PROJECT SUMMARY REPORT 1721-S

EFFECTIVENESS COMPARISON OF TXDOT QUALITY CONTROL/QUALITY ASSURANCE AND METHOD SPECIFICATIONS

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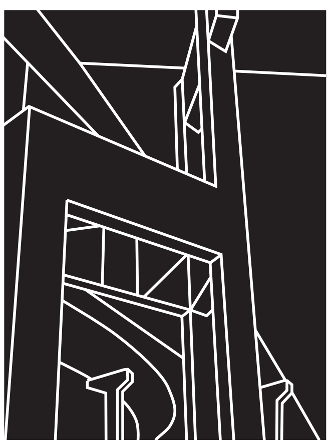

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16. Abstract

This is the first and final report for research project 0-1721, "Effectiveness Comparison of TxDOT Quality Control/Quality Assurance and Method Specifications." This study was established and sponsored by TxDOT to evaluate the quality of the hot mix asphalt concrete produced under quality control/quality assurance (QC/QA) specification item 3063. During the first phase of this project, an extensive amount of technical and numerical information was gathered and analyzed. During the second phase of this project, various other activities were carried out, including a survey of other states to assess their approach in developing and implementing QC/QA specifications, a physical survey of QC/QA and non-QC/QA specification projects in Texas, and a limited evaluation of the cost of the projects. The report presents the results, findings, conclusions, and recommendations based on the collected information and on the work performed during the course of this research project.

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by

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Project Summary Report Number 1721-S

Research Project 0-1721

Project Title: "Effectiveness Comparison of Former HMAC Specifications and the Most Current QC/QA Specification for HMAC"

Conducted for the

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DISCLAIMERS

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PREFACE

This is the first and final report for research project 0-1721, "Effectiveness Comparison of TxDOT Quality Control/Quality Assurance and Method Specifications." This study was established and sponsored by TxDOT to evaluate the quality of the hot mix asphalt concrete produced under quality control/quality assurance (QC/QA) specification item 3063. The research period for the project was scheduled for 1 year, September 1996 through August 1997. During the first phase of this project, conducted between September 1996 and February 1997, an extensive amount of technical information and numerical information was gathered and analyzed. During the second phase of this project, various other activities were carried out, including a survey of other states to assess their approach in developing and implementing QC/QA specifications, a physical survey of QC/QA and non-QC/QA specification projects in Texas, and a limited evaluation of the cost of the projects. This report presents the results, findings, conclusions, and recommendations based on the collected information and on the work performed during the course of this research program.

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The authors also acknowledge the efforts of Sean Lin, who was highly involved in carrying out the required statistical analysis of the data. The support of the Center for Transportation Research is also greatly appreciated.

TABLE OF CONTENTS

IMPLEMENTATION STATEMENT

The results of this research study indicate that, in general, the quality control/quality assurance (QC/QA) specification item 3063 has not been serving its intended purpose. Based on the findings of this research, there are problems associated with random sampling, control parameters, payment levels, and the quality of the final product. These problems need to be addressed effectively in a modified QC/QA specification.

As a result of this research program, and having taken into account the highly valuable comments received from district personnel and contractors, a number of modifications are proposed. It is expected that incorporating these changes into the QC/QA specifications will improve both the quality and effectiveness of these specifications. The proposed modifications have been identified and presented in this research report (1721-S). Examples include utilization of continuous pay factors, an improved procedure for determination of pay factors, a sampling procedure, and a designation of the job mix formulas (JMFs).

The following is a list of implementation recommendations:

1. It is highly recommended that continuous pay factors be used instead of stepped pay factors. It is also recommended that payments be decided based on percent conforming or percent defective material rather than on mean absolute deviations (MAD), given the shortcomings of the MAD procedure. The procedure outlined in Chapter 5 is proposed for this purpose.

2. It is important that efforts be made to ensure proper random sampling. At this point, there is no assurance that sampling is truly random, and there is no assurance that test results are from sampled specimens. Appropriate and clear guidelines are essential in this respect.

3. It is recommended that different options for lot size be eliminated and only one option, preferably one similar to option 2 of item 3063, be utilized. In a similar manner, it is recommended that JMF 1 and JMF 2 be combined as a single job mix formula (JMF).

4. All the hot mix asphalt concrete (HMAC) produced and placed should be subjected to the same requirements, including the first and last days of production and paved shoulders.

5. A form of quality control plan should be made a part of the QC/QA specifications developed by the Department. There are a number of usable forms that may be used as a guide, two of which are illustrated in the body of this report. As an aid, a manual or guide on the interpretation and use of QC/QA specifications can be prepared to provide needed information to all personnel involved in the design, use, and control of construction performed under these types of specifications. There are guides available from National Cooperative Highway Research Program (NCHRP) projects and information available from other states to help in this regard. Because TxDOT is

implementing QC/QA specifications in different items of construction (i.e., asphalt, portland cement, and concrete), it is recommended that short courses be conducted to aid with implementation of the specifications utilizing the manuals recommended above.

SUMMARY

The quality control/quality assurance (QC/QA) specifications have been in use by the Texas Department of Transportation (TxDOT) since 1993. Within the first 2 years of implementing the new specifications, concerns were raised by Department personnel regarding the quality and cost effectiveness of the products delivered under QC/QA specification item 3063, “Quality Control/Quality Assurance of Hot