC/QA	QC/QA	
Maine		QC/QA			QC/QA	QC/QA	QC/QA		QC/QA		QC/QA	QC/QA	QA
Maryland	QC/QA			QC	QA	QC/QA	QC/QA		QC/QA			QC/QA	
Michigan		QC			QC/QA	QC/QA	QC/QA	QC/QA				QA	QA
Minnesota	QC/QA	QC/QA		QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QA		QC/QA	QC
Mississippi	QC/QA	QC			QC/QA	QC/QA	QC/QA		QC/QA		QA	QA	QA
Missouri		QC/QA			QC/QA	QC/QA	QC/QA				QC/QA	QC/QA	QC/QA
Nebraska		QC/QA			QC/QA	QC/QA	QC/QA	QC/QA				QC/QA	QC/QA
Nevada		QA	QC		QA	QA	QA	QC		QC	QC	QA	QA
New Hampshire	QC/QA	QC		QC/QA		QA		QC/QA			QC	QC	QA
New Jersey	QC/QA		QC/QA	QC/QA		QC/QA	QC/QA		QC/QA		QC/QA		QC/QA
New York	QA	QC/QA		QA	QC/QA	QC/QA	QC/QA		QC/QA		QC/QA	QC/QA	
North Carolina	QC/QA		QC/QA	QC/QA		QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QC/QA	QA
North Dakota		QC/QA			QC/QA	QC/QA		QC/QA				QC/QA	

Table 3.2 (Continued)

SHA	Agg. Grad. (extract)	Agg. Grad.	Clay Content	Asphalt Content (extract)	Asphalt Content	VTM	VMA	Voidless Unit Weight	Dust-to-Asphalt Ratio	TSR	Mix Temp.	Mat Density	Smooth-ness
Ohio	QC/QA	QC/QA		QC/QA	QC/QA	QC/QA	QC		QC/QA		QC	QC	
Oklahoma		QC/QA			QC/QA	QC/QA						QC/QA	
Oregon		QC/QA	QC/QA		QC/QA	QC/QA	QC/QA	QC/QA		QC	QC/QA	QC/QA	QC
Pennsylvania	QC/QA	QC/QA		QC/QA	QC/QA	QC		QC	QC		QC/QA	QC	QC
South Carolina	QC	QC		QA		QA	QC	QC			QC	QC/QA	
South Dakota		QC/QA			QA	QC/QA		QC/QA			QC/QA	QC/QA	QA
Texas	QC	QC		QC	QC	QA	QC					QA	
Utah		QC/QA			QC/QA	QC/QA	QC/QA				QC	QC/QA	QC
Vermont	QC	QC			QC	QC/QA					QC	QA	
Virginia		QC/QA			QC/QA						QC/QA	QC/QA	QC/QA
Washington		QA			QA			QA				QA	
West Virginia		QC/QA			QC/QA	QC/QA	QC/QA					QC/QA	QA
Wisconsin	QC/QA	QC/QA			QC/QA	QC/QA	QC/QA	QC/QA					
Wyoming	QC	QC/QA			QA	QC					QC	QC/QA	QA

From Table 3.2, it can be seen that extracted and non-extracted aggregate gradations, clay content, extracted and non-extracted asphalt contents, VTM, VMA, voidless unit weight, dust-to-asphalt ratio, tensile strength ratio (TSR), mixture temperature, mat density, and smoothness make up the majority of the mixture and mat characteristics that are being controlled through quality control and quality assurance testing. Other mixture and mat characteristics that are sometimes required by the state for quality control and quality assurance testing include aggregate moisture content, liquid limit and plastic limit (LL&PI), coarse and fine aggregate angularities (FAA and CAA), Marshall stability, Marshall flow, bulk and maximum specific gravities, Superpave compaction gyratory numbers, mat thickness, and cross slope.

3.2.7 Certification of QC/QA Testers

Precise and accurate testing is an essential part of an asphalt pavement QC/QA specification program. Test results are many times used to determine the payment amount that a contractor will receive for its work. It usually doesn't matter whether the results are from quality assurance or quality control testing, because in most cases the two are made to complement one another. Many QC/QA specifications are set up in such a way that a few quality assurance tests verify a group of quality control tests. In these cases, both sets of tests need to be accurate and precise to avoid any conflict that may occur between the SHA and the contractor. To make the construction process as seamless as possible, certification is often required of material testers.

All of the responding SHAs having an asphalt pavement QC/QA program require some level of certification of the persons doing the testing. Of the 38 SHAs responding to the question, all but Alaska require that all testing technicians doing quality control testing be certified. Alaska is the only SHA that does not require any certification for technicians, supervisors, or engineers for quality control testing. Only 10 of the 38 SHAs require the quality control testing supervisors be certified. Of the 38 responding SHAs, all but Nebraska and Vermont require that all technicians doing quality assurance testing be certified. Nebraska and Vermont are the only SHAs not to require any certification for quality assurance testing. Only 8 of the 38 SHAs require the quality assurance testing supervisors be certified.

3.2.8 Variable Control Levels

Not all projects are treated in the same respect. If a project is large or is deemed important by the SHA, the way the quality of that project is controlled may differ. Or, if a project is small enough, quality control of the materials may not be needed at all. These are the reasons why some SHAs may have different levels of control. These different levels of control are defined by their differing test requirements. If a project is considered very important, the SHA may require a larger variety of tests or a higher testing frequency to ensure a quality product.

Eighteen of the 39 responding SHAs use an asphalt pavement QC/QA specification that utilizes multiple levels of control. Among these SHAs, the number of levels of control ranges from two to six. Seven of the SHAs utilize two different levels of control, four of them utilize three, three utilize four, one is utilizing five, one is utilizing six different levels of control, and the rest did not provide the number of control levels used. The factors that influence the choice of level of control used on a project are summarized in Table 3.3. None of the 18 SHAs base their choice of level of control on the type of project funding or available personnel. Most of them, on the other hand, base their choice of level of control for a project on the quantity of material being produced. Some other factors that play a role in choosing the level of control are type and application of mixture, quality characteristics, mixture verification process at the start of production, and results of completed tests.

Table 3.3 Factors Used in Determining the Level of Control

SHA	Quantity of Material	Traffic Loads	Type of Facility	Type of Construction	Others
Alaska	X				
Arkansas	X				Type of mix
California					Quality characteristic
Colorado	X				Mix verification process at the start of production
Illinois			X	X	
Kansas	X				
Kentucky		X		X	Based on mix type/application
Maine	X	X	X	X	
Missouri	X			X	
New York		X	X		
Oregon	X				
Pennsylvania	X			X	
South Dakota					Results of completed tests
Vermont	X				
Washington	X				
West Virginia	X				
Wisconsin	X				
Wyoming	X	X	X		

At different levels of control, the requirements of QC/QA vary. Table 3.4 shows some of the differences among the different levels of control for each of the 18 SHAs. These differences include quality control testing frequency, quality assurance testing frequency, and the number of properties controlled. Some others are also included in the table.

3.2.9 Incentive and Disincentive Policies

QC/QA is usually built upon a statistically based specification, which is based on random sampling, where properties of the desired product or construction are described by appropriate statistical parameters (TRB, 1999). By knowing the properties that are representative of a quality product, SHAs are able to test and measure those properties to determine the quality of the product produced. With this ability, SHAs can pay the contractor for the product that was produced regardless of the bid price. This use of pay adjustment is a disincentive to the contractor, and is intended to encourage the production of a quality product. Incentives are also used in a similar fashion. All of the SHAs responding to the question use disincentives in their programs, and all but four of them use incentives. The SHAs not using incentives are Maryland, North Dakota, Virginia, and Wisconsin. Maryland, however, is in the process of including incentives.

Table 3.4 Variations among Different Levels of Control

SHA	QC testing frequency	QA testing frequency	Number of properties	Others
Alaska				Number of acceptance tests
Arkansas				Additional testing
California	X	X		
Colorado	X		X	
Illinois	X	X		
Kansas	X	X		
Kentucky				Volumetric properties of mixes on mainline and shoulder applications (i.e., AC, AV, VMA, density, leveling)
Maine		X	X	
Missouri	X			
New York	X	X		
Oregon	X	X	X	Visual inspection along with previous test results indicating specification product has been supplied for job less than 2500 tons
Pennsylvania		X		
South Dakota	X	X	X	
Vermont		X		
Washington		X		Reduction in frequency for jobs less than 2500 tons
West Virginia	X			
Wisconsin	X	X		
Wyoming	X	X	X	

The asphalt mixture and mat attributes that are considered by the SHAs for adjusting pay are summarized in Table 3.5. Mat density, asphalt content, air voids, aggregate gradation, and smoothness are commonly used asphalt pavement attributes used in the adjustment of contractor pay. VMA, thickness, G_{mm}, cross-slope, and lab densities are some of the others that are considered by a few of the SHAs. The pay factor ranges corresponding to these attributes can also be found in Table 3.5. These pay factor ranges are representative of the range of product quality the SHA is willing to accept. Twenty of the 39 SHAs responding to the question use an equation that combines all of the individual pay factors. The composite pay factor (PF_c) equations provided can be seen in Table 3.6.

3.2.10 Program Evaluations

Twenty-four of the respondents having an asphalt pavement QC/QA program have evaluated their programs for effectiveness. Three of them are currently in the process of performing such an evaluation. The majority of the programs are under constant review, either in a formal or informal manner.

Of the SHAs that did a formal or informal evaluation of their QC/QA program, the majority of them were mostly concerned with a select few asphalt mixture properties. Ninety-one percent of the respondents used asphalt content as a variable for evaluation, 83 percent used density data, 78 percent used air void data, and 70 percent used aggregate gradation data. VMA was also used as a variable to evaluate programs by 48 percent of the SHAs that had responded. Dust-to-asphalt ratio, film thickness, rutting, and smoothness were among some of the other characteristics used in asphalt pavement QC/QA program evaluations.

The lengths of time between asphalt pavement QC/QA program implementation and evaluation ranged from six months to six years. These account for the majority of formal evaluations. Many informal evaluations are performed on a continuous or periodic basis.

Overall, the results of asphalt pavement QC/QA specification program evaluations have been very positive. Of the 24 responding SHAs that evaluated their QC/QA specification program, Maryland was the only one claiming to have mixed reviews and to discover that its program was still in need of adjustment. The other 23 programs proved to be effective. Alabama, California, Colorado, Georgia, Indiana, Maine, Pennsylvania, and Texas have all had the results of their evaluative analyses published.

