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Development of a Sustainable Quality Assurance Program for Transportation Infrastructure

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DEVELOPMENT OF A SUSTAINABLE QUALITY ASSURANCE PROGRAM FOR TRANSPORATION INFRASTRUCTURE

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ABSTRACT

One of our nation's most valuable assets is our roads and bridges, and its ability to move people and goods. The prosperity of our nation is dependent on the quality of our infrastructure and system, which is directly dependent on the condition of our highways. State and federal departments of transportation realize the importance of Quality Assurance (QA). From experience they have learned that non-conforming material or construction practices can result in premature failure of highway components. Major attention and resources have been devoted to the development of QA programs to address this concern.

State Highway Agency's (SHA) across America are faced with the challenge of addressing a deteriorating infrastructure system under constrained financial budgets, reduction in staffing levels, increasing public demand for better and faster construction of projects and the public scrutiny of how State funds are spent. Demands on state work forces have never been greater. With limited resources and ever-increasing demands for services, SHA's are implementing new technologies and innovations for the purpose of improving and optimizing their QA programs under existing conditions and available resources. The objective of the dissertation is to provide SHA's with recommendations for the development of an effective, efficient and sustainable QA program. 0428

To achieve the project objective a comprehensive literature review was conducted, with a focus on the ingredients in which SHA's differ most, Quality Control (QC) and Acceptance. The purpose of the literature review was to determine the state of practice of SHA's QC and Acceptance practices and

policies. An evaluation into the use of Contractor Performed Quality Control (CPQC) test results to supplement agency Acceptance testing was performed. A detailed investigation was conducted on the use of consultant engineering testing services to supplement agency QA staffing. The cost effectiveness was evaluated through a cost analysis of RIDOT in-house acceptance testing versus consultant engineering testing services.

The findings indicate that the evolution of QA programs which started back in the 1960's is still very much ongoing today. The result is a large spectrum of QA programs, resulting in QA programs which differ significantly from one state agency to another. The area where QA programs differ most is in the QC and Acceptance arena. How SHA's have delegated QC roles and responsibilities to the contractor significantly impact the overall efficiency, effectiveness and sustainability of a QA program. QC policies and requirements, including a QC plan requirement, should be consistently implemented, monitored and enforced on each and every project that a SHA puts out for bid. The contractor's QC role and responsibilities cannot begin and end at the plant. It was found that the use of CPQC is essential to a successful QA program.

The use of CPQC test results to supplement agency Acceptance testing will reduce the number of test that an agency must perform. The use of consultant engineering testing services to supplement agency QA staffing will allow SHA's to meet peak workload demands more cost effectively. The recommendations derived from this dissertation can help SHA's improve the efficiency, effectiveness and sustainability of its QA program.

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INTRODUCTION

1.1 Background and Significance of Work

Quality Assurance (QA) is an evolutionary process that has been taking place since the 1960s. The importance of QA became evident as a result of the AASHO Road Test conducted in Ottawa, Illinois from 1956 to 1960 (NRC 1960). "It was during the construction of this project (AASHO Road Test) that a sufficient number of unbiased test results of construction materials and techniques became available to expose the true variability of these test results and their relationship to specifications" (Bowery, F. 1976). Results from this Road Test project brought to light the large magnitude of the variability in materials and construction processes used within similar test. To address the variability of material and products statistical tools were developed and implemented into construction sample testing to allow quantification and consideration of variability. Through statistical analysis and testing State Transportation Agencies (STA) sought to establish quality measures such as the mean, the standard deviation, the percent defective, the percent within limits, the average absolute deviation, and the quality index of a material all for the purpose of establishing acceptance quality limits. The history of this evolution is documented through the following FHWA regulations and research reports:

- In 1969 the FHWA published "Quality Assurance in Highway Construction" which summarized the results of a number of states' research concerning the variability of measurements of the characteristics of materials and construction.

- In 1971 the TRB issues Special Report #118 "Quality Assurance and Acceptance Procedures." At the time of this report 25 Highway agencies were reported to be working in the area of statistically oriented specifications.
- In 1979 the TRB Synthesis of "Statistically Oriented End Result Specifications," which reported that 32 states are using, planning to use or have tried some form of statically oriented end result specification.
- FHWA Title 23, Part 637 Code of Federal Regulations (23 CFR 637), the FHWA's Quality Assurance Procedures for Construction. This regulation adopted in 1995 requires that each State Highway Agency (SHA) develop a QA program for the National Highway System.

Today, over 50 years since the AASHO Road Test, the strategies and practices used by SHAs to ensure quality and to meet 23 CRF637 requirements continue to evolve and encompass a wide variety of QA approaches. The result is a large spectrum of QA programs. On one end of the spectrum are the QA programs that rely on material and method specifications/provisions. On the other end of the spectrum are the QA programs with a wide variety of QA Specifications including the use of Contractor Performed Quality Control (CPQC) test results for Acceptance and the use of warranties in place of Acceptance testing. In between is a mix of various approaches resulting in QA programs which vary significantly from one state agency to another. More important, is the finding that QA practices and policies vary significantly from one project to another within the same SHA. QA programs have evolved into basically three main ingredients; QC, Acceptance and Independent

Assurance (IA), depicted in Figure 1. The manner in which these ingredients are administered and blended makes for many different versions of such programs. In the traditional separation of responsibilities, contractors are responsible for QC and state DOTs are responsible for acceptance and IA. However, with the enactment of the federal regulation 23 CFR 637B in1995, which permits the use of contractor QC tests for acceptance, the roles of state DOTs and contractors have become less clear and distinct. For years the inspection requirement for QC was the responsibility of SHAs. Today, most SHAs are moving towards shifting the QC responsibility from the SHA (owner) to the contractor. Throughout this dissertation the term owner is used in place of SHA. The SHA agency is owner of the final product and as such, has and must maintain final say in the acceptance of the work performed by the contractor. How this transfer of QC from the owner to the contractor has evolved varies significantly from one SHA to another. Most SHAs are in agreement that QC is the contractor's responsibility but the development and implementation of QC requirements and policies have been a low-key effort by SHAs. It is for this very reason that contractor QC roles and responsibilities vary significantly from one SHA to another. Even more problematic is the finding that contractor QC roles and responsibilities vary from one project to another within the same SHA. This results in confusion and the intermingling of QC responsibilities between the SHA and the contractor.

SHAs across America are faced with the challenge of addressing a deteriorating infrastructure system under constrained financial budgets, increasing public demand for better and faster construction of projects and the public scrutiny of how State funds are spent. QA programs have a significant impact on the SHAs budget and overall reputation. A program not properly staff or managed will have a negative impact in the overall QA operating cost. In addition, a program not properly managed or staff will also likely result in inferior quality work. Since the agency must operate and maintain the completed project, inferior quality work will significantly impact the agencies future budgets as the work will need to be maintained or replaced sooner than the expected service life. When a SHA fails to deliver quality projects within an established budget there is a detrimental effect on future programs and loss of faith on the agencies abilities to provide quality work and manage public funds. For a QA program to be efficient and effective all three components, QC, Acceptance and IA, must be founded on clear and concise policies and the delegation of responsibilities must be understood by both the owner and the contractor. For a QA program to be sustainable it must be developed, implemented and managed in a cost effective manner. One of our nation's most valuable assets is our roads and bridges and its ability to moves goods and people. The success of our nation is dependent on the condition of our highway system, which is directly dependent on the quality of construction. With the administration and implementation of QC and Acceptance being left to the individual SHAs there is a need for information exchange on QC and Acceptance policies and procedures.

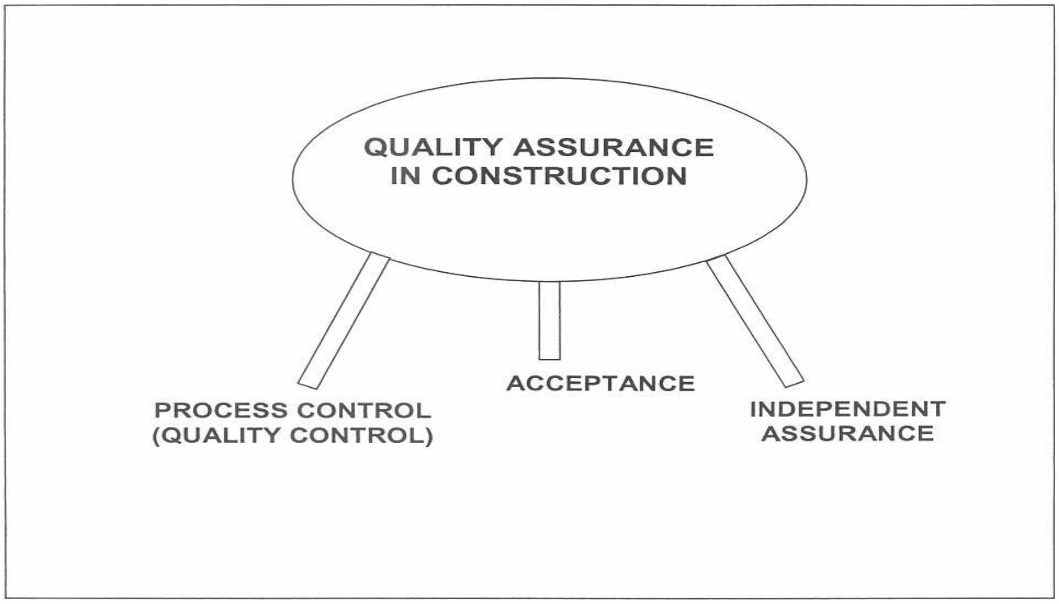


Figure 1 Elements of Quality Assurance

(Source: NCHRP Report "Using the Results of Contractor-Performed Test in QA)

1.2 Objectives and Methodology of the Dissertation

1.2.1 Objective of Dissertation

SHAs across the Country are operating under severe financial constraints and reduced budgets. This, in combination with a reduction in staff, attributed to retirement and or transfer to the private sector, SHAs are burdened with having to doing more with less while addressing a nationwide deteriorating infrastructure system. To meet these demands SHAs are reevaluating existing procedures, policies and practices and developing new innovative ways to meet the overall QA requirements.

The objective of the dissertation is to provide SHAs with recommendations for the development of an effective, efficient and sustainable QA program. The following are this author's definitions and interpretation of effective, efficient and sustainable:

- Effective: To be successful in achieving a desired or intended result. A QA program is effective when the end results of its policies and requirements result in products/materials that meets or exceeds specifications requirements. An effective QA program will assure quality work.
- Efficient: Working in a well-organized and competent manner that prevents waste of effort, resources and expense. An efficient QA program is properly staffed and the roles and responsibilities are clearly designated. The resources are monitored and managed to maximize productivity and use of expertize.
- Sustainable: To be able to meet today's needs without compromising the ability to meet the same needs in the future. A good example is how a QA program is staffed. A QA program that is staffed to meet peak workload demand periods will incur the cost of paying for staff when there is no work. In the private sector a company staffed in this fashion will not survive in its competitive environment. A sustainable QA program is one that a SHA can maintain and support with available resources in the present and the future.

To achieve this objective the dissertation evaluated SHAs practices and policies associated with the QC and Acceptance components of the QA program. The focus has been placed on QC and Acceptance because it is these two components of a QA program in which SHAs policies and practices differ most. How STAs have transferred the QC role to the contractor and how SHAs manage and perform Acceptance Testing can significantly impact the overall effectiveness, efficiency and sustainability of the overall QA program. The findings of this dissertation indicate that changes to current QC practices and policies and modifications in the manner in which SHA's perform Acceptance Testing, can improve the efficiency of the SHAs QA program and reduce operating cost.

1.2.2 Methodology

To achieve the project objective the following operations were performed:

- A comprehensive literature review was conducted, with a focus on the ingredient in which SHAs differ most, QC and Acceptance. The purpose of the literature review is to determine the state of practice of SHAs QC and Acceptance practices and policies. Information from several NCHRP questionnaire surveys, reports and Synthesis as well as in-person interviews and phone calls with SHA Officials, contractors and consultants are incorporated into the literature review.
- A review of RIDOT's past and current QA policies, practices and procedures was conducted.   By understanding how a SHA has blended the three ingredients of its QA program; QC, Acceptance and IA, one can then identify areas where changes in policies or practices and innovations can be implemented to improve the overall efficiency, effectiveness and sustainability of a SHAs QA program.
- A review and analysis of the first use of CPQC on a Rhode Island Department of Transportation (RIDOT) project was performed. The project was the Replacement of the Sakonnet River Bridge Project constructed 2008.   With the first time implementation of CPQC both the Agency and the Contractor entered this venture with many concerns and apprehensions. As the Project Manager for this project I can attest that the implementation of CPQC proved

to be very successful in achieving higher quality work and presenting the Department with the ability to collect QC data that had never been available before. The database established with QC data and Acceptance data provided a means of verifying QC results during the life of the project. The database has also been used, after the project completion, to perform statistical analysis for the evaluation of control limits for Percent-Within-Limits (PWL) specifications. The importance of developing a database of QC and Acceptance test results was realized as a result of the implementation of CPQC. At the time of this research, RIDOT continues to implement CPQC but only on a small percentage of selected projects. Lessons learned from the use of CPQC on this project are incorporated into this dissertation.

- Evaluate the use of CPQC test results to supplement agency Acceptance Testing. As SHAs shift the QC role to the contractor, agencies are noting a significant increase in field QC testing being performed by the contractors testing consultant. Many STAs have developed validation procedures, which in accordance with FHWA 23 CFR 637B Final Rule, then permits the agency to supplement its Acceptance Testing with CPQC QC test. By reducing agency testing SHAs have improved the overall QA efficiency and cost effectiveness of its QA program.
- Evaluate the benefits and disadvantages of the use of consultant engineering testing services to supplement SHAs QA personnel. Contractors have realized the benefits and cost effectiveness of outsourcing and have been implementing this practice since the early 1970’s. Contractors hire consultant engineering

services to perform work that they are not staffed to perform or to supplement their staff when the work load exceeds their capacity. Simply stated, contractors hire consultant services on a as needed basis. Funding for SHA infrastructure projects vary from one year to the next. In addition, here in the New England area, peak workload period is generally from May through October, with contractors typically shutting down their concrete and asphalt production plants from December to March. Staffing to meet peak workload periods is costly and inefficient. SHAs can mirror the practices and management strategies used by the Contracting Industry (CI) and realize the benefits of a more cost efficient means of providing a service. With the financial strain that most SHAs are operating under today the implementation of consultant engineering services needs to be evaluated and considered as a means to meet agency QA testing requirements in a more efficient and cost effective manner.

- Conduct cost analysis to compare the cost of RIDOT in-house Acceptance Testing verses consultant engineering testing cost. The direct and indirect cost associated with both RIDOT Materials Inspectors and Consultant Testing Inspectors were used to perform a cost analysis. To validate the methodology used for the cost analysis performed in this dissertation a similar cost analysis performed by the New York State Department of Transportation, comparing the cost of in-house engineering verses consultant engineering cost, was reviewed and included in this report.

1.3 Organization of the Dissertation

1.3.1 Chapter 2

Chapter 2 consists of the findings from the literature review. The present state of practice of SHAs QA policies and practices are included in this chapter. The findings indicate that SHAs QA programs still differ from one SHA to another. The findings also show that the transfer of QC from the SHA to the contractor is still an ongoing process and the amount of QC delegated to the contractor is very much influence by the relationship and trust between the agency and contractors. The findings also show an increase in SHA use of CPQC test results to supplement agency Acceptance Testing. As SHAs develop more confidence in the validation of CPQC test results it is expected that the number of SHAs implementing this innovation will increase. There is also clear indication of a significant increase in the use of consultant engineering services to supplement agency QA personnel.

1.3.2 Chapter 3

Chapter 3 is a review and analysis of RIDOT's first use of Contractor performed Quality Control on the Replacement of the Sakonnet River Bridge Project. The review consists of the following:

- History of the Sakonnet River Bridge
- Innovations incorporated into this project
- The Implementation of CPQC
- The development of a QC and Acceptance database
- Performance of statistical analysis on database
- Lessons learned, best practices identified

1.3.3 Chapter 4

Chapter 4 presents information, state of practice and recommendations on the use of CPQC test results to supplement agency Acceptance Testing and the use of consultant engineering services to supplement SHA QA staff. The following is contained in Chapter 4:

- RIDOT's Current QC and Acceptance practices and policies
- Implementation of CPQC test results to supplement agency Acceptance testing
- Implementation of engineering consultant services to supplement agency QA staff.
- In-house verses consultant engineering testing services cost analysis
- Summary of cost analysis

1.3.4 Chapter 5

Chapter 5 includes conclusions and recommendations on the following:

- Quality Control
- The use of CPQC test Results to supplement agency Acceptance testing
- The use of consultant engineering testing services to supplement agency QA staff
- Independent Assurance
- Future work recommendations

1.4 Summary

A major concern for SHAs has always been the actual quality of the work performed. SHAs have devoted major attention and resources to QC and QA activities to address this concern. It is the goal of this study, through the evaluation of existing SHA QA programs and through the synthesis of best practices derived from the literature review, to provide SHAs with recommendations that can be implemented to improve the efficiency, effectiveness and sustainability of a QA program.

1.5 References

Bowery, F.E., Jr., and S.B. Hudson, (1976) NCHRP Synthesis of Highway Practice 38: Statistically Oriented End-Result Specifications, Transportation Research Board, National Research Council, Washington, D.C., 40 pp.

CHAPTER 2

LITERATURE REVIEW

2.1 Definitions

The purpose of this literature review was to investigate and develop an understanding of what has already been done, how it has been researched and what are the key issues on the subject matter of Quality Assurance (QA). As stated 23 CFR Subpart B Section 637.201, the purpose of QA is "To prescribe policies, procedures, and guidelines to assure the quality of materials and construction in all Federal-aid highway projects on the National Highway System" (FHWA, Revised 2015). QA programs have evolved since the 1960's and the evolution continues today with STAs implementing new technologies and innovations to meet 23 CFR 637 requirements and to develop more efficient and sustainable QA Programs. With these changes and developments, it is understandable, that one of the first issues encountered in this literature review was the lack of consensus regarding critical definitions. The words, terms and phrases used in QA programs and specifications are specialized vocabulary whose meaning and definition often differs from one SHA to another. This is a concern that was noted by S. Hughes where he wrote "One problem associated with QA programs and specifications since their inception have been differing interpretations of the specialized vocabulary used in these programs." (Hughes et al. 1999). One often finds terminology in various state DOT specifications and QA policies that differ with those in TRB's, "Glossary of Highway Quality Assurance Terms".

For the purpose of clarity and consensus this research followed the terminology and definitions of those stated in TRB's, "Glossary of Highway Quality Assurance

Terms" (Transportation Research Circulator Number E-C037, 2002). The following terms and definitions are the ones most commonly used in the QA arena.

Quality Assurance Elements

- **Quality Assurance (QA).** All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service.
- **Quality Control (QC).** Also called process control. Those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality being produced in the end product.
- **Acceptance**. The process of deciding, through inspection, whether to accept or reject a product, including what pay factor to apply.
- **Inspection.** The act of examining, measuring, or testing to determine the degree of compliance with requirements.
- **Independent Assurance.** A management tool that requires a third party, not directly responsible for process control or acceptance, to provide an independent assessment of the product or the reliability of test results, or both, obtained from process control and acceptance.
- **Verification.** The process of testing the truth or of determining the accuracy of test results, by examining the data or providing objective evidence, or both.

- **Validation**. The process of verifying the soundness or effectiveness of a product (such as a model, a program, or specifications) thereby indicating official sanction.
- **Dispute Resolution**. Also called conflict resolution. For QA programs permitting the use of contractor test results in the acceptance decision, an agreed-upon procedure to resolve conflicts resulting from discrepancies, between agency and contractor results, of sufficient magnitude to have an impact on payment.

Types of Specifications

- **Materials and Methods Specifications**. Also called method specifications, recipe specifications, or prescriptive specifications. Specifications that require the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material. Each step is directed by a representative of the highway agency.
- **End Result Specifications**. Specifications that require the contractor to take the entire responsibility for supplying a product or an item of construction. The highway agency's responsibility is to either accept or reject the final product or to apply a pay adjustment commensurate with the degree of compliance with the specifications.
- **Quality Assurance Specifications**. A combination of end result specifications and materials and methods specifications. The contractor is responsible for QC

(process control), and the highway agency is responsible for acceptance of the product.

- **Statistically Based Specifications**. Also called statistical specifications or statistically oriented specifications. Specifications based on random sampling, and in which properties of the desired product or construction are described by appropriate statistical parameters.
- **Performance Specifications**. Specifications that describe how the finished product should perform over time
- **Performance-Based Specifications**. QA specifications that describe the desired levels of fundamental engineering properties
- **Warranty Specifications**. A type of performance specifications that guarantees the integrity of a product and assigns responsibility for the repair or replacement of defects to the contractor.
- **Performance Warranties**. Specifications that hold the contractor fully responsible for product performance during the warranty period

Acceptance Plans

- **Acceptance Plan**. An agreed-upon procedure for taking samples and making measurements or observations on these samples for the purpose of evaluating the acceptability of a lot of material or construction.
- **Lot**. Also called population. A specific quantity of similar material, construction, or units of product, subjected to either an acceptance or process control decision.

- **Split Sample**. A type of replicate sample that has been divided into two or more portions representing the same material.
- **Independent Sample**. A sample taken without regard to any other sample that may also have been taken to represent the material in question
- **Pay Factor**. A multiplication factor, often expressed as a percentage, used to determine the contractor's payment for a unit of work, based on the estimated quality of work.

Quality Related Terms

- **Quality**. (1) The degree of excellence of a product or service. (2) The degree to which a product or service satisfies the needs of a specific customer. (3) The degree to which a product or service conforms to a given requirement.
- **Quality Measure**. Any one of several means that have been established to quantify quality. Some examples of quality measures are the mean, the standard deviation, the percent defective, the percent within limits, the average absolute deviation, and the quality index.
- **Percent Within Limits (PWL).** The percentage of the lot falling above the LSL, beneath the USL, or between the LSL and the USL
- **Specification Limit(s).** The limiting value(s) placed on a quality characteristic, established preferably by statistical analysis, for evaluating material or construction within the specification requirements.
- **Sample Standard Deviation (s).** A measure of the dispersion of a series of results around their average, expressed as the square root of the quantity

obtained by summing the squares of the deviations from the average of the results and dividing by the number of observations minus one.

Process Control

- **Control Chart**. Also called statistical control chart. A graphical method of process control that detects when assignable causes are acting on a production process and when normal, expected variation is occurring.
- **Controlled Process**. Also called process under statistical control. A production process in which the mean and variability of a series of tests on the product remain stable, with the variability due to chance cause only
- **Tolerance Limit(s) (upper, lower).** Also called tolerance(s). The limiting value(s) placed on a quality characteristic to define its absolute conformance boundaries such that nothing is permitted outside the boundaries.
- **Control Limit(s) (upper, lower).** Also called action limit(s). Boundaries established by statistical analysis for material production control using the control chart method. When values of the material characteristic fall within these limits, the process is "under control." When values fall outside the limits, this indicates that there is some assignable cause for the process going out of control."

Statistics

- **Statistic.** A summary value calculated from a sample of observations. Some examples are the sample standard deviation, the sample mean, and the regression coefficients estimated from the sample.
- **Confidence Interval**. An estimate of an interval in which the estimated parameter will lie with prechosen probability (called the confidence level). The end points of a confidence interval are called confidence limits.

Hypothesis Testing

- **Significance Level (α).** The probability of rejecting a null hypothesis when it is in fact true
- **Hypothesis**. A statement concerning the value of parameters or form of a probability distribution for a designated population or populations.
- **Null Hypothesis (H0).** The hypothesis being tested. [Contrary to intuition, the null hypothesis is often a research hypothesis that the analyst would prefer to reject in favor of the alternative hypothesis. The null hypothesis can never be proved true. It can, however, be shown, with specified risks of error, to be untrue. If it is not disproved (i.e., not rejected), one usually acts on the assumption that there is no reason to doubt that it is true.]
- **Alternative Hypothesis (Ha).** The hypothesis to be accepted if the null hypothesis is disproved (i.e., rejected).
- **Type I error**. Erroneous rejection of the null hypothesis.
- **Type II error**. Erroneous acceptance of the null hypothesis.

2-2 Status of Knowledge

The evolution that has taken place in QA programs has been driven by several factors. Two of the major factors were the AASHO Road Test and the construction of the Interstate Highway. The AASHO Road Test project revealed unexpectedly large variabilities in measured properties of highway construction materials and products. The construction of the Interstate System brought to light the need for more construction inspectors to oversee the rapidly growing interstate system under Materials and Methods Specifications. Before the AASHO Road Test, specifications, with few exceptions, were materials and methods specifications. Materials and Methods specifications require the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material. Each step is directed by a representative of the highway agency. This type of specification restricts the contractor from implementing new innovations that may result in better, faster and smarter ways of constructing a project. It also tends to obligate the agency to accept the completed work regardless of the quality of the final product. It is difficult to hold the contractor responsible for deficient work when the work was performed as prescribed and directed by the owner. In addition, material and method specifications places a burden on STAs staffing required to oversee and direct the process. This burden became evident during the building of the Interstate Highway which amplified and spotlighted the need for technological advances to increase construction speed, the need of more construction inspectors to oversee the construction and the need to develop and implement QA specifications.   As stated in an article found in Public Roads “State highway agencies may have been at least partly motivated to implement QA specifications because they had too few inspectors to oversee the rapidly growing interstate system under Materials and Methods Specifications" (Kopac .P.A, 2002).

The QA evolution continues to be an ongoing endeavor. The downsizing that took place within many state transportation agencies in the 1990s resulted in a significant reduction in Construction and Material Testing positions. As a result STAs are now faced with the challenge of addressing a deteriorating infrastructure system under constrained financial budgets, minimal staffing, increasing public demand for better and faster construction of projects and the public scrutiny of how State funds are spent. As with many Federal, State and local agencies, STAs are now burdened with the task of having to do more with less and do it faster and better. To do this STAs are incorporating innovative ideas and strategies into their QA programs such as; the use of contractor QC test results to supplement agency Acceptance testing , the use of consultant testing services to help STAs meet work load staffing demands more cost effectively, the use of warranties in lieu of Acceptance Testing and Design-Build-Operate -Maintain (DBOM) projects. The evolution has gone from Materials and Methods projects, where the SHA has total control and contractor has little to no control to DBOM projects where the SHA has little to no control and the contractor has total control. This is the change in the philosophy of project management that is leading the QA evolution. This research has found that even though there is abundant evidence of an increase in contractor involvement in QA and overall project management there is still a lack of confidence among STAs and contractors. As with the transfer of QC responsibilities from the owner to the contractor many see these new innovations as "putting the fox in charge of the hen house" (Figure 2). As noted in the Contractor Performed Quality Control on KyTC Projects research report "At the same time that state departments of transportation (DOT) are allowing contractor-performed quality control, they are also concerned about using the contractor-reported data for acceptance and payment purposes. The question is; are we putting the fox in charge of guarding the chickens?"(Mahboub et al. 2014). Today, when STAs are looking to develop efficient and sustainable QA Programs, the reluctance to transfer responsibilities and roles, due to lack of trust, still remains a major concern and obstacle.

Figure 2 Fox in charge of the hen house

When STAs first started to delegate the QC role to the contractor the analogy of the Fox guarding the hen house was widespread. Today, the majority of STAs have delegated most QC responsibilities to the contractor. What was questionable and a major concern then is now standard practice. SHAs across the country are incorporating more contractor involvement in the design, construction, management, operation and maintenance of projects. The practice of a SHA hiring a contractor for the equipment and manpower to build a project is now evolving into more of a partnership between the SHA and a contractor. These types of partnership can result in better quality projects because it is to the advantage of both the agency and the contractor to design and build a quality product since both have stakes in the operation and maintenance of the final product. These changes do not come easy. With Method and Materials specification projects STAs have become accustomed to having total control over the manufacturing and placement of the materials and product, total QC control. Through this control STAs believed that they would achieve the required quality of the final products. It has now been tested, proven and accepted by STAs that it is the contractor, the producer and installer of a product or material that has the most control of the overall quality of the final product. Historically, the responsibility for QC has been with the STA. When the shift of QC from the agency to the contractor occurred, the QC roles and responsibilities became confused and intermingled between the agency and the contractor. This was a result of the reluctance of SHAs to relinquish total QC control and low keyed efforts in the development and implementation of clear and concise QC polices and requirements. This literature review confirms that this intermingling of QC responsibilities between

SHA's and contractors still exist today. How this transfer of responsibility has taken place varies significantly from one STA to another and often within an agency depending on the product, material or project size. Today many STAs still have State Inspectors at the contractor's plant. SHA Materials Inspectors responsibilities are Acceptance Testing and IA testing. These responsibilities do not require an inspector to be assigned and stationed at a contractor's plant. State Resident Engineers and inspectors are assigned air meters, slump cones and cylinders and are required to perform field testing at concrete placements because there no contractor QC personnel on site. This type of testing is a QC responsibility that should and must be performed by the contractor to assure quality of the material and final product.

2-3 Current QA Programs

To understand why so many variations of QA programs exist, specifically in QC and Acceptance, this research looked at how STAs addressed the many elements and factors that comprise a QA program. 23 CFR 637.207 sets forth the requirements within a STAs QA Program as follows:

(a) Each State transportation department's (STD's) quality assurance program shall provide for an acceptance program and an independent assurance (IA) program consisting of the following:

(1) Acceptance program.

(i) Each STDs acceptance program shall consist of the following:

(A) Frequency guide schedules for verification sampling and testing which will give general guidance to personnel responsible for the program and allow adaptation to specific project conditions and needs.

(B) Identification of the specific location in the construction or production operation at which verification sampling and testing is to be accomplished.

(C) Identification of the specific attributes to be inspected which reflect the quality of the finished product.

(ii) Quality control sampling and testing results may be used as part of the acceptance decision provided that:

(A) The sampling and testing has been performed by qualified laboratories and qualified sampling and testing personnel.

(B) The quality of the material has been validated by the verification sampling and testing. The verification testing shall be performed on samples that are taken independently of the quality control samples.

(C) The quality control sampling and testing is evaluated by an IA program.

(iii) If the results from the quality control sampling and testing are used in the acceptance program, the STD shall establish a dispute resolution system. The dispute resolution system shall address the resolution of discrepancies occurring between the verification sampling and testing and the quality control sampling and testing. The dispute resolution system may be administered entirely within the STD.

23 CFR 637 provides STA's with flexibility in the development of its QA Program. The decisions that a STA must address when developing a QA program are many. These decisions are made based on what works best for the individual STA QA program. For an understanding of the differences in QA programs from one STA to

another, the following are a small sample of the decisions agencies must consider in the development of its QA program:

- The development of frequency guide schedules for verification sampling and testing,
- Type of specifications to be used.
- What attributes will be used for QC and acceptance.
- What types of test will be used.
- Who will perform the testing?
- What will be the acceptance /rejection criteria, will there be pass or fail or pay adjustment factor.
- What are the qualification requirements for QC and Acceptance inspectors? Qualified or certified?
- How much of the QC role will be given to the contractor.
- Will a QC Plan be required?
- Who will be responsible for development of the QC plan, the STA or the contractor?
- Will consultants be used for QC and or Acceptance?
- Will Contractor QC test results be used for Acceptance? If so, what will be the validation testing requirements?

STAs differ on how they view these elements and as a result each STA implements strategies and policies into their QA Program that works best for their agency and achieves compliance with 23 CFR 637. The goal of this regulation, as is the goal of every QA program, is to ensure that the materials and workmanship incorporated into each federal-aid highway construction project on the NHS are in conformity with the requirements of the approved plans and specifications. With all the decisions that go into the making of a QA Program and considering the different needs and resources of STAs, it is understandable why so QA programs differ so significantly from one STA to another.

2-4 Findings from Literature Review

One of the objectives of this research is to develop a better understanding of the different strategies, practices and policies that STAs have selected and implemented in the development of their QA Programs. With this understanding best practices can be identified and recommendations developed for implementation into SHAs QA Programs. To develop this understanding a thorough literature review was conducted and supplemented with phone interviews with various STAs and follow up in person interviews with STAs officials and Contractors. This research also utilized a Questionnaire survey conducted for NCHRP Synthesis 346 State Construction Quality Assurance Programs (Hughes S.C., 2005). The objective of this survey was to solicit information on the QA methods and procedures used by government agencies. This survey was sent to 50 STAs, the District of Columbia, FHWA Federal Lands Division and Canadian provinces. Responses to the survey were received from 43 STAs the District of Columbia and FHWA Federal Lands Division. The survey focused on major construction areas; soils and embankment, aggregate base and subbase, Hot-Mix Asphalt and Portland Cement Concrete for paving and structures.