The use of QC/QA specifications demands that many tests be performed before, during, and after the construction of asphalt pavement. This large amount of testing may increase the initial cost of construction. The use of incentives or bonuses may also cause a similar increase. Of 37 SHAs responding to the question, 10 claim that QC/QA is increasing the cost of construction, one states that it probably is, 18 claim that they are seeing no such increase, and five don't know whether QC/QA is causing increases in construction cost or not. The remaining three SHAs claim that there are increases in construction costs for some projects due to QC/QA but that they are washed out overall. Of 30 SHAs, 15 estimate that 80 percent or more of the QC/QA projects bid receive an incentive.

Table 3.5 Asphalt Pavement Attributes Used for Payment Adjustments and Their Corresponding Pay Factor Ranges

SHA	Pay Factor for Mat Density	Pay Factor for Air Voids	Pay Factor for Asphalt Content	Pay Factor for Aggregate Gradation	Pay Factor for Smoothness	Pay Factor for Other Attributes	
						Attributes	Pay Factor
Alabama	0.80 to 1.02	0.80 to 1.02	0.80 to 1.02		0.80 to 1.05		
Alaska	0.75 to 1.05		0.75 to 1.05	0.75 to 1.05	$10,000 to $20,000		
Arkansas	N/A	N/A	N/A		3.0% to -4.0%		
California	0.75 to 1.05		0.75 to 1.05	0.75 to 1.05			
Colorado	0.75 to (1.025 to1.060)		0.75 to (1.025 to 1.060)	0.75 to (1.025 to 1.060)	0.0 to 0.10/sq. yd		
Florida	0.75 to 1.05		0.80 to 1.00	0.80 to 1.00			
Georgia	0.50 to 1.00	0.50 to 1.00	0.50 to 1.00	0.75 to 1.00	0.65 to 1.00		
Idaho	0.75 to 1.05	N/A	0.75 to 1.05	N/A	Grinding to 1.05		
Illinois	0.80 to 1.05	0.80 to 1.05	0.80 to 1.05				
Indiana	N/A	0.85 to 1.05	0.85 to 1.05	0.85 to 1.05			
Kansas	0.70 to 1.04	0.800 to 1.030			$203 to $152/0.1 mile section/lane		
Kentucky	0.85 to 1.05	0.85 to 1.05	0.85 to 1.00	0.75 to 1.00		VMA	0.85 to 1.00
Maine	0.55 to 1.05	0.55 to 1.05	0.55 to 1.05		0.75 to 1.05	VMA	0.55 to 1.05
Maryland	0.75 to 1.00		0.75 to 1.00	0.75 to 1.00			
Michigan	0.75 to 1.06	0.75 to 1.04	0.75 to 1.04			G_{mm}	0.75 to 1.04
Minnesota	0.50 to 1.04	0.50 to 1.00	0.50 to 1.00	0.50 to 1.00	0.50 to 1.00		
Mississippi	0.70 to 1.00	0.50 to 1.00	0.75 to 1.00	0.75 to 1.00	0.90 to 1.05	VMA	0.75 to 1.00
Missouri	0.00 to 1.05	0.00 to 1.05	0.00 to 1.05		0.93 to 1.07	VMA	0.00 to 1.05
Nebraska	0.70 to 1.00	0.50 to 1.02			0.90 to 1.05		
Nevada		0.70 to 1.05	0.70 to 1.05	0.70 to 1.05	0.90 to 1.05		
New Hampshire		0.75 to 1.05	0.75 to 1.05	0.75 to 1.05	0.75 to 1.05	Thickness, cross slope	0.75 to 1.05
New Jersey		N/A			N/A	Thickness	

N/A indicates that there is a pay factor range, but the numbers are unavailable.

Table 3.5 (Continued)

SHA	Pay Factor for Mat Density	Pay Factor for Air Voids	Pay Factor for Asphalt Content	Pay Factor for Aggregate Gradation	Pay Factor for Smoothness	Pay Factor for Other Attributes	
						Attributes	Pay Factor
New York	0.60 to 1.05	0.85 to 1.05			N/A		
North Carolina	0.50 to 1.00	0.50 to 1.00	0.50 to 1.00	0.70 to 1.00			
North Dakota	N/A		N/A				
Ohio	0.70 to 1.04		0.70 to 1.00	0.70 to 1.00	Replace to 1.05		
Oklahoma	0.50 to 1.00	0.79 to 1.00	0.80 to 1.00	0.76 to 1.00	0.80 to 1.03		
Oregon	0.75 to 1.05		0.75 to 1.05	0.75 to 1.05	0.75 to 1.05		
Pennsylvania	0.50 to 1.00		0.50 to 1.00	0.50 to 1.00	bonus: $0 to $300/0.1 lane-mile		
South Carolina	0.85 to 1.05	0.85 to 1.05	0.85 to 1.05			VMA	0.85 to 1.05
South Dakota	0.85 to 1.05	0.85 to 1.05			0.90 to 1.04		
Texas	0.700 to 1.050					Lab Density	0.70 to 1.05
Utah	$0.91 to -2.27/ton		$0.91 to -2.27/ton	$0.91 to -2.27/ton	N/A		
Vermont	0.80 to 1.03	0.93 to 1.03					
Virginia	N/A		N/A	N/A	N/A		
Washington	0.75 to 1.02		0.75 to 1.03	0.75 to 1.03			
West Virginia	0.88 to 1.00	0.92 to 1.00 (Superpave)	0.92 to 1.00 (Superpave)				
Wisconsin		0.50 to 1.00	0.75 to 1.00	0.75 to 1.00		VMA	0.75 to 1.00
Wyoming	0.50 to 1.10		0.75 to 1.05	0.75 to 1.05	N/A		

N/A indicates that there is a pay factor range, but the numbers are unavailable.

Table 3.6 Composite Pay Factor Equations Used by SHAs for Adjusting Payment

SHA	Composite Pay Factor Equation
California	PF_C = Sum of ($W_i \times PF_{QCi}$) where, W = weighting factor, PF_{QC} = individual quality characteristic pay factor, i = quality characteristic index number.
Colorado	PF_C = 0.20 × Gradation + 0.30 × AC + 0.50 × Density Smoothness is a separate element.
Idaho	$PF_C = 0.40 \times PF_{DENSITY} + 0.30 \times PF_{ASPHALT} + 0.30 \times PF_{AGGREGATE}$
Illinois	PF_C = 0.50 × (PWL) + 0.55, with a final pay cap of 1.03 where PWL = percent within limits.
Indiana	PF_C = 0.20 × AC + 0.35 × Mat Density + 0.35 × AV + 0.10 × VMA
Kentucky	PF_C = 0.10 × AC + 0.25 × AV + 0.25 × VMA + 0.40 × Density (by cores) for mix accepted by volumetrics, i.e., Superpave mix used on mainline applications.
Maine	PF_C = 0.60 × Density + 0.20 × Voids + 0.10 × VMA + 0.10 × AC On pilots, smoothness is a separate pay adjustment.
Missouri	$PF_C = 0.25 \times (PF_{DENSITY} + PF_{AC} + PF_{VMA} + PF_{AIRVOIDS})$ Smoothness applied separately. Removal required if total pay factor less than 50%.
Nebraska	(Single Air Void) × (Ave. of 4 Air Void) × (Density) All pay adjustments apply to mainline tonnage. Only density adjustments apply to shoulder tonnage.
New Hampshire	Weight factors: gradation, 0.15; AC, 0.15; AV, 0.20; thickness, 0.10; smoothness, 0.30; and cross slope, 0.20.
New Jersey	Currently it is the average of the individual pay factors for air voids, thickness, and smoothness, but a new specification is being developed, which is believed to be a significant improvement.
Oklahoma	PF_C = [3 × (AC + AV + Density) + Gradation]/10 Smoothness is independent.
Oregon	Factors depend on type of HMA. Smoothness is evaluated separately.
Pennsylvania	$Lp = Cp \times [(2P_D + P_M)/400]$ where Lp = lot payment, Cp = contract unit price per lot, P_D = density, P_M = sum of %AC & % passing #200 sieve payment factors.
South Carolina	$LPF = 0.20 \times PF_{AC} + 0.35 \times PF_{AV} + 0.10 \times PF_{VMA} + 0.35 \times PF_{DENSITY}$
South Dakota	50:50 between mat density and AV.
Texas	TPA = (A + B)/2 where A = bid price × production lot quantity × pay adjustment factor for production, B = bid price × placement lot quantity tested for air voids × pay adjustment factor for placement + bid price × placement lot quantity not tested for air voids × 1.00.

3.3 Region 8 Responses

The evaluation of the effectiveness of WYDOT's QC/QA specification in decreasing HMA variability is being used as a case study for this research. This case study is meant to be a springboard to the evaluation of the effectiveness of all QC/QA specifications in decreasing HMA variability. Next in line are the SHAs that form Region 8, which is defined by the Federal Highway Administration. WYDOT is one of these states. There are five others, Colorado, Montana, North Dakota, South Dakota, and Utah. Each one of these SHAs responded to the questionnaire that was distributed. The information that was gathered about their QC/QA specification programs with the questionnaire is presented individually for each of these five SHAs.

3.3.1 CDOT's QC/QA Specification Program

According to their response to the questionnaire, the Colorado Department of Transportation (CDOT) has had a QC/QA program for asphalt pavements since 1992. It started as a pilot program at that time and was adopted as a standard in 1995. In this period of time, CDOT's QC/QA program was significantly modified twice. The modifications as quoted from the questionnaire are as follows. "Based on historical data since the inception of QC/QA we reduced the standard deviations used in the pilot program. The second modification was to allow the engineer to accept asphalt using void properties for QC/QA." Since the 1992 implementation of this program, CDOT has completed more than 250 projects under their asphalt pavement QC/QA program. Projects of all sizes, for Interstate, primary, and secondary roadways are being constructed under CDOT's QC/QA specification program. This program was evaluated for effectiveness three years after implementation. The report for this evaluation titled "Hot Bituminous Pavement QA/QA Pilot Projects Constructed in 1994 and Summary of the 1992-1994 QA/QC Pilot Program" was written for CDOT in 1995 by Bud A. Brakey. From this evaluation, it was found that CDOT's QC/QA program for asphalt pavement proved to be effective. Some of the asphalt mix properties that were used in the evaluation include density, asphalt content, and aggregate gradations.

Within CDOT's QC/QA program, the SHA is responsible for conducting the quality control testing. The SHA is also responsible for evaluating the quality control test results and initiating corrective action when necessary. CDOT is, however, changing the SHA's and contractor's roles in quality control. Currently, both the SHA and the contractor are doing quality control testing, but the contractor's testing is required only to assure that the material is meeting specifications throughout the project. CDOT is now moving toward accepting the contractor's quality control test results for incentive and disincentive payment purposes. The SHA also does quality assurance testing, of which the number of tests performed for a typical project varies significantly. CDOT is not moving to change either the SHA's or the contractor's involvement with quality assurance testing in any way. Quality assurance testing is used for quality control test result verification. The approximate ratio between the number of quality assurance and quality control tests performed per project is 1:10. The mixture properties required by the SHA to be tested for both quality control and quality assurance purposes are mat density, asphalt content, voidless unit weight, and aggregate gradation. All testing technicians are required to be certified to perform quality control and quality assurance testing under CDOT's QC/QA specification program.

CDOT's asphalt pavement QC/QA program depends on three different levels of control. The level of control used for a given project is dependent on the quantity of material used for that project and the mix verification process at the start of production. Both the quality control testing frequencies and the number of control properties vary among these different levels of control. There are also three different levels, or classes, of specified asphalt mixture properties. The choice of which specified mixture properties are used for a given project depends on the traffic loads. The required mixture properties specified within in these different classes are L.A. abrasion resistance, compaction energy, stability, voids in production mix, temperature, VMA, minimum tensile strength retained, voids in laboratory mix, and VFA. Most of these are considered only in the design process, but some are used to determine the quality of the asphalt mix and pavement. Both incentives and disincentives are used in CDOT's QC/QA program. The attributes being used to adjust the pay are mat density, asphalt content, aggregate gradation, and smoothness. Smoothness is considered as a separate pay item. The pay factor for smoothness ranges from 0.0-0.10/square yard. The pay factor ranges for all the rest of these attributes range from 0.75-(1.025-1.060). The upper limit on the pay factors for these varies on the number of results. The equation used to factor together the individual pay factors is: 0.20 × (Gradation) + 0.30 × (Asphalt Content) + 0.50 × (Density). The attributes being used to adjust the pay do not vary with the mix design method used. About 95 percent of the projects let under CDOT's QC/QA program are receiving incentives, but is not increasing the cost of construction.

3.3.2 MDT's QC/QA Specification Program

The Montana Department of Transportation (MDT) does not use a true QC/QA specification for asphalt pavement. In response to the questionnaire, MDT sent a letter with the following statement: "Under our program, the state does all quality assurance testing. The contractor generally does some quality control testing. This is generally limited to density control and the results of this testing is not reported to the state. We do density testing on the finished product for acceptance. The program includes incentives and disincentives on several items including cold feed gradations, density, and ride (IRI). On larger projects we have an asphalt test trailer on site."

3.3.3 NDDOT's QC/QA Specification Program

The North Dakota Department of Transportation's (NDDOT) asphalt pavement QC/QA specification program was implemented for asphalt pavements in 1994. To date, approximately 70 projects, about 10 per year, have been completed under NDDOT's QC/QA program. This QC/QA program is used on projects 10,000 tons or greater in size on interstate, primary, and secondary road types. Since implementation, four major changes to the program have been made. The first change is that NDDOT now requires bituminous technician training for contractor and state personnel; second, NDDOT has added independent assurance testing; third, NDDOT has shifted the responsibility for the mix design to the contractor for QC/QA. The fourth change was made to integrate Superpave with QC/QA. In the first year after implementation, NDDOT's QC/QA program was evaluated for effectiveness. The evaluation was an internal evaluation performed by the NDDOT Construction and Materials Divisions. Density, aggregate gradations, VMA, asphalt content, air voids, dust/asphalt ratio, and film thickness data was used for the evaluation. From this evaluation, it was found that NDDOT's asphalt pavement QC/QA program proved to be effective. The results of the evaluation have not been published.

Within NDDOT's asphalt pavement QC/QA program, the contractor is responsible for conducting the quality control testing. The responsibility for evaluating the quality control test results and initiating corrective action is shared between the contractor and the SHA. Besides this involvement in quality control, the SHA also does quality assurance testing. A minimum of 10 percent of the frequency required for quality control tests is required of the SHA for quality assurance testing throughout most of the project. About two quality assurance tests are performed per day for a typical project. Quality assurance tests are used for quality control test result verification, initial correlation, and for confirming asphalt mix quality. NDDOT is not moving to change the contractor or SHA's involvement with quality control or quality testing in any way. The mixture properties required by the SHA to be tested for both quality control and quality assurance purposes are: mat density, asphalt content, voidless unit weight, air voids, and aggregate gradation. All testing technicians are required to be certified to perform both quality control and quality assurance testing. The NDDOT district materials coordinators are required to be certified to perform quality assurance testing.

The QC/QA program that NDDOT uses for asphalt pavements does not have different levels of control. It does, however, have four different levels, or classes, of specified asphalt mixture properties. The class of required properties used for a project depends on the traffic loads and the type of facility being constructed. The characteristics specified within these required mixture properties are: L.A. abrasion resistance, stability, film thickness, voids in production mix, VMA, dust-to-asphalt ratio, flow, voids in laboratory mix, and percent crushed fines. NDDOT uses disincentives within their QC/QA specification program to help control quality. These disincentives are applied to mat densities, asphalt content, and aggregate gradations. These attributes do not vary with the mix design methods used. Incentives are not used in this program. An equation for factoring together the individual pay factors is not used. The overall cost of construction, according to NDDOT, has not increased with the implementation of their QC/QA specification program.

3.3.4 SDDOT's QC/QA Specification Program

The South Dakota Department of Transportation (SDDOT) implemented a QC/QA program for asphalt pavements in 1997. To date, approximately 100 projects have been completed under this program. These projects were 10,000 tons and greater in size and included interstate, primary, and secondary roadways. Since implementation, yearly minor changes to the program have been made. An evaluation of SDDOT's QC/QA specification program proved the program to be effective. The properties used in the evaluation were density, aggregate gradation, asphalt content, and rutting. Data for most of these properties were collected yearly through cores taken from some of the projects constructed. The results of the evaluation have not been published.

Within SDDOT's QC/QA specification program, the contractor is responsible for performing the quality control testing, evaluating the results of those tests, and initiating corrective action when processes are out of specification. Quality assurance testing is the responsibility of the SHA. The approximate ratio between the number of quality assurance and quality control tests performed for a typical project is 1:5. The exact number of quality assurance tests, however, varies significantly from one project to another. The quality assurance test results are used for quality control test result verification and initial correlations. SDDOT is not moving to change either the SHA's or contractor's involvements with quality assurance or quality control testing. Independent assurance sampling is also a part of SDDOT's QC/QA program. Independent assurance samples are taken by SDDOT regional lab personnel at a rate of one per 10,000 tons of mix produced. The mixture properties required by the SHA to be tested for quality control purposes are: mat density, voidless unit weight, LL and PI, air voids, aggregate gradation, and temperature. The mixture properties required by the SHA to be tested for quality assurance are: mat density, asphalt content, smoothness, voidless unit weight, LL and PI, air voids, aggregate gradation, and temperature. All testing technicians must be certified to do both quality control and quality assurance testing.

SDDOT's QC/QA specification program uses multiple levels of control. These levels of control are based on a minimum testing frequency requirement and are dependent only on the results of the completed tests. With changes in level of control, both quality control and quality assurance testing frequencies, and the number of control properties vary. This QC/QA program also makes use of three different classes of specified mixture properties. The class of specified mixture properties used depends on traffic loading. The characteristics specified within these three different classes are: L.A. abrasion resistance, compaction energy, stability, voids in production mix, temperature, VMA, dust-to-asphalt ratio, flow, minimum tensile strength retained, voids in laboratory mix, and mix moisture content. For incentive/disincentive purposes, mat density, air voids, and smoothness are used. Mat density and air voids have possible pay adjustment ranges of 0.85 to 1.05, and the possible pay adjustment range for smoothness is 0.90 to 1.04. These attributes that are being used for pay adjustment do not vary with mix design method. In determining the overall pay factor, the individual pay factors for mat density and air voids are factored together weighted equally at 50 percent. Smoothness is a separate pay factor altogether. Overall, the QC/QA program is increasing the cost of construction. Approximately 80 percent of the projects let under SDDOT's QC/QA program are receiving incentives.

3.3.5 UDOT's QC/QA Specification Program

The Utah Department of Transportation (UDOT) implemented an asphalt pavement QC/QA program in 1997. Currently, about 90 projects have been constructed under this program. This QC/QA program is used for projects greater than 10,000 tons involving interstate, primary, and secondary roadways. Since implementation, the program has been significantly modified twice. The first modification involved the removal of referee testing. The second modification involved the introduction of incentives and disincentives for VMA. The program was evaluated for effectiveness one year and three years after implementation. The program proved to be effective. The evaluations were not published.

Within the QC/QA specification program, the contractor is responsible for conducting and evaluating quality control testing and for initiating necessary corrective actions. Quality assurance testing is performed by the SHA. Four quality assurance tests per lot per day are performed for a typical project. The approximate ratio between the number of quality assurance and quality control tests performed is 1:1. These quality assurance tests are used for final pay adjustments and acceptance. UDOT is not moving to change either the SHA's or contractor's involvements with quality control or quality assurance. The mixture properties required by the SHA to be tested for quality control purposes are: mat density, asphalt content (T-308), smoothness, air voids, aggregate gradation (T-308), VMA, and temperature. The mixture properties required to be tested for quality assurance purposes are: mat density, asphalt content (T-308), air voids, aggregate gradation (T-308), and VMA. Under this program, certification for all quality control and quality assurance testing technicians is required.

UDOT's QC/QA specification program does not utilize multiple levels of control. There are, however, two different classes of specified asphalt mixture properties. These two classes are dependent on the type of facility being constructed. The characteristics specified within these classes are minimum percent asphalt, and VMA. UDOT uses an incentives/disincentives policy that is based on dollars/ton. For mat density, asphalt content, and aggregate gradation, a pay adjustment range of –\$2.27/ton to +\$0.91/ton is used. Pay adjustments for smoothness are under a different specification, where the bonuses are based on tonnage. UDOT does not use a single equation to factor together the individual pay factors. The attributes being used to adjust pay do not vary with mix design method. About 80 percent of the projects let under this QC/QA program are receiving incentives. Overall, this program is not increasing the cost of construction.

3.4 Chapter Summary

A comprehensive questionnaire regarding asphalt pavement QC/QA specification programs was written and was distributed to the 50 SHAs in July 2001. There were 45 responses to the questionnaire. All of the responses to this questionnaire were summarized, and the individual responses of those SHAs that are in Region 8 were presented individually.