2.4.1 Types of QA Programs for Soils and Embankments

QA programs for processed materials for soils and embankment as well as aggregate base and subbase consist mostly of materials and methods QA provisions as a result of the materials large degree of heterogeneity. By definition heterogeneity means different in kind, unlike, composed of parts of different kinds; having widely dissimilar elements or constituents. As stated by McMahon in Quality Assurance in Highway Construction "the variability of the material itself impedes the use of overall standard deviation as a measure of contractor performance." (McMahon, T.F., et al. 1990). The responses from the questionnaire support this theory with 25 of the 45 STAs reported using primarily materials and methods provisions in their QA programs, 23 use QA programs where the agency is responsible for QC and Acceptance, 16 use QA programs with the contractor controlling quality and the agency performing acceptance, and only 6 use QA programs with the contractor controlling both the quality and contractor tests used in the acceptance decision (Figure 3). It is not surprising to find that over half of the agencies reporting are still taking on the QC role. With the variability of the material impeding the use statistical analysis, STAs tend to want to keep the QC role. One common factor derived from the questionnaire is the use of compaction and moisture content as the attributes used most often for QC and Acceptance of soils and embankments (Figure 4).

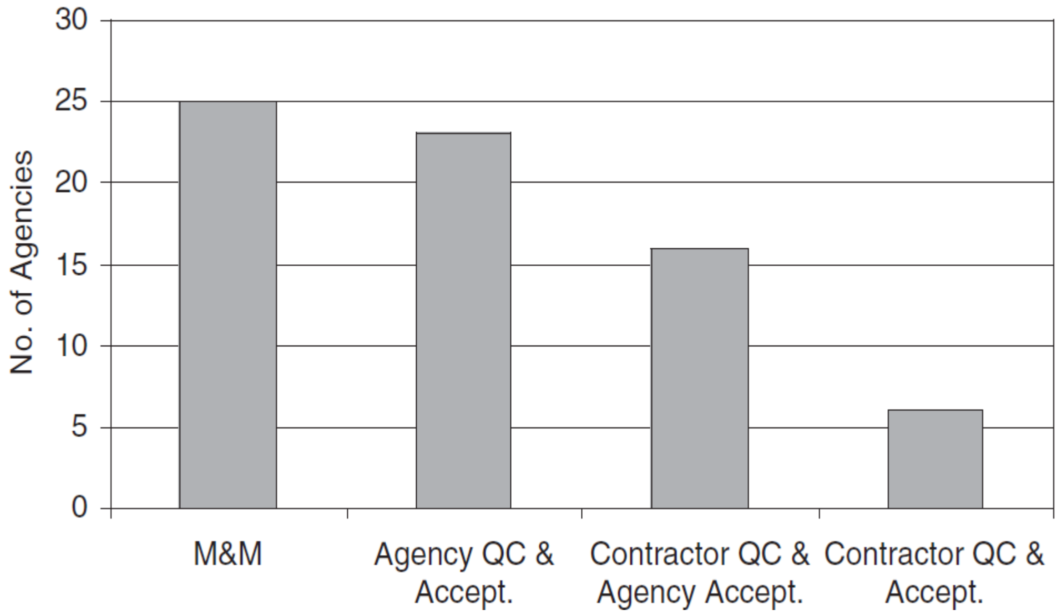


Figure 3 Types of QA programs used for soils and embankments. (Source: NCHRP Synthesis 346)

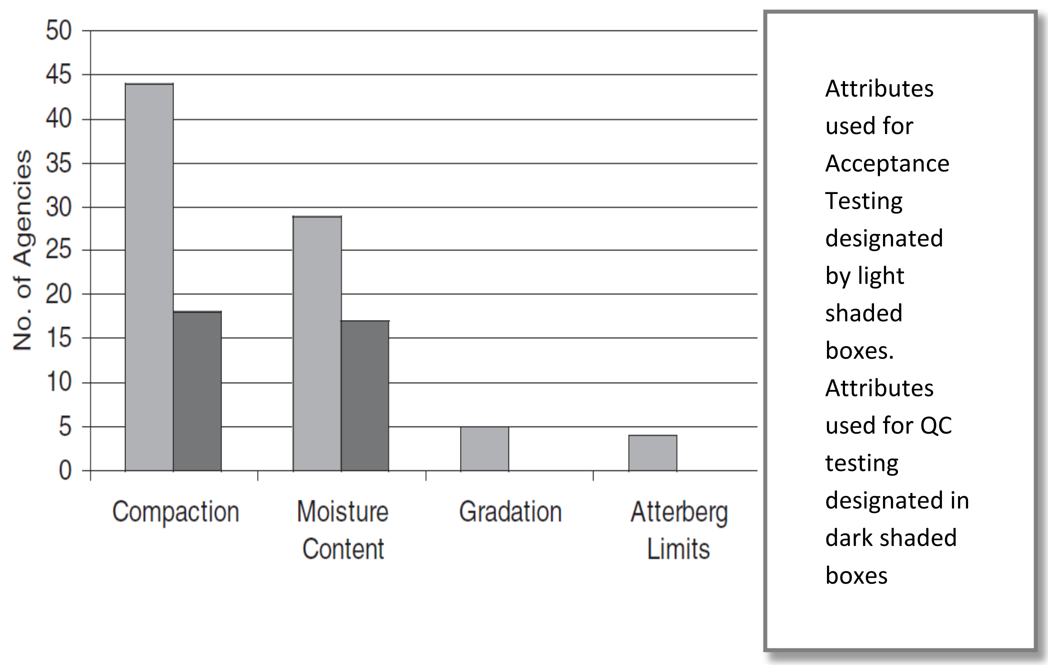


Figure 4 Attributes used for QC and Acceptance of soils and embankments. (Source: NCHRP Synthesis 346)

2.4.2 - Types of QA Programs for Aggregate Base and Subbase

Of the 45 respondents, 15 of the STAs QA consist of materials and methods provisions, 14 of the STA's use QA programs with the agency controlling quality and performing acceptance, 21 use QA programs with the contractor controlling the quality and the agency performing the acceptance, and 10 use QA programs with the contractor controlling the quality and the agency using contractor test results in the acceptance decision (Figure 5). As with soils and embankments the variability of the material lends itself to the use of materials and methods type of QA. The attributes most often used for QC and Acceptance for aggregate base and subbase are gradation (15), compaction (20), and moisture content (14) (Figure 6)

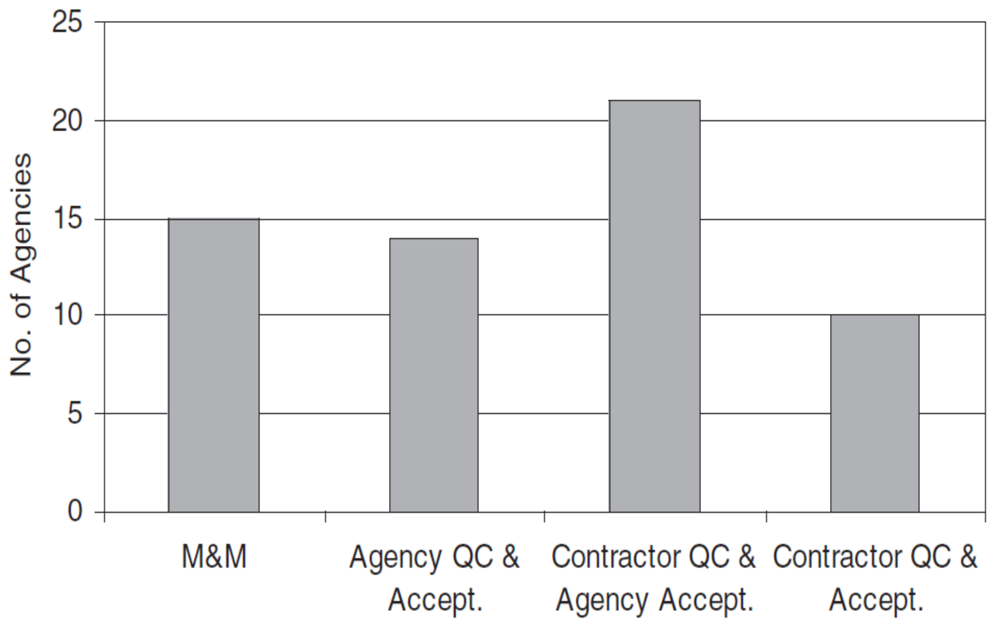


Figure 5 Types of QA programs used for aggregate base and subbase. (45 responses) M&M = materials and methods. (Source: NCHRP Synthesis 346)

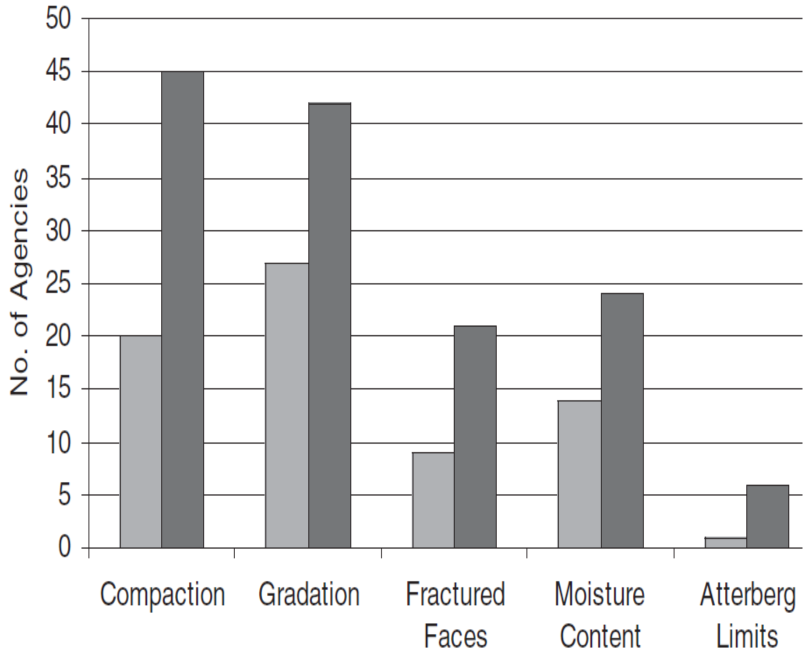


Figure 6 Attributes most often used for QC and acceptance of aggregate base and subbase
(Source: NCHRP Synthesis 346)

2.4.3 - Types of QA Programs for HMA

Responses from the Questionnaire clearly showed that the majority of STAs QA programs use statistically based specifications. Only 2 out of the 45 STAs that responded still use materials and methods provisions for HMA. Materials and methods specifications are rarely used for HMA. Figure 7 shows that out of the 45 STA that responded 25 reported using a QA program with the contractor performing QC and the agency using contractor QC test results for Acceptance. That is more than 50% of the STAs using contractor QC test results for Acceptance. The attributes most often used for QC and Acceptance for HMA are Gradation, Asphalt Content and Compaction (figure 8). The Questionnaire confirmed that the use of contractor QC test results for Acceptance is most prevalent with HMA. The large percentage of STAs using contractor QC test results for Acceptance is a direct result of the properties of HMA and the fact that HMA statistically based specifications have been developed and in use longer by more agencies than for any other material. There is more confidence in the validation of contractor QC test results as a result. As more and more STAs move in the direction of performance based specifications and end result specifications, it is expected that the use of contractor QC test results for Acceptance will also increase. This is a sign of the evolution that is currently taking place in the development of STAs QA programs. The importance of testing must be based more on the selection of attributes to test and type of test to perform rather than who performs the actual testing. Once STAs develop confidence in the validation of contractor QC test results, the use of contractor QC test results for Acceptance will be as common as is the practice of contractor performed quality control (CPQC) is today.

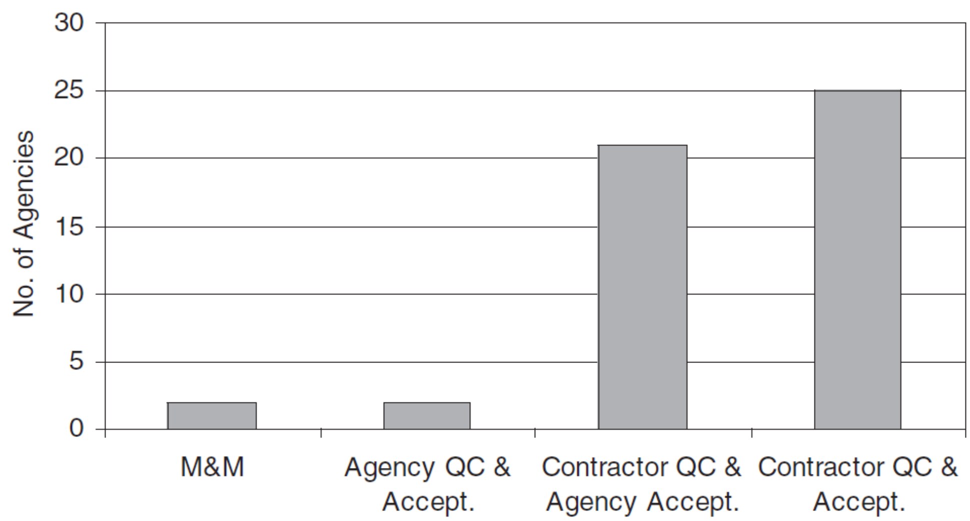


Figure 7 QA programs for HMA (45 responses) (Source: NCHRP Synthesis 346)

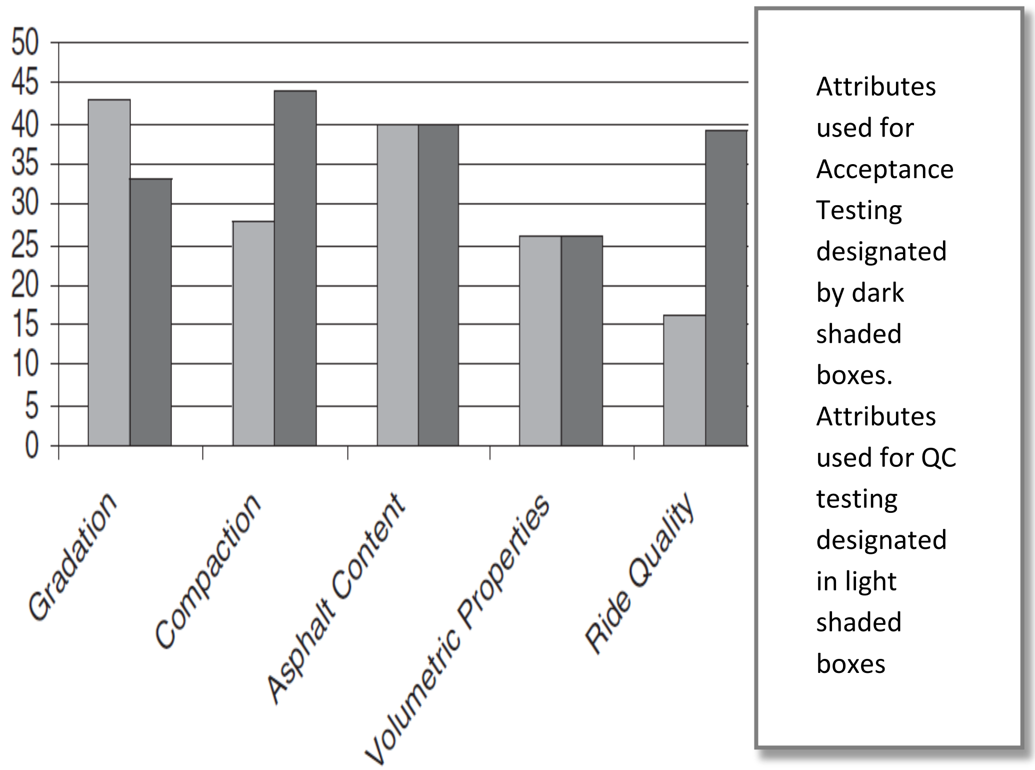


Figure 8 Attributes most often used for QC and Acceptance for HMA (45 responses)(Source: NCHRP Synthesis 346)

2.4.4 - Types of QA Programs for PCC Paving (PCCP)

The use of statistically based QA programs with PCCP is at the early stages with most STAs but its use has increased in the past decade. Studies conducted by Chamberlin for the Performance-Related Specifications for Highway Construction and Rehabilitation indicate that "the use of performance-related specifications for PCCP is on the increase and appear to be ahead of the use of this type specification for HMA" (Chamberlin, W.P., 1995). STAs have reported an increase in PCCP for intersection improvements and construction. As seen in figure 9 of the 40 STA that responded 16 STAs use QA programs with Contractor QC and Agency Acceptance and 13 STAs use contractor QC and contractor test results used for Acceptance. The most commonly used attributes used for QC are air content, gradation and slump. The most commonly used attributes for Acceptance are air content, used by 38 agencies and thickness, used by 36 agencies (see figure 10).

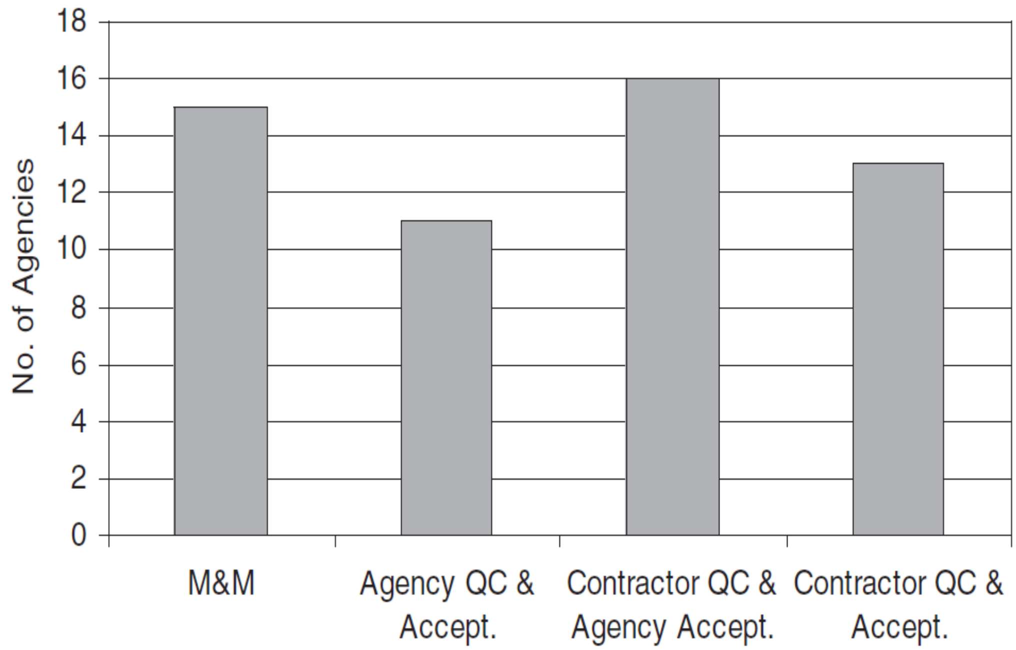


Figure 9 QA programs for PCCP (40 responses)
(Source: NCHRP Synthesis 346)

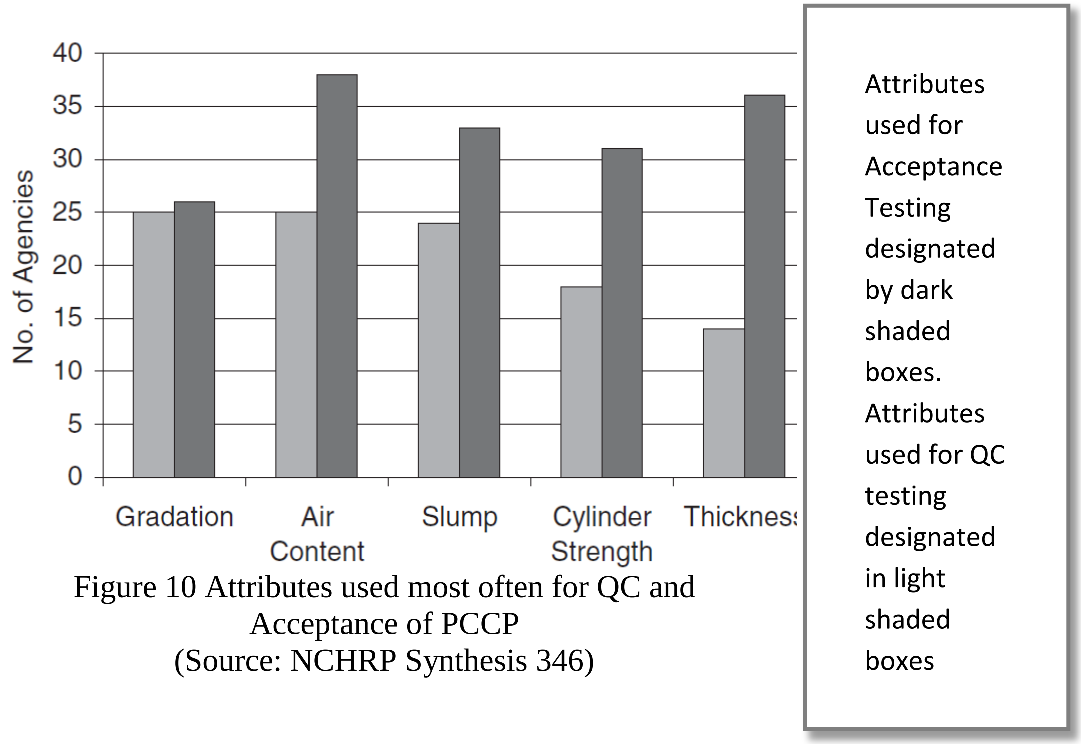


Figure 10 Attributes used most often for QC and Acceptance of PCCP
(Source: NCHRP Synthesis 346)

2.4.5 Types of QA Programs for PCC Structures

QA programs for PCC structures are very similar to the QA programs for PCC paving. The use of statistically based specifications is in the increase but is currently not used as often as with HMA. The survey responses showed that of the 43 responses, 25 agencies use material and methods provisions (Figure 11). The attributes most commonly used for QC and Acceptance are gradation, slump, air content, cylinder strength and water/cement (W/C) ratio (Figure 12). The purpose of QC is to monitor quality characteristics of the product so that adjustments can be made as needed to assure that the process is producing material that meets or exceeds specification requirements. To assure that the process is in "control". Selecting the proper product characteristics to test and developing a testing frequency for testing/monitoring that will allow for timely implementation of corrective actions is the foundation of an efficient and effective QC process. A concern regarding the responses from this questionnaire is the use of cylinder breaks for QC. Out of the 49 STA's that responded 22 reported using cylinder break strength test for QC. Concrete mix properties such as air content, slump and gradation are appropriate QC quality characteristics. Each of these characteristics can be tested, monitored and modified while the product is in production. Therefore these are good material properties for QC testing because they provide information that can be used to make corrections to the concrete mix while in the production and placement stage. The use of cylinder break strength tests as a QC attribute does not fit into this QC definition. Cylinder break strength test are conducted at 3, 7 or 28 days after the placement. The information learned from test conducted after the placement cannot be used to monitor or adjust the mix during production. While concrete cylinder break strength tests are beneficial for the development/testing of mix designs or for payment calculations, it is not a good QC attribute.

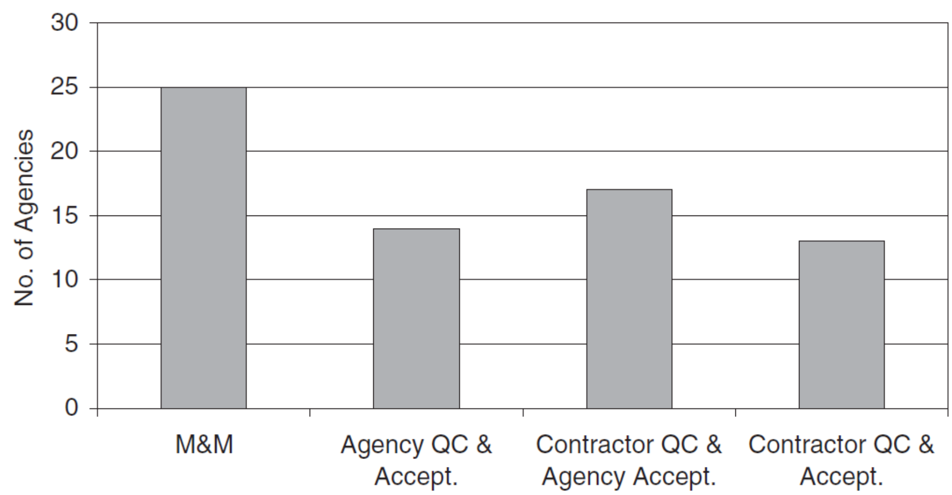
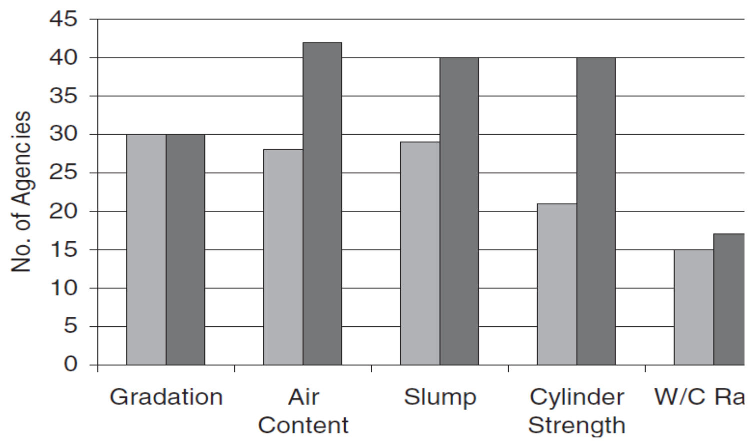


Figure 11 QA programs for PCC structures (Source: NCHRP Synthesis 346)



Attributes used for Acceptance Testing designated by dark shaded boxes. Attributes used for QC testing designated in light shaded boxes.

Figure 12 Attributes used most often for QC and Acceptance of PCC structures (Source: NCHRP Synthesis 346)

2.5 - Independent Assurance

The third component of a QA program is Independent Assurance (IA). The survey questionnaire sought to determine how the IA unit in each agency is organized and what its function is. There are two ways in which IA is used by STAs. The first is the narrower context which is, to provide an independent assessment of QC and Acceptance test results. The seconder, broader view, is one where IA performs an assessment of the overall QC and Acceptance process. Responses from the questionnaire and through phone calls with STA Officials supports that IA is being conducted by most STAs in compliance with 23 CFR 637; however, the manner in which IA is organized within an agency varies greatly, as does the level of staffing, even when normalized by agency budgets. Figure 13 represents total IA full time employees performing sampling, testing and training roles. From the 29 responding STAs there is a staffing variation from 4 to 35 full time IA employees. To see if the significant difference in IA Full- time employees had a direct link to the STAs budget the survey used the agency's construction and maintenance budget as a normalizing factor. The results can be seen in Figure 14 which show that staffing varies from 0.5 IA full time employees per hundred million dollars to 16 IA fulltime employees per hundred million dollars.

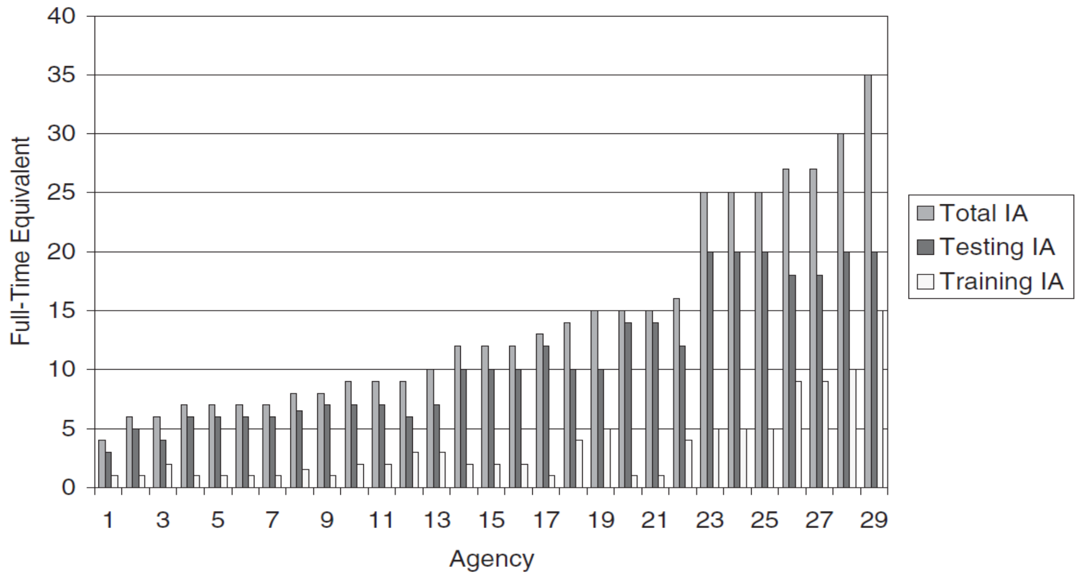


Figure 13 Total Full Time sampling, testing and training IA Employees (Source: NCHRP Synthesis 346)

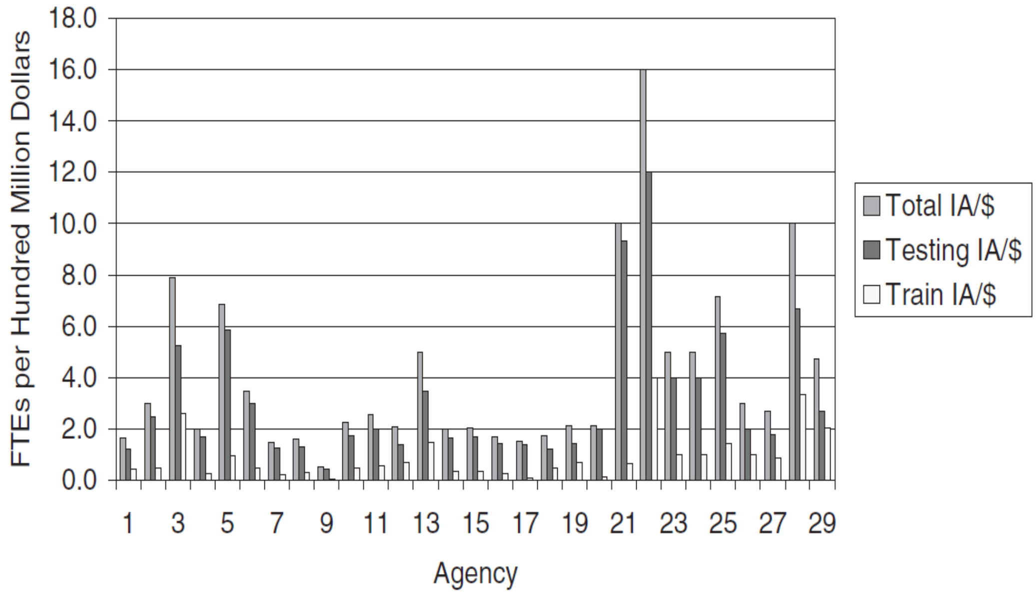


Figure 14 IA full time employees staffing per hundred million dollar construction and maintenance budget. (Source: NCHRP Synthesis 346)

2.6 - Use of Outside Consultant to Perform QA

The use of outside consultants to perform QA by STAs is a widespread practice and increasing at an aggressive rate. Responses from the NCHRP Synthesis 346 survey indicated that 35 out of the 45 agencies use consultant for their QA program. That equates to 78% of the agencies that implement the use of consultants within their QA programs. Back in 1998 NCHRP Synthesis of Highway Practice 263 "State DOT Management Techniques for Material and Construction Acceptance" reported that "17 agencies of 39 responding (44%) indicated that they contracted some QA testing outside of their workforce" (Smith R.G 1998). In less than one decade the percentage of agencies that utilize outside consultants within their QA programs has nearly doubled. Table 1 represents the wide range of products tested by outside consultant services for STAs.