From the summary of the responses, the following conclusions could be made. Of the 45 SHAs that responded to the questionnaire, 40 or nearly 90 percent have implemented an asphalt pavement construction QC/QA specification program. The first of these QC/QA specification programs emerged as early as 1968, but most of the programs (more than 80 percent) were implemented after 1985. For most of the SHAs, implementation of a QC/QA specification is a relatively new venture, and as a result the QC/QA specifications for asphalt pavement construction are still in the stages of development. Each SHA that uses a QC/QA specification for asphalt pavement construction has its own version of a similar concept. Different versions of the QC/QA specification concept may vary significantly in requirements. The differences include the scope of QC/QA, quality control responsibilities, quality assurance responsibilities, quality assurance testing, properties to be tested, certification of testers, variable control level, and incentive and disincentive policies. In general, previous evaluations of asphalt pavement QC/QA specifications by individual SHAs have resulted in positive reviews. As a result of QC/QA specification, some SHAs are seeing an increase in initial construction costs, while most of them are not.

Along with Wyoming, Colorado, Montana, North Dakota, South Dakota, and Utah make up Region 8 as defined by the FHWA. Of the five additional SHAs, four utilize a QC/QA specification program for the construction of asphalt pavement. Montana does not have such a program. Colorado implemented a pilot program for QC/QA in 1992, which was adopted as a standard in 1995. North Dakota implemented its program 1994. South Dakota implemented its program in 1997. Utah implemented its program in 1997. All of these QC/QA specification programs are very new. The details of these programs vary among the four different SHAs.

4. DATA COLLECTION

4.1 Introduction

After a new specification has been implemented and has been in use for a short period of time, it is important to determine the effectiveness of that new specification in terms of pavement quality improvements. The first step in doing this evaluation is the collection of necessary data. Usually, these data are collected by means of a statistically designed experiment. Such a method would ensure the collection of the most credible and useful data possible. However, this controlled method of data collection is not always possible, and usually the thought of doing an evaluation comes after the fact. In these cases, an alternative method of data collection must be found. One alternative is to gather data that have already been collected for other purposes. This is not always the case, but QC/QA specifications usually have a very large amount of existing data ready to be collected and used to analyze the QC/QA specification. These data come from the great amount of testing associated with quality control and quality assurance. However, not all data collected outside of an experiment are useful, so great care needs to be taken to determine what data can and should be used for analysis. After determining the best type of data to use for a statistical evaluation of the specification, a useful set of such data must be collected, sorted, and prepared for analysis. In this chapter, the data that are needed for the evaluation of the effectiveness of QC/QA specifications in decreasing variability is discussed, followed by a description of the data set that was used to evaluate WYDOT's QC/QA specification.

4.2 The Type of Data Needed

The type of data needed to evaluate the effectiveness of a specification must be closely associated with both the differences between the specification and its predecessor and the expected effects the use of the specification will have on the materials being produced. In the case of a QC/QA specification, the major difference between it and the previous non-QC/QA specification comes with the increased amounts of testing performed throughout the production and placement of the HMA. This increased testing is intended to help the contractor in keeping better control of the quality of the mix being produced. With more frequent testing, the contractor is able to detect any problems with the mix production operations more quickly and allows for the quick adjustments needed to continue the production of a quality mix. A quality mix is a mix that adheres to the project's asphalt mix design. A mix that significantly deviates from the design is undesirable. Decreasing the variability about the mix design of the HMA being produced is the major focus in the evaluation of a QC/QA specification. This focus covers the major difference between the new specification and the old, and the expected effects the specification will have on the materials produced.

For a more detailed analysis, other factors should also be considered. These factors are associated with the variations that can be found among the many different projects that are being built under the new specification. The year of construction, whether RAP was included in the mix, and the classifications of the roadways being paved are just a few additional factors that could provide for a more detailed analysis. The year that the project is constructed would help to explain the variations that may result from minor adjustments to the QC/QA specification that may occur over time, and may also reflect the learning curve that is so often associated with introduction of a new specification. Including RAP use as a factor in the analysis will reveal whether or not a QC/QA specification demonstrates similar control of HMA produced of recycled materials as it does with HMA produced of virgin materials. The effect of road classification could be an indirect measure of the effect of roadway importance or the caliber of the contractor doing the job. Year constructed, RAP use, and road classification are the additional three factors that were considered in evaluating the effectiveness of WYDOT's QC/QA specification in decreasing variability. These are just three examples of factors that could be used to broaden the conclusions of an analysis. There are many other factors that could also be considered. The factors that are used should be unique to the QC/QA specification being evaluated.

In order to statistically measure the effects that a QC/QA specification is having on HMA variability, a data set closely related to the quality of the mix was to be collected. The variability of an asphalt mix is indicated by the absolute deviation of the mix from the project's mix design. A mix design consists of the aggregate gradation, asphalt content, and volumetric properties that characterize the HMA that is optimal for certain service conditions. The aggregate gradation is described by the JMF. The volumetric properties are the VMA and the VTM. These are the HMA properties that describe the consistency of HMA, and the variability of these four properties reflects the variability of the HMA as a whole. All HMA characteristics stem from these four properties.

The data set must consist of measurements of the properties of the HMA that is being produced throughout production, and the design values to which they are to be compared. Also, information regarding the additional factors that are to be considered in the evaluation is needed.

4.3 Sources of Existing Data

WYDOT had a large amount of data on file useful in evaluating the effectiveness of their QC/QA specification in decreasing HMA variability. These data were a result of the great amount of testing that is required with the use of the QC/QA specification. Frequent testing and monitoring is essential to control the HMA being produced. These tests measure the properties and consistency of the HMA and are representative of the HMA that was produced under the QC/QA specification. These were compared directly to the project's mix design to determine the level of adherence. These available data are typical in the case of most QC/QA specifications. Similar data were also found to support the performance of the non-QC/QA specification. These data were the result of the verification and quality assurance tests performed by WYDOT. These were representative of the HMA that was produced under the non-QC/QA specification. The amount of data available for the representation of the non-QC/QA specification was much less than the amount of data available for the QC/QA specification, but these unbalances are easily accounted for. The information needed to connect the additional factors to the different sections was found with the filed data. The JMF letters were also available. These were used to confirm the design value or target values for the data collected for the different pavement sections constructed.

The data sets representing the HMA produced under WYDOT's QC/QA and non-QC/QA specification are unbalanced in two regards, but these unbalances were easily accounted for. The first unbalance comes with the amount of data available to represent the two specifications. Due to the nature of the specifications, the QC/QA specification has much more supporting data than does the non-QC/QA specification. This unbalance, however, was easily accounted for by statistically weighting the data. The quality of the pavement sections with the larger amounts of test data are better represented and therefore were assigned a larger weight. The other apparent unbalance in the data comes from the non-uniform testing. For one, the testing was done under two different specifications. Secondly, the contractor performed nearly all the testing under the QC/QA specification, and testing done under the non-QC/QA was done solely by WYDOT. The sets of data seem to lack balance, but in fact they do not. Qualified testers under a uniform testing standard performed all tests. This makes the tests equal regardless of who did the testing and when the testing was done. The data set collected to evaluate the effectiveness of WYDOT's QC/QA in decreasing HMA variability is credible.

Even though all of the data required for an evaluation were on file at the WYDOT central office, they still needed to be gathered and organized. This process turned out to be fairly tedious but was relatively easy compared to the experimental testing alternative. The information needed was not all located in one place, nor was it in a form that was easily useable. The data were intended solely for the control of mixture production and for pay adjustments during the pavement construction period. After that, the data were stored away, never to be used again. However, the data were successfully collected, validated, and placed into a spreadsheet format where the data could easily be used and manipulated.

4.4 Finished Data

The data set collected for evaluation of WYDOT's QC/QA specification was from the first four years of the specifications use, 1997-2000. Use of WYDOT's specification progressively increased from just a few selected sections in 1997 to nearly full use in 2000. The data set consisted of 223 different pavement sections. An attempt was made to collect data on all of the asphalt pavement sections constructed within the four-year time period, but there were a few projects that went undiscovered. The breakdown of these sections with regards to specification, year, RAP, and road classification can be found in Table 4.1. There are two specifications, non-QC/QA and QC/QA; four years, 1997, 1998, 1999, and 2000; and five different road classifications, interstate utilizing virgin materials, interstate utilizing RAP, primary, secondary, and urban. There were a few federal and county Roadways, but due to their small number they were not included in the evaluation. RAP was integrated with road classification because all of the sections utilizing RAP were interstates.

Table 4.1 The Distribution of Test Sections Among Specification Type, Road Classification, and Year Constructed

Roadway Classification	# of QC/QA Sections				# of non-QC/QA Sections				Totals
	1997	1998	1999	2000	1997	1998	1999	2000	
Interstate	0	1	11	22	6	5	2	0	47
Interstate, w/ RAP	0	8	10	6	5	2	0	0	31
Primary	2	9	33	21	7	3	3	2	80
Secondary	1	3	14	12	8	6	3	0	47
Urban	0	0	0	2	13	3	0	0	18
Totals	3	21	68	63	39	19	8	2	**223**

There were one to 42 different test results representing each of the 223 pavement sections. Nearly all of these tests included extracted aggregate gradations and extracted asphalt content, VMA, and VTM measurements. Some of the tests performed did not include measurements of all of these properties. However, this did not affect the data set in any way. Many of the test forms also included the mix design and JMF. These values were confirmed using the JMF letters. If the values could not be confirmed, they were excluded from the data set. This reduced the data set, but it guaranteed accuracy of the data. About 10 percent of the original data set was excluded due to inability to confirm the values that were presented. The 233 pavement sections of Table 4.1 were the asphalt pavement sections that remained. The data collected for analysis of the variability of the HMA produced under WYDOT's QC/QA specification can be found Appendix B.

4.5 Chapter Summary

Data for the evaluation of the effectiveness of WYDOT's QC/QA specification in decreasing variability were collected. The data set consisted of test results from previously performed quality control, quality assurance, and verification tests. The available test results for 233 pavement sections constructed under the QC/QA and non-QC/QA specification in 1997 thru 2000 were collected. Information regarding the year of construction, the road classification, and the use of RAP was also collected. This data and information will be used in the evaluation of the effectiveness of WYDOT's QC/QA specification in decreasing HMA variability.

5. DATA ANALYSIS

5.1 Introduction

Effectiveness of the QC/QA specification can be measured with an analysis of the data set that was collected. An asphalt pavement QC/QA specification is meant to improve the pavement by decreasing the deviation of the HMA from the project's mix design through quality control/process control. This asphalt mix design is the combination of the aggregate gradation and asphalt content that will result in the best performing HMA. This combination of ingredient quantities when compacted is characterized not only by its aggregate gradation and asphalt content, but also by its volumetric properties. The quality of the HMA that is produced can be measured against these properties. Any mix produced that does not adhere to the mix design will perform at a less than optimal level. This deviation is very critical and therefore is the main focus of QC/QA specification evaluation. In evaluating the effectiveness of WYDOT's QC/QA specification in decreasing HMA variability, analysis of variance (ANOVA) was the main statistical tool used to analyze the data sets. ANOVA was used to evaluate the mean HMA variability of the pavement sections considered, where HMA variability is the absolute deviation between the mix produced and the mix design value. Interaction plots and Tukey's multiple comparisons were used in support of the ANOVA. Minitab was the statistical analysis software used in the evaluation of WYDOT's QC/QA specification.

5.2 Analysis Preparation

Before the data from WYDOT could be statistically analyzed, it was necessary to do some preliminary calculations. The data set that was collected consisted of the aggregate gradations, asphalt contents, VMA, and VTM for the HMA that was produced. The target values were also available. The difference between the measured and target values were calculated for all test results for every HMA property. The absolute value of these deviations was then calculated. The average of these absolute deviations for each individual pavement section represents the variability of HMA produced for that section. The distribution of these average values represents the variability of the HMA being produced under each specification. This was done for the #200 sieve, #30 sieve, #8 sieve, #4 sieve, ½-inch sieve, ¾-inch sieve, asphalt content, VMA, and VTM. Distribution plots of average pavement section deviations from the target value for the aggregate gradation, asphalt content, VMA, and VTM can be found in Figures 5.1 and 5.2. These distributions are the intermediate steps taken in calculating the variability distributions. The distribution plots of average pavement section variability about the target value for aggregate gradation, asphalt content, VMA, and VTM can be found in Figures 5.3 and 5.4. These are the values that were statistically analyzed to measure the changes in variability with QC/QA specification use. A distribution that is closer to zero (the target value) represents less HMA variability. The distributions are represented by box-plots. The line across the middle of the box represents the distribution median. The lines making up the borders of the box represent the first quartile. One quarter of the data lie between the median and each first quartile line. The lines protruding from the box represent the smallest and largest quarters of the data. Any stars apart from the box represent possible outliers. After calculating the average values for all the individual sections, weights were calculated. The weight was set equal to the number of tests representing the HMA produced for a single section. This accounted for lacking representation. The idea was that the mean of 25 deviations is more representative of the materials produced than the mean of only one or two. These weights were in the range of one to 42.

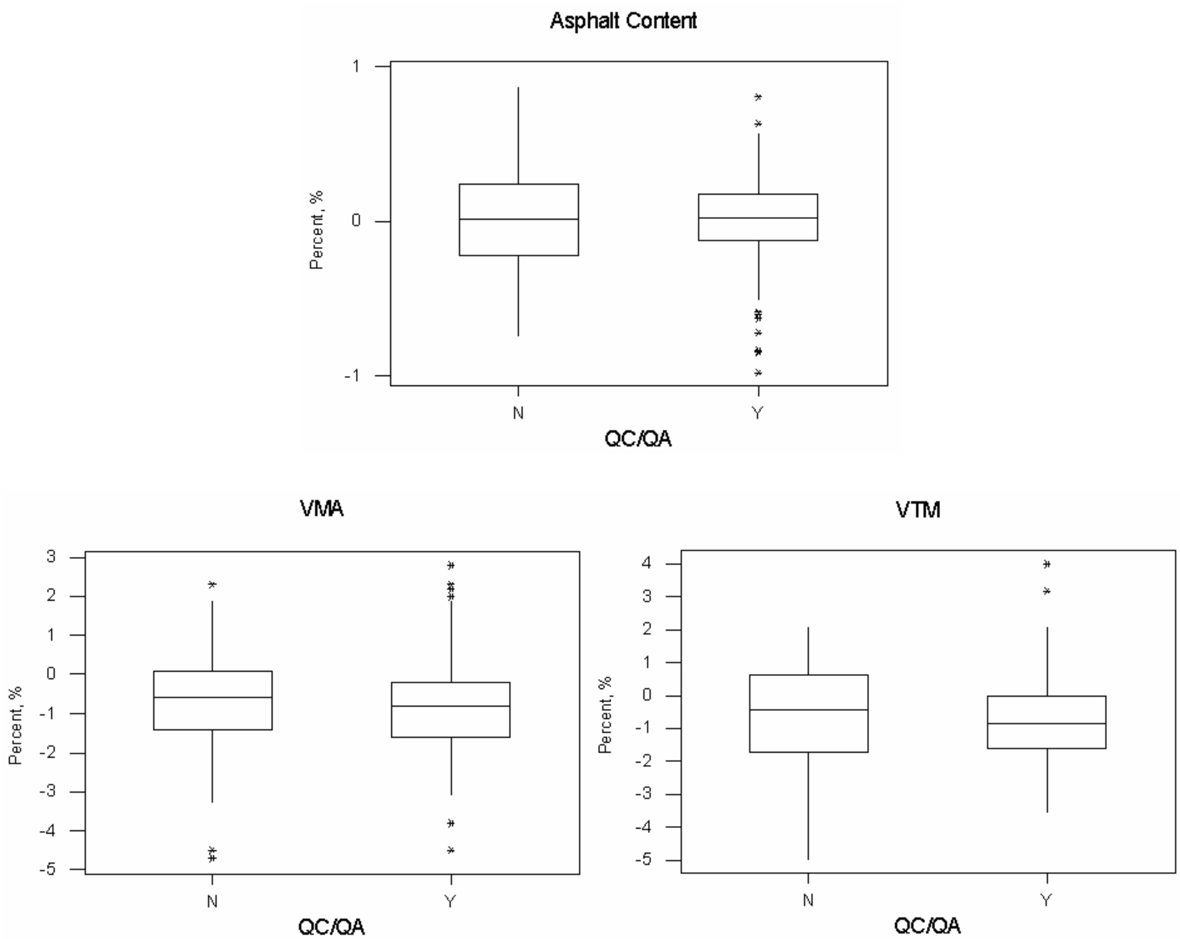


Figure 5.1 Distribution Plots of Average Pavement Section Deviations from the Target Value for Asphalt Content and HMA Volumetrics

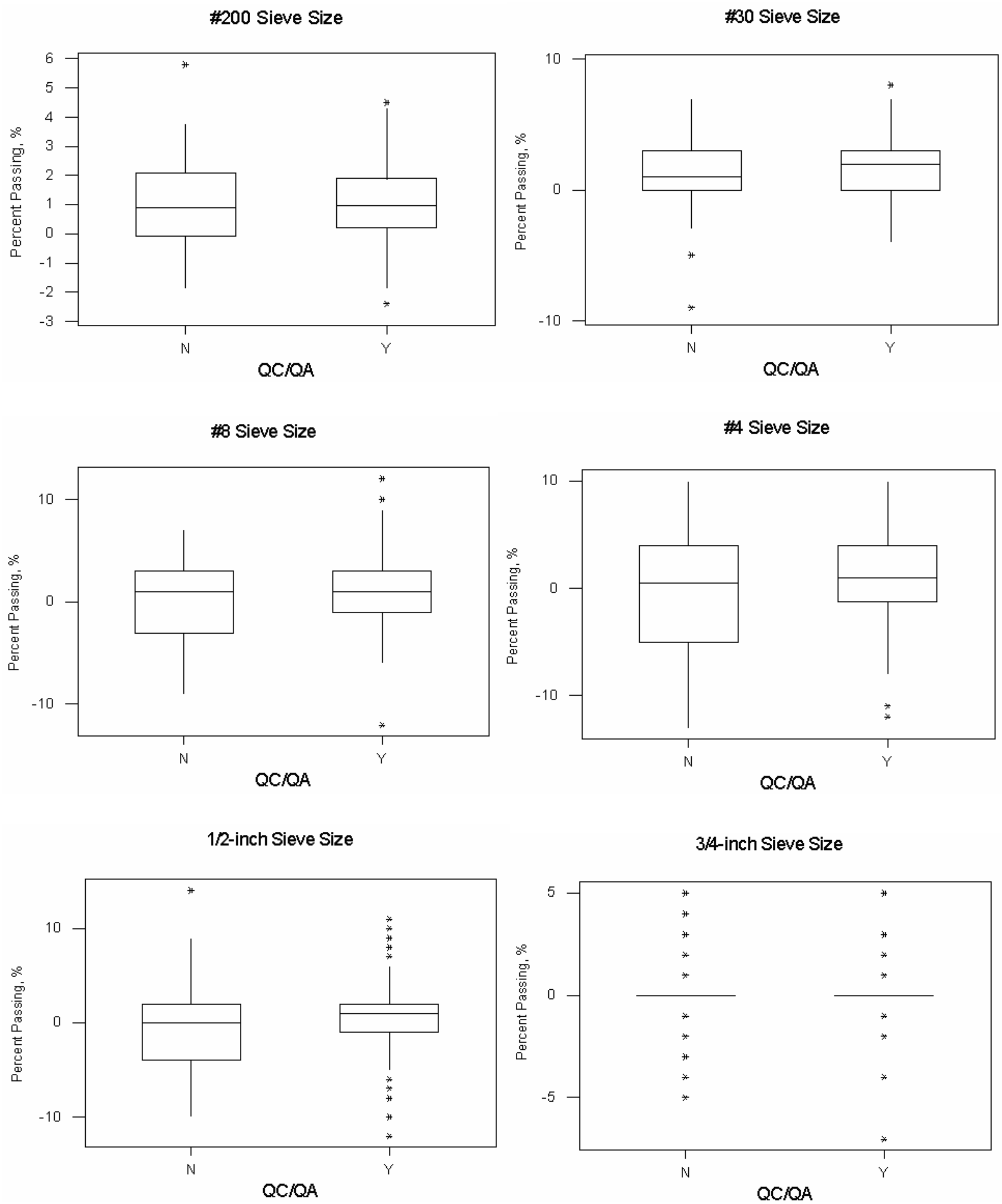


Figure 5.2 Distribution Plots of Average Pavement Section Deviations from the Target Value for Aggregate Gradation