Table 1 Products Tested by Consultants (Source: NCHRP Synthesis 346)

Products Tested	No. of Agencies
All	13
PCC	8
HMA	5
Prestressed and precast PCC	4
Structural steel	3
Soils	3
Aggregates	2

The use of outside consultant services for QA is increasing for many reasons. In 2014 a study was undertaken by the University of Colorado Boulder and Eastern Tennessee State University (Torres, V., et al. 2014). An electronic survey of 44 STAs was conducted for purpose of summarizing the state-of-practice in the use Construction Engineering Inspection (CEI) consultant services. Responses from the survey showed that inspection services were used mostly for construction, geotechnical, material testing and quality management. Figure 15 shows the volume of CEI consultant work estimated as the percentage of total highway funding per state transportation agency. As depicted in Figure 15 the CEI budgets varied from zero to 35.5%. RIDOT reported a 6.55% budget use on outside consultant services. Figure 16 represents the number of CEI contracts issued in 2013. The numbers of CEI contracts awarded in 2013 range from 0 to 350. Considering Michigan and Florida as outliers, the average number of CEI contracts issued per STA in 2013 was 23. RIDOT awarded 30 CEI contracts in 2013. RIDOT is not unfamiliar with the benefits associated with the use of outside consultant services.

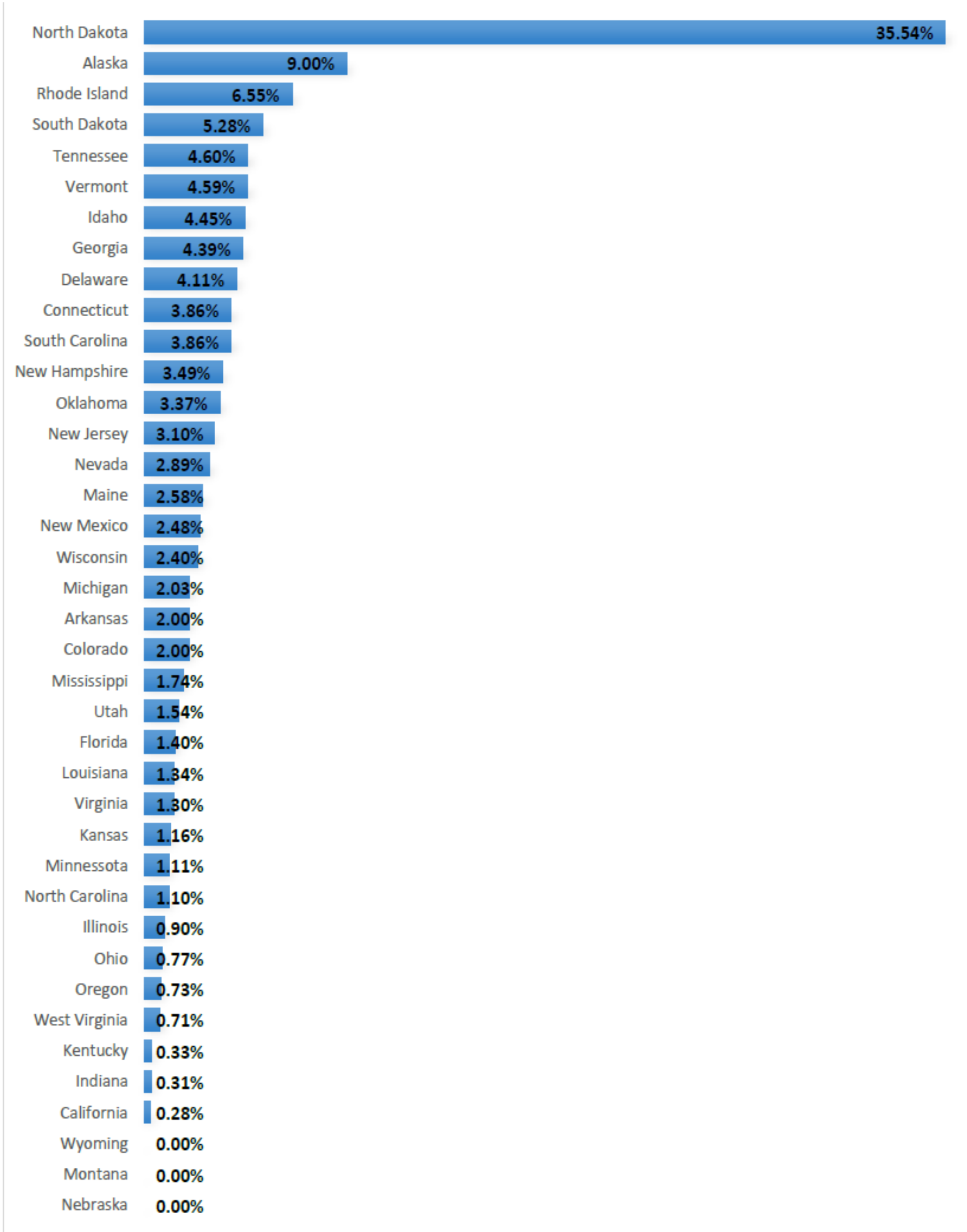


Figure 15 CEI consultant work estimated as percentage of total highway funding per state transportation agency. (Source: Construction Engineering Inspections Services Guidebook for Transportation Agencies.)

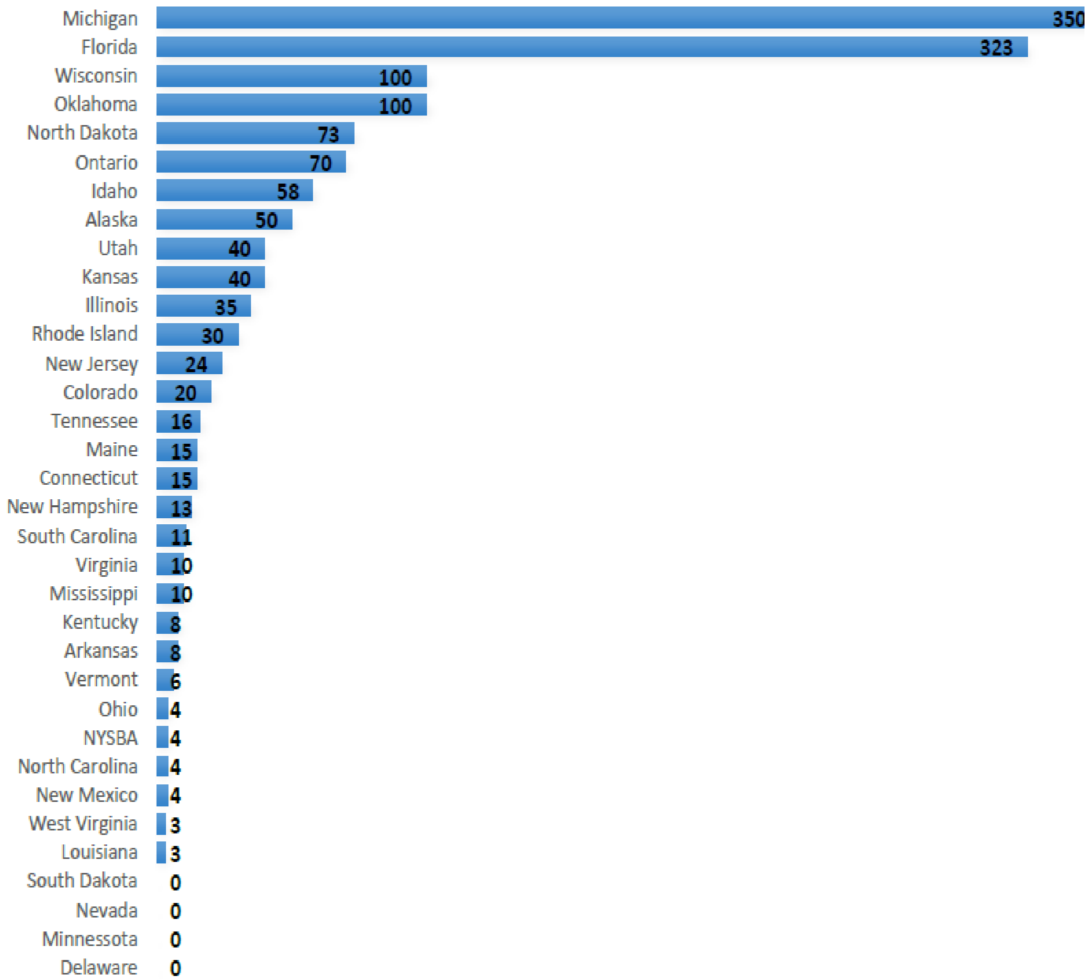


Figure 16 STA's Construction Engineering Inspection contracts in 2013 (Source: Construction Engineering Inspections Services Guidebook for Transportation Agencies.)

STA's overwhelming agreed that the three main benefits from the implementation of outside consultant services are:

- Improves ability to handle peak workloads
- Provides flexibility of increasing or reducing staff quickly
- Provide expertize that may not otherwise be available in-house.

The three main challenges from the implementation of outside consultant services reported by the respondents were:

- Familiarizing consultants with STA procedures
- Ensuring CEI consultant qualifications
- Minimizing cost of CEI consultants when compared to in-house inspections.

Through proper management of consultant usage, including reporting of hours worked and proper classification for required inspection work, minimizing consultant cost can and has been achieved by contractors since the early 1970's. SHAs can realize the benefits that contractors have realized through proper management and usage of consultant services. The use of outside consultant in a STAs QA program provides the STAs with the improved ability to handle peak workloads, provide the flexibility of adding or reducing staff quickly, and bring special expertise that may not otherwise be available in-house. These benefits allow a STA to optimize its inspection capabilities while minimizing cost associated with over staffing and cost of acquiring specialty services.

QA continues to be an evolving process. This was proven beyond a doubt by the response to the NCHRP Synthesis 346 Questionnaire question: Do you anticipate significant changes in your QA program for any product in the near future?. Twenty three out of the 45 STAs that responded reported that they anticipate significant changes in the near future in their QA programs. Samples of the responses are as follow:

California DOT

- For manufactured materials; when the department implements a materials management system, the department will no longer perform QA on a project-by-project basis, but will release material on a manufacturer's track record.
- Implement requirement for contractors to develop a QC plan with minimum acceptable frequency and observations including identification of a quality manager. Department QA will be "Did they follow the plan?" and perform statistically valid random sampling and separate tests.

Colorado DOT

- Will implement move to using contractor's test results as part of the acceptance decision for HMA when Colorado DOT acceptance is based on voids.

Kentucky DOT

- Moving toward contractor total project QC by 2005. Contractor will be required to have qualified individuals to cover all disciplines. Agency will perform verification and use contractor test results as part of the acceptance decision.

Louisiana DOT

- Use contractor surface tolerance test results as part of the acceptance decision for ride quality.

Montana DOT

- Develop QA program using contractor test results in the acceptance decision for HMA, PCCP, and aggregate surfaces.

New York DOT

- Developing a comprehensive QA procedure to reduce or eliminate the need for individual methods/procedures for each material.

South Carolina DOT

- Develop QA program using contractor/producer test results in the acceptance decision for PCCP and structural steel

Texas DOT

- The contractor test results will be used in the acceptance decision with agency verification testing at a reduced rate.

2.7 - Summary of Literature Review

The results from this literature review confirm that there is a broad spectrum of QA programs being implemented by STAs across the country. Every STA has tailored their QA program according to the agency's needs, goals and available resources. There is not a "one-size-fit –all" QA program. With the many variables involved in the development of a QA program this broad spectrum is to be expected. Though QA's vary significantly from one STA to another there is an overall consensus in the QC shift from the owner to the contractor. There seems to be general agreement, or at least no serious controversy, as to the value of contractor QC. How this QC transfer from the owner to the contractor has evolved and continues to evolve, accounts for the differences in policies and practices regarding the contractors QC responsibilities. The SHAs QC policies and practices differ from one project to another. QC contractual requirements are tailored to fit the project. For major RIDOT projects The Department incorporates CPQC into the projects contractual requirements. The contractors QC role and responsibilities are clearly stated as contractual requirements. The contractor is required to submit a QC plan for Departmental review and approval prior to the start of any work. Since the 2008 Replacement of the Sakonnet River Bridge Project there have been several major projects that RIDOT has made CPQC a contractual requirement, they include the Replacement of the Pawtucket River Bridge 550 Project, The Replacement of the Providence Viaduct Bridge Project and the Appanoug Circulator Project. For each of these projects the contractor hired outside consultant inspection services to perform project wide QC. This included consultant construction inspectors, field material inspectors and lab technicians and certified and approved laboratory testing. These major projects where CPQC is incorporated into the contract represent a small percentage of the actual number of projects that the Department puts out to bid. For the majority of the projects without CPQC the contractor QC starts and ends at the contractor's plant. For example, a contractor placing a concrete foundation will first request approval from the agency to use an agency approved mix design. The materials that makeup the mix, such as the coarse and fine aggregate, are tested. The mix is developed in the plant in accordance with materials and methods specifications. The concrete is then tested before it leaves the plant.   On a project with CPQC there will be a contractor QC inspector or the consultant inspector hired by the contractor on site with slump cones, air meters and cylinders to test the concrete before it is placed. In addition the QC inspector will assure that the ground where the material will be placed has been compacted to required density levels. On a project where there is no CPQC there is no contractor QC inspector on site. It is the STA Construction

Inspector or Materials Inspector that will conduct slump test or run an air meter test on the mix. A scheduled Acceptance Test often turns into QC testing as required adjustments are implemented into the mix. These tests are typically classified as "Informational Only Testing". The information derived from these test is whether the product is in compliance with specifications. This is QC testing that must be performed by the contractor. It is the contractor that must monitor his production process so that necessary modification can be implemented in a timely fashion to insure control of the production process.

SHAs have been and continue to mix and mingle QC roles, from one material to another and from one project to another. This is the confusion that has arisen with the transfer of QC from the SHA to the contractor. Another case where this is evident is in placement of gravel subbase for sidewalk placement. On a project with CPQC there will be a contractors QC representative with nuclear gage density testing equipment verifying that the contractor's compaction is achieving soil density requirements prior to the placement of the concrete or asphalt sidewalk. On a project without CPQC it is the Construction Inspector that must call the agency's Materials Inspector, who may or may not be on site, when he suspects that the compaction is not meeting required soil density. The Construction Inspector does not have a nuclear density testing device nor is he certified to operate one. He is basically making his judgement on visual inspection. That in itself is a problem. How can you visually tell when a material has 98% compaction or 80% compaction? When the RIDOT Materials Inspector arrives on site he will then perform a nuclear density test to determine if the compaction has achieved 95 – 98 % compaction as required. What typically happens next is, if the test fails, the Materials Inspector informs the foremen in charge of the gravel placement crew. The foreman then directs the laborer running the plate compactor to compact the area again. The Materials Inspector will then retest the area. If 95% - 98% compaction is achieved the area is accepted and sidewalk placement can proceed. If it does not meet compaction density requirements the contractors crew continues compaction efforts until required compaction is achieved. There are many flaws to this practice. First and most important is that the agency will not know how many areas did not achieve proper compaction because of the lack of contractor QC. The early cracking and settlement of sidewalks is a consequence of this type of practice. It is not possible for SHAs construction inspectors to monitor every construction operation 100% of the time; this was realized back during the ASSHO Road Test project. For the Replacement of the Sakonnet River Bridge Project it was not uncommon to have more than 10 construction operations ongoing concurrently. RIDOT anticipated this workload and it is for this reason that the project was selected as the pilot project for CPQC. QC, both at the plant and at the project field level should and must be the contractor's responsibility. SHAs can no longer afford to perform the field QC testing that can best be performed by the contractor. The cost of doing so and the cost resulting from inferior quality work as a result of the absence of CPQC cannot and should not be borne by a SHA.

Contractors across the country have learned the benefits of implementing consultant inspection services. The increase from 44% to 78 % of STAs implementing the use of outside consultant services indicates that STAs are also realizing the benefits of supplementing their staff with outside consultant inspection services.

Contractors have implemented outside consultant inspection services when QC has been transferred over to them. The result has been more testing then what would have taken place with the traditional Acceptance testing being performed by the agency. With this new revelation it naturally follows that more and more STAs are using CPQC test results for acceptance. From the information gathered from this study it is clear to see that as STAs become more confident with COQC test result validation that more agencies will incorporate CPOQC test results into the Acceptance portion of their QA programs.

2.8 - References

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Chapter 3

Quality Control at the Sakonnet River Bridge Project

3-1 History of the Sakonnet River Bridge

The Sakonnet River Bridge was built in 1956 to replace the Stone Bridge. The Stone Bridge, built in 1907 in Rhode Island to carry Rte. 138 over the Sakonnet River between the Towns of Portsmouth and Tiverton (Figure 17). In August of 1954, Hurricane Carol destroyed the Stone Bridge. By the late 1990s, the Sakonnet River Bridge's design had become obsolete, and transportation planners began to develop a plan for the bridge's future. In 2003, the Rhode Island Department of Transportation announced plans for a $120 million (USD) replacement bridge just north of the existing bridge. In 2008, the Sakonnet River Bridge was closed to heavy commercial vehicle weighing over 18 tons. Vehicles over this weight limit were required to re-rout over the Mount Hope Bridge via Rte. 136/114. The State solicited bids for bridge replacement work in the fall of 2008. The RIDOT had prepared cost estimates for a concrete design bridge and a steel design bridge. The engineers cost estimate for concrete design was $201,052,317.68 and $162,864,137.58 for the steel design. The RIDOT put out two contracts for bid, Rhode Island Contract # 2008-CB-056 for the steel design bridge and Rhode Island Contract # 2008-CB-057 for the concrete design bridge. The lowest bid for either the steel or the concrete design would be awarded the contract. As expected, the steel design came in at the lowest bid price. Contractors, is particularly true in this area of the country, are more experienced with building steel bridges then they are with building concrete bridges. Cardi Corporation was the low bidder and awarded the contract at a bid cost of $163,677,992.00. At an award cost of $163,677,992.00 the Replacement Project of the Sakonnet River Bridge was largest single contract awarded in the RIDOT history.

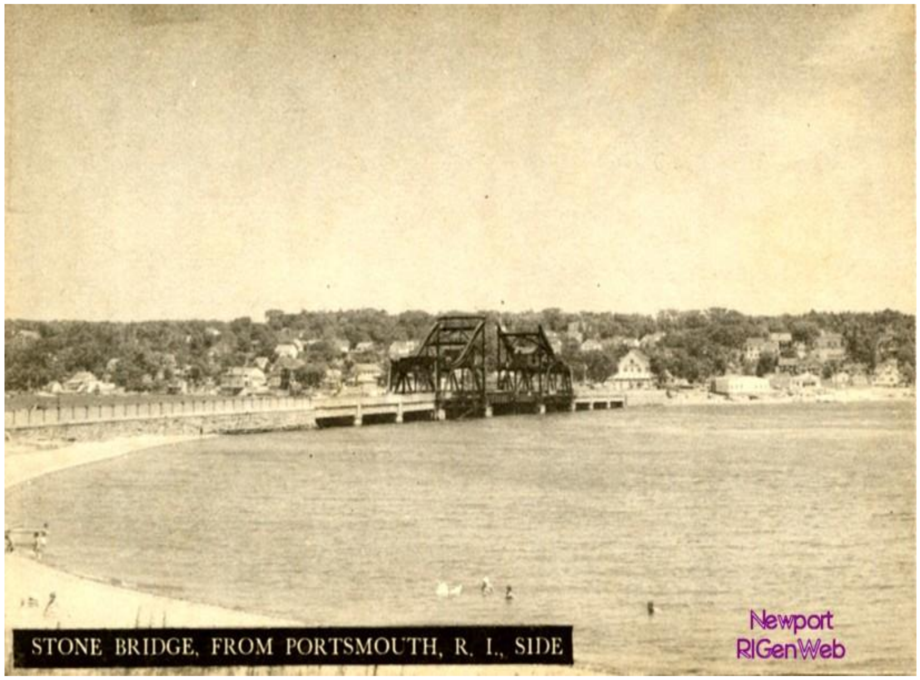

Figure 17 Stone River Bridge

3-2 Innovations Incorporated at the Sakonnet River Bridge Project

3-2-1 72 Inch Pipe Piles in Place of H-Piles

There were many innovations incorporated into this project. One such innovation was the use of 72-inch diameter steel pipe piles, in place of the typical H-Piles, to support the bridge pier foundations. Prior to the letting of the Replacement Project of the Sakonnet River Bridge RIDOT put out two test pile projects, several subsurface investigation projects and conducted various geotechnical studies for the purpose of developing a design for the supports of the new bridge structure. The design phase program involved static and dynamic load testing on H-Piles and large diameter pipe piles with capacities in excess of 6000 kips. An innovative solution was developed for the large diameter pipe piles that forced plugging and increased pile capacity, and hens, significantly reducing pile lengths compared to originally design open pipe piles. The innovative design, its verification in load test and construction resulted in a very large cost savings to the State.

RIC 2006-CB-012 tested 36 inch and 48-inch open-ended steel pipe piles. RIC 2007-CB-006 tested several 72 open and closed ended steel pipe piles. Both test projects took place at the Portsmouth side adjacent to the area of the new bridge abutment. Figure 18 represents a load-bearing test on a 48-inch open-ended steel pipe.

Figure 18 Load test on 48-inch steel pipe pile

Test results from two test pile projects, subsurface investigation projects and geotechnical studies enabled RIDOT to develop the final pier footing designs for the new bridge. The final design consisted of nine piers. Piers #1, #8 &#9, located on the Tiverton and Portsmouth bridge abutments, designed on End bearing H-Piles. Piers #2, #3 &#7, located in the shallow portion of the river, designed on friction H-Piles. Piers #4, #5 &#6, located in the channel and deepest section of the Sakonnet River were designed on friction and end bearing 72-inch steel pipe piles. The "forced plugging " of these 72-inch pipe piles was achieved through the incorporation of a 2½ inch thick, steel plate welded inside the pipe, 40 feet from driving end of the pipe. The plate contained a 14-inch diameter hole to relieve soil and water pressure. Figure 19 is a representation of this steel plate used to seal the driving end of the pipe pile. The purpose of this steel plate is to incorporate end-bearing capacity to the pipe. Without this plate, the bearing capacity of the 72-inch steel pipe pile will the bearing capacity achieved through friction. During the test pile project RIC 2007-CB-006, it was determined that a combination of end bearing and friction would significantly reduce the depths that the piles would need to be driven.

In March 2014 the National Steel Bridge Alliance (Division of AISC) in conjunction with the World Steel Bridge Symposium, Toronto, Canada awarded the Sakonnet River Bridge Project the Merit Award for innovative bridge foundation evaluation.

Figure 19 End Bearing Steel Plate

3.2.2 Partnering

Partnering was implemented in the Sakonnet River Bridge Project as a pilot program. Partnering was a practice that neither the agency nor the contractor had much experience in. Partnering works as follows:

- The contractor and the agency agree on and select a third party person/consultant to run the partnering sessions.
- All cost associated with partnering are shared equally between the agency and the contractor.

- Meetings took placed at a mutually agreed upon location and schedule.
- Partnering outcomes are not contractually binding and cannot violate contractual requirements.

Partnering brings all the key players involved in the project oversight together. This includes all field and upper Management personnel. The main goal is to create a "team" and to develop a team approach to the resolution of all issues. The following are the major benefits derived from Partnering at the Sakonnet River Bridge Project:

- Help develop and maintain open communication channels between RIDOT and the contractor, both at the field level and at the upper management level.
- At the very onset of the project, the importance of upper management allowing and supporting field level decision making was established. This allows small problems to be resolved before they turned into major problems. This resulted in the resolution of problems quicker and typically at a lower cost to the agency.
- This project had a significant amount of shop drawings with 60-day review periods. Through partnering the review periods were dramatically reduced by the Department and the contractor mutually agreeing to allow electronic submissions of "draft" submittals between the contractor and the Department. Through these electronic submittals, comments and revisions took minimal time. When no further revisions were required then the contractor would submit the final shop drawing.
- Daily meetings between the contractor's superintendent and the project Resident Engineer were agreed upon to discuss the days scheduled operations.

- Weekly schedule meetings were conducted to evaluate project schedule, upcoming major events, actions required by the contractor and actions required by the agency.
- The importance of teamwork was institutionalized on every SHA and contractor individual involved in the project.

3.2.3 Transfer of QC (CPQC)

One of the most significant innovations incorporated into this project was the transfer of Quality Control from the owner to the contractor; Contractor Performed Quality Control (CPQC). For decades, the Department has served as Quality Control for the contractor by defining what parameters indicate quality and indicating when they have achieved a satisfactory product. A solution was needed that would transfer the responsibility of QC to the contractor, while also maintaining the final decision for Acceptance. The answer was a pilot project in which the contractor would perform all QC testing, both in the plant and in the field. The Department would conduct Acceptance testing at a lesser rate as the basis of payment. This transfer of QC from the owner to the contractor marked the very first use of CPQC for RIDOT. Prior to this pilot project the only field-testing performed was that of RIDOT's Materials Acceptance Testing personnel. Acceptance Testing is not QC. Acceptance Testing is a check on the QC process and its results. Acceptance testing does not provide information back to the contactor in a timely manner so that he can correct and or adjust the product to meet specifications. Acceptance testing must be viewed and managed by SHAs as check on the contractors QC by verifying conformance –to-specifications through Acceptance Testing. The Replacement Project of the Sakonnet

River Bridge items of work included over 30 million Lbs. of steel, 250,000 CY of earth work, 26,996 CY concrete, 76,000,000 LB of bituminous mix, 12,511 LF of drainage lines, 380,000 LF of geo-grid material, 165,000 SF of stay in place forms and 47,000 LF of Mechanically Stabilized Earth (MSE) for wall construction. From the preliminary design stage of this project, the RIDOT came to the realization that the QC testing required for this project would consume all of RIDOT's Material Section staffing and material testing resources.

In 2006 a book was published titled "Asphalt Mix Design and Construction Past, Present and Future" which was edited by K.W.Lee, which stated, "There is a national trend in state departments of transportation (DOTs) toward allowing contractor-performed quality control" (Mahboub et al. 2006). In 2008 when the Replacement Project of the Sakonnet River Bridge went out to bid this marked the first RIDOT CPQC project. There was resistance from both the owner and the contractor with the implementation of this innovation of CPQC. On the owner's side, as with other innovations such as Design Build Projects, there was the hurdle of relinquishing control and concern of loss in overall quality. There are several concerns associated with the reluctance to relinquish QC control to the contractor. First is the lack of confidence in the contractor's test results. Opponents of the transfer QC to the contractor often used the analogy of the "Fox Guarding the Hen House". The validation of CPQC test results is the key to the successful implementation of CPQC and the implementation of the use of CPQC test results for Acceptance. Another factor is the misconception that the owner can control QC better than the contractor can. Time and experience has proven that it is the contractor, the producer and installer of the product, with the most control of the quality of the final product. It is from this understanding and acceptance that most STAs are shifting the QC role to the contractor. On the contractor's side, there was the concern of how would a QC program be implemented and monitored and at what cost. Most contractors were also aware of the fact that they were not equipped or staffed to perform overall project QC. Contractors in general consist of construction workers and managers with limited quality control personnel. Contractor's QC personnel typically work in the plant where their role is to assure that their product produced at the plant meets specification requirements. It is there where the contractors QC personnel and RIDOT Materials testing personnel test the ingredients going into a Portland Cement Concrete (PCC) mix or a Hot Mix Asphalt (HMA). The final product is tested before it leaves the plant to assure that the mix design has produced a product that meets specification requirements. This is not to say that Contractors are not capable of performing project QC testing. Contractors, in general, do not have the personnel or equipment to perform project QC because they were not required to do so in the past. Cardi Corporation, one of the largest contractors here in the State of Rhode Island, did not have the staff to perform the QC role and associated responsibilities required for the Replacement Project of the Sakonnet River Bridge. This was especially true when it came to performing the on-site field related QC testing and inspections. Cardi had the option of hiring full time material inspectors or contract with an outside inspection service. Cardi hired ATC Construction and Materials Testing Services as their subcontractor to perform all QC testing on the project. The contractor's schedule of work was aggressive and included simultaneous operations of roadwork, bridge, and water work. The roadwork comprised of work such as the removal and installation of roadways, drainage systems, utilities, retention ponds, and MSE walls. More important the roadwork included the handling and stock piling of material, including contaminated soils. The bridgework consisted of construction of pier foundations, concrete placement for pier foundations and pier stems, steel girder fabrication and erection and concrete deck placement. The water work consisted of cofferdams construction, dewatering and concrete placement for pier footings. With all of these operations ongoing concurrently the amount of testing was truly overwhelming.

3-3 The Implementation of CPQC

3.3.1 QC Plan

The key to the successful implementation of CPQC is the QC Plan. RIDOT understood this concept and therefore included in its Request for Proposal (RFP) the contractual requirement that the contractor must submit a QC Plan to the Department for review and acceptance prior to the start of any work. The objective of a QC plan is to measure and monitor those material properties characteristic's that impact the quality of production, thereby enabling timely corrective actions to prevent the incorporation of non-conforming material into the project.   Agencies can specify the QC plan requirements in one of two approaches. One is for the agency to stipulate the minimum QC requirements and properties that the QC plan must contain. The other is to specify all the requirements and properties that require testing. The disadvantage to the first is that you may only get a plan that meets the minimum QC requirements. There are two disadvantages to the second approach, first by stating all the testing requirements the contractor may view the QC plan as the agency's plan rather than the contractors plan. This can have great liability issues. The second disadvantage is that being too prescriptive opens the door for claims when something was inadvertently omitted. RIDOT selected the first approach. To insure that a proper overall project wide QC Plan was established, it was designated as a shop drawing submittal which required Departmental approval before any work could commence on the project. This allowed the contractor to design and construct a QC plan that incorporated the testing and inspection of activities that the contractor specified to produce acceptable material. There were many iterations of the contractor's QC plan but after several submissions and revisions, the Plan was approved. A good Quality Control Plan will clearly indicate the use of random testing and event/ process testing. Both are essential to the effectiveness of a QA plan since both have very different functions. The purpose of random testing is to evaluate the quality of the total population through random sampling. The purpose of event/ process testing is to assure the quality of the process when a change has occurred. For example, when a new load of sand is introduced in the making of a concrete mixture, this requires an event/process test to assure that the new sand and the final product are within specifications. The success of CPCQ is dependent in the full understanding of the QC plan by the contractor, the sub-contractor and every RIDOT individual involved in the project. Aside from the contract and plans, the QC plan was the most important document on site. The QC plan provided information on what material needed to be tested and at what frequency. It also provided the name and contact information of the individual in charge of QC both in the plant as well as in the field. With so many different operations occurring concurrently throughout the entire the project the QC plan served as a road map to

RIDOT personnel and the contractors testing consultant for required material testing. This was the first project where the Resident Engineer had contractor QC inspectors on site with a QC plan to monitor and perform field material testing. Figure 20 shows the contractor QC organizational chart f or this project.

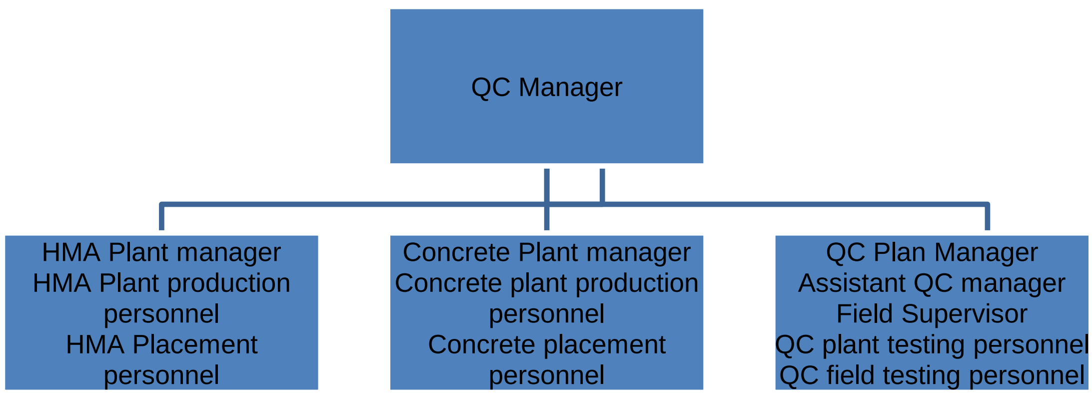

Figure 20 Contractor QC Organization Chart

3.3.2 Observed Increase in QC Field Testing

At the very start of construction operations, RIDOT field personnel noted a change in field inspections. A significant increase in the amount of testing was taking place throughout the project. There were ATC field inspectors conducting test at every gravel placement, concrete placement and HMA placement. This was a major change in QC practice and something that RIDOT Construction and Materials inspectors had not witnessed before. Prior to the implementation of CPQC, RIDOT's Materials Inspectors and Construction Inspectors performed all field-testing. RIDOT, as with the majority of SHAs report that QC is the contractor's responsibility and that Materials Inspectors are there to perform Acceptance Testing when in reality, they are also performing QC testing. This is evident since contractor QC personnel are not on site on most RIDOT projects where CPQC is not a contractual requirement. The RIDOT Materials Section has a limited staff and Construction Inspectors are often required to oversee more than one operation. Acceptance testing can be viewed as "spot checking" to assure that the contractors product is in conformance with specifications requirements. The frequency of Acceptance Testing is determined and established in accordance with RIDOT's Master Schedule of Testing Manual (RIDOT 2010). The Master Schedule of Testing Manual (MST) contains a template that specifies the material type, test type, test description (included frequency of testing) and method of testing. For example, In the MST template you will find that for the use of a material classified as "Fill Gravel Borrow" the tests required are "One 50 lbs. sample per 1000 CY or less for gradation testing" and "One (1) field density test per 1,000 CY or less." Specifications for a typical sidewalk construction operation require a 5-foot wide, 12 inch depth gravel base. One thousand CY would allow you to construct 5400 linear feet of sidewalk base. By MST requirements, only one RIDOT Acceptance test is required per 1000 CY or less. Without CPQC that equates to over a mile of sidewalk construction with only one field inspection, the Acceptance test. This is not a fault of RIDOT acceptance testing procedures. Acceptance testing is not QC testing. The purpose of Acceptance testing to provide assurance that the materials and workmanship incorporated into every highway construction project are in close conformity with the requirements of the plans and specification. The frequency of testing for any material is a direct relationship to the level of risk that the STA is willing to take. RIDOT Materials Inspectors and Construction Inspectors were not accustomed to seeing actual CPQC field testing taking place on a project. The fact that QC testing frequency far exceeds the frequency for Acceptance testing is because each serves a different purpose.   The purpose of QC testing is to make sure that the process is in control. QC frequency of testing must allow the contractor the opportunity to incorporate changes, on a timely fashion, to assure that the product complies with specifications requirements. Acceptance testing is a spot check to assure that the contractors QC is serving its purpose, to assure material compliance with specifications and for use in payment. When the Contractor hired ATC to take on the QC role the contractor assigned all liabilities associated with the quality of the product to ATC. All material found to be unacceptable by our Material Acceptance Inspectors would require removal and or be subjected to a significant pay reduction factor. Any cost associated with unacceptable material was now the contractors QC consultants responsibility.   The transfer of responsibility from the Contractor to the subcontractor increased the level of risk to the subcontractor. To reduce his level of risk the subcontractor established a QC plan that incorporated a testing frequency that provides a level of confidence that the material incorporated into the project will meet all specification requirements. It is important to note that the frequency of testing developed by the materials testing subcontractor far exceeded the frequency of testing in the original QC plan submitted by the Contractor. Simply stated, without CPQC there is no contractor QC in the field. The only testing taking place is that performed by the RIDOT. If RIDOT Materials Inspectors are responsible for only Acceptance testing, then where is the QC? CPQC places QC responsibilities on the contractor where they rightfully belong. The significant amount of QC testing that took place at the Sakonnet River Bridge Project is proof that CPQC will result in overall better quality and more productive and efficient use of RIDOT materials personnel.

3.4 Issues that arose with the Implementation of CPQC

3.4.1 Communication Problems

Several issues arose associated with the use of CPQC. The first problem encountered was the issue of communication. Operations on this project consisted of land work, water work and bridgework. These operations were taking place on both the Tiverton and Portsmouth sides of the bridge. RIDOT and the contractor had assured proper staffing levels but the required lines of communication were not established. As a result scheduling and providing coverage on operations became an issue. For example, there was a concrete placement scheduled on the Portsmouth side of the bridge. The operation was cancelled because the reinforcement bars were not constructed in accordance with plans and specifications. The concrete trucks that had arrived on site for this placement were dispatched to the Tiverton side and for use on another operation. The Contractors QC inspectors were informed of this change but RIDOT's Construction and Materials Inspectors were not. As a result, there was no RIDOT Construction or Materials Inspectors to oversee this operation.   With many concurrent operations taking place throughout the project on both the Portsmouth and Tiverton ends of the bridge, this lack of communication was the cause of several such incidents. This problem was resolved by meeting with the Contractor and ATC. The

QC Plan notification requirement was clarified and brought to everyone's attention. In addition, two very simple practices were incorporated; one was the exchange of cell phone numbers between RIDOT's crew and the ATC crew. Second, it was mutually agreed that due to the constant changes that occur on a day-to-day basis, RIDOT Inspection staff would meet with the ATC inspection staff, at the start of every workday. Communication between RIDOT and ATC improved immensely. RIDOT and ATC both understood and agreed that they had to work closely together as a team to make CPQC work.

3.4.2 Non Compliance Test Report Submissions

Another problem encountered was ATC's non-compliance with the timely submission of QC test results to RIDOT. The QC plan was very specific on time requirements for the submission of QC test Results. This was the contractors own plan and it was the Contractor that established the time requirements. ATC was not getting test results to RIDOT in accordance with the Plan. This requirement was especially critical on this project because some of the existing soils throughout the site contained contaminates. The degree of contaminants varied significantly from one location on the site to another. It was clearly stated in the contract that no soils shall leave the site prior to testing, classification and approval from RIDOT. The goal was to use as much of the on-site material as possible. To comply with this contractual requirement, the contractor had to establish stockpiled areas for all material excavated. The stockpile would be tested and classified. If the Department did not receive test results from a stockpile that stockpile was designated as unsuitable and could not be used. The delay in receiving test results from ATC put the contractor in jeopardy of having to stop work. Any off-site material that the contractor brought to the project was at his own expense and had to come from an approved source. With the existing Sakonnet River Bridge being closed to heavy vehicles getting material on to the site was time consuming and expensive. To find a resolution to this issue RIDOT met with the Contractor and ATC met. There were two major causes surrounding this issue. First, ATC took the samples early in the morning, but due to the significant amount of testing required throughout the workday, they would wait until the end of the day's operation to deliver the material to their lab. By this time of the day, the lab technicians had left for the day so the samples could not tested until the next day. The second problem was that several tests took longer to perform than the time allotted for in the QC plan. As a result of the different levels of contaminates, some testing procedures took longer than others did. One very important innovation incorporated into this project was the implementation of "Partnering". Further discussion on partnering will follow later in this report but it is important to note that RIDOT and the Contractor work on issue resolutions from the standpoint that RIDOT and the Contractor are on the same team working together to achieve the same goals. To resolve the issue RIDOT agreed to modify the QC plan to extend the time needed to perform the tests. ATC agreed to incorporate a call-in procedure with their lab so someone would be dispatched to the site to pick up samples when needed. It is important to note that for CPQC to be successful open communication and cooperation is essential.

3.4.3 Concerns with Contractor QC Test Results

One of the most significant issues that arose from the implementation of CPQC was the concern with the validity of the contractor's QC test results. As previously noted, RIDOT field personnel noted a change in field inspections. A significant increase in the amount of testing was taking place throughout the project. At first, the increase in testing conducted by ATC provided RIDOT with a sense of assurance. As the level of operations increased so did the amount of ATC testing. As CPQC test results reports were generated it became clear to the RIDOT that the previous system consisting of separate printed test results with no simple method of reference or comparison will not work with CPQC. Prior to this pilot project, the contractor did not have QC field personnel on site performing field QC. As a result, the Department did not receive any field test reports from the contractor. The only test reports that the RIDOT received were RIDOT Materials Acceptance Test reports and contractor's plant production reports. With CPQC, the contractors QC subcontractor was performing the majority of the testing and providing test results stating that the work complies with specifications. Concerns regarding the validity of the test results began to emerge. Being RIDOT's first CPQC project, the concerns were understandable. With the implementation of CPQC field-testing, it was clear that a comparison would need to be established between Owner Acceptance test results and CPQC test results in order to gage the effectiveness of the contractors QC and the validity of CPQC for this project and for future CPQC projects.

RIDOT field Materials and Construction Inspectors collaborated with ATC to compile a database consisting of Contractor performed QC results and State performed

Acceptance Test results. The data was narrowed-down to include only data collected on large-scale concrete placement operations. These placements utilize a specific type of mix known as “Mass Concrete” with mix proportions that are standard from pour to pour. There are three main specifications included in the construction contract for field measured concrete properties. These include concrete temperature, slump and air content. The significance of these properties is as follow:

- The temperature of a concrete mix affects the rate of hydration reaction which directly affects the final strength and permeability of the concrete.
- The slump test is used as a means of checking that the correct amount of water has been added to the mix. The water to cement ration largely determines the strength and durability of the concrete.
- Air content (air entrainment) is a necessary component of concrete mixtures exposed to freezing and thawing environments. The entrained air provides empty spaces within the concrete that act as reservoirs for the freezing water thereby reducing damage to the concrete due to repeated cycles of freezing and thawing.

Through the determination and dedication of our Materials, Construction and ATC field inspectors a database of all Mass Concrete placements, reporting agency Acceptance Test results and contractor QC test results for temperature, slump and air was compiled throughout the life of the project. There were two driving forces behind this initiative. First, as previously mentioned ATC was conducting significantly more testing then owner Acceptance testing. This meant that there was a significant amount of work incorporated into the project with only ATC test results testing for conformance. The RIDOT Construction and Materials personnel wanted assurance that ATC test results were reliable. The second drive behind this initiative was that both the owner and the Contractor wanted CPQC to succeed. For the very first time, RIDOT saw contractor QC personnel on site testing the material as it arrived on site and testing the placement of the material. The significant increase in testing performed by the contractor was a clear indication that CPQC works. For ATC, this was an opportunity to show a SHA that outside consultant inspection services can be used to perform project QA testing. It was a win-win situation for the owner and the contractor. Figure 21 is a field photo of RIDOT and ATC testing personnel performing test on a concrete mix.

3.5 Statistical Analysis of Database

3.5.1 Control Charts, F-Test, t-Test

The data collected for performing simple comparison of ATC test results with RIDOT's Acceptance test results was later used to perform statistical analysis testing. While working on my Master's Degree at the University of Rhode Island (URI), I had the opportunity to enroll In a course entitled Statistics ISE 513 Quality Systems. While attending this course, I had the opportunity to work with a Mr. Joseph Godino. Mr. Godino was a Senior Civil Engineer with the RIDOT and the Materials /Construction liaison at the Replacement of the Sakonnet River Bridge Project.

Figure 21 RIDOT and ATC testing personnel performing test on a concrete mix

Mr. Godino and I conducted various statistical analysis tests utilizing the database collected on this project. To evaluate the overall stability of the QC process in the production of Mass Concrete, RIDOT Acceptance and contractor QC test results for temperature, slump and air percentage were used to create Xbar ($\bar{X}$) -R Charts and Xbar ($\bar{X}$) -S charts using the statistical software Minitab 17. $\bar{X}$ - R Charts and $\bar{X}$ - S charts are variables control charts that examine the stability of the process by plotting the range, mean and standard deviation of the data over time. The $\bar{X}$ - S Chart and the $\bar{X}$ - R Charts consist of center lines that display the Mean of all the data ($\bar{\bar{X}}$), the average Range of all the data ($\bar{R}$) and the average Standard Deviation ($\bar{S}$) of all the data. The subgroup sample size of the data used for the control charts was n=6. Each point on the $\bar{X}$ - $\bar{R}$ control charts represents the average range of 6 tests. Each point on the $\overline{X}$ - $\overline{S}$ Chart represents the average standard deviation of 6 tests. The $\overline{\overline{X}}$ center line on both the $\overline{X}$ - R and $\overline{X}$ - S charts represents the mean of all the data. Above and below the center lines on both charts are the Upper Control Limit (UCL) and Lower Control Limit (LCL) lines. Control limits are based on a multiple of the standard deviation of the data. Usually the multiple is 3 and thus the limits are called 3-sigma (σ). The significance of 3σ is that it sets the process parameter at 0.27% which is the recognized and accepted rational and economical guide to minimum economic lose established by the developer of control charts, Mr. Walter A. Shewhart, an American physicist, engineer and statistician (1891 – 1967). A relationship exists between the size of the subgroup and the variation within the subgroup. Control charts factor unbiasing constants in the calculation of UCL's and LCL's to account for this expected variation due to the size of the subgroup. Table 2 shows $\overline{X}$ - S constants for n=2 through n=10 subgroup sizes. Constants A_3, B_3, B_4 and C_4 are unbiasing constants based on the size of the subgroup.

Table 2 Xbar-S Constants

N	A_3	B_3	B_4	C_4
2	2.659	0.000	3.267	0.7979
3	1.954	0.000	2.568	0.8862
4	1.628	0.000	2.266	0.9213
5	1.427	0.000	2.089	0.94
6	1.287	0.030	1.97	0.9515
7	1.182	0.118	1.882	0.9594
8	1.099	0.185	1.815	0.965
9	1.032	0.239	1.761	0.9693
10	0.975	0.284	1.716	0.9727

Sample calculation of $UCL_{\bar{X}}$ & $LCL_{\bar{X}}$ and $UCL_{\bar{S}}$ & $LCL_{\bar{S}}$ for RIDOT air % Acceptance test results.

From Figure 27 we get $\bar{\bar{X}} = 8.172$ and $\bar{S} = 1.166$.

With n=6, from Table 2 we get : $A_3 = 1.287$, $B_3 = .030$, $B_4 = 1.97$

Equations used for calculation:

$UCL_X = \bar{\bar{X}} + A_3 \bar{S}$, $LCL_X = \bar{\bar{X}} - A_3 \bar{S}$

$UCL_S = B_4 S$ $LCL_S = B_3 \bar{S}$

<u>UCL and LCL for $\bar{\bar{X}}$</u>

$$UCL_X = \bar{\bar{X}} + A_3 \bar{S}$$
$$= 8.172 + 1.287*1.166$$
$$= 9.673$$

$$LCL_X = \bar{\bar{X}} - A_3 \bar{S}$$
$$= 8.172 – 1.287*1.166$$
$$= 6.678$$

<u>UCL and LCL for $\bar{S}$</u>

$$UCL_S = B_4 S$$
$$= 1.97 * 1.166$$
$$= 2.297$$

$$LCL_S = B_3 \bar{S}$$
$$= .030 * 1.166$$
$$= .035$$

Calculated UCLs and LCLs for $\bar{\bar{X}}$ and $\bar{S}$ match UCLs and LCLs produced by Minitab output on Figure 27.

Figures 22 through Figure 27 represent the Xbar-R and Xbar-S Control Charts for RIDOT Acceptance Test results. Figures 28 through Figure 33 represent the Xbar-R and Xbar-S Control Charts for the contractors QC test results. Tables 3 through Table 5 represent RIDOTs test result data used to develop Acceptance Control Charts. Tables 6 through Table 8 represent contractor QC test results data used to develop contractor QC Control Charts. The Control Charts for both agency Acceptance and contractor QC test result data for slump and air indicate that the process was in control. By examining the chart one can see that the points vary randomly around the centerline (mean), there are no trends or patterns present and the points are within the control limits. This indicates that the variability of our test samples is stable. The Control Charts for both agency Acceptance and contractor QC test results for temperature indicate that this property of the Mass Concrete mix was not in control. The establishment of databases of actual field QC and Acceptance Testing test results can be beneficial to the Department. This Department can utilize this information in the development of specification upper and lower control limits. A specification is only as good as the ability to produce the product within the specification control limits consistently. A specification with parameters too difficult to attain will result in a higher cost to manufacture, resulting in higher bid cost for the item of work. Specification control limits derived from past test data with proven record of accomplishment of the ability to meet control limits with limited variability, will result in better specifications and less contract disputes/litigation associated specification requirements. The ability to establish proper control limits opens the opportunity to incorporate Percent-Within-Limit (PWL) specifications in projects. PWL specifications allow a SHA to incorporate both incentives and disincentives for material performance. With PWL Specifications, test results are plotted against a set of control limits. The amount of payment for the item of work, incentive or disincentive is based on where the test results fall within the limits. This creates an incentive for the contractor to produce a better quality product knowing the monetary value of good quality and the penalty for poor quality. Establishing databases provide the Department with the ability to identify and select properties of materials that are controllable. By selecting properties of materials that are controllable and have a direct affect the quality of the final product, PWL specifications can be used to encourage contractors to produce better quality products. For this study, the control charts clearly indicate that for Mass Concrete, air percentage and slump properties, are controllable and quantifiable, therefore, excellent candidates for PWL usage. Control Charts for temperature identify this property as one too difficult to control and therefore would not be a candidate for PWL usage.

In addition to developing Control Charts, Two Sample F-Test for Variances and Two Sample t-Test Assuming Equal Variances were run using the established database. The purpose of performing the tests was to evaluate how much variance exists between the agency Acceptance test results and the contractor QC test results. A sample size of 80 RIDOT Acceptance air percent test results and 80 contractor QC air percent test results were used to conduct the testing. Table 9 represents RIDOT Acceptance air test data and Table 10 represents the contractors QC air test data. With a sample size of n=80 normal distribution was assume in accordance with the central limit theorem. Table 11 represents the summary of RIDOT Acceptance test results and Contractors QC test results for the overall database established. Table 12 represents the results of the Two-Sample F-Test for Variance. All three test indicate that at a significance level of alpha (α) =0.05 the results are not statically significant. We therefore fail to reject the null hypothesis that ợ (QA air)/ ợ (QC air) = 1.

Table 13 represents the results of the Two-Sample t-Test Assuming Equal variances. The log of all RIDOT Acceptance test results and all contractors QC test results that were taken to develop the database are included in Appendix A.

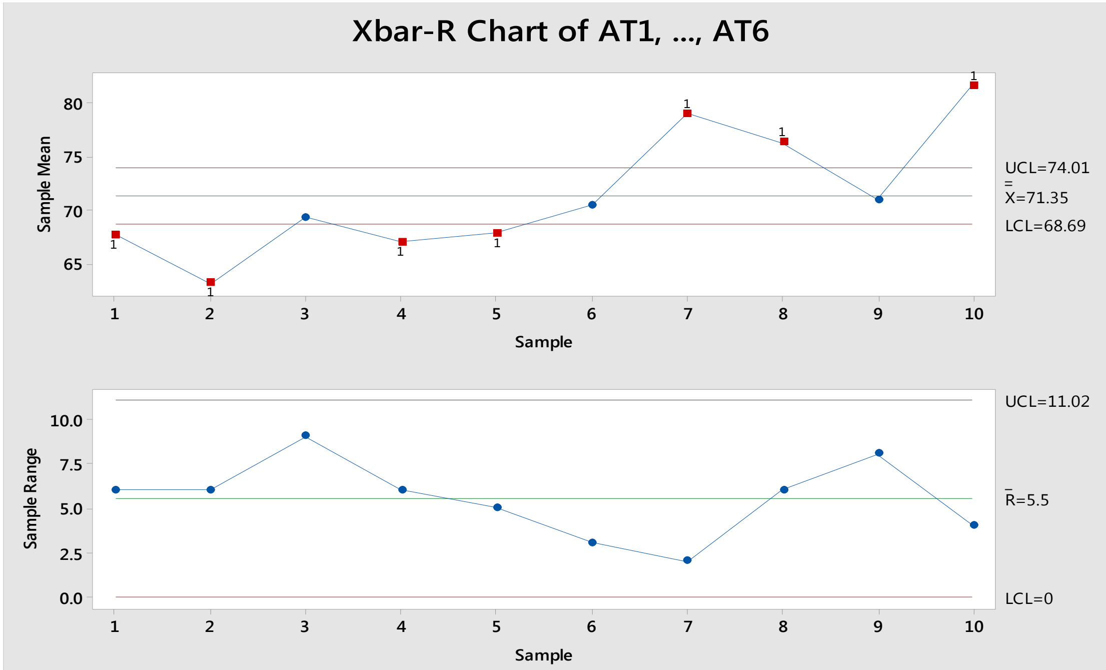

FIGURE 22 Xbar-R Chart for RIDOT Acceptance Temperature Tests

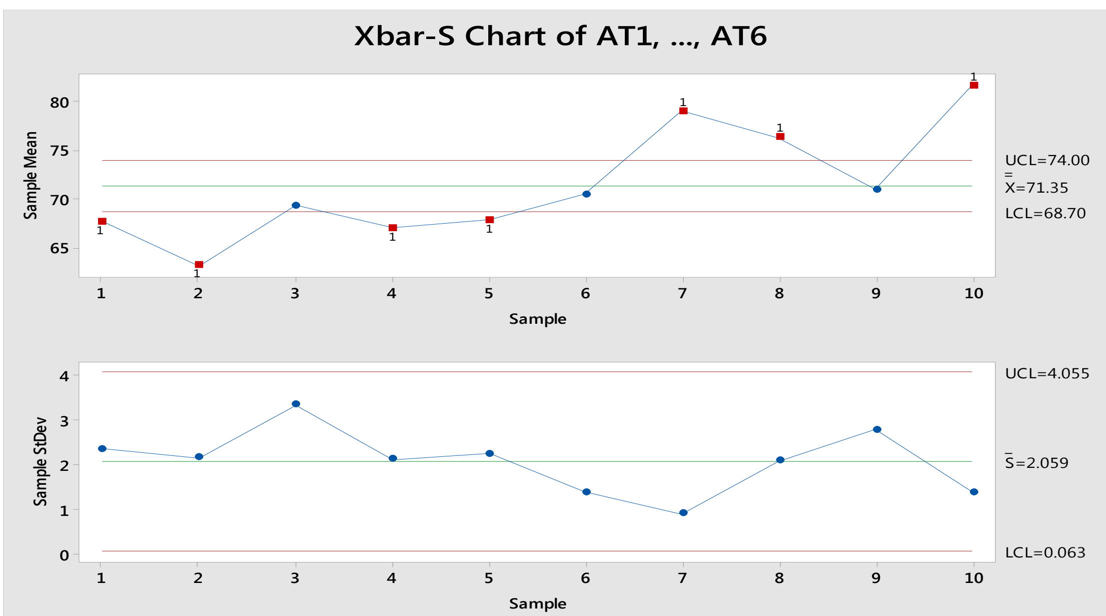

FIGURE 23 Xbar-S Chart for RIDOT Acceptance Temperature Tests

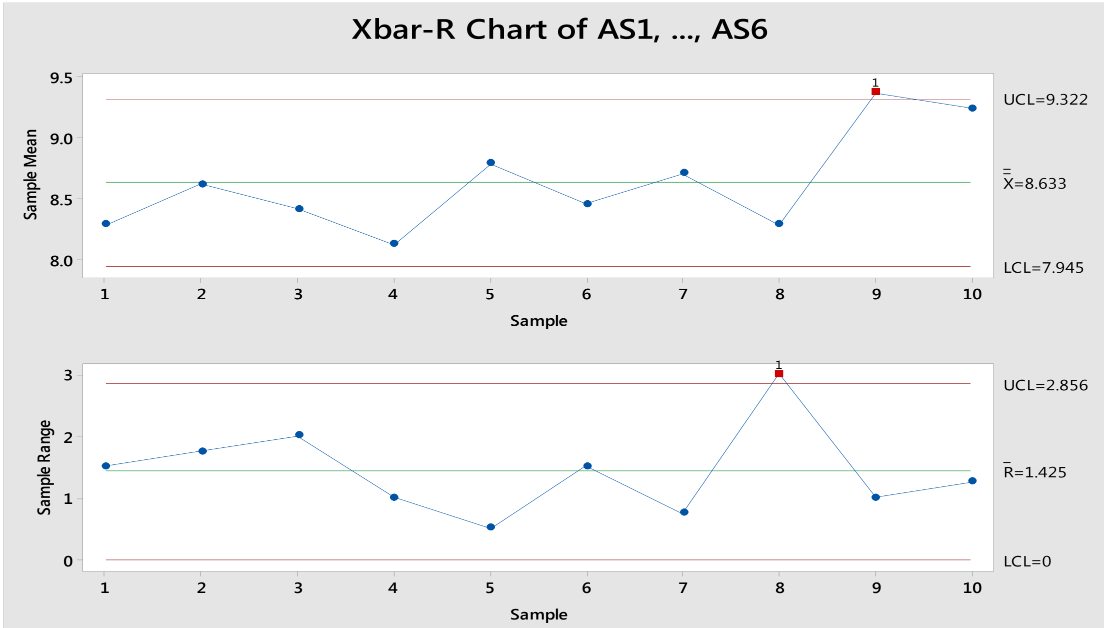

FIGURE 24 Xbar-R Chart for RIDOT Acceptance Slump Tests

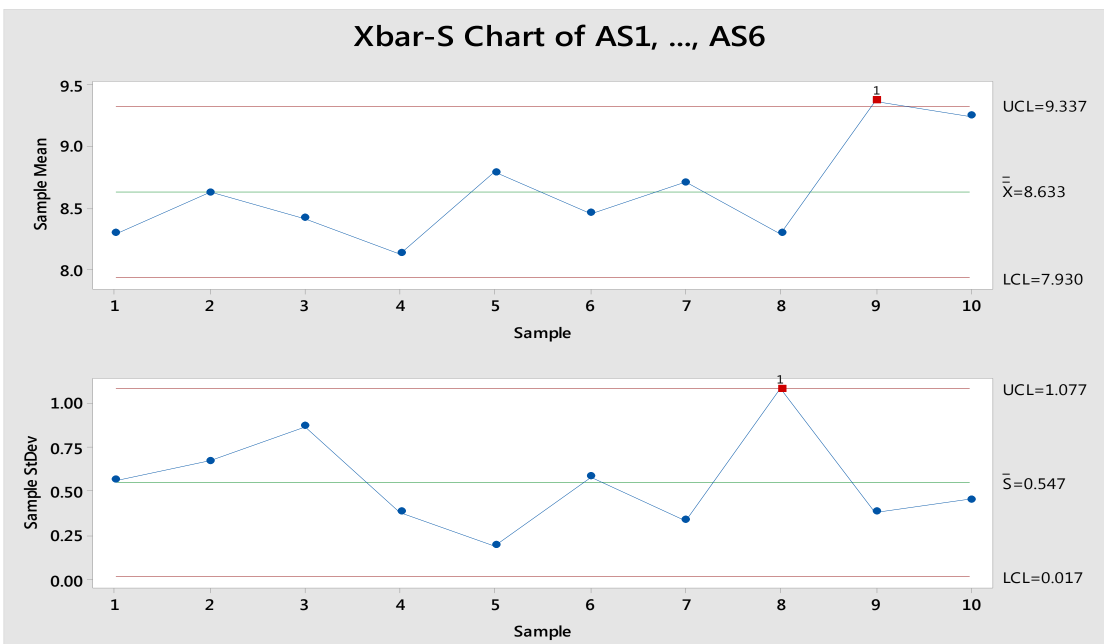

FIGURE 25 Xbar-S Chart for RIDOT Acceptance Slump Tests

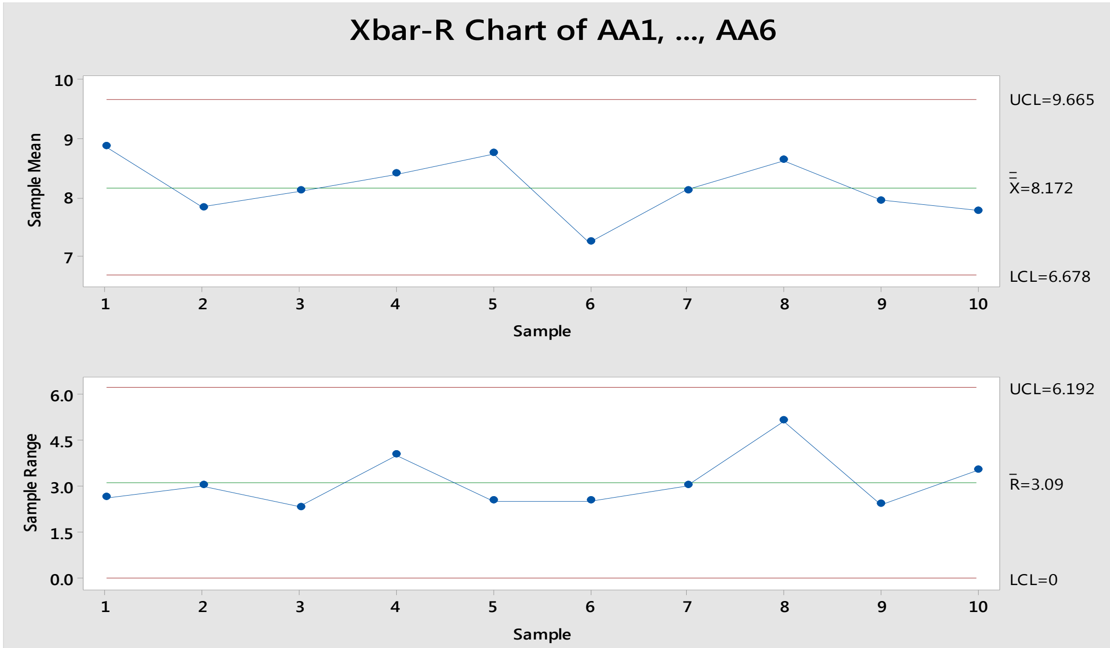

FIGURE 26 Xbar-R Chart for RIDOT Acceptance Air Tests

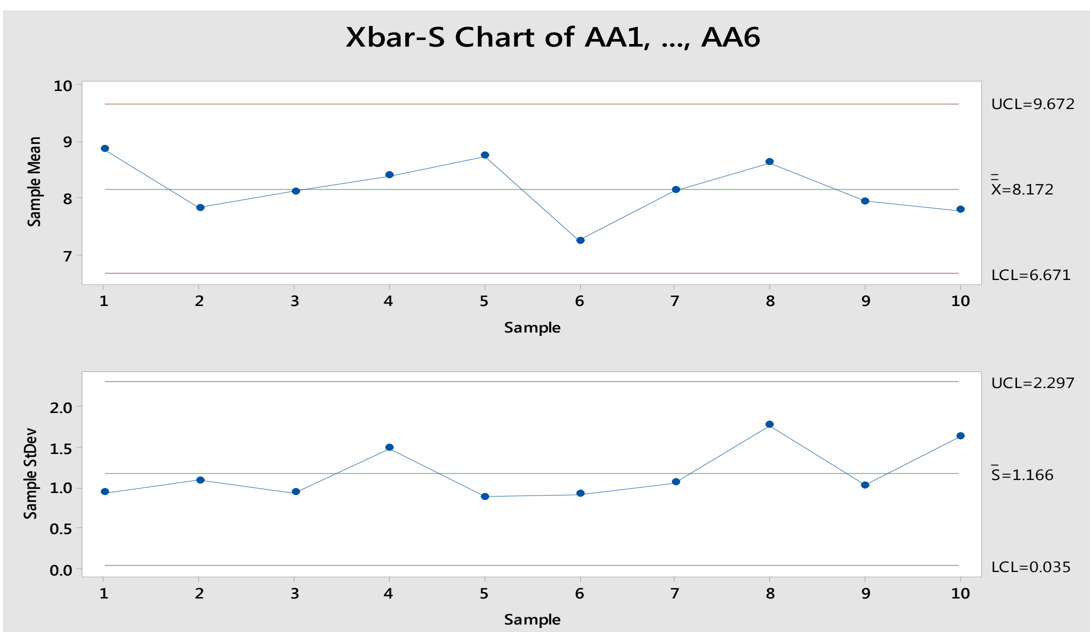

FIGURE 27 Xbar-S Chart for RIDOT Acceptance Air Tests

TABLE 3 RIDOT Acceptance Temperature Data

Acceptance Temperature Data (all pours n=6)									
Date	AT1	AT2	AT3	AT4	AT5	AT6	Xbar	Stdev	Range
4/19/10	70	68	64	66	68	70	67.667	2.338	6.000
4/27/10	67	64	63	62	61	62	63.167	2.137	6.000
5/10/10	67	64	70	73	72	70	69.333	3.327	9.000
5/18/10	68	68	70	66	66	64	67.000	2.098	6.000
6/12/10	66	66	66	68	70	71	67.833	2.229	5.000
6/17/10	69	71	70	69	72	72	70.500	1.378	3.000
8/12/10	78	78	79	80	80	79	79.000	0.894	2.000
9/17/10	74	76	75	76	80	77	76.333	2.066	6.000
6/3/11	76	68	70	70	72	70	71.000	2.757	8.000
8/1/11	79	82	82	82	83	82	81.667	1.366	4.000
							71.350	**2.059**	**5.500**
							Xbarbar	**Sbar**	**Rbar**