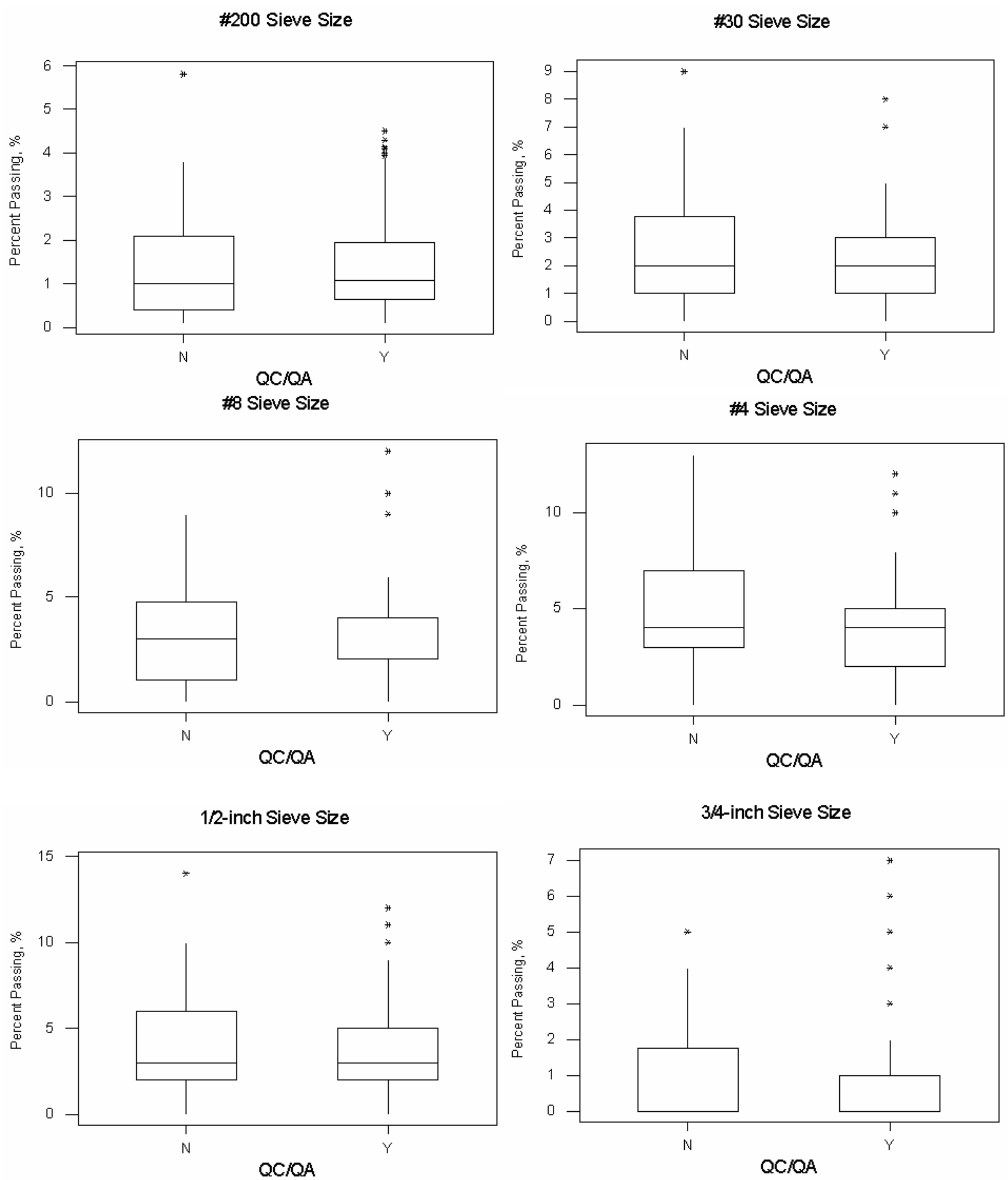


Figure 5.3 Distribution Plots of Average Pavement Section Variability about the Target Value for Aggregate Gradation

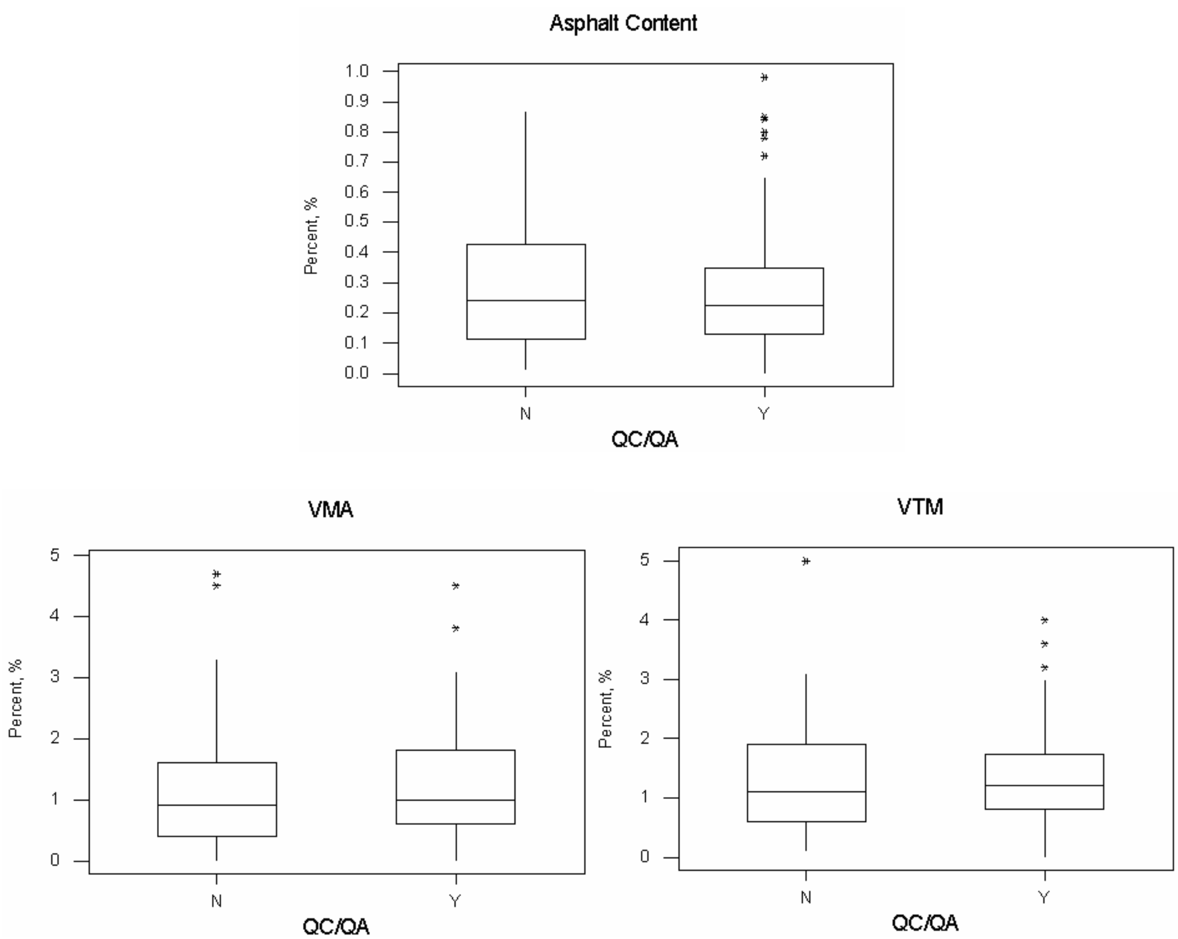


Figure 5.4 Distribution Plots of Average Pavement Section Variability about the Target Value for Asphalt Content and HMA Volumetrics

5.3 Analysis Tools

5.3.1 ANOVA

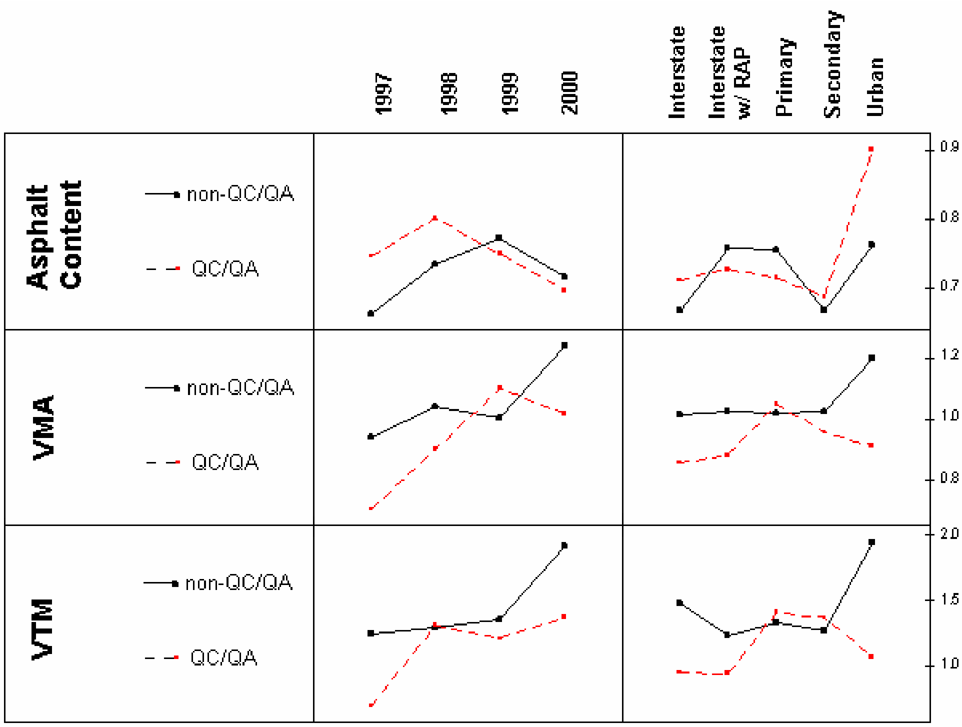
ANOVA is the main statistical analysis tool used in analysis of the data set. It is used to measure the responses of the treatment groups in a data set by testing the null hypothesis that all of the treatment means are the same, or if some of them differ. The null hypothesis for this test is H_0: $\mu_1=\mu_2 =\ldots= \mu_k$. Restating this question in terms of models, it could be asked whether the model of a single mean can adequately describe the data, or if we need the model of separate treatment group means. ANOVA is a method for comparing the fit of two models (Oehlert, 2000). A factorial treatment structure was used in the evaluation of the effectiveness of WYDOT's QC/QA specification in decreasing HMA variability. Oehlert (2000) writes, "A factorial treatment structure exists when the *g* treatments are the combinations of the levels of two or more factors" (p. 165). The factors used in the evaluation include the year the section was constructed and the road classification in which RAP was integrated. These factors were in addition to the main factor, specification. The reason these factors were chosen was discussed in chapter 4. Each treatment in this factorial treatment structure is a combination of one level of each of the factors. The specification factor has two levels, QC/QA and non-QC/QA. There are four levels of year, 1997, 1998, 1999, and 2000. There are five levels of road classifications, interstate using virgin materials, interstate utilizing RAP, primary, secondary, and urban. One of these treatments, for example, is variability in 1997 for interstates using virgin material under the QC/QA specification. A 3-dimensional matrix can represent all of the possible treatments. Table 4.1 is a representation of this matrix in a 2-dimensional manner. The major concepts of this factorial analysis are main effect and interaction. The main effects solely describe the variation within the levels of a single factor. The effect of interaction between factors describes the variation within a single combination of levels of factors. Specification*Year is one example of an ANOVA interaction, where the means of QC/QA*1997, QC/QA*1998,…, non-QC/QA* 2000 would all be compared. Usually, all possible interactions are considered in the ANOVA, unless it is known *a priori* that some of the interactions are not useful. For the analysis performed on WYDOT's data, year by specification and road classification by specification were the only two interactions considered. The end result of an ANOVA are p-values that describe the probability of the null hypothesis, H_0: $\mu_1=\mu_2 =\ldots= \mu_k$, is true for each of the main effects and interactions considered.