TABLE 4 RIDOT Acceptance Slump Data

Acceptance Slump Data (all pours n=6)									
Date	AS1	AS2	AS3	AS4	AS5	AS6	Xbar	Stdev	Range
4/19/10	8 3/4	8 1/4	8 3/4	7 1/4	8 1/2	8 1/4	8.292	0.557	1.500
4/27/10	8	9	7 3/4	9	9 1/2	8 1/2	8.625	0.666	1.750
5/10/10	7 1/2	9 1/2	9	7 1/2	9	8	8.417	0.861	2.000
5/18/10	8 1/2	8 1/4	8	8 1/2	8	7 1/2	8.125	0.379	1.000
6/12/10	8 1/2	8 3/4	8 3/4	8 3/4	9	9	8.792	0.188	0.500
6/17/10	8 3/4	8 1/4	7 1/2	8 1/4	9	9	8.458	0.579	1.500
8/12/10	9	9	8 1/4	9	8 1/2	8 1/2	8.708	0.332	0.750
9/17/10	8 3/4	9	9 1/4	8 1/4	6 1/4	8 1/4	8.292	1.077	3.000
6/3/11	9	9 1/2	9	9 1/4	10	9 1/2	9.375	0.379	1.000
8/1/11	9 1/2	9 3/4	9 1/2	9	8 1/2	9 1/4	9.250	0.447	1.250
							8.633	**0.547**	**1.425**
							Xbarbar	**Sbar**	**Rbar**

TABLE 5 RIDOT Acceptance Air Data

Acceptance Air Content Data (all pours n=6)									
Date	AA1	AA2	AA3	AA4	AA5	AA6	Xbar	Stdev	Range
4/19/10	10.7	8.5	8.1	8.7	8.8	8.4	8.867	0.931	2.600
4/27/10	9.8	8.0	8.0	7.4	7.0	6.8	7.833	1.084	3.000
5/10/10	9.5	7.4	7.6	9.0	7.2	8.0	8.117	0.930	2.300
5/18/10	9.5	7.4	10.0	6.0	9.0	8.5	8.400	1.476	4.000
6/12/10	9.5	9.0	9.0	9.0	7.0	9.0	8.750	0.880	2.500
6/17/10	6.4	7.6	8.5	7.6	7.4	6.0	7.250	0.907	2.500
8/12/10	10.0	7.0	8.5	7.4	8.0	7.9	8.133	1.050	3.000
9/17/10	9.5	9.5	5.9	8.0	11.0	7.9	8.633	1.761	5.100
6/3/11	8.5	9.2	8.8	6.8	7.5	6.9	7.950	1.021	2.400
8/1/11	9.0	6.2	6.8	6.0	9.5	9.2	7.783	1.618	3.500
							8.172	**1.166**	**3.090**
							Xbarbar	**Sbar**	**Rbar**

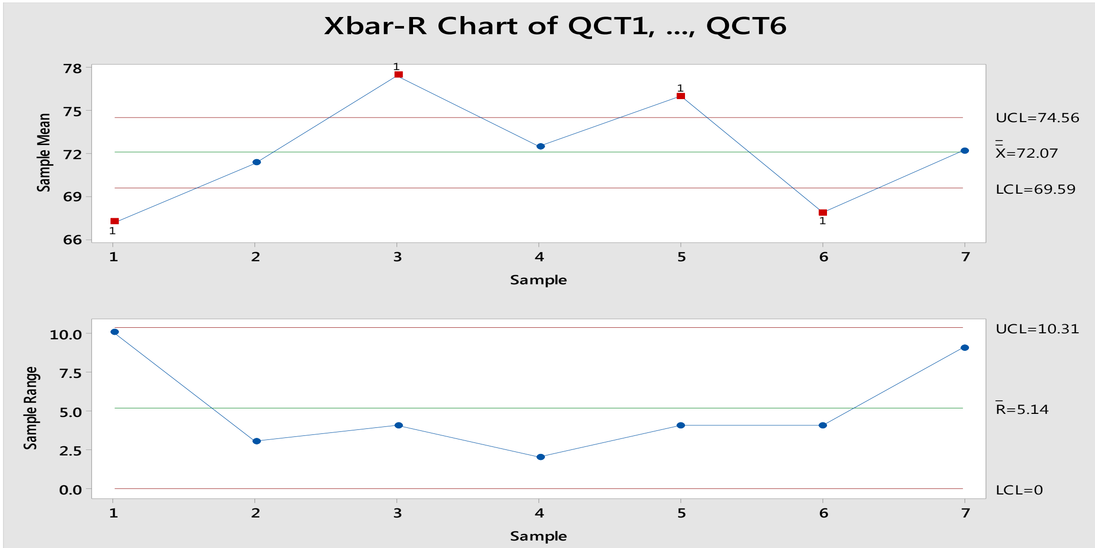

FIGURE 28 Xbar-R Chart Contractor QC Temperature Tests

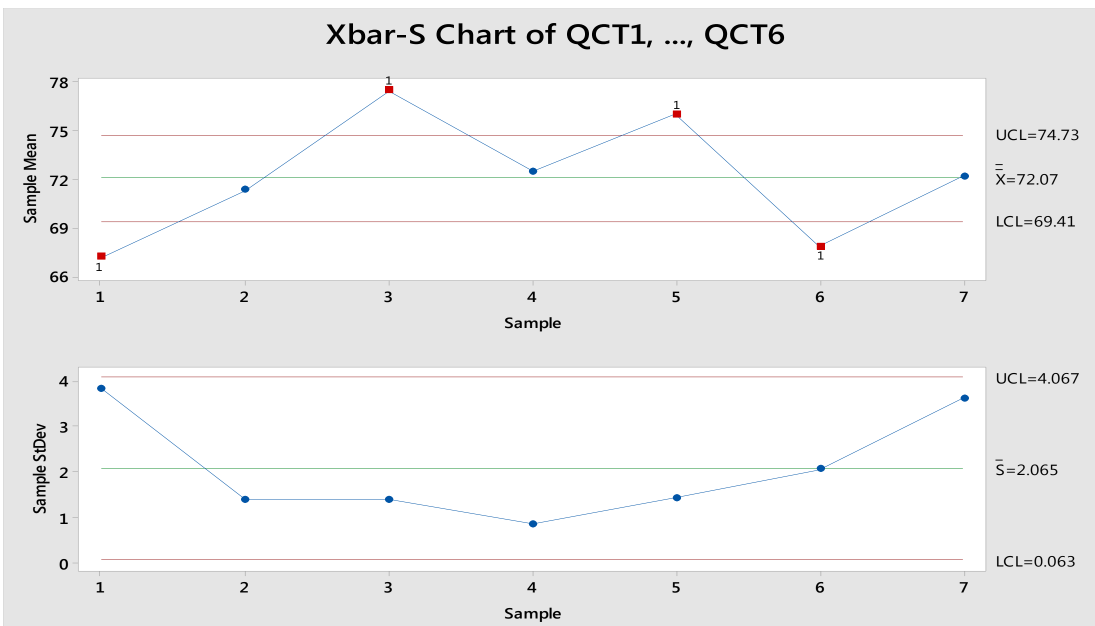

FIGURE 29 Xbar-S Chart Contractor QC Temperature Tests

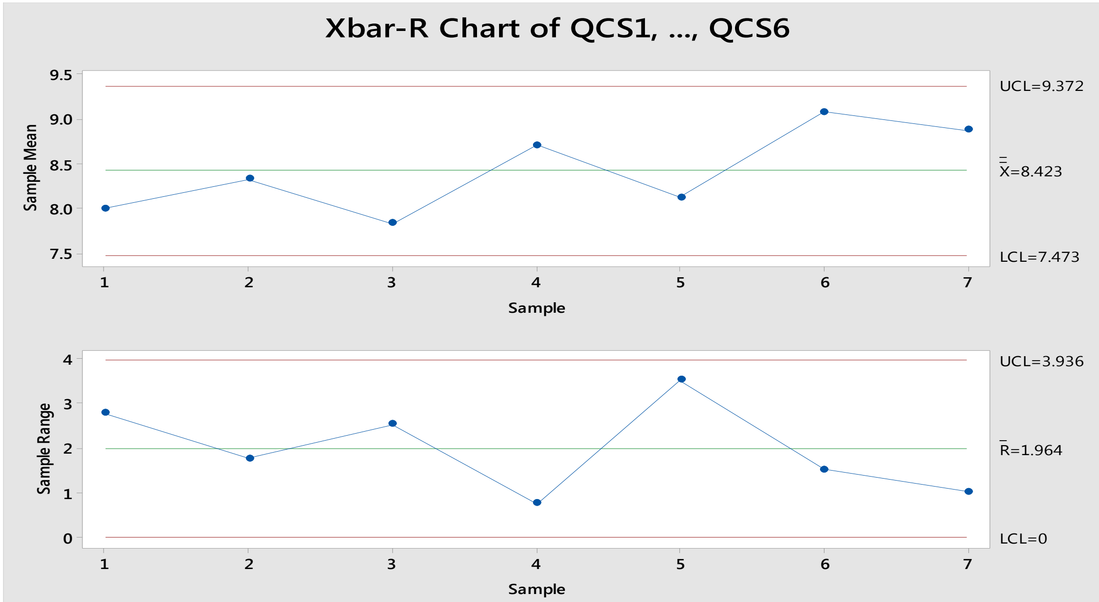

FIGURE 30 Xbar-R Chart Contractor QC Slump Tests

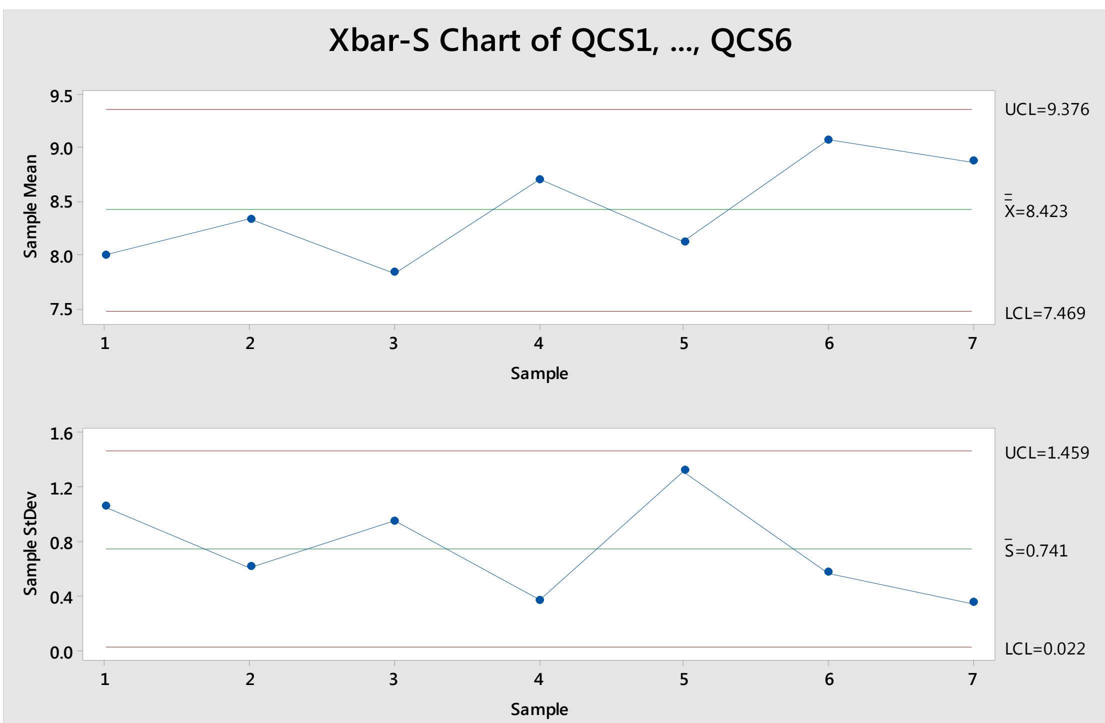

FIGURE 31 Xbar-S Chart Contractor QC Slump Tests

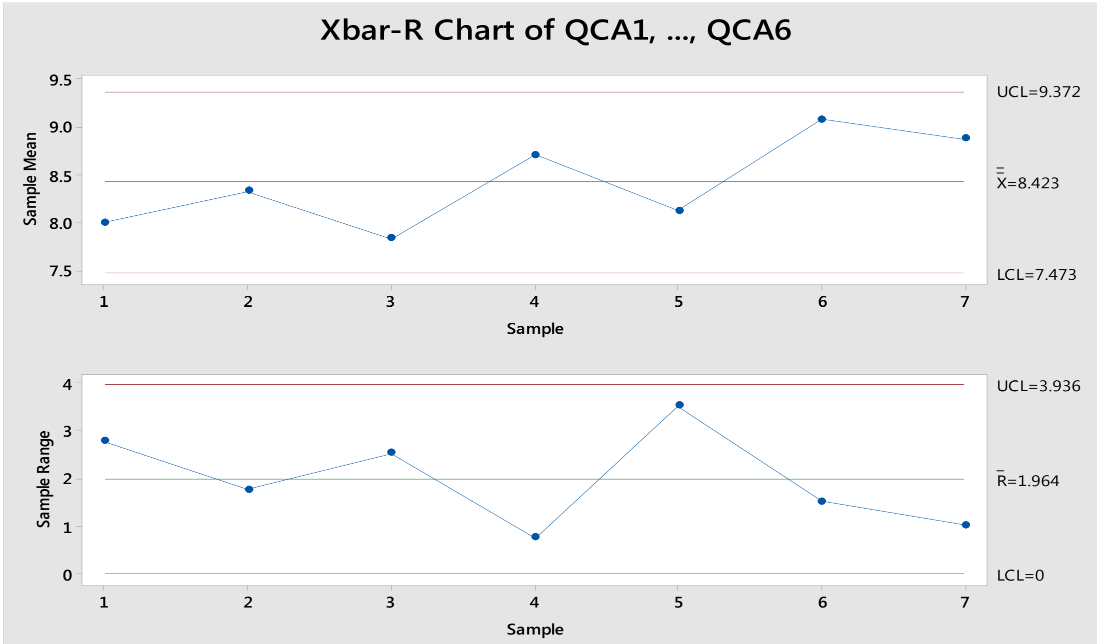

FIGURE 32 Xbar-R Chart Contractor QC Air Tests

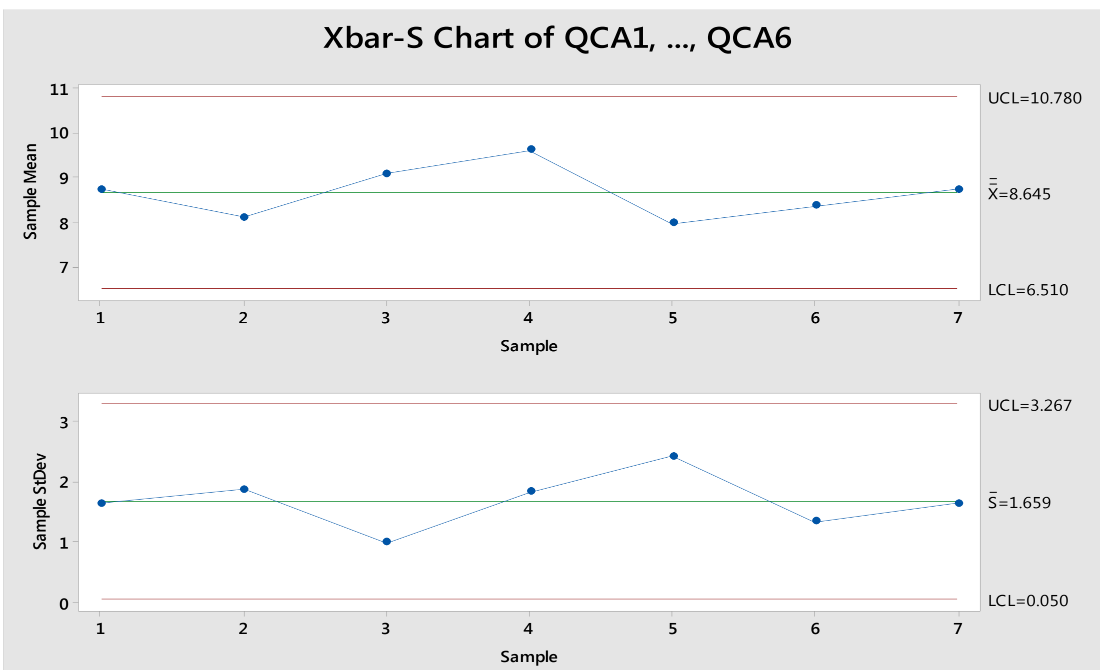

FIGURE 33 Xbar-S Chart Contractor QC Air Tests

TABLE 6 Contractor Quality Control Temperature Data

Quality Control Temperature Data (all pours n=6)									
Date	QCT1	QCT2	QCT3	QCT4	QCT5	QCT6	Xbar	Stdev	Range
4/6/10	60	66	68	70	69	70	67.167	3.817	10.000
6/12/10	70	70	71	71	73	73	71.333	1.366	3.000
6/26/10	77	77	76	77	78	80	77.500	1.378	4.000
7/30/10	71	73	73	73	73	72	72.500	0.837	2.000
9/14/10	75	76	74	76	77	78	76.000	1.414	4.000
6/13/10	70	66	66	66	69	70	67.833	2.041	4.000
6/25/10	70	68	70	72	76	77	72.167	3.601	9.000
							72.071	**2.065**	**5.143**
							Xbarbar	**Sbar**	**Rbar**

TABLE 7 Contractor Quality Control Slump Data

Quality Control Slump Data (all pours Acceptance n=6)									
Date	QCS1	QCS2	QCS3	QCS4	QCS5	QCS6	Xbar	Stdev	Range
4/6/10	8 1/4	8 3/4	6	7 3/4	8 1/2	8 3/4	8.000	1.049	2.750
6/12/10	7 1/4	8 1/4	8 3/4	8 1/4	9	8 1/2	8.333	0.606	1.750
6/26/10	6 1/4	7 1/2	7 1/2	8 1/2	8 3/4	8 1/2	7.833	0.944	2.500
7/30/10	9	8 1/4	8 1/4	8 3/4	9	9	8.708	0.368	0.750
9/14/10	5 1/2	8 3/4	8 3/4	9	8 1/2	8 1/4	8.125	1.311	3.500
6/13/10	8 3/4	10	9 1/2	8 3/4	8 1/2	9	9.083	0.563	1.500
6/25/10	9	9	9 1/4	8 1/4	9	8 3/4	8.875	0.345	1.000
							8.423	**0.741**	**1.964**
							Xbarbar	**Sbar**	**Rbar**

Table 8 Contractor Quality Control Air Data

Quality Control Air Content Data (all pours n=6)									
Date	QCA1	QCA2	QCA3	QCA4	QCA5	QCA6	Xbar	Stdev	Range
4/6/10	11.0	7.0	10.5	8.0	8.0	7.8	8.717	1.625	4.000
6/12/10	5.0	10.0	10.0	8.0	8.0	7.6	8.100	1.849	5.000
6/26/10	10.5	10.0	9.0	8.2	8.2	8.5	9.067	0.975	2.300
7/30/10	6.2	11.0	10.6	10.8	10.0	9.0	9.600	1.815	4.800
9/14/10	4.5	6.4	7.9	7.8	10.2	11.0	7.967	2.396	6.500
6/13/10	11.0	7.8	7.4	8.2	8.0	7.7	8.350	1.326	3.600
6/25/10	10.0	10.5	8.2	7.4	6.8	8.0	8.483	1.462	3.700
							8.612	**1.636**	**4.271**
							Xbarbar	**Sbar**	**Rbar**

TABLE 9 RIDOT Acceptance Air Test Data For F-Test and t-Test

4.4	5.8	8.6	6.0	8.1	9.5	9.0	10
5.0	4.5	8.5	7.2	8.7	7.4	8.5	9.5
4.5	7.0	6.0	7.1	8.8	7.6	7.9	7.8
5.0	5.1	7.2	10.5	8.4	9.0	7.1	10.5
5.2	8.1	6.0	7.6	9.8	7.2	7.8	9.0
5.2	8.0	7.2	8.5	8.0	8.0	9.7	8.5
4.0	5.3	8.7	7.2	8.0	9.5	9.0	4.9
4.0	5.6	8.5	7.4	7.4	7.4	8.5	7.3
4.0	8.5	7.0	10.7	7.0	10	6.0	5.0
8.5	10	7.6	8.5	6.8	6.0	7.2	5.5

TABLE 10 Contractor QC Air Test Data for F-Test and t-Test

5.0	5.3	12	6.0	8.0	9.5	8.1	8.0
6.8	7.8	8.0	7.8	7.8	8.9	7.0	8.4
6.4	8.0	7.5	7.8	8.6	10	6.6	8.5
6.4	5.2	8.1	9.0	8.6	9.7	7.0	8.5
7.0	9.0	8.1	8.7	8.0	8.0	7.8	8.1
8.6	5.0	6.1	7.6	9.7	9.1	9.0	7.0
3.5	7.4	8.6	11	10.8	9.0	8.0	7.2
4.5	7.8	8.5	7.0	9.0	10.8	8.2	7.0
9.0	6.8	7.4	10.5	8.3	7.8	7.4	5.5
6.6	9.0	6.1	8.0	9.7	8.0	9.2	8.1

TABLE 11 Summary of Owner Acceptance and Contractor QC Test Results

Summary Statistics	Owner Acceptance			Quality Control		
	Temp.	Slump	Air	Temp.	Slump	Air
Average	71.492	8.465	8.192	73.424	8.310	8.455
Varience	45.151	1.074	2.484	41.427	1.131	2.244
Standard Deviation	6.719	1.036	1.576	6.436	1.064	1.498
n (total samples)	301	304	306	433	461	451
N (population total)	1294	1294	1294	1294	1294	1294

TABLE 12 Two-Sample F-Test For Variances

F-Test Two-Sample for Variances		
Null hypothesis	ơ(QA air) / ơ(QC air) = 1	
Alternative hypothesis	ơ(QA air) / ơ(QC air) ≠ 1	
Signficance Level	α = .05	
	Contractor QC Results	*RIDOT QA Results*
Mean	7.437	7.913
Variance	2.917	2.254
Observations	80	80
df	79	79
F	1.293	
P(F<=f) one-tail	0.127	
P(F<=f) two-tail	0.254	
F Critical one-tail	1.451	
An F statistic greater than the ctritical value is equivalent to a p-value less than alpha (α) and both mean that you need to reject the null hypothesis.		
Since our F value is less then F Critical and our p-value is greater than alpha, we fail to reject the null hypothesis.		

TABLE 13 Two Equal Variances Sample t-Test Assuming

t-Test: Two-Sample Assuming Equal Variances		
Null hypothesis	ơ(QA air) / ơ(QC air) = 1	
Alternative Htpothesis	ơ(QA air) / ơ(QC air) ≠ 1	
Significance level	α = .05	
	Contractor QC Results	*RIDOT QA Results*
Mean	7.437	7.913
Variance	2.917	2.254
Observations	80	80
Pooled Variance	2.585	
Hypothesized Mean Difference	0	
df	158	
t Stat	-1.858	
P(T<=t) one-tail	0.032	
t Critical one-tail	1.654	
P(T<=t) two-tail	0.065	
t Critical two-tail	1.975	
Since t statistic is less than t Critical and P two tail is greater than alpha α we fail to reject reject the null hypothesis		

3-6 Findings from the Sakonnet River Bridge Project

RIDOT's first venture into the use of CPQC at the Sakonnet River Bridge Project proved to be an overall success and has served as a model for the implementation of CPQC on several major projects including; The Pawtucket River Bridge (Bridge 550), The Providence Viaduct Bridge Project, and most recently the Appanoug Circulator Project. The following are the findings from the critical evaluation of CPQC at the Sakonnet River Bridge:

- Outside consultant, require a lead-time to become familiar with agency procedures and policies. A good QC Plan provides the necessary documentation and information but one-on-one training will expedite the learning process. RIDOT Inspectors met with the contractor's QC consultant inspectors to discuss procedures and practices and exchange forms that are required to meet RIDOT Procedure of Uniform Record Keeping Manual (PURK).
- Everyone involved on the project had a thorough understanding of the QC Plan. Without this understanding and implementation of the Plan, CPQC would not have succeeded.
- Any changes or modifications to the QC Plan had to go through as a change to the contract. This gave the QC Plan the contractual enforcement authority required.
- Communication between the Contractor and RIDOT was essential on a project of this magnitude. The daily meeting with the RIDOT field personnel and the contractor proved invaluable.

- This project brought to light the fact that a project without CPQC is a project without onsite QC. The implementation of CPQC resulted in a significant increase in field-testing of materials and placements. With RIDOT Materials Inspectors strictly performing Acceptance Testing, RIDOT field inspectors began to question the contractor QC test results. What occurred on this project was that RIDOT Construction Inspectors were seeing a lot of work unfolding before their eyes with nothing but Contractor QC test results to support the quality of the work. This was new to RIDOT personnel and as a result, they needed validation of the contractor's QC data. What RIDOT was seeing for the first time was the benefits derived with the shifting of QC responsibility from the owner to the contractor.
- Responses from the questionnaire sent to STAs and the concern with the contractor's QC test results on this project clearly indicate that a lack of trust still exist between the SHAs and the contractor. RIDOT experienced this first hand on this project. RIDOT also found a way to resolve this issue. Through the developing of a database of contractor QC and RIDOT Acceptance Test results, comparison of contractor and agency testing was possible.
- The development of this database proved to be more valuable than simple contractor and agency test comparisons. Through the statistical analysis of this database the Department learned that basic statistical testing, such as the development of Xbar-R and Xbar-S control charts can be used in future projects to monitor the stability and compliance of CPQC test results. The control charts also provide the Department with valuable information for the development of

specification control limits which in turn can be used in the development of standard specifications and Percent-Within-Limits specifications. Additional statistical test, such as F-Test, can validate CPQC test results. Once the Department has confidence in the validation of CPQC test results then, as permitted by 23 CFR 637B Final Rule, CPQC test results can be used to supplement agency Acceptance Testing.

- Partnering played a significant role to the overall success of this project. At the very first partnering meeting, it was established that upper management would allow and support a field-level-decision-making practice. RIDOT and the contractor took the position that they would work as a team, to help each other, accomplish the common goal of constructing a quality project. This dedication and commitment to teamwork was the foundation to the overall success of this project.

The use of CPQC on the Sakonnet River Bridge Project proved to be a success. There is no doubt that the significant increase in field-testing performed on the Sakonnet River Bridge, because of the implementation of CPQC, improved the overall quality of the work on this project. From this pilot project, we learned that the transfer of QC from the SHA to the contractors provides the agency with many benefits and opportunities to improve the overall QA program. The following are but a few of the benefits and opportunities realized because of CPQC:

- It is the contractor with the most capabilities to control, monitor and improve the quality of his work. This is true in the production stage as well as the construction and or placement of the material.

- Because of the additional testing that is associated with CPQC the SHA can develop QC and Acceptance test result databases for use on future CPQC projects. The information can be used for monitoring and for the development of standard and PWL specifications.
- Statistical analysis of database can lead to validation procedures for CPQC test results. The ability to supplement SHA Acceptance testing with CPQC test results can help a SHA improve the efficiency and cost effectiveness of its QA program.
- The majority of a SHAs projects are not major projects. The success realized from CPQC on major projects will certainly be realized on smaller less complex projects. The key to the development and implementation of CPQC are clear and concise QC policies and requirements that remain consistent from one project to the next, regardless of size or cost of the project. It is the size and complexity of the QC plan that should vary depending on the size and complexity of the project, not the QC policies. CPQC and QC plans should be a requirement on every project, regardless of size or type of work performed. To prevent confusion and the intermingling of QC roles and responsibilities QC policies must be clear, concise and consistent from one project to the next.

References

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Rhode Island Department of Transportation, 2010 "Master Schedule of Testing Manual".

Chapter 4

RIDOT In-House Acceptance Testing verses Consultant Acceptance Testing Cost Analysis

4-1 RIDOT's Current QC and Acceptance Practices and Policies

The objective of this dissertation is to provide SHAs with recommendations on how to improve the efficiency and sustainability of its QA program. The findings from this dissertation conclude that most SHAs QA programs are founded on the three fundamental components; QC, Acceptance Testing and IA. It is in the QC and Acceptance Testing components where SHAs differ most. These two components are also the areas in which changes and the implementation of innovations can bring about the most benefits to a SHAs QA program. In addition to the research conducted for this dissertation, my 28 years of experience and observations as a Resident Engineer and Managing Engineer for the RIDOT will be included in these findings.

SHAs QC practices and policies vary from one project to another with QA programs being tailored to agencies needs and resources. The transfer of QC from the agency to the contractor is still very much in the evolutionary phase. The Sakonnet River Bridge Project was RIDOT's first venture into the implementation of CPQC. This project marked the first transfer of QC from the owner to the contractor. Since this project, RIDOT has implemented CPQC on several major projects but has not institutionalized the practice of CPQC on all of its projects. On selected projects where CPQC is implemented the QC responsibilities are clearly and contractually designated to the contractor. The contractor's QC role and responsibilities are contractual requirements, including the requirement of a quality control plan before any work can commence on the project. In other projects the designation of QC roles and responsibilities are silent. On these projects, the QC roles and responsibilities are unclear and often intermingled/shared between RIDOT and the contractor. It is common to find on projects where QC roles and responsibilities are silent that the contractors QC begins and ends at the contractor's plant. Where QC is silent, there is a general agreement/understanding that the contractor is responsible for QC and SHA is responsible for Acceptance but generally there are no QC contractual policies, procedures, QC plan or contractor field QC personnel. The contractors QC role and responsibilities begins and ends at the contractor's plant. Through Acceptance Testing RIDOT Materials Inspectors are taking on QC responsibilities. It is the SHAs Acceptance Inspectors that identify unacceptable work through the Acceptance Testing process. The contractor is notified and responsible to correct the problem. This may include removal or modification of the material. This type of practice places the burden of QC on the Agency. If the RIDOT Materials or Construction Inspectors do not detect the unacceptable material, it will remain in place. The New England Transportation Technician Certification Program Manual states under Scope of Acceptance Activities the following, "Agency personnel should ensure that the contractor is performing all Quality Control activities in accordance with the approved QC Plan. This requires that the Agency Technicians and Inspectors be thoroughly familiar with the specific provisions contained in the QC Plan and that they monitor the Contractor's QC sampling, testing and inspection activity on a regular basis throughout production and placement of construction materials"(NETTCP 2008). When the contractor does not have QC inspectors assigned to the field to monitor the placement of construction material and when there is not a project QC Plan, the contractor is simply not performing QC. As a result of the contractor not performing field QC the RIDOT Materials Inspectors and Construction Inspectors have been burden with performing testing that far exceeds the Acceptance Testing frequencies stated in RIDOTs Master Testing Schedule Manual. Acceptance test frequencies were established to provide a "spot check" on the quality of the work being incorporated into the project. Acceptance testing is to monitor the adequacy of the contractors QC effectiveness. Acceptance testing frequencies were not developed to perform QC. Without CPQC the only line of defense against the incorporation of unacceptable material into the project is RIDOT's Acceptance Inspectors and RIDOT's Construction Inspectors. In my years of service with the RIDOT, it was evident that projects without CPQC had no contractor QC inspectors on site. As a result RIDOT Acceptance Materials Inspectors were burdened with performing QC responsibilities. One common example is when RIDOT Acceptance Materials Inspectors perform Acceptance Testing for compaction of subbase material. RIDOT Acceptance Material Inspectors would use their Field Nuclear Gage Testing Equipment to test the density of the compacted material. If the contractor's compaction efforts did not result in the required material density, the RIDOT Acceptance Materials Inspectors would direct the contractor to perform additional compaction on the material. Upon completion of the additional compaction, RIDOT's Material Inspector would perform another nuclear gage density test. If the retest indicated that the material achieved the required density level, then the material was accepted. If it did not meet the required density level, the process was repeated, additional compaction and retesting. This is QC testing that imposes a staffing and financial burden on the Department and is a direct result of the lack of contractor QC. On RIDOT projects where CPQC is not a contractual requirement, there are no contractor QC inspectors with Field Nuclear Gage Testing Equipment on site to test sub-base and base material for compaction density. Without the personnel and required testing equipment how is the contractor's crew placing the gravel subbase and base for roadways, sidewalks, drainage structures, foundations and other infrastructure components assuring that the material has been compacted to specification density? RIDOT Acceptance Materials Inspectors have been and continue to be burden with performing QC testing on projects where QC is silent. This practice was evident at the Sakonnet River Bridge Project when the RIDOT field inspectors began to question the contractor's QC test results. They were accustomed to having RIDOT Acceptance Materials Inspectors performing QC and Acceptance testing. Now, with the contractor's QC inspectors performing the QC testing and RIDOT Acceptance Materials Inspectors onsite performing only Acceptance Testing, a concern over the reliability of the contractor's QC test results arose. This was a clear sign that RIDOT Acceptance Materials Inspectors were now performing Acceptance Testing and that the contractor was performing the QC testing. When asked who was responsible for QC and who was responsible for Acceptance Testing most STAs responded that the contractor is responsible for QC and the agency is responsible for Acceptance. In many STAs this is stated without any QC policies in place. Without the delegation of clear, well defined, enforceable contractual QC policies, most STAs find that field QC testing is limited to that performed by STA

Materials Inspectors under the umbrella of Acceptance Testing. By establishing CPQC on every SHA project, the plant and field-testing responsibilities associated with QC are delegated to the contractor, where they rightfully belong. SHAs can improve the efficiency and sustainability of its QA Program by requiring the contractor to perform all QC responsibilities and eliminating all RIDOT Materials testing beyond those stated in the Master Testing schedule. The additional cost, time and staffing expended on the intermingling of QC testing, negatively affects the overall efficiency and sustainability of a SHAs QA program. SHAs can reduce the overall QA cost, improve efficiency and sustainability by making the transfer of QC to the contractor through clear and contractual QC policies for "all" RIDOT projects. QC policies, practices and requirements that differ from one project to the next only create confusion to the contractor and to the state inspectors. Regardless on the type of operation or size of the project, QC needs to be contractually delegated to the contractor through policies that the contractor can follow and state inspectors can monitor. Every project from the building of a bridge to a small pavement marking operation must require a contractor QC Plan submission. It is this QC Plan that will tell RIDOT how the contractor will assure QC, both in the plant and in the field.