5.3.2Interaction Plots

An interaction plot is a graphic for assessing the relative size of main effects and interaction (Oehlert, 2000). These are used in support of the ANOVA. The ANOVA is a useful tool, but its capabilities are limited to describing whether or not the null hypothesis is true with p-values. It is not capable of describing which mean is not the same when the null hypothesis is rejected, or the values of the means. The interaction plots visually describe the relationship of all the treatment means within a two-way interaction setting. For example, the two interactions that were considered in the analysis of WYDOT's data were year by specification, and road classification by year. The interaction plot for each of these would have the first factor on the y-axis, the second factor on the x-axis, and a scale along the right vertical edge. The interaction plots for the evaluation of the effectiveness of WYDOT's QC/QA specification in decreasing variability can be found in Figures 5.5 and 5.6.

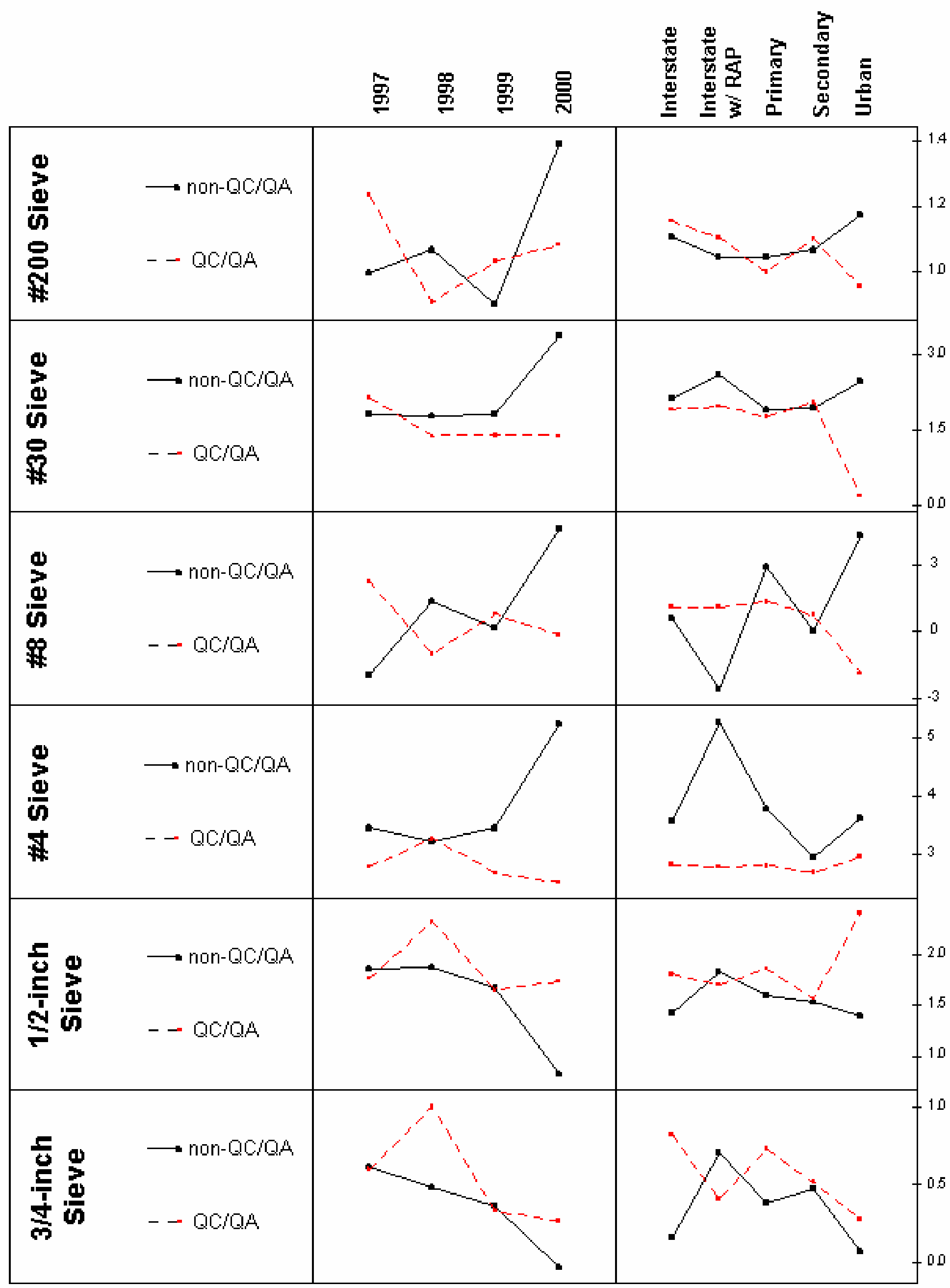
5.3.3Multiple Comparisons

An ANOVA can give us an indication that not all treatment groups have the same mean response, but an ANOVA does not, by itself tell us which treatments are different or in what ways they are differ. To do this, the treatment means need to be looked at (Oehlert, 2000).Unlike interaction plots, a p-value is associated with a contrast. Multiple comparisons is a way to make several related tests or interval estimates at the same time (Oehlert, 2000). Tukey's pair-wise comparisons were used in the analysis of WYDOT's data. Tukey's pair-wise comparisons compare every treatment mean to all treatment means. The result is a p-value, a probability of seeing differences of the magnitude observed if the means are the same.



Note: All values are transformed and are not actual averages, but are relatively correct.

Figure 5.5 Minitab Interaction Plots for the Asphalt Content and HMA Volumetrics



Note: All values are transformed and are not actual averages, but are relatively correct.

Figure 5.6 Minitab Interaction Plots for the Aggregate Gradation

5.4 HMA Variability Analysis

The effect that WYDOT's QC/QA specification had on HMA variability was the main focus of the analysis conducted. This was measured statistically using the weighted pavement section variability that was calculated. The distributions of the variability for the different HMA properties considered can be found in Figures 5.3 and 5.4. The variability data were input into an ANOVA as a factorial design. The factors were specification, year, and road classification. Because RAP was only used in the construction of interstate sections, it was integrated into road classification. Interactions between year and specification, and road classification and specification were also considered. The input for the ANOVA consisted of these five main effects. An analysis was performed for the aggregate gradation, the asphalt content, the VMA, and the VTM. The aggregate gradation analysis consisted of six different sieve sizes. The significance level used for the statistical analyses was $\alpha = 0.05$. All of the original Minitab output for this analysis can be found in Appendix C. This output includes the ANOVA tables, the interaction plots, and the relevant Tukey's pair-wise comparisons.

5.4.1 Aggregate Gradation

For analysis of the effects of QC/QA use on the aggregate gradation of an HMA, six sieve sizes were analyzed separately. These sieve sizes included the #200, #30, #8, #4, ½-inch, and ¾-inch.

Analysis of the variability data for the aggregate revealed that there was on average a decrease in variability with the use of a QC/QA specification for all sieve sizes. Many of these decreases in variability, however, were not statistically significant. The decrease in variability is visually evident in the variability distributions of Figure 5.3 and 5.4. A smaller box that is closer to zero (the target value) in the box plot distributions indicates this decrease for QC/QA over non-QC/QA. Seventy-five percent of the variability lies between the top of the box and zero. The top of the box is lower for QC/QA than it is for non-QC/QA for all sieve sizes. The median is also lower in many cases. The only statistically significant change in variability with a change in specification was with the #4 sieve size. This was indicated by a p-value = 0.05. All the other sieve sizes, including the #200 sieve, had a p-value greater than 0.05. The p-values for the main effect of specification from the ANOVA tables are tabulated in Table 5.1. The analysis also considered the effects of road classification and year and the interactions between these two factors and specification type. These factors were significant in a few cases. The #200 sieve value indicated that the specification by year interaction term was significant, and the #4 sieve value indicated that the road classification and the specification by road classification interaction were both significant factors. The p-values for all of the main effects in the ANOVA can be found in Table 5.1.

Table 5.1 Minitab ANOVA p-value Outputs for the Main and Interaction Effects Considered

Parameter	Sources of Effect in ANOVA				
	Specification	Year	Road Class.	Year *Spec. Interaction	Road Class. *Spec. Interaction
#200 Sieve	0.81	0.16	0.37	0.03*	0.74
#30 Sieve	0.17	0.47	0.41	0.43	0.36
#8 Sieve	0.22	0.52	0.10	0.53	0.16
#4 Sieve	0.05*	0.70	0.02*	0.18	0.04*
½-inch Sieve	0.33	0.05*	0.76	0.47	0.57
¾-inch Sieve	0.53	0.12	0.90	0.43	0.16
Asphalt Content	0.68	0.69	0.17	0.68	0.61
VMA	0.51	0.63	0.87	0.73	0.85
VTM	0.40	0.68	0.71	0.83	0.41

* represents statistical significance with a significant level of 0.05.

The specification by year interaction for the #200 sieve had a p-value = 0.03. The nature of the significance of this interaction is revealed through Tukey's pair-wise comparisons. The significant Tukey pair-wise comparisons indicated a significant increase in variability from 1998 to 1999 and 2000 within the pavements constructed under the QC/QA specification. The difference between 1998 and 1999 has a p-value = 0.04, and the difference between 1998 and 2000 has a p-value = 0.00. This indicates an increase in variability over time with use of the QC/QA specification. This increase can be seen in the year by specification interaction plot for the #200 sieve in Figure 5.6.