4-2 Implementation of CPQC Test Results for Acceptance Testing

SHAs are responsible for Acceptance Testing and IA. The policies and practices associated with these two components of RIDOT's QA Program have been evaluated to determine their efficiency and cost effectiveness. RIDOT's IA and Acceptance Inspectors consist of experienced, qualified and certified Inspectors who perform all IA and Acceptance Testing responsibilities.   There is a clear and distinct separation between IA and Acceptance roles and responsibilities. There are two ways in which IA is used by STAs. The first is the narrower context which is, to provide an independent assessment of QC and Acceptance test results. The seconder, broader view, is one where IA performs an assessment of the overall QC and Acceptance process. RIDOT's IA section performs a hybrid of these approaches. It provides an independent assessment of QC and Acceptance test results while providing an assessment of the overall QC and Acceptance process.

Per Federal Regulations, Acceptance is the SHAs responsibility. All acceptance activities must be performed by RIDOT or its designated agent, such as an outside consultant inspection service under contract with the Department. The Code of Federal Regulations 23 CFR637.207 also permits the use of CPQC test results for acceptance under specific conditions.   The number of STAs implementing the use of contractor QC test results for Acceptance is increasing. The NCHRP Questionnaire showed that of the responding STAs, more than 50% use CPQC test results for Acceptance with HMA.   The accepted use of CPQC test results to supplement Agency Acceptance testing is directly related to the material tested, level of confidence in validating the contractors QC test results and the overall level of confidence that the State has with its local contractors.   Every CPQC test result used to supplement SHA Acceptance testing, equates to one less acceptance test that the agency will need to perform. The use of CPQC test results to supplement Acceptance Testing will reduce the amount of testing now performed by SHAs. Before a SHA can implement the use of CPQC test results to supplement Acceptance Testing, the SHA must assure that the contractor has been designated all QC responsibilities. When the contractor is performing both plant and field QC testing it is then that the SHA will realize a significant increase in field materials testing. It is then that the SHA will have available the required data needed to develop validation procedures for CPQC test results. It is then that the SHA can benefit by supplementing it Acceptance Testing with CPQC test results. It is a logical process which involves assuring the complete transfer of QC from the SHA to the contractor. This must encompass all QC responsibilities, both in the plant and in the field. The SHA will then realize an increase of field testing by the contractors QC personnel. From this increase in testing the SHA can establish a database of CPQC and agency Acceptance test results. Through statistical analysis of the database a SHA can develop validation procedures for CPQC test results. Once the agency has developed confidence in the validation procedures then CPQC test results can be used to supplement agency Acceptance Testing. The findings of this research support the incremental implementation of CPQC test results to supplement RIDOT Acceptance Testing. The use of CPQC test results to supplement Acceptance Testing will reduce the amount of testing now performed by agency Materials personnel. The key to the success of the use of CPQC test results to supplement Acceptance Testing is the complete transfer of QC from the owner to the contractor and the validation of CPQC test results. SHAs can improve the overall efficiency and cost effectiveness of its QA program through the implementation of CPQC test results to supplement agency Acceptance Testing. At the time of this research, the RIDOT has not implemented the use of CPQC test results to supplement RIDOT Acceptance Testing. STAs across the country are realizing the cost benefits associated with the implementation of CPQC test results for Acceptance. RIDOT will need to consider this alternative as it faces increase workloads with reduced staff and budget constraints.

4-3 Implementation of Outside Consultant Testing Services

Many STAs are implementing outside consultant inspection services to supplement their QA programs. Responses from the NCHRP Synthesis 346 survey questionnaire reported 78% of the responding STA's implement the use of consultants within their QA programs. Agencies implement consultant inspection services for a variety of reasons, including:

- The ability to increase or decrease staffing levels to meet current workload. STA funding for infrastructure work varies from year to year. Therefore the number of projects that an agency puts out for construction also varies from year to year. No agency can afford to staff to handle peak workload periods. An agency that staffs to handle peak periods will find itself paying for employees when there is no work. The use of consultant inspection services helps provide the additional help when needed. Consultant services are hired to perform a specific task. Once the task is completed and the consultant services are no longer needed they are let go. Back in the early 1990's I worked with RIDOT in the development of a Master Price Agreement (MPA) contract for the RIDOT. It was MPA 429 "Temporary Inspection Services". The goal of this MPA was to fill the void of Construction Inspectors required during RIDOT's peak construction period between May and October. At the time there were those who opposed this MPA. Their position was that the

Department should hire more inspectors. The department realized that once hired, a DOT employee can remain a DOT employee for his or her entire career, regardless of workload. This was not a viable option to meet peak period demands. The ability to implement inspectors when needed and as needed was just one of the benefits derived from this MPA. Another benefit was the significant reduction in overtime cost through the use of temporary inspectors for night time operations. For the past 10-15 years RIDOT has been increasing the amount of night time construction projects. Night time operations reduce congestion and mitigate traffic delays caused by work zones. RIDOT inspectors have an established work shift, typically 7:00AM – 3:30PM. Work outside of the regular work schedule results in overtime cost to the Department. As a result most night time construction operations were covered by inspectors on an overtime basis. This MPA provided night time inspection services for the Department without incurring overtime cost.

- To acquire expertize that the Department is lacking. RIDOT is very familiar with this practice. For the Sakonnet River Bridge Project RIDOT implemented several specialty consultant services such as underwater inspectors, Wave Equation Analysis Program (WEAP) specialist, Steel weld specialist and various other services.
- To meet schedule constrains. A Department will generally have projects where schedules are critical. A project must be started and completed within a specified time frame. If the Department does not have the staff to design and manage the project delays or postponements will occur. Projects that do not go

out for construction at their proposed scheduled times will result in additional cost to the Department. This may be due to escalation cost or cost associated with Right-of-Ways and property agreements. When additional help is needed to get a project out on time or to meet a peak demand period, from an administrative viewpoint, a consultant can hire more help much faster than a government agency can negotiate a contract or hire more staff.

- To bring innovation and quality. The goal of every STA is to serve the public. The consultant's goal is to survive in a competitive environment and make a profit. To do so the consultant must remain strong, lean and on the cutting edge. Consultants compete to stay in business. They need to be the best in their game. To do so they hire and fire and keep only the very best. SHAs operate in very significantly different manner. A SHA decisions cannot simply be based on cost. A SHA is primary goal is to serve the public. A SHAs hiring and retaining of employees practices is also significantly different from that of the private sector. RIDOT hires full time employees with pre-established pay level step increments. One common complaint often heard from State workers is they have reached their top step pay grade level. This typically occurs when an employee has been with the State over ten (10) years. Once an employee reaches this pay grade level the only pay increases that the employee will see are those increases that all state workers receive when their union contracts are renegotiated every 2 to 3 years. This type of system does not provide any motivation or incentive for an employee to excel at his position. Consultant employees know that their employment is directly related to their abilities, skills, qualifications, dedication to the company and their wiliness to work. Both the consultant inspection service and its inspectors want to bring innovation and quality to a project to assure future work from the Department of Transportation. If they cannot perform the work at a competitive price and deliver quality work, they will not survive in the business.

There are many reasons why both STAs and general construction contractors are supplementing their own staffs with outside consultant services. One deciding factor in the decision of performing the work in-house or outsourcing is cost. SHAs are implementing various strategies and innovations seeking the most cost effective means of performing QA testing. This dissertation will sought to provide the RIDOT with information on whether the implementation of outside consultant inspection services to supplement RIDOT's QA staff can reduce cost, improve efficiency and sustainability of the overall QA program. A Cost analysis of RIDOT in-house Acceptance Testing verses consultant inspection service Acceptance Testing will be conducted in this dissertation to find answers to these questions.

Studies of the outsourcing of engineering services, including but not limited to design, QC and Acceptance testing, have been carried out since the early 1980's, and continue to be undertaken up to the present day. A literature review, of early and recent studies, was conducted to identifying procedures and methodologies used to perform the cost effectiveness analysis in these studies. The findings of this research can best be summarized by a statement included in a study conducted by the Caltrans Division of Research and Innovation in 2011, "Comparing In-House Staff and Consultant Cost for Highway Design and Construction". This report conducted an independent study of the cost and benefits of hiring consultants to address temporary increases in workload. The findings are summarized as follow, "We did not find a wealth of recent research that attempts to provide a quantitative analysis of costs. Questions of validity appear throughout the literature discussing cost comparison methods and models, and there appears to be no definitive methodology used to generate accurate and comprehensive cost comparisons. While the literature contains frequent references to overhead costs as one of the most problematic elements of the cost comparison question, we did not uncover a solution to this problem. Properly accounting for the long-term cost implications of contracting out work or performing it in-house is another area that appears to require further examination." (Caltrans 2011). There is no shortage of published studies and reports conducted to quantify the cost-effectiveness of in-house verses outsourcing. Various approaches and strategies have been implemented to accomplish this goal but no single approach appears as the tool or model that defines whether outsourcing is cost effective. There are studies that support both sides of the argument. An interesting observation to note is that state DOT sponsored studies conclude that outsourcing cost more than in house. Whereas, studies conducted and commissioned by trade associations conclude that the use of consultants is more cost-effective. This leaves to suspect the bias in the performance of some of these cost analysis studies. This research sought to identify the methodology used to perform the cost analysis for both State sponsored studies and trade association sponsored studies. Though the studies provided more of a personal proprietary account of how the analysis was performed rather than a quantitative methodological approach two types of analysis approaches were used, in various combinations, in many of the studies. First was the "Direct/Current Cost" approach. This approach uses current cost for cost comparison of in-house verses consultant. This approach appears to be a simple comparison in which the cost of in-house labor, equipment and overhead are compared to the cost of consultant's labor, equipment and overhead cost. The difficulties with this approach were best stated in writing in Infrastructure Outsourcing: Leveraging Concrete, Steel, and Asphalt with Public-Private Partnerships which stated, "It is not difficult to determine the cost of consultants—it is simply the amount paid—the cost of an in-house project depends on accurate recording of time spent on the project, the estimation of overhead, and the accounting of the cost of activities associated with the project (travel and subsistence, materials, supplies, and lab tests). Time sheets are not often a priority in state departments, and since many state employees are required to work on multiple tasks simultaneously, the record of time allocation is not very accurate."(Moore et….2008). Most STA's cannot accurately establish a project overhead cost. Another fault of this approach it that it does not take into account any long-term cost associated with performing the work in-house or outsourcing the work.

The second approach, referred to as the "Life Cycle " approach takes the "Direct Cost" approach one-step further and includes long-term cost in the analysis. The "Life Cycle" approach is a more logical approach to use when performing a cost effectiveness analysis between a STA and an outside consultant because the STA cost associated with labor, equipment and overhead continue to accrue for as long as these resources remain with the STA. With outside consultants, once the work for which they were hired for is completed, all consultant cost end. There is no long-term cost with outside consulting. There are many difficulties in conducting an accurate cost effectiveness analysis between a STA and a private consultant service. The following are major difficulties and challenges reported from case studies and encountered in the development of a cost effectiveness analysis for the RIDOT:

- When you compare a STA to a private consultant service, you are comparing two very different entities with very different goals. The RIDOT primarily goal is to serve the public. Though it strives to operate in a cost efficient manner profit is not a STA primary objective. The primary goal of any business is to make money and survive in a competitive environment. STAs hiring practices and policies are significantly different from that of a business. Businesses hire and retain employees based on current available workload. In the private world when the workload does not justify the staffing, employees lose jobs. STA funding levels vary from one year to the next. As a result the numbers of projects that go out for construction also vary from one year to the next. RIDOT does not lay-off employees when the workload is low. This is not a factor that is accounted for in any cost analysis methodology.
- STA overhead costs are difficult to calculate. The overhead cost rates vary significantly from one STA to another. RIDOT Materials and Construction Inspectors are often assigned to multiple projects. It is difficult for the agency to assure that the inspectors are accurately charging time to every project that they work on. This overhead calculation becomes more complicated when accounting for office and supervisory personnel time. From the studies conducted, the ability to report accurate and reproducible overhead cost was

the most reported concern when validating analysis. Regarding the validation and methodology used by STAs to calculate overhead cost NCHRP Synthesis 313 findings reported the following; “The studies reviewed for this synthesis include many attempts to ascertain the true value of the overhead burden borne by the state DOTs to make a fair and appropriate comparison of costs. There are differences of opinion about how to account for these costs. In addition, questions arise concerning utilization rates, how to account for non-project-related time for state employees in overhead, which management expenses can be distributed to projects by means of indirect overhead charges, proper accounting of insurance, utility and building expenses, and a variety of other factors. Ultimately, little agreement exists on these approaches, nor does any single approach surface as the defining model for this report.”(National Cooperative Highway Research Program 2003). The true cost of in-house engineering and QA testing is difficult to accurately establish due to the inability to accurately establish overhead cost associated with these tasks.

- The ability to reduce overtime on STA projects because of consultant inspection services if not accounted for in most cost effectiveness studies.

  For the past 10-15 years RIDOT has been increasing the amount of night time construction projects that go out for construction. Night time operations reduce congestion and mitigate traffic delays caused by work zones. RIDOT inspectors have an established work shift, typically 7:00AM – 3:30PM. As a result most night time and operations outside of the regular work schedule hours are covered by RIDOT inspectors on an overtime basis. Consultant

Inspection Services can provide inspectors for night shift operations without incurring overtime cost. Consultants have the geographical mix and leverage to operate multi-shift environments. This ability to reduce overtime with consultant inspectors is not captured in cost analysis studies because most agencies to not keep accurate timekeeping records.

- Determining the actual cost associated with consultant oversight is unreliable. STA's cannot report accurate cost associated with consultant oversight. The cost of consultant oversight varies from one STA agency to another and from one operation to another within the same agency. The studies indicate that the experience and relationship that the agency has with the consultant and the type of service being contracted, are main factors in determining consultant oversight cost. Management practices will significantly affect the cost associated with consultant oversight. An audit conducted for the North Carolina DOT reported "The time management system in place does not accurately capture employee time spent supervising consultant contracts. Therefore, we cannot accurately identify consultant supervision costs" (Renfrow 1992).
- STAs do not keep accurate records of consultant work and therefore they cannot accurately report actual consultant cost. The lack of accurate records prevents the accurate analysis of whether outsourcing is cost effective. Whether Current Cost or the Life Cycle approaches are used, accurate records are required to make a valid case on the cost effectiveness of outsourcing. A 1998 audit performed for the Virginia DOT (VDOT) noted that, "Despite the

fact that consultants are an increasingly significant mechanism through which VDOT accomplishes its work, the department does not adequately maintain and track meaningful consultant data to enable it to make sound decisions on consultant use. Without such management system in place, VDOT is in no position to determine the effectiveness of outsourcing. (Virginia Department of Transportation 1998).

Section 4-4 In-House verses Outside Consultant Testing Services Cost Analysis

The findings of this dissertation indicate that neither the “Direct” nor the “Life Cycle” approaches can account all the factors that affect the outcome in a cost analysis of outsourcing verses performing the work in-house. The research also supports the fact that the accuracy of the data used in either approach will significantly affect the outcome. To conduct a cost analysis of RIDOT’s in-house Acceptance Testing verses consultant engineering testing services the “Life Cycle “approach was selected because it includes long-term cost in the analysis. A cost analysis between a public agency, such as a STA and a private business, such as a consultant engineering testing service must take into consideration long-term cost. To assure the accuracy and validity of the data used for this analysis the data will be received directly from the RIDOT, the consultants engineering testing firms and through reputable RI State government web sites. Fiscal year 2015 was selected for the cost analysis because 2015 salary data was available for RIDOT Materials Inspectors and Six (6) Consultant Inspection Engineering firms. Table 14 represents the 2015 & 2016 hourly rates submitted by six (6) consultant engineering firms to perform Materials Inspection Services under MPA Contract 429 “Temporary Inspection Services”. The contractual qualifications for Level II inspectors provided by the engineering firms are equivalent to the qualifications and certifications of RIDOT's Tech III Materials Inspectors. It is for this reason that the cost analysis will be a confined to Level 2 Consultant Materials Inspectors and RIDOT Tech III Materials Inspectors. This dissertation will also include cost information for RIDOT Tech IV Materials Inspectors and for Consultant Engineering Level I Inspectors. This information is solely for informational purposes. Since the greater portion of Acceptance Testing is performed by RIDOT Tech III Materials Inspectors the analysis will be restricted to RIDOT Tech III Inspectors and Consultant Engineering Level 2 Inspectors. Out of the six (6) Engineering firms that submitted hourly rates for RIDOT MPA 429 "Temporary Inspection Services" only five (5) submitted rates for the Level 2 Materials Inspector. The consultant hourly rates submitted for Materials Inspectors Level 2 were $77.33, $73.00, $80.00, $75.75 and $45.00. The rate of $45.00/hour appears to be an outlier and therefore will not be included in the cost analysis. The calculated average hourly rate for a consultant Level 2 Materials Inspectors was $76.78. Table 15 represents the consultant's average hourly rate summary. To verify the validity of the rates submitted for the Level 2 Material Inspectors I compare the rates to a current project with CPQC, the Providence Viaduct Bridge Project, which started in April 2013 and scheduled for completion in September 2016. This project, like the Sakonnet River Bridge Project, also contractually required CPQC. The prime contractor hired a consultant engineering and testing firm to perform all QC work. The Providence Viaduct Project is comparable to the Replacement of the Sakonnet River Bridge Project and the Pawtucket River Bridge 550 Project. This project involved significant soils, Portland

Cement Concrete and HMA testing. The project Superintendent informed me that the consultant's materials inspector cost per day ranged from $400.00/day to $600.00/day. This $600.00/day cost equates to $75.00 hourly rate for the average 8 hour day. I was also informed by the prime contractor that the cost of the project as of September 2016 was just a little over $66,000,000.00. The total cost for the consultant engineering testing firm as of September 2016 was $400,000.00. This equates to 0.6%. At the start of this research I had contacted several engineering testing firms to learn how engineering testing firms determine their cost to provide project wide QC. Most firms reported that they base their bid to perform project QC on the number and types of test that will be required and on the overall project cost. A general consensus among the engineering and testing firms was that ten years ago, as a rule of thumb, the cost to perform project QC was generally 1.5% to 2.0% of the total project cost. Today, as a result of the competitive environment, they are happy to win a bid at 1.0% of the project cost. The fact engineering and testing consultant cost for the providence Viaduct Project was less than 1.0% is not surprising. It actually represents what occurs when more and more projects require CPQC and more engineering inspection firms bid on the work. The hourly rate of $75.00 for the Providence Viaduct Project Materials Inspectors substantiates the $76.78 average hourly rated that will be used in this analysis.

To get the annual pay salaries of RIDOT Material Tech III and Tech IV Inspectors I went on a site called State of Rhode Island Transparency Portal. This State website allows you to do a RI State Employee Payroll Search. At the time of this research RIDOT showed a total of thirteen (13) Tech III Materials Inspectors and

Three Tech IV Materials Inspectors. Table 16 shows the RIDOT Tech III Materials Inspector 2015 individual base salary, average base salary, individual overtime, average overtime and individual total earned (base salary plus overtime) and average total earned (average base salary plus average overtime). Table 17 shows the RIDOT Tech IV Materials Inspector 2015 individual base salary, average base salary, individual overtime, average overtime and individual total earned (base salary plus overtime) and average total earned (average base salary plus average overtime).

Table 14 Hourly Rates of Six Engineering and Testing Firms

	YEAR '15-'16					
	CONSULTANT #1	CONSULTANT #2	CONSULTANT #3	CONSULTANT #4	CONSULTANT #5	CONSULATANT #6
Construction and Maintenance Inspector Level 1						
Straight Time	$37.00	$52.25	$41.45	$55.00	$54.00	$52.00
Overtime >8hrs per day	$46.00	$78.38	$49.90	$80.00	$77.25	$70.00
Construction and Maintenance Inspector Level 2						
Straight Time	$50.00	$73.15	$85.05	$80.00	$75.76	$57.00
Overtime >8hrs per day	$66.00	$109.73	$100.75	$105.00	$108.25	$80.00
Construction Record Keeper						
Straight Time	$36.00	$56.43	$44.55	$65.00	$48.00	$30.00
Overtime >8hrs per day	$44.00	$84.65	$53.65	$95.00	$68.50	$30.00
Materials Inspector Level 1						
Straight Time	$38.00	$45.98	$34.50	$55.00	$54.00	$35.00
Overtime >8hrs per day	$47.00	$68.97	$41.45	$80.00	$77.25	$35.00
Materials Inspector Level 2						
Straight Time	N/A	$77.33	$73.00	$80.00	$76.75	$45.00
Overtime >8hrs per day	N/A	$116.00	$87.75	$105.00	$108.25	$50.00

Table 15 Engineering and Testing Firms Average Hourly Rate

Engineering Firm	2015 & 2016 Hourly Rates
Consultant # 2	$77.33
Consultant # 3	$73.00
Consultant # 4	$80.00
Consultant # 5	$76.75
Consultant # 6	$45.00
	Average using all 5 hourly rates=$70.42
	Average omitting $45.00 rate = $76.78

Table 16 RIDOT Tech III Materials Inspectors 2015 Earnings

Name	Annual Salary $	Overtime $	Other earning$	Total earnings $
Inspector A	61,276.80	8,263.55	150	69,366.95
Inspector B	60,000.20	5906.41	150	65,739.93
Inspector C	62,092.68	14,330.20	1,528.59	77,628.07
Inspector D	61,276.80	12,485.54	323.3	73,762.24
Inspector E	61,154.08	3,103.38	150	61,154.08
Inspector F	61,099.30	17,109.48	1,862.57	79,743.67
Inspector G	63,177.66	21,924.54	963.16	85,741.96
Inspector H	61,276.90	19,384.73	496.59	80,834.72
Inspector I	62,182.90	14,783.77	281.93	76,925.20
Inspector J	60,799.18	13,142.12	369	73,993.85
Inspector K	60,944.78	13,575.29	150	74,353.46
Inspector L	48,714.90	9,112.50	150	56,927.47
Inspector M	60,000.20	12,518.87	150	72,352.39
Average Base Annual Salary = $60,307.41				
Average Overtime = $12,741.57				
Average Total Earnings (Direct Cost) = $72,963.38				

Table 17 RIDOT Tech IV Materials Inspectors 2015 Earnings

Name	Grade	Annual salary $	Overtime $	Other Earnings $	Total Earnings $
Inspector A	TECH IV	72,362.42	5,886.21	150	78,020.28
Inspector B	TECH IV	65,198.12	4778.15	150	69,254.82
Inspector C	TECH VI	72,212.40	13,628.63	150	85,612.68
Average base salary		**$ 69,924.31**		**Average Total earnings**	**$ 77,629.26**
Average OT		**$ 8,097.66**			
		-	-		

To calculate the total cost of a RIDOT employee we need to include Overhead Cost and Fringe Benefits Cost to the employee's base salary. To assure the accuracy of the data for this analysis I went to the Department of Transportation and received from them their reported 2015 Overhead Cost Rate (RIDOT calls this "In-Direct Cost Rate") and their reported 2015 Fringe Benefits Cost Rate (RIDOT calls this "Labor Additive Cost Rate"). RIDOT Indirect cost rate for 2015 was reported as 0.919. RIDOT Labor Additive Cost for 2015 was reported as 0.931. The fiscal year 2015 In-Direct cost rate and the Labor Additive Cost Rate were confirmed with RIDOT Financial Manager. The formula to calculate the 2015 average total cost of a Tech III Materials Inspector = Average Base Salary + ((Average Base Salary * Labor Additive Cost Rate) + (Average Base Salary * Indirect Cost Rate)). Table 18 represents total cost results for a RIDOT Tech III Materials Inspector. The same calculations were performed to find the 2015 average Total Cost of a Materials Tech IV Inspector. Table 19 shows results for a RIDOT Tech IV materials Inspector.

Table 18 Total Cost Calculations for a Materials Tech III Inspector

2015 Total Cost Calculations for a RIDOT Tech III Materials Inspector
Total Cost = \$60,307.41+ ((\$60,307.41*0.931) + (\$60,307.41*0.919)
Total Cost= \$60, 307.41 + \$56,146.20 +\$55,422.51
2015 Average Total Cost for a RIDOT Materials Tech. III Inspector = \$171,876.12

Table 19 Total Cost Calculations for a Materials Tech IV Inspector

2015 Total Cost Calculations for a RIDOT Tech IV Materials Inspector
Total Cost =\$69,924.31 + ((\$69,924.31 *0.931) + (\$69,924.31 *0.919)
Total Cost= \$69,924.31 + \$65,099.53 +\$64,260.44
The 2015 Average Total Cost for a RIDOT Materials Tech. IV = \$199,284.28

RIDOT Tech III and Tech IV average base salaries will be converted into an average hourly rate for the purpose of performing a RIDOT hourly rate comparison to the average consultant's hourly average rate. To convert the average annual salary to an hourly rate I will divide the annual salary by 2080 (52 week per year * 40 hour work week=2080 hours/year). Table 20 represents the average Tech III and Tech IV RIDOT Material Inspectors total annual cost converted to an hourly rate.

Table 20 Annual 2015 RIDOT Material s Inspector total cost converted to hourly rate

Average Tech III Inspector total cost \$171,876.12/year ÷ by 2080 hours/year = \$82.63/hour
Average Tech IV Inspector total cost \$199,284.28/year ÷ by 2080 hours/year = \$95.81/hour

Section 4-5 Summary of Cost Analysis

The results from this analysis show that the hourly rate of $82.63 for a RIDOT Tech III inspector is greater than the $76.78 rate for a consultant inspection service Level 2 Materials Inspector. To validate the methodology employed in this cost analysis other similar cost analysis studies were research for comparison. New York State DOT (NYSDOT) performed a similar cost analysis in 2008 to determine the cost of In-House Design Engineer verses an outside consultant Design Engineer. NYSDOT average direct salary for an in-house Design Engineer was calculated at $74,463.28. Fringe Benefits were reported at 45.53% and Overhead at 103.47%. Table 21 shows calculation of the total cost of a NYSDOT In-House Design Engineer. NYSDOT took the average 2007 salary of a consultant Design Engineer from U.S. Department of Labor Statistics to be $ 58,624.37. The Fringe Benefits was 27.87% and Overhead Cost Rate was 124.63%. To this a 10% allowable profit cost was added to the total consultant Design Engineer cost. In our analysis the hourly rate provided by the engineering inspection firms included overhead, benefits and profit. The total cost calculation for NY consultant Design Engineer is shown in Table 22.

Table 21 total cost of a NYSDOT In-House Design Engineer.

Summary of a NYSDOT In-House Design Engineer Cost		
Direct Cost		$ 74,463.28
Fringe	45.53% x direct cost	$ 33,903.13
Overhead	103.47% x direct cost	$ 77,047.16
Total		$ 185,413.57
Convert to Hourly Rate $185,413.57 ÷ 2080 = $89.14		

Table 22 Summary of a NY Consultant Design Engineer Cost

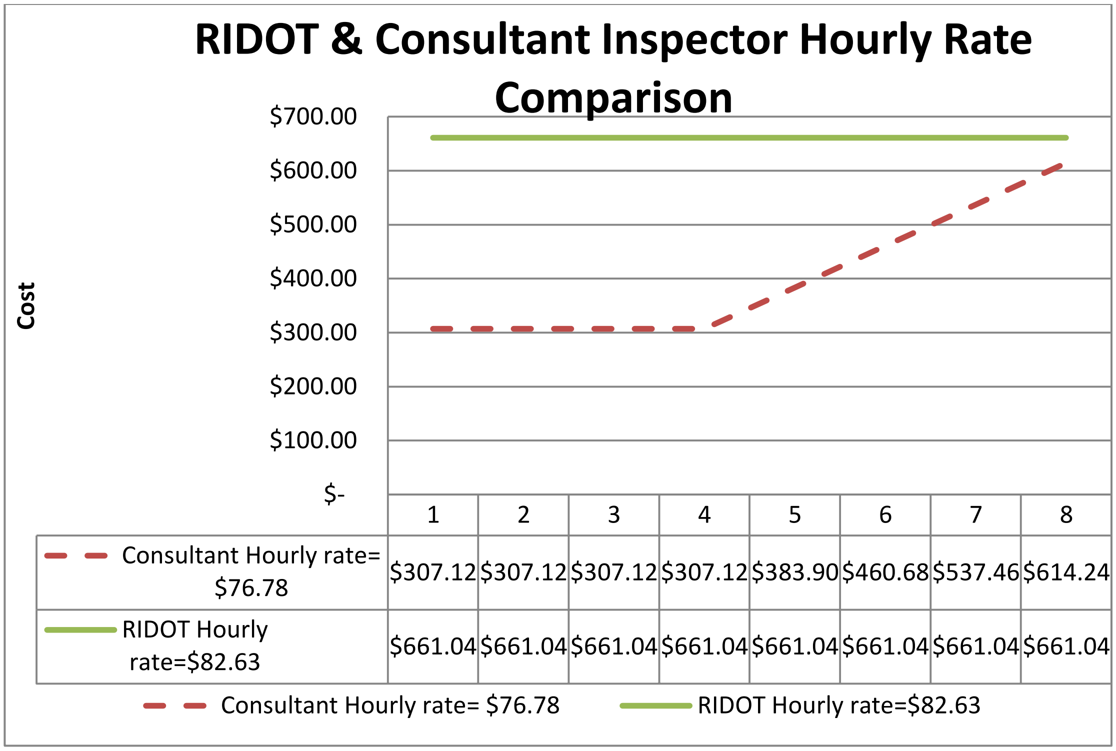
Summary of Consultant Design Engineer Cost

Direct Cost		$ 58,624.37
Fringe	27.87% x direct cost	$ 16,341.22
Overhead	(152.5% – 27.87%) x direct cost	$ 73,060.95
Profit	10.00% x (direct cost + fringe + overhead)	$ 14,802.65
Total		$ 162,829.19

Convert to Hourly Rate $162,829.19 ÷2080 = $78.28

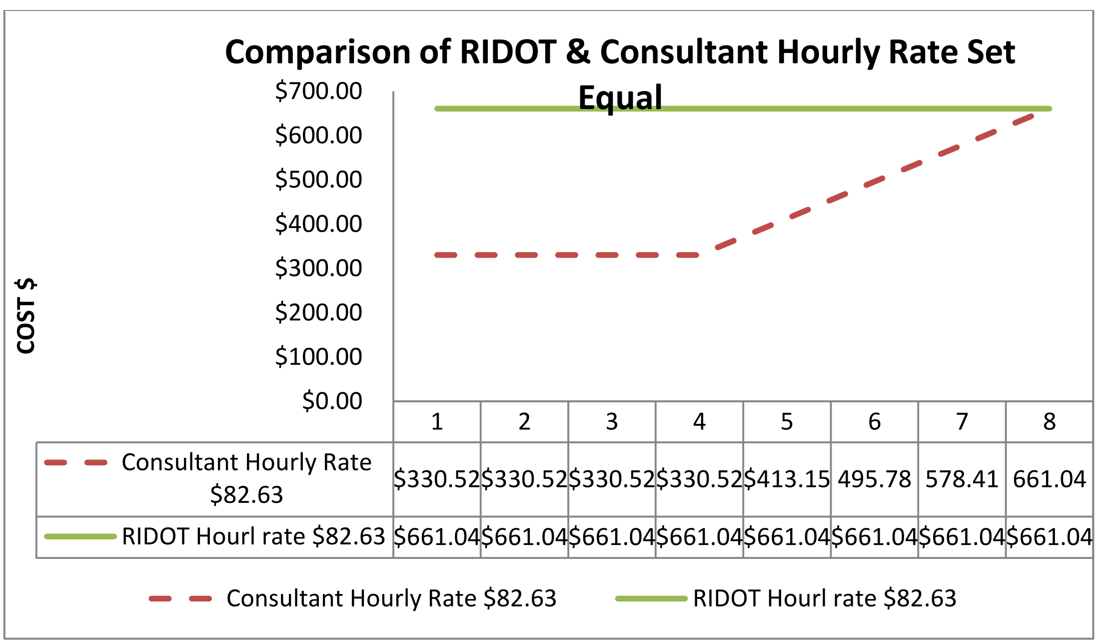
The NYSDOT 2008 cost analysis concluded that it was more cost effective to use outside consultant Design Engineers than In-House Design Engineers. NYSDOT attributed this result to the generous and attractive packages that NYSDOT employees receive. The NYSDOT study reported “It might be anticipated that the cost of an engineer would be the same whether he or she is in the public or private sector; however this study found that because of the generous benefits package provided by the State of New York, the large amount of paid time off, and a reduced work week compared to the private sector, the in-house engineer actual expected cost to the tax payer exceeds the cost of a private engineer by at least 15%.” (F. H. Griffis, 2008). The methodologies used for the NYSDOT cost analysis study are similar to those used for this 2015 RIDOT cost analysis. The results of RIDOT’s cost analysis using 2015 salaries, Overhead and Fringe Benefits rates are very similar to the results of the 2008 cost analysis conducted by the NYSDOT. Both studies found that the cost of In-house Engineers and Technicians are higher than the cost of consultant engineers and technicians. It is important to note that the result of these cost analysis do not tell the whole story. What the cost analysis fails to show are the hidden costs associated with in-house services. With in-house you pay for the inspector and equipment for as long as it remains with the agency. Whether there is work for that inspector or equipment the agency must continue paying. The major benefit associated with outsourcing is that the Department pays for the service as needed and only when needed. For example, a project has one concrete placement scheduled for 8:00 AM. The operation and required testing is completed by 11:00AM. If there are no further placements scheduled for the day the consultant Materials Inspector gets paid 4 hours and is done for the day at a total cost to the Department of $307.12. The State Materials Inspector gets paid the full 8 hour ($661.04) even is there are no other operations to cover for that day. Another example is the operation that gets cancelled due to the weather. The consultant materials inspector is notified and told not to report for work. There is no cost to the agency. The State materials inspector is paid the full 8 hours ($661.04) even though there is no work taking place as a result of adverse weather conditions. RIDOT makes every effort to fully utilize each and every inspector but highway construction operations are strongly affected by adverse weather conditions. Even during RIDOT's peak construction period, May – October, severe rain conditions could stop a concrete or HMA placement operation for days. There are many benefits associated with outside consultant inspection services that cannot accurately be accounted for in the cost analysis. Consultant inspectors do not have regular work schedule hours. This allows the agency to establish the inspectors work schedule when the testing is required. This cost savings strategy is one of the main reasons why contractors select to outsource project QC. The Construction Industry (CI) has learned and benefited from the advantages of outsourcing work. They have learned from experience that keeping a full time field QC staff and required testing equipment and laboratories is simply not cost efficient. Figure 34 represents a graph of the consultant hourly rate of $76.78 and the RIDOT Materials Tech III Inspector average hourly rate of $82.63. This graph represents some very important benefits associated with the use of consultant inspection services. As shown on graph the consultant is paid a 4 hour minimum for the first 4 hours of work. With most testing operations being completed within this 4 hour period, this represent a cost savings of $661.04 minus $307.12 = $353.92 for every day that a consultant inspection service is used. The graph also represents a cost savings even if the consultant inspector is used for the entire day. For further representation of the cost effectiveness in the use of outside consultant services, graphs were constructed with consultant hourly rates equal to RIDOT Tech III Material Inspector rate of $82.63 and with consultant rate 25% greater than the RIDOT rate of $82.63. Figure 35 represents the comparison with equal pay rates. As shown on the graph at the 4 hour minimum pay requirement there is a $661.04 – 330.52 = $330.52 savings to the Department. What this graph also shows is that right up until the final 8 hours of the day the Department is still paying less for the consultant inspector. Figure 36 shows that even at a rate of $103.29, which equates to 25% greater than the 2015 RIDOT Tech III Materials Inspector hourly rate of $82.63, that the first 6 hours the consultant inspector is still more cost effective then the RIDOT Materials Inspector. This is valuable information for the Department. Through careful management in the implementation of consultant services the Department can significantly reduce it cost associated with Acceptance Testing and improve the efficient and sustainability for the overall QA Program.

To keep this cost analysis on the conservative end the average base salary used in these calculations does not include overtime. As shown in Table 16 the average overtime earned by a RIDOT Tech III Materials Inspector is $12,741.57. If overtime were to be included in the 2015 earnings that would raise the average salary to $72,963.38. Overtime was not included in the calculations because it is a variable component of the total employee's salary. RIDOT needs to evaluate is the amount of overtime being charged for Acceptance Testing and its effect on the sustainability of the overall QA Program. The average overtime cost of $12, 741.57 per inspector equates to 21% of the average base salary of $60,307.41. This value of 21% is a significant cost to RIDOT's overall QA program. In addition to the added overtime cost another factor to consider is the efficiency and performance of the worker through these extended hours of operation. A detailed study into how and why overtime is being accrued will likely show material placement operations that run beyond the regular working hours of Monday through Friday 7:00AM – 3:30PM. Any work outside of the Monday through Friday 7:00AM – 3:30PM spectrum is overtime for a RIDOT Materials Inspector. Consultant inspectors are scheduled to be on site only when testing is required. There is no down time, sick pay, vacation pay or holiday pay. There are no regular hours of work. There is no overtime for day, night or weekend work. Through the use and proper management of consultant inspection services RIDOT can significantly reduce the existing 21% overtime cost resulting in the improvement in the efficiency and sustainability of the overall QA Program.



	1	2	3	4	5	6	7	8
Consultant Hourly rate= $76.78	$307.12	$307.12	$307.12	$307.12	$383.90	$460.68	$537.46	$614.24
RIDOT Hourly rate=$82.63	$661.04	$661.04	$661.04	$661.04	$661.04	$661.04	$661.04	$661.04

Figure 34 Consultant Hourly Rate $76.78 Comparison to RIDIOT Rate $82.63



	1	2	3	4	5	6	7	8
Consultant Hourly Rate $82.63	$330.52	$330.52	$330.52	$330.52	$413.15	495.78	578.41	661.04
RIDOT Hourl rate $82.63	$661.04	$661.04	$661.04	$661.04	$661.04	$661.04	$661.04	$661.04

Figure 35 Comparison of RIDOT and Consultant Hourly Rates Set_Equal

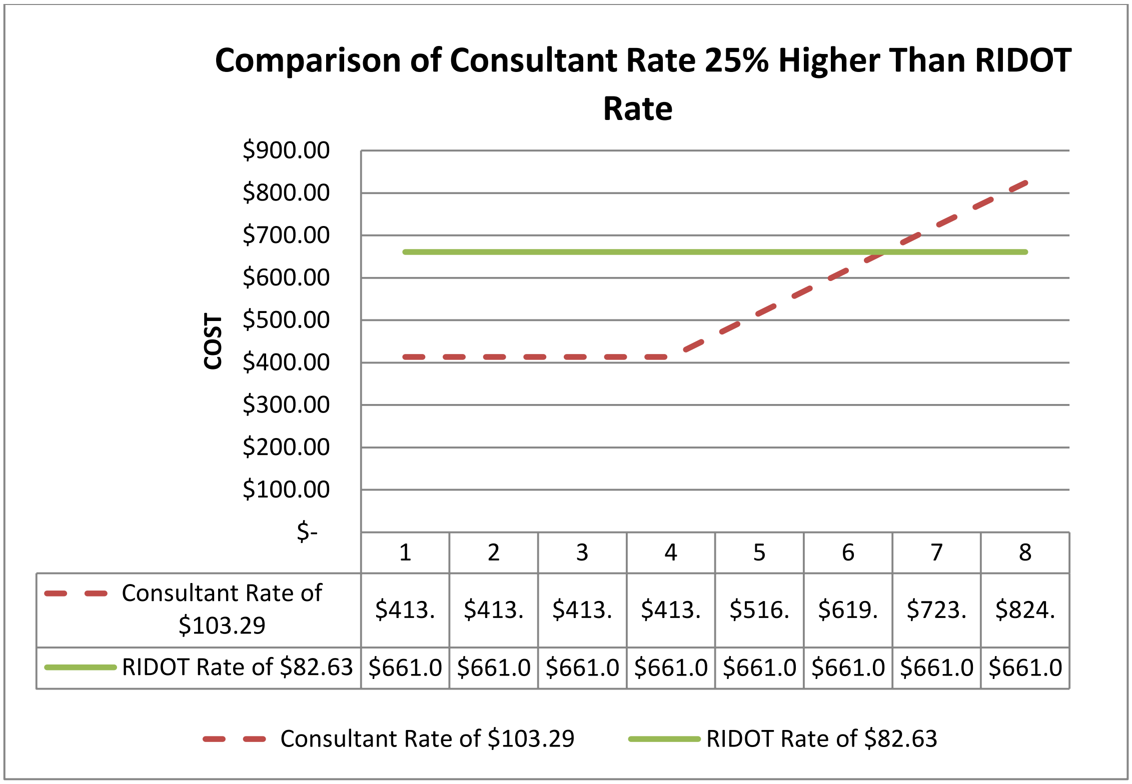


Figure 36 Comparison of Consultant Rate 25% Higher Than RIDOT Rate

The findings of this cost analysis are not intended to suggest that all SHA Materials Testing personnel be replaced with outside consultant testing services. SHAs need to and must maintain qualified and certified material testing personnel to maintain agency oversight and control of its QA program. What the findings do indicate is that SHAs can benefit by supplementing its QA staff with consultant engineering testing services to handle the peak work load periods and to provide the required testing during the time frames outside of the agencies 7:00 AM – 3:30 PM regular work schedule. As SHA employees leave service either through retirement or simply going to the private sector, decisions will need to be made as to how those vacancies will be filled. SHAs are now operating under tighter budgets and under the watchful eye of the public as to how the States money is being spent. With infrastructure funding varying from one year to the next and with construction activities ranging from "peak demand periods" to "no work" during winter shut down periods, staffing needs must be given serious consideration. Staffing to meet peak work load periods is neither efficient nor cost effective but still the agency must provide the testing coverage during this period. Consultant engineering testing services can help SHAs meet the peak work load demand periods and provide testing services outside an agency normal hours of operations on an on-call as-needed basis. The cost savings associated with the implementation and proper management of consultant engineering testing services can improve the efficiency and cost effectiveness of a SHAs QA program.

4.6 References

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CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

State Highway Agencies (SHAs) across the country are faced with the challenge of addressing a deteriorated infrastructure system while burdened with severe financial constraints and a continuing reduction in staffing levels. To meet this challenge SHAs continue the evolution of their individual QA programs with the ultimate goal of building a better quality longer lasting infrastructure. SHAs are adapting and implementing new ideas, technologies, innovations and management strategies to optimize available resources and develop more efficient and effective QA programs. With the incorporation of FHWA 23 CFR 637B Final Rule, Quality Assurance Procedures for Construction, SHAs were given more flexibility in designing their QA programs, including permitting the use of CPQC test results for Acceptance. The findings from this dissertation confirm that SHA's QA programs consist of the three main ingredients; QC, Acceptance Testing and Independent Assurance (IA). It is how these three ingredients have been blended that accounts for the differences in QA programs from one SHA to another. There is not a boiler plate or a one-size- fits –all QA program. Transportation agencies have developed QA programs that have been customized to meet their individual States needs and available resources. The importance of QA became evident as a result of the AASHO Road Test conducted in Ottawa, Illinois from 1956 to 1960. Today, over 50 years since the Road Test, the strategies and practices used by SHAs to ensure quality and to meet 23 CRF637 requirements encompass a wide variety of approaches which has resulted in a broad spectrum of QA programs.

5.1.1 Quality Control (QC)

For a QA program to be efficient, effective and sustainable all three components; QC, Acceptance and IA must be functional. Of the three components, IA is the component where SHA are most consistent on regarding the IA roles and responsibilities. The majority of SHAs assume the IA role and responsibilities in its entirety. In general, the literature review supports that IA is being conducted by most SHAs in compliance with 23 CFR 637.

QC is the component that differs mostly from one SHA to another. The reason for this is that QC is a component that requires contractor involvement. There is little disagreement that QC is the contractor's responsibility. However, how QC is delegated to the contractor is where SHAs differ most. It is widely accepted that QC should be the contractor's responsibility. It is the contractor that manufactures the product and it is the contractor that constructs the product. It is therefore the contractor with the most ability to control the QC process for both the manufacturing and the construction of the product. Where the disagreement exists is in the delegation of QC responsibilities to the contractor. The literature review clearly shows that SHAs are still assuming QC responsibilities, mainly so when it comes to field QC. The contractors QC responsibilities cannot begin and end at the contractor plant. Both field QC and plant QC are essential component of the overall QC process and both are the responsibility of the contractor. If the contractor does not have designated QC personnel in the field to perform the required field QC testing then these tests are routinely being performed by agency material inspectors under the umbrella of "Acceptance Testing". The delegation of QC responsibilities to the contractor differs from one SHA to another for many reasons including low keyed efforts from STAs in the development and implementation of QC policies, reluctance of the agency to relinquish control and lack of trust between the agency and the contractor.

The transfer of QC from the SHA to the contractor differs significantly from one SHA to another and in many agencies from one project to another. As a result QC responsibilities and roles are not clearly designated. This often results in the intermingling of QC responsibilities between the agency and the contractor. How QC is delegated to the contractor significantly impacts the agencies overall QA program. RIDOT first incorporated Contractor Performed Quality Control (CPQC) back in 2008 for the Sakonnet River Bridge Replacement Project. The contractual language for this project was very clear and concise as to the delegation of QC responsibilities to the contractor. CPQC for this project resulted in a significant increase in field QC testing never witness before by the Department resulting in better quality project wide.

CPQC was a success for this pilot project and continues to be used on RIDOT major projects, such as; the Pawtucket River Bridge 550 Project and the Providence Viaduct Bridge Project At the time of this study the RIDOT has not incorporated CPQC on all of its projects. On projects where CPQC is not a contractual requirement the contractors QC roles generally start and end at the contractor's production plant. In my 28 years as an Engineer for the RIDOT it was common practice to witness RIDOT Materials Inspectors performing testing that far exceeded those required by the RIDOT Master Schedule of Testing Manual. It is through this additional testing that RIDOT Materials Inspectors assure the quality of work on RIDOT projects. This additional testing comes at a cost to the Department and a strain on the Materials Section staffing.

5.1.2 CPQC Test Results for Acceptance Testing

At the time of this project the RIDOT Materials Sections retains and performs the entire acceptance function. As stated above, on projects where CPQC is not required the QC roles and responsibilities are intermingled and the Materials Acceptance Inspectors are burden with the task of performing field QC testing. Before a SHA can implement the use of CPQC test results to supplement Acceptance Testing, the SHA must assure that the contractor has been designated all QC responsibilities. When a contractor is performing project wide QC the SHA will then realize an increase of field testing by contractor QC personnel. This increase in contractor QC testing, as a result of CPQC, will provide SHAs a valuable database resource of CPQC test results and agency Acceptance Test results. Through statistical analysis of these databases a SHA will be able to develop validation procedures for CPQC test results. Once the Department has achieved a level of degree of confidence with its validation procedures, then CPQC test results can be used to supplement agency Acceptance Testing. Every contractor quality control test result that can be validated and used to supplement agency acceptance testing equates to one less Acceptance Test that the agency needs to perform. The use of CPQC test results to supplement agency Acceptance Testing will improve the overall efficiency and cost effectiveness of a SHAs QA program.

5.1.3 Consultant Testing Services for Acceptance Testing

RIDOT Materials Section is experiencing a reduction in staffing level as a result of retirement and or employees leaving to the private sector. Efficient and cost effective staffing with full-time employees is a difficult task to accomplish. By nature, road and bridge construction work is extremely affected by weather conditions. Here in the New England area, the peak work period is between the months of May and October. SHAs cannot afford to staff to meet peak workload demands. A SHA that staffs to handle peak workloads, it will find itself paying for inspectors when there is no work taking place. With funding for infrastructure projects varying from one year to the next, full time staffing becomes an even more difficult. SHAs are looking for alternative cost effective management strategies to meet construction inspection and material testing staffing needs. The use of outside consultant engineering testing firms is a solution. The use of consultant testing services provides the ability to increase or reduce staffing levels to meet current workloads (peak and low periods), bring expertize and quality to the project and reduce the current 12% Materials Inspectors overtime rate.

A life cycle cost analysis was conducted in this dissertation comparing the cost of RIDOT In-house Acceptance Testing verses outside consultant Acceptance Testing. The outcome of the cost analysis showed that it is less expensive and more cost effective to use outside consultant testing services than in-house RIDOT Acceptance Materials Inspectors.

RIDOT will need to make staffing decisions in the very near future. SHAs need to evaluate whether supplementing its QA staff with consultant engineering testing services provides a more cost effective solution to its staffing requirements. Contractors have benefitted from the use of consultant services since the early 70's. Contractors have become extremely proficient at managing consultant services by optimizing their use while minimizing overall QC cost. SHAs can use the consultant engineering testing services as a "Force Multiplier" during the peak workloads periods. The use of consultant services can allow SHAs to optimize its current resources and provide a cost effect way of meeting peak workload demands without over staffing. As SHAs experience future reduction in full time personnel the agency should implement the cost analysis evaluation process to determine what is the most cost effective solution is for the Department, hiring additional full time personnel or using additional consultant engineering testing services to meet current workload demands.

5.2 Recommendations

1. Clear, concise and consistent QC policies should be incorporated into every SHA project. QC policies, practices and requirements that differ from one project to another create confusion and often result in the intermingling of QC responsibilities between the Department and the contractor. This intermingling of QC responsibilities has a negative impact in quality, diminishes the overall effectiveness of QA Program and increases QA cost therefore affecting the sustainability of the overall QA Program.

2. Every transportation project should require the submittal of a Quality Control Plan before the start of any work. A Quality Control Plan describes what actions the contractor will take to meet RIDOT QC requirements and policies. It is therefore the best tool that RIDOT field inspectors have to monitor and enforce QC requirements.
3. The size and type of project should not change or alter SHAs QC policies and requirements. The difference between a $200 million dollar bridge project and a $300 thousand sidewalk replacement project is the cost and the quantity and types of items of work to be incorporated into the project. The QC policies and requirements should remain the same. A Quality Control Plan should still be required for the assurance of quality work. The majority of SHAs construction projects are not 100 million dollar projects. Most projects are much smaller in size and cost. It is these smaller projects that represent the bulk of SHAs work and it is in these projects where contractor field QC needs to be addressed. Consistency eliminates confusion and intermingling of QC responsibilities.
4. SHAs should consider the use of CPQC test results to supplement agency Acceptance Testing. Before a SHA can implement the use of CPQC test results to supplement Acceptance Testing, the SHA must assure that the contractor has been designated all QC responsibilities. The use of CPQC test results to supplement Acceptance Testing will reduce the amount of testing now performed by SHAs Materials personnel. The Federal Highway has

approved the use of CPQC test results to supplement agency Acceptance Testing because it works and can help SHAs improve quality, reduce agency staffing burdens and help SHAs develop more efficient and sustainable QA programs.

5. The increase in testing that result from the implementation of CPQC has enabled SHAs to develop databases of CPQC test results and agency Acceptance Testing test results. Through statistical analysis of these databases SHAs will be able to develop CPQC validation procedures, control limits for Percent –Within-Limits specifications (PWL), control charts to monitor production processes. SHAs need to take every available opportunity to collect, establish and maintain CPQC test result and Acceptance Testing test result databases.

6. SHAs should consider the use of consultant testing services to supplement agency Acceptance Testing and overall QA staffing to help meet peak work periods more efficiently and cost effectively, bring innovation and quality to the project, and help reduce the current 12% overtime rate for agency materials Inspectors. Consultant services can help a SHA optimize existing resources while improving the overall efficiency, effectiveness and sustainability of its QA program.

7. SHAs should consider establishing a separate knowledge management section within the Department to address the concern of erosion of expertizes and complete reliance on consultants.

8. SHAs should consider selecting a pilot project in which one or more innovations can be implemented and monitored. Innovations such as CPQC, the use of CPQC test results to supplement agency Acceptance Testing and the use of consultant engineering testing services should be implemented, managed and monitored on pilot projects.

SHAs QA programs have been and continue to evolve to adapt to new technologies, innovations and needs. There is a new philosophy that is growing regarding the relationship between SHAs and the Construction Industry. Back in the 1960's QA programs consisted mostly of Materials and Methods Specifications with total agency control. Today, as per the definition of QA Specifications, SHAs QA programs consist of more of a combination of end result specifications and materials and methods specifications, with many agencies using CPQC test results to supplement agency Acceptance Testing. What most SHAs are reporting is the realization of more and more contractor involvement. With new concepts on how projects should be designed and built what is clearly evident is the increase in contractor participation in the design, construction and overall project management. QA has evolved from the time where contractors had very little control in the design and construction of a project, as is the case with material and methods specification projects, to projects where the contractor has nearly total control, such as a Design-Build-Operate and Maintain (DBOM) project.

Practices and policies that got SHAs here today will not get SHAs where we need to be tomorrow. SHAs across our great Country are partnering with contractors to find smarter and better ways of addressing our current infrastructure needs. SHAs will need to build better relationships with the contracting industry. Develop and implement new technologies, innovations, project and personnel management strategies that will allow SHAs meet current and future demands. The recommendations respectfully presented in this dissertation are presented with the hope of improving the overall quality, effectiveness, efficiency and sustainability of SHAs Quality Assurance Programs.

APPENDIX A
DATA BASE

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	**Date**	**Load #**	**# of loads**	conc temp	slump	Air	conc temp	slump	AIR
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	12/8/09	1	39	-	-	-	-	3	5.0
MC	12/8/09	2	39	60	2	4.4	-	5	6.8
MC	12/8/09	3	39	59	6 1/4	5.0	-	6 1/4	6.4
MC	12/8/09	5	39	-	-	-	-	7	6.4
MC	12/8/09	6	39	58	3 1/4	4.5	63	7	7.0
MC	12/8/09	7	39	60	6 1/4	5.0	60	7 1/2	8.6
MC	12/8/09	8	39	-	-	-	-	6 1/4	3.5
MC	12/8/09	9	39	-	-	-	-	4	4.5
MC	12/8/09	11	39	62	6	5.2	-	-	-
MC	12/8/09	13	39	66	2 1/2	5.2	-	-	-
MC	12/8/09	15	39	-	7	4.0	-	-	-
MC	12/8/09	16	39	-	-	-	58	8 1/4	9.0
MC	12/8/09	17	39	60	6 1/2	4.0	-	7 1/4	6.6
MC	12/8/09	18	39	60	6 1/2	4.0	-	-	-
MC	12/8/09	20	39	60	8	8.5	-	-	-
MC	12/8/09	21	39	63	6	5.8	-	5 3/4	5.3
MC	12/8/09	25	39	63	5 1/2	4.5	-	-	-
MC	12/8/09	26	39	-	6 1/2	7.0	59	8 1/2	7.8
MC	12/8/09	27	39	62	8 1/4	5.1	-	-	-
MC	12/8/09	29	39	-	-	-	-	9	8.0
MC	12/8/09	30	39	64	7	8.1	-	-	-
MC	12/8/09	33	39	-	-	8.0	-	6	5.2
MC	12/8/09	34	39	-	-	-	-	3 1/2	9.0
MC	12/8/09	37	39	66	3 1/2	5.3	-	-	-
MC	12/8/09	38	39	62	3 3/4	5.6	62	5	5.0
MC	3/2/10	1	7	-	-		-	7 1/4	7.4
MC	3/2/10	2	7	-	-		67	7 3/4	7.8
MC	3/2/10	3	7	64	8	8.5	-	-	-
MC	3/2/10	4	7	-	-		-	8 1/2	6.8
MC	3/2/10	6	7	70	8 1/2	10.0	-	8 1/4	-
MC	3/20/10	1	75	-	-	-	68	8 1/2	9.0
MC	3/20/10	2	75	-	-		71	6 1/2	12.0
MC	3/20/10	5	75	70	8 1/2	8.6	67	8 1/2	8.0
MC	3/20/10	10	75	-	-		68	8 1/4	7.5

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	**Date**	**Load #**	**# of loads**	conc temp	slump	Air	conc temp	slump	AIR
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	**3/20/10**	**11**	**75**	68	8	8.5	-	-	-
MC	**3/20/10**	**13**	**75**	-	-	-	66	8 1/4	8.1
MC	**3/20/10**	**16**	**75**	65	8 1/4	6.0			
MC	**3/20/10**	**17**	**75**	-	-	-	66	8 1/4	8.1
MC	**3/20/10**	**23**	**75**	68	8 3/4	7.2	-	-	-
MC	**3/20/10**	**24**	**75**	-	-	-	66	9 1/4	6.1
MC	**3/20/10**	**28**	**75**	66	8 3/4	6.0	-	-	-
MC	**3/20/10**	**29**	**75**	-	-	-	68	8 1/4	8.6
MC	**3/20/10**	**33**	**75**	-	-	-	74	8 1/2	8.5
MC	**3/20/10**	**37**	**75**	69	8 3/4	7.2	-	-	-
MC	**3/20/10**	**38**	**75**	-	-	-	74	8 1/4	7.4
MC	**3/20/10**	**39**	**75**	70	8 1/2	8.7	-	-	-
MC	**3/20/10**	**43**	**75**	-	-		71	8 1/2	6.1
MC	**3/20/10**	**49**	**75**	-	-	-	67	9	6.0
MC	**3/20/10**	**50**	**75**	68	9 1/2	8.5	-	-	-
MC	**3/20/10**	**54**	**75**	65	8 1/2	7.0	69	8	7.8
MC	**3/20/10**	**56**	**75**	-	-	-	68	8 1/2	7.8
MC	**3/20/10**	**61**	**75**	70	8 1/2	7.6	-	-	-
MC	**3/20/10**	**64**	**75**	-	-	-	68	8 1/4	9.0
MC	**3/20/10**	**65**	**75**	70	8 3/4	6.0	-	-	-
MC	**3/20/10**	**66**	**75**	-	-	-	68	8 1/4	8.7
MC	**3/20/10**	**71**	**75**	68	8 1/2	7.2	-	-	-
MC	**3/20/10**	**73**	**75**	-	-	-	65	8 3/4	7.6
MC	**4/6/10**	**1**	**11**	-	-		70	8 1/4	11.0
MC	**4/6/10**	**2**	**11**	63	9	7.1	66	8 3/4	7.0
MC	**4/6/10**	**4**	**11**	68	6 1/4	10.5	-	-	-
MC	**4/6/10**	**5**	**11**	-	-		68	6	10.5
MC	**4/6/10**	**7**	**11**	-	-	-	70	7 3/4	8.0
MC	**4/6/10**	**8**	**11**	70	8	7.6	69	8 1/2	8.0
MC	**4/6/10**	**10**	**11**	68	8 1/4	8.5	-	-	-
MC	**4/6/10**	**11**	**11**	-	-	-	70	8 3/4	7.8
MC	**4/9/10**	**1**	**9**	-	-	-	67	9	8.6
MC	**4/9/10**	**2**	**9**	68	8 1/2	7.2	68	8	8.6
MC	**4/9/10**	**5**	**9**	68	8 1/2	7.4	-	-	-

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of loads	conc temp	slump	Air	conc temp	slump	AIR
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	4/19/10	1	17	-	-	-	71	7 1/4	9.7
MC	4/19/10	2	17	70	8 3/4	10.7	70	9	10.8
MC	4/19/10	3	17	68	8 1/4	8.5	68	8 1/2	9.0
MC	4/19/10	6	17	64	8 3/4	8.1	-	-	-
MC	4/19/10	7	17	-	-	-	67	7 3/4	8.3
MC	4/9/10	8	9	-	-	-	66	8 3/4	8.0
MC	4/19/10	9	17	-	-	-	65	8	9.7
MC	4/19/10	10	17	66	7 1/4	8.7	67	7 1/4	9.5
MC	4/19/10	12	17	68	8 1/2	8.8			
MC	4/19/10	15	17	70	8 1/4	8.4	70	8 1/4	8.9
MC	4/27/10	1	17	67	8	9.8	68	7 1/4	10.0
MC	4/27/10	2	17	-	-	-	67	8 3/4	9.7
MC	4/27/10	3	17	64	9	8.0	-	-	-
MC	4/27/10	6	17	63	7 3/4	8.0	66	7 3/4	8.0
MC	4/27/10	8	17	-	-	-	65	6 1/2	9.1
MC	4/27/10	9	17	62	9	7.4	-	-	-
MC	4/27/10	11	17	61	9 1/2	7.0		9	
MC	4/27/10	12	17	-	-	-	64	9 1/4	9.0
MC	4/27/10	16	17	62	8 1/2	6.8	-	-	-
MC	5/10/10	1	16	67	7 1/2	9.5	63	8 3/4	10.8
MC	5/10/10	2	16	-	-	-	65	9	7.8
MC	5/10/10	3	16	64	9 1/2	7.4	-	-	-
MC	5/10/10	4	16	-	-	-	68	9	8.0
MC	5/10/10	6	16	70	9	7.6	69	9	8.1
MC	5/10/10	8	16	-	-	-	70	7 1/4	7.0
MC	5/10/10	9	16	-	-	-	69	7 1/4	6.6
MC	5/10/10	11	16	73	7 1/2	9.0	-	-	-
MC	5/10/10	13	16	72	9	7.2	73	8 1/4	7.0
MC	5/10/10	15	16	70	8	8.0	-	-	-
MC	5/18/10	1	17	-	-	-	68	8 1/2	7.8
MC	5/18/10	2	17	68	8 1/2	9.5	70	8	9.0
MC	5/18/10	5	17	68	8 1/4	7.4	67	8	8.0
MC	5/18/10	6	17	-	-	-	68	9	8.2
MC	5/18/10	7	17	-	-	-	69	9	7.4
MC	5/18/10	8	17	70	8	10.0	70	8	9.2
MC	5/18/10	10	17	66	8 1/2	6.0	-	-	-
MC	5/18/10	12	17	-	-	-	67	9	8.0

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	**Date**	Load #	# of loads	conc temp	slump	Air	conc temp	slump	AIR
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	5/18/10	14	17	66	8	9.0	-	-	-
MC	5/18/10	15	17	-	-	-	65	8	8.4
MC	5/18/10	16	17	64	7 1/2	8.5	-	-	-
MC	5/22/10	1	96	68	8	7.9	68	8	8.5
MC	5/22/10	2	96	-	-	-	71	8 1/2	8.5
MC	5/22/10	3	96	-	-	-	66	6 1/2	8.1
MC	5/22/10	8	96	67	9 1/2	7.1	62	8 1/2	7.0
MC	5/22/10	11	96	-	-	-	70	8 1/4	7.2
MC	5/22/10	12	96	68	8 1/4	7.8	-	-	-
MC	5/22/10	15	96	-	-	-	65	7 1/4	7.0
MC	5/22/10	17	96	68	7 3/4	9.7	64	8 1/4	8.5
MC	5/22/10	19	96	-	-	-	70	8 1/2	8.1
MC	5/22/10	22	96	68	8 3/4	9.0	78	9	8.6
MC	5/22/10	25	96	-	-	-	64	8 1/2	9.0
MC	5/22/10	30	96	70	8 1/4	8.5	-	-	-
MC	5/22/10	32	96	-	-	-	62	8 3/4	5.0
MC	5/22/10	33	96	-	-	-	65	8 1/2	6.4
MC	5/22/10	39	96	68	9	6.0	-	-	-
MC	5/22/10	42	96	-	-	-	64	8 1/4	7.0
MC	5/22/10	44	96	68	8	7.2	-	-	-
MC	5/22/10	49	96	-	-	-	70	9	7.8
MC	5/22/10	50	96	70	8 1/4	10.0	-	-	-
MC	5/22/10	54	96	70	7 1/2	9.5	-	-	-
MC	5/22/10	55	96	-	-	-	67	8	6.8
MC	5/22/10	62	96	70	8 1/4	7.8	65	8	7.6
MC	5/22/10	67	96	70	7 3/4	10.5	70	7 3/4	10.1
MC	5/22/10	70	96	-	-	-	70	8 1/2	10.0
MC	5/22/10	71	96	-	-	-	69	8 1/4	10.0
MC	5/22/10	77	96	70	8	9.0	-	-	-
MC	5/22/10	81	96	-	-	-	69	8 1/2	9.9
MC	5/22/10	84	96	-	-	-	70	7 3/4	8.4
MC	5/22/10	85	96	72	8 1/2	8.5	-	-	-
MC	5/22/10	87	96	-	-	-	73	8 3/4	9.1
MC	5/22/10	92	96	-	-	-	70	8 1/2	5.2
MC	5/22/10	93	96	-	-	4.9	-	-	-
MC	5/22/10	94	96	72	8 1/4	7.3	71	8 1/4	7.2
MC	5/22/10	95	96	-	-	-	72	6 3/4	7 .2