The #4 sieve proved to be affected the most by changes in specification. First, as mentioned earlier, less variable HMA was produced on average under the QC/QA specification than was under the non-QC/QA specification. This was seen in the variability distribution in Figure 5.3 but can also be seen with the interaction plot in Figure 5.6. Road classification was also significant with a p-value = 0.02, along with the interaction between specification and road classification with a p-value = 0.04. The plots of these interactions indicated that the variability under the QC/QA specification is low and fairly constant, in contrast to an on average higher and sporadic variability under non-QC/QA. The largest improvements that occurred with the change in specification were with the interstate sections that had utilized RAP material. This was indicated by a p-value = 0.02. From the interaction plot, there also seems to be an improvement with variability in HMA production for interstate sections utilizing virgin materials, primary, and urban roadways with use of a QC/QA specification, but the improvements are not statistically significant. From the Tukey's pair-wise comparisons, it also seems that the variability under a QC/QA specification improved from 1998 to 1999 and 2000. The only statistically significant difference, however, is between 1998 and 2000, which is indicated by a p-value = 0.02. Similar improvements are also seen with the ½-inch and ¾-inch sieve sizes with p-values equal to 0.00 for the comparisons between both 1998 and 1999, and 1998 and 2000. A similar trend is seen with the #30 sieve size. This sieve size saw a decrease in variability from 1997 to 1998 and leveled out at a minimum. This decrease in variability, however, is not statistically significance. These trends can be seen in the interaction plots of Figure 5.6. Improvements over time may be correlated to a learning curve.

There is one last observation regarding the effect of QC/QA specification use on aggregate variability. For the fine aggregates (greater than or equal to the #4 sieve size), the difference between the variability observed for the QC/QA and non-QC/QA specifications became more and more significant with increases in sieve size. With this progression, QC/QA specifications had an increasingly greater improvement. This can be seen in the variability plots of Figure 5.3, and can also be seen with the progressively decreasing p-values for specification in Table 5.1. For the #200 sieve there were no improvements observed, and for the #4 sieve there were some statistically significant improvements.

5.4.2 Asphalt Content

From a general observation of the variability plot in Figure 5.4 for asphalt content, there seems to be an average decrease in variability with the use of a QC/QA specification. This decrease in variability was not, however, statistically significant. This was indicated in the ANOVA table by a p-value = 0.68. The analysis also considered the effects of road classification, year, and the interactions between these two factors and specification. These main effects and interactions all proved to be insignificant in the analysis of asphalt content. The p-values for the main effects and interactions can be found in Table 5.1. Regardless of the p-value in the ANOVA table, the year by specification interaction plot, which can be seen in Figure 5.6, indicated a similar trend as was seen for the aggregate gradation. Variability seemed to decrease from 1998 to 1999 and 2000 with use of the QC/QA specification. The Tukey's pair-wise comparisons revealed that the difference between 1998 and 2000 was statistically significant with a p-value = 0.00.

5.4.3 VMA

The analysis of the variability data for the VMA content revealed that there was no change in variability of the VMA within the HMA with use of a QC/QA specification. This variability, like the others, is about the HMA target value. A p-value = 0.51 in the ANOVA table indicated that there was no change in VMA variability. This can also be observed by looking at the variability distribution plot in Figure 5.4. If anything, the variability in VMA with use of the QC/QA specification seemed to increase. The analysis also considered the effects of road classification, year, and the interactions between these two factors and specification. These main and interaction effects were all insignificant. The ANOVA p-values for the main effects can be found in Table 5.1.

5.4.4 VTM

From the variability plot in Figure 5.4, there seems to be a slight decrease in variability with the use of the QC/QA specification. Analysis of the variability data for the asphalt content revealed that this decrease was not statistically significant. This was indicated in the ANOVA table by a p-value = 0.40. The analysis also considered the effects of road classification, year, and the interactions between these two factors and specification type. These main and interaction effects were all statistically insignificant. The p-values for these main effects can be found in Table 5.1. Tukey's pair-wise comparison between the different road classifications indicated a difference in the variability of VTM between Interstates utilizing both virgin and recycled materials and primary roadways constructed under the QC/QA specification. The interstate sections proved to have less variability than the Primary roadways. This was indicated by p-values equal to 0.00. This difference can be seen in the interaction plot of Figure 5.5.

5.5 Chapter Summary

A statistical analysis was performed on the variability data collected from WYDOT, which represented asphalt pavements constructed in 1997 thru 2000 under both WYDOT's new QC/QA specification and their non-QC/QA specification. An ANOVA was the main statistics tool used in analysis of the data. Interaction plots and Tukey's multiple comparisons were used to support the ANOVA. The data set analyzed had a factorial structure which included two factors in addition to specification. The additional two factors were year and road classification. The interactions between year and specification, and road classification and specification were also considered in the analysis. The use of RAP was also considered as an integral part of road classification. A number of conclusions were made from the statistical analysis of the variability data.

WYDOT's QC/QA specification on average decreased the variability of nearly all of the HMA properties analyzed, but these decreases were statistically significant for only one. These decreases were evident for all the aggregate sieve sizes, the asphalt content, and the VTM. The improvement was statistically significant for the #4 sieve. The QC/QA specification seemed to increase the variability of the VMA.

Use of the QC/QA specification saw evidence of improvement over time for the variability of the #4, ½-inch, and ¾-inch sieve sizes. This also occurred with asphalt content. Nearly all of these decreases over time were statistically significant with p-values less than 0.05. The #8 sieve size seemed to also decrease and stabilize at a minimum, but this decrease was not significant. Significant differences in variability of pavements constructed under the QC/QA specification between the years 1998 and 2000 occurred with the #4, ½-inch, and ¾-inch sieve sizes, and asphalt content, and significant differences between 1998 and 1999 occurred for the ½-inch and ¾-inch sieves.

The decrease in variability of the fine aggregate sizes with QC/QA specification use developed greater significance with increases in the sieve sizes.

VTM variability was significantly less for Interstates sections using both virgin materials and RAP, than it was for Primary sections under the same QC/QA specification.

6. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study was to evaluate the effectiveness of QC/QA specifications in decreasing HMA variability. WYDOT's QC/QA specification was evaluated as a case study. The results of this case study do not necessarily apply to all QC/QA specifications. The many details that are involved can cause QC/QA specifications to vary drastically from one another. As a result of this variety, a questionnaire was written and distributed to the 50 SHAs. The objective of this questionnaire was to gather basic information about the QC/QA specification programs being used nationwide. The conclusions from both this survey and the evaluation of the effectiveness of WYDOT's QC/QA specification in decreasing HMA variability are presented in this chapter, followed by recommendations for further research.

6.1 Conclusions from Survey

A summary of the responses to the questionnaire leads to the following conclusions:

1. Of 45 SHAs that responded to the survey, 40 or nearly 90 percent have implemented an asphalt pavement construction QC/QA specification program.

2. There was a 100 percent response rate from the SHAs that form Region 8 of the FHWA. Of the six Region 8 SHAs, five have a QC/QA specification program for the construction of asphalt pavements. Montana is the only one that does not have such a program. Colorado implemented a pilot program for QC/QA in 1992, which was adopted as a standard in 1995. North Dakota implemented its program 1994. South Dakota implemented its program in 1997. Utah implemented its program in 1997. These QC/QA specification programs are all very new. The details of these programs vary among the four different SHAs.

3. Although the first QC/QA program emerged as early as in 1968, most of the programs (more than 80 percent) were implemented after 1985. The QC/QA specifications for asphalt pavement construction are still in the stages of development.

4. For most of the SHAs, implementation of a QC/QA specification is a relatively new venture. Each SHA that uses a QC/QA specification for asphalt pavement construction has its own version of a similar concept.

5. Different versions of QC/QA programs may vary significantly in requirements. The differences include the scope of QC/QA, QC responsibilities, QA responsibilities, QA testing, properties to be tested, certification of testers, variable control level, and incentive and disincentive policies.

6. Previous evaluations of asphalt pavement QC/QA specifications by individual SHAs have resulted in positive reviews. As a result of QC/QA specification, some SHAs are seeing an increase in initial construction costs, while most of them are not.

6.2 Conclusions from the Case Study

The methodology that was used to evaluate the effectiveness of WYDOT's QC/QA specification in decreasing HMA variability throughout production is as follows:

1. List possible factors that may affect QC/QA specification performance.

2. Collect a relevant data set along with information regarding the corresponding factors from previous pavement jobs.

3. Prepare data for analysis by doing the necessary calculations.

4. Analyze data using a statistics package capable of performing an analysis of variance (ANOVA), interaction plots, multiple comparisons, and basic statistics.

5. Draw conclusions.

An evaluation of the effectiveness of WYDOT's QC/QA specification in decreasing HMA variability was conducted as a case study using this methodology. From this case study, the following conclusions were drawn:

1. WYDOT's QC/QA specification on average decreased the variability of nearly all of the HMA properties analyzed, but these decreases were in most cases statistically insignificant. These decreases were evident for all the aggregate sieve sizes, the asphalt content, and the VTM. The improvement was statistically significant for the #4 sieve. The QC/QA specification seemed to increase the variability of the VMA, but the increase was not statistically significant.

2. Use of the QC/QA specification saw evidence of improvement over time for the variability of the #4, ½-inch, and ¾-inch sieve sizes. This also occurred with the asphalt content. Nearly all of these decreases over time were statistically significant with p-values less than 0.05. The #8 sieve size seemed to also decrease and stabilize at a minimum, but this decrease was not significant. Significant differences in variability of pavements constructed under the QC/QA specification between the years 1998 and 2000 occurred with the #4, ½-inch, and ¾-inch sieve sizes, and the asphalt content, and significant differences between 1998 and 1999 occurred for the ½-inch and ¾-inch sieves.

3. The decrease in variability of the fine aggregate sizes with QC/QA specification use developed greater significance with increases in the sieve sizes.

4. VTM variability was significantly less for interstates sections using both virgin materials and RAP than it was for primary sections under the same QC/QA specification.

6.3 Recommendations

It is recommended that the methodology used in to evaluate effectiveness of WYDOT's QC/QA specification for asphalt pavement construction in decreasing HMA variability be used for evaluation of other QC/QA specifications. It is recommended that these evaluations start with the other SHAs in Region 8 besides Wyoming, including Colorado, North Dakota, South Dakota, and Utah. It is also recommended that the information gathered with the QC/QA specification program questionnaire be considered in these evaluations. The information regarding Region 8 SHAs is presented with the most detail and therefore will be the most beneficial.

Decreases in HMA variability are only a short-term benefit of QC/QA specification use. Decreased HMA variability is indicative of the improvements in pavement quality and performance but cannot be used accurately to measure these long-term benefits. Therefore, it is also recommended that when data reflecting these long-term improvements can be collected a cost-benefit analysis be conducted to measure the actual impacts of QC/QA specification use.

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