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	6/12/10	1	17	-	-	-	70	7 1/4	5.0
MC	6/12/10	2	17	-	-	-	70	8 1/4	10.0
MC	6/12/10	3	17	66	8 1/2	9.5	71	8 3/4	10.0
MC	6/12/10	5	17	66	8 3/4	9.0	-	-	-
MC	6/12/10	7	17	66	8 3/4	9.0	-	-	-
MC	6/12/10	8	17	-	-	-	71	8 1/4	8.0
MC	6/12/10	11	17	68	8 3/4	9.0	-	-	-
MC	6/12/10	13	17	70	9	7.0	73	9	8.0
MC	6/12/10	15	17	71	9	9.0	-	-	-
MC	6/12/10	16	17	-	-	-	73	8 1/2	7.6
MC	6/17/10	1	17	-	-	-	76	7 3/4	8.4
MC	6/17/10	2	17	69	8 3/4	6.4	74	8	6.6
MC	6/17/10	5	17	-	-	-	77	8 1/4	12.0
MC	6/17/10	6	17	71	8 1/4	7.6	77	8 1/2	8.0
MC	6/17/10	7	17	-	-	-	77	8 3/4	7.6
MC	6/17/10	8	17	70	7 1/2	8.5	76	7 3/4	9.0
MC	6/17/10	10	17	69	8 1/4	7.6	75	8 3/4	8.0
MC	6/17/10	13	17	72	9	7.4	-	-	-
MC	6/17/10	16	17	72	9	6.0	77	8 1/2	6.4
MC	6/26/10	1	15	-	-	-	77	6 1/4	10.5
MC	6/26/10	2	15	76	7 3/4	9.4	77	7 1/2	10.0
MC	6/26/10	4	15	-	-	-	76	7 1/2	9.0
MC	6/26/10	6	15	76	8 1/4	7.8	-	-	-
MC	6/26/10	7	15	-	-	-	77	8 1/2	8.2
MC	6/26/10	11	15	79	9	8.0	78	8 3/4	8.2
MC	6/26/10	13	15	-	-	-	80	8 1/2	8.5
MC	7/7/10	1	16				76	7 1/4	9.0
MC	7/7/10	2	16	76	7 1/2	12.4	76	7 1/2	12.0
MC	7/7/10	3	16	76	7	8.9	76	6 3/4	8.5
MC	7/7/10	4	16				76	7 1/4	8.0
MC	7/7/10	5	16				75	8 1/2	6.4
MC	7/7/10	8	16				77	8 1/2	6.2
MC	7/7/10	10	16	80	8 3/4	6.4			
MC	7/7/10	13	16				78	8 3/4	8.4
MC	7/7/10	14	16	80	7 1/4	7.8			
MC	7/9/10	1	93	75	9	6.6	76	9	7.0
MC	7/9/10	2	93				76	9	6.0
MC	7/9/10	6	93				77	9	7.3

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	7/9/10	9	93					9 3/4	
MC	7/9/10	10	93				79	9	7.1
MC	7/9/10	11	93					9 1/2	
MC	7/9/10	12	93				78	8 3/4	6.0
MC	7/9/10	13	93					9 1/4	
MC	7/9/10	14	93				78	9	7.5
MC	7/9/10	15	93				79	9	11.0
MC	7/9/10	16	93				80	7 3/4	12.5
MC	7/9/10	17	93				75	8 3/4	11.0
MC	7/9/10	18	93				78	8 3/4	8.0
MC	7/9/10	19	93	80	8 1/2	7.9	78	8 1/4	8.5
MC	7/9/10	24	93				83	6	11.0
MC	7/9/10	28	93				84	9	11.5
MC	7/9/10	29	93				82	8 1/2	8.6
MC	7/9/10	30	93				86	8 1/2	9.5
MC	7/9/10	31	93	84	9	8.5			
MC	7/9/10	32	93				86	8 3/4	8.8
MC	7/9/10	36	93				81	8	10.0
MC	7/9/10	39	93	82	9	7.0			
MC	7/9/10	43	93	82	9	6.6			
MC	7/9/10	44	93				82	9	9.0
MC	7/9/10	47	93				80	9	7.6
MC	7/9/10	49	93				81	2 1/2	7.0
MC	7/9/10	52	93				80	7 1/2	8.5
MC	7/9/10	53	93					9 3/4	
MC	7/9/10	54	93				79	8	8.0
MC	7/9/10	55	93				81	9	9.0
MC	7/9/10	56	93	80	9	6.0	82	7 1/2	6.0
MC	7/9/10	58	93	81	8 3/4	9.0			
MC	7/9/10	63	93				79	8 3/4	7.0
MC	7/9/10	65	93				79	9	7.1
MC	7/9/10	66	93	80	9	6.4			
MC	7/9/10	73	93				79	9	7.0
MC	7/9/10	76	93		9 3/4				
MC	7/9/10	82	93				78	9	9.1
MC	7/9/10	83	93	78	9	10.0			
MC	7/9/10	86	93				76	8 1/4	8.5
MC	7/9/10	90	93	76	8 1/2	8.0			

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	7/9/10	92	93				79	8 1/4	9.2
MC	7/15/10	1	7				78	1/2	
MC	7/15/10	2	7	78	6 3/4	10.0	77	7	10.4
MC	7/15/10	3	7				75	7	9.6
MC	7/15/10	4	7				76	7 1/4	9.9
MC	7/15/10	5	7						
MC	7/15/10	6	7						
MC	7/15/10	7	7	72	9 1/4	7.8	71	8 1/2	7.4
MC	7/29/10	1	10				79	8 3/4	11.0
MC	7/29/10	2	10				76	8 1/2	8.0
MC	7/29/10	3	10	72	8 1/4	9.6			
MC	7/29/10	7	10	70	8	8.0			
MC	7/29/10	9	10				75	9	7.6
MC	7/30/10	1	8				71	9	6.2
MC	7/30/10	2	8	72	8 3/4	12.0	73	8 1/4	11.0
MC	7/30/10	3	8				73	8 1/4	10.6
MC	7/30/10	4	8				73	8 3/4	10.8
MC	7/30/10	5	8				73	9	10.0
MC	7/30/10	7	8	76	9	8.5	72	9	9.0
MC	8/3/2010	1	10	-	-	-	74	8	11.6
MC	8/3/2010	2	10	74	9	8.5	74	8 1/4	8.5
MC	8/3/2010	3	10	-	-	-	72	9	8.5
MC	8/3/2010	5	10	-	-	-	73	8	10.6
MC	8/3/2010	6	10	-	-	-	74	8 3/4	10.6
MC	8/3/2010	8	10	76	9	6.2	-	-	-
MC	8/5/10	1	8				76	8 3/4	8.3
MC	8/5/10	2	8	76	9	8.5	77	9	8.4
MC	8/5/10	5	8	76	9	8.5			
MC	8/5/10	6	8				77	9	8.7
MC	8/12/10	1	27				79	6 1/4	10.0
MC	8/12/10	2	27				75	8 3/4	8.5
MC	8/12/10	3	27	78	9	10.0			
MC	8/12/10	6	27				77	9	7.0
MC	8/12/10	7	27	78	9	7.0			
MC	8/12/10	10	27				76	8 1/4	8.0
MC	8/12/10	11	27				77	8 1/2	10.0
MC	8/12/10	12	27	79	8 1/4	8.5			

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	8/12/10	14	27				78	8 1/2	8.6
MC	8/12/10	15	27				78	8 3/4	8.7
MC	8/12/10	17	27	80	9	7.4			
MC	8/12/10	18	27	80	8 1/2	8.0			
MC	8/12/10	24	27	79	8 1/2	7.9	80	8 1/2	8.0
MC	8/12/10	26	27				80	8 1/4	6.4
MC	8/24/10	1	4	72	7 3/4	10.0	73	8	10.5
MC	8/24/10	2	4				70	9	8.3
MC	8/24/10	3	4	70	8 1/2	10.0			
MC	9/1/10	1	75	76	9	8.0	76	8 3/4	8.8
MC	9/1/10	2	75				78	8 1/4	7.5
MC	9/1/10	9	75	77	8 3/4	8.0	77	8 1/2	7.2
MC	9/1/10	12	75	-	-	5.8	77	8 1/4	11.0
MC	9/1/10	13	75				76	9	6.6
MC	9/1/10	20	75	74	-	*5.5*	-	9 1/2	5.8
MC	9/1/10	21	75				-	9	4.0
MC	9/1/10	22	75	77	9	8.5	77	8 3/4	8.7
MC	9/1/10	24	75				75	9	5.5
MC	9/1/10	25	75	77	8 3/4	5.5	79	8	6.5
MC	9/1/10	26	75				77	9	9.4
MC	9/1/10	27	75				77	7 1/2	8.7
MC	9/1/10	28	75				77	8	10.6
MC	9/1/10	29	75				80	7	11.0
MC	9/1/10	31	75	80	8 1/2	7.0			
MC	9/1/10	36	75	80	8 3/4	8.2			
MC	9/1/10	37	75				80	8 3/4	7.6
MC	9/1/10	38	75	82	8 1/4	10.5			
MC	9/1/10	40	75				85	7 1/4	10.0
MC	9/1/10	42	75	82	8 1/2	6.8			
MC	9/1/10	44	75				82	8 3/4	14.5
MC	9/1/10	49	75				81	8 1/4	8.8
MC	9/1/10	50	75	84	8	9.5			
MC	9/1/10	52	75				84	8 1/2	7.0
MC	9/1/10	55	75	86	8 3/4	9.0			
MC	9/1/10	58	75	85	8	9.0	82	8 1/2	9.4
MC	9/1/10	66	75	82	8	7.6	80	8 1/2	7.4
MC	9/1/10	68	75				82	8 1/2	9.0
MC	9/1/10	70	75	86	7 1/2	8.0			

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	9/1/10	73	75	83	8 1/4	8.9	83	7 1/2	8.5
MC	9/2/10	1	6				83	6 1/4	7.9
MC	9/2/10	2	6				82	7 1/4	8.5
MC	9/2/10	3	6	85	8 1/4	8,5			
MC	9/2/10	5	6	85	8 1/2	11.0			
MC	9/2/10	6	6				84	9 1/4	8.2
MC	9/10/10	1	10				74	6 3/4	11.0
MC	9/10/10	2	10	73	8 1/2	9.5	75	8 1/4	9.2
MC	9/10/10	3	10	73	8	7.9			
MC	9/10/10	6	10				76	7 3/4	10.6
MC	9/10/10	7	10	78	8	7.6			
MC	9/13/10	1	6				70	6 3/4	9.6
MC	9/13/10	2	6				72	7	11.0
MC	9/13/10	3	6	70	8 3/4	9.0			
MC	9/13/10	6	6	69	8 3/4	7.0	69	8 3/4	8.1
MC	9/14/10	1	12				75	5 1/2	4.5
MC	9/14/10	3	12				76	8 3/4	6.4
MC	9/14/10	4	12	74	9	7.5	74	8 3/4	7.9
MC	9/14/10	5	12				76	9	7.8
MC	9/14/10	6	12				77	8 1/2	10.2
MC	9/14/10	9	12	80	7	10.5	78	8 1/4	11.0
MC	9/17/10	1	25				74	6 1/2	10.8
MC	9/17/10	2	25				75	7 3/4	10.0
MC	9/17/10	4	25	74	8 3/4	9.5	74	9	9.2
MC	9/17/10	6	25				74	9 3/4	8.3
MC	9/17/10	7	25	76	9	9.5			
MC	9/17/10	9	25	75	9 1/4	5.9	74	9	7.2
MC	9/17/10	14	25	76	8 1/4	8.0	77	8 1/2	7.6
MC	9/17/10	16	25				78	8 1/2	9.1
MC	9/17/10	19	25	80	6 1/4	11.0			
MC	9/17/10	21	25				78	8	9.9
MC	9/17/10	22	25	77	8 1/4	7.9			
MC	**9/24/10**	**1**	**14**				**73**	**7 1/2**	**10.4**
MC	9/24/10	2	14				73	8 1/2	9.9
MC	9/24/10	5	14	78	7 3/4	11.0	76	7 3/4	10.4
MC	9/24/10	8	14	78		11.5	77	8 1/2	11.0
MC	9/24/10	13	14	78	8 1/4	9.5	76	8 3/4	9.5

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	9/30/10	1	6				73	8	8.9
MC	9/30/10	2	6	72	9	8.2	73	9 1/4	7.9
MC	9/30/10	5	6	72	8 1/4	7.2			
MC	9/30/10	1	14				78	5 3/4	7.6
MC	9/30/10	2	14	77	8 1/2	10.5	77	8 3/4	10.3
MC	9/30/10	6	14				78	7 3/4	6.1
MC	9/30/10	9	14	78	7 3/4	8.7	78	8 1/2	9.1
MC	9/30/10	12	14				78	9	7.9
MC	9/30/10	13	14	78	8 1/2	8.6			
MC	10/5/10	1	3				67	8 3/4	9.2
MC	10/5/10	2	3	66	8 1/2	6.2	66	9	6.5
MC	10/5/10	3	3	66	8 3/4	6.2			
MC	10/8/10	1	14				63	8 3/4	5.4
MC	10/8/10	2	14				59	9	8.5
MC	10/8/10	3	14				64	9	7.3
MC	10/8/10	8	14	70	9	7.4			
MC	10/8/10	10	14				72	9	7.5
MC	10/8/10	11	14				74	8 3/4	7.5
MC	10/8/10	12	14	74	9	11.0			
MC	10/14/10	1	3	63	8 1/2	8.0	64	8 1/4	7.9
MC	10/14/10	2	3	64	8	9.6	67	7 1/2	9.9
MC	10/22/10	1	10				62	7 3/4	9.6
MC	10/22/10	2	10				64	8 3/4	8.5
MC	10/22/10	3	10	61	9 1/2	9.1			
MC	10/22/10	4	10				65	8 1/2	9.1
MC	10/22/10	8	10	62	8 3/4	8.0			
MC	10/22/10	9	10				64	8 3/4	8.7
MC	10/26/10	1	10				70	7 1/2	10.8
MC	10/26/10	2	10				68	8	9.4
MC	10/26/10	3	10	64	9	10.0			
MC	10/26/10	8	10	70	8 3/4	8.2	69	8 1/4	8.5
MC	12/1/10	1	5				67	8	9.0
MC	12/1/10	2	5	64	8 1/2	8.5	66	8 1/4	8.0
MC	12/1/10	4	5	62	8 1/2	6.8	64	9	7.6
MC	12/2/10	1	4	64	8 1/4	10.0	66	8	9.0
MC	12/2/10	2	4				64	8 1/2	8.5
MC	12/2/10	3	4	61	9	9.0			
MC	1/11/11	1	4				72	7	7.8

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	1/11/11	2	4	72	7 3/4	9.0	74	7 3/4	7.9
MC	1/11/11	3	4	79	7 3/4	8.5			
MC	1/17/11	1	3	63	8 1/2	7.0	63	7 1/2	6.3
MC	1/17/11	2	3	64	9	8.0	63	8 1/2	7.8
MC	2/18/11	1	29				68	7 1/4	7.0
MC	2/18/11	2	29				65	8	8.1
MC	2/18/11	3	29	70	8 1/2	11.5			
MC	2/18/11	6	29	68	7 3/4	10.5			
MC	2/18/11	7	29				66	8 1/2	7.5
MC	2/18/11	9	29	70	9	9.0	71	8 1/4	7.5
MC	2/18/11	11	29				69	8	9.6
MC	2/18/11	13	29	70	8 1/2	11.0			
MC	2/18/11	14	29	64	9	7.4			
MC	2/18/11	17	29				68	8 3/4	8.5
MC	2/18/11	20	29	70	9	8.6			
MC	2/18/11	21	29				70	8 1/4	8.0
MC	2/18/11	24	29	68	8 1/2	10.0			
MC	2/18/11	25	29				68	8 1/2	7.2
MC	2/18/11	26	29	66	8 1/2	9.5			
MC	3/9/11	1	7				69	8	6.2
MC	3/9/11	2	7				72	7	9.0
MC	3/9/11	3	7	72	8	9.0			
MC	3/9/11	5	7	75	9	9.5			
MC	3/9/11	6	7				74	8 1/2	7.2
MC	3/9/11	7	7				72	5 1/4	5.0
MC	4/16/11	1	7				60.5	9	9.0
MC	4/16/11	2	7				63	8 1/2	10.0
MC	4/16/11	3	7	62	8 3/4	8.6			
MC	4/16/11	4	7				62	9	7.8
MC	4/16/11	5	7	61	9	7.0			
MC	4/26/11	1	5	60	8 1/4	10.5	62	9	10.4
MC	4/26/11	2	5				62	8 1/2	9.5
MC	4/26/11	3	5	64	7 1/2	11.0	67	7 1/4	11.0
MC	4/26/11	4	5				60	10	9.5
MC	4/26/11	5	5				-	10 3/4	9.0
MC	5/3/11	1	28				62	9	8.2
MC	5/3/11	2	28				64	9	8.6
MC	5/3/11	4	28	62	9	9.5			

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	5/3/11	6	28	60	9	8.5	63	8 3/4	7.8
MC	5/3/11	11	28				65	9	8.3
MC	5/3/11	14	28	62	9 3/4	7.8			
MC	5/3/11	15	28	63	9 3/4				
MC	5/3/11	16	28	63	9	6.7		8 3/4	
MC	5/3/11	17	28	63	9 3/4	7.6			
MC	5/3/11	18	28	63	9 1/2	7.9	66	9	7.7
MC	5/3/11	19	28	63	9	8.0			
MC	5/3/11	21	28	64	9	7.8	68	9	7.8
MC	5/3/11	23	28				68	7 1/2	9.9
MC	5/3/11	25	28	64	8 1/2	8.6			
MC	5/3/11	26	28				66	8 1/2	7.8
MC	5/13/11	1	6				62	7	9.0
MC	5/13/11	2	6				63	7 1/4	9.0
MC	5/13/11	3	6	62	8 3/4	8.5	63	7	8.3
MC	5/13/11	5	6	65	9	9.5	66	9	9.0
MC	5/16/11	1	29				66	4 1/2	8.5
MC	5/16/11	2	29				65	5	10.0
MC	5/16/11	3	29				63	7 1/4	9.5
MC	5/16/11	4	29	63	9 3/4	8.5			
MC	5/16/11	6	29	64	9 1/4	9.0			
MC	5/16/11	8	29				63	8 1/2	10.0
MC	5/16/11	9	29	63	9 1/2	10.0			
MC	5/16/11	10	29	60	9	9.0			
MC	5/16/11	11	29				62	5 3/4	10.5
MC	5/16/11	12	29				62	7	11.0
MC	5/16/11	13	29	60	9	9.0			
MC	5/16/11	17	29	62	9	10.0			
MC	5/16/11	18	29				61	9 3/4	8.5
MC	5/16/11	22	29	60	9 1/4	8.0			
MC	5/16/11	24	29	62	9 1/4	8.5	61	10	9.0
MC	5/16/11	27	29	60	9 1/4	7.6			
MC	5/27/11	1	81				71	8	8.0
MC	5/27/11	2	81				69	8	8.2
MC	5/27/11	3	81				69	8 3/4	8.2
MC	5/27/11	5	81	67	9	7.0			
MC	5/27/11	9	81				70	8 1/2	8.5
MC	5/27/11	10	81	68	9 1/4	*7.8*			

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	5/27/11	11	81				72	8 1/2	8.5
MC	5/27/11	12	81				70	8 3/4	6.4
MC	5/27/11	15	81					8 3/4	6.6
MC	5/27/11	19	81	70	9 1/2	7.2			
MC	5/27/11	23	81				70	9	9.0
MC	5/27/11	27	81	70	9	8.0			
MC	5/27/11	28	81				69	8 3/4	7.8
MC	5/27/11	30	81				70	9 1/4	8.0
MC	5/27/11	34	81	70	9 1/2	6.1			
MC	5/27/11	35	81	70	9 3/4	8.0			
MC	5/27/11	39	81				72	8 1/4	7.6
MC	5/27/11	41	81				71	9	6.2
MC	5/27/11	42	81	70	9 3/4	8.8			
MC	5/27/11	43	81				72	8 1/2	7.4
MC	5/27/11	46	81				73	9	8.5
MC	5/27/11	50	81	74	8 3/4	*8.8*			
MC	5/27/11	51	81				75	8 1/2	10.6
MC	5/27/11	53	81	72	8 1/2	10.2			
MC	5/27/11	55	81				74	8	10.5
MC	5/27/11	59	81	76	8	14.0			
MC	5/27/11	61	81				74	8	10.8
MC	5/27/11	67	81				75	8 1/2	9.0
MC	5/27/11	70	81	76	8 1/2	10.5	75	8 1/4	10.8
MC	5/27/11	75	81	76	8	7.0			
MC	5/27/11	76	81				75	8	8.5
MC	5/27/11	80	81	78	8 1/2	6.0	75	8 1/4	8.0
MC	6/3/11	1	31				71	8 1/4	9.0
MC	6/3/11	2	31	76	9	8.5	67	9	9.5
MC	6/3/11	5	31				69	9 1/2	10.5
MC	6/3/11	7	31	68	9 1/2	9.2			
MC	6/3/11	10	31				70	9 1/2	9.0
MC	6/3/11	12	31				69	9 1/2	10.0
MC	6/3/11	14	31	70	9	8.8			
MC	6/3/11	17	31	70	9 1/4	6.8			
MC	6/3/11	18	31				71	9	8.7
MC	6/3/11	22	31				75	9 1/2	8.2
MC	6/3/11	25	31	72	10	7.5			
MC	6/3/11	28	31				72	9	9.5

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	6/3/11	29	31	70	9 1/2	6.9			
MC	6/10/11	1	20				75	9	8.3
MC	6/10/11	2	20				75	9 1/4	8.6
MC	6/10/11	3	20	71	9 1/4	8.5			
MC	6/10/11	11	20				77	9 1/4	9.4
MC	6/10/11	13	20	76	9 1/4	8.5			
MC	6/10/11	17	20	72	8 3/4	8.0			
MC	6/10/11	18	20				76	9	9.0
MC	6/10/11	19	20				76	8 3/4	9.2
MC	6/13/11	1	19				70	8 3/4	11.0
MC	6/13/11	2	19	63	9 1/2	8.0	66	10	7.8
MC	6/13/11	3	19				66	9 1/2	7.4
MC	6/13/11	4	19				66	8 3/4	8.2
MC	6/13/11	8	19				69	8 1/2	8.0
MC	6/13/11	9	19	64	8 3/4	*7.4*			
MC	6/13/11	12	19	68	9	9.0			
MC	6/13/11	14	19				70	9	7.7
MC	6/13/11	15	19	66	8	7.6			
MC	6/17/11	1	31				73	9	10.8
MC	6/17/11	2	31		9	*5.6*	73	9 1/4	6.0
MC	6/17/11	5	31				76	9	9.9
MC	6/17/11	7	31	72	9	8.8	75	9 1/2	10.0
MC	6/17/11	13	31	72	10	5.3			
MC	6/17/11	15	31				75	10 1/4	7.5
MC	6/17/11	18	31	71	10.5	5.7			
MC	6/17/11	19	31	71	9 1/2	7.4			
MC	6/17/11	20	31				75	9 3/4	10.0
MC	6/17/11	21	31				74	9 3/4	6.2
MC	6/17/11	25	31	73	8 3/4	7.4	76	8 3/4	8.0
MC	6/17/11	27	31	71	9	10.5			
MC	6/17/11	28	31				73	9 1/2	6.6
MC	6/21/11	1	13	69	7	9.2	74	8	10.6
MC	6/21/11	2	13				73	8 3/4	9.3
MC	6/21/11	3	13	70	8 1/4	8.0	74	8 1/4	8.0
MC	6/21/11	8	13	72	8	7.4			
MC	6/21/11	10	13				75	9	7.3
MC	6/21/11	11	13	71	8 3/4	7.7			
MC	6/21/11	13	13				76	8 1/4	8.1

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	6/24/11	1	13				71	8	9.9
MC	6/24/11	2	13				71	9	9.6
MC	6/24/11	4	13	66	7	8.5			
MC	6/24/11	6	13				73	7	9.5
MC	6/24/11	7	13	70	7 3/4	10.5	73	7 1/2	10.6
MC	6/24/11	10	13	70	9	8.5			
MC	6/24/11	13	13				76	8	10.8
MC	6/25/11	1	14				70	9	10.0
MC	6/25/11	2	14	70	9 3/4	10.5	68	9	10.5
MC	6/25/11	5	14				70	9 1/4	8.2
MC	6/25/11	6	14	71	8 1/2	7.5	72	8 1/4	7.4
MC	6/25/11	12	14	74	8 3/4	6.0	76	9	6.8
MC	6/25/11	14	14	74	8 1/2	7.5	77	8 3/4	8.0
MC	6/28/11	1	59				76	8 1/2	8.6
MC	6/28/11	2	59	76	8 1/2	9.2			
MC	6/28/11	6	59				78	9	10.1
MC	6/28/11	9	59		9	10.5			
MC	6/28/11	11	59	77	9 3/4	8.5			
MC	6/28/11	15	59				78	9 1/4	9.4
MC	6/28/11	18	59				79	9	7.7
MC	6/28/11	19	59	79	9 1/4	10.0			
MC	6/28/11	22	59	80	9 1/4	9.0			
MC	6/28/11	24	59				80	9	9.8
MC	6/28/11	28	59				74	8 3/4	8.9
MC	6/28/11	30	59	76	8 3/4	9.0			
MC	6/28/11	32	59				75	9 1/4	8.5
MC	6/28/11	35	59	75	9 1/2	10.5			
MC	6/28/11	36	59	78	9 1/4	8.4	76	9 1/4	8.2
MC	6/28/11	44	59				76	9	5.8
MC	6/28/11	45	59	78	8 1/4	13.0	77	8 3/4	12.0
MC	6/28/11	46	59				77	8 1/2	10.0
MC	6/28/11	48	59	76	7 1/2	7.4	75	8 3/4	8.0
MC	6/28/11	54	59				76	9	7.9
MC	6/28/11	55	59	78	7 1/2	9.0			
MC	6/28/11	58	59				76	8 3/4	7.1
MC	6/28/11	59	59	76	8	7.9			
MC	7/9/11	1	19				76	8 1/4	10.8
MC	7/9/11	2	19	72	8 1/2	9.0	75	9	9.2

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	7/9/11	4	19				78	9 1/4	8.6
MC	7/9/11	6	19				79	6 1/2	10.8
MC	7/9/11	7	19	76	8 1/2	9.0		9 1/4	
MC	7/9/11	8	19				81	8	8.6
MC	7/9/11	9	19				81	7	7.5
MC	7/9/11	11	19	78	8	7.2			
MC	7/9/11	12	19				81	8 3/4	7.0
MC	7/9/11	16	19	80	8 1/4	5.9			
MC	7/9/11	17	19				81	8 1/4	6.9
MC	7/11/11	1	18				78	8 1/2	7.0
MC	7/11/11	2	18				79	8 1/2	9.0
MC	7/11/11	4	18	76	9	9.0			
MC	7/11/11	6	18	78	8	8.5			
MC	7/11/11	7	18				82	8 1/2	9.4
MC	7/11/11	10	18	78	9 1/4	8.5			
MC	7/11/11	13	18				83	8 1/2	7.0
MC	7/11/11	16	18	81	8	10.5	84	8 1/2	9.6
MC	7/13/11	1	18				84	8 1/4	7.3
MC	7/13/11	2	18				85	8 1/2	7.0
MC	7/13/11	3	18	81	8 3/4	8.0			
MC	7/13/11	4	18				85	8 1/2	8.2
MC	7/13/11	9	18	80	9	6.2	84	9	5.9
MC	7/13/11	10	18				86	8 3/4	7.8
MC	7/13/11	11	18	83	9	5.7	84	9	5.5
MC	7/13/11	12	18	82	8 3/4	10.5	86	9	9.5
MC	7/13/11	13	18				86	9	7.0
MC	7/13/11	14	18				86	9	9.5
MC	7/13/11	16	18	85	8	11.0	87	8 1/2	9.3
MC	7/13/11	17	18				86	9 1/4	11.5
MC	7/13/11	18	18				85	9	8.9
MC	7/15/11	1	14				78	8 1/4	8.9
MC	7/15/11	2	14				79	9 3/4	8.2
MC	7/15/11	3	14				81	10	7.2
MC	7/15/11	4	14				79	10	7.6
MC	7/15/11	5	14				81	9 1/2	8.2
MC	7/15/11	6	14				82	8 3/4	9.1
MC	7/15/11	7	14	82	8 3/4	7.5	82	9	7.2
MC	7/15/11	9	14				82	9	8.4

Concrete Samples				Owner Acceptance			Quality Control		
Mix Type	Date	Load #	# of Loads	conc temp	slump	Air	conc temp	slump	Air
		Specifications:		50-90	5-9	6-11	50-90	5-9	6-11
MC	7/15/11	10	14	81	9	9.0			
MC	7/15/11	12	14				84	8 1/2	10.5
MC	7/28/11	1	13				78	8 1/2	8.4
MC	7/28/11	2	13	77	10	8.6	79	9	8.8
MC	7/28/11	3	13				80	9	9.5
MC	7/28/11	7	13	80	9	8.0			
MC	7/28/11	8	13				83	9	7.9
MC	7/28/11	11	13	82	8 1/2	8.5	85	8 3/4	9.0
MC	8/1/11	1	13				84	7	8.9
MC	8/1/11	2	13	79	9 1/2	9.0	82	9	9.5
MC	8/1/11	3	13						
MC	8/1/11	4	13				85	9	8.4
MC	8/1/11	6	13						
MC	8/1/11	7	13	82	9 3/4	6.2	86	9 3/4	7.3
MC	8/1/11	8	13	82	9 1/2	6.8	86	9	7.3
MC	8/1/11	9	13	82	9	6.0	86	9	6.0
MC	8/1/11	10	13	83	8 1/2	9.5	86	7 1/2	10.0
MC	8/1/11	11	13				86	8 1/2	7.0
MC	8/1/11	12	13	82	9 1/4	9.2			
MC	8/2/11	1	20				84	5 1/2	8.6
MC	8/2/11	2	20				80	9	8.6
MC	8/2/11	3	20				82	8 1/4	7.2
MC	8/2/11	5	20	80	9	9.0	83	9	9.0
MC	8/2/11	6	20				83	9	8.6
MC	8/2/11	10	20	80	9 1/4	8.0			
MC	8/2/11	15	20	80	9	9.0	83	9	8.6
MC	8/2/11	17	20	80	8 3/4	9.0	84	8 3/4	9.1
MC	8/25/11	1	20				78	8	10.0
MC	8/25/11	2	20				78	9	7.6
MC	8/25/11	3	20	75	9	6.4			
MC	8/25/11	8	20	81	9 1/4	6.8	80	10	7.2
MC	8/25/11	9	20	78	9	8.0		9	8.0
MC	8/25/11	10	20					9 1/2	7.8
MC	8/25/11	13	20					8 1/2	7.0
MC	8/25/11	15	20	79	9	8.0			
MC	8/25/11	16	20				83	8 1/4	8.2
MC	8/25/11	17	20	79	8 1/2	10.0			

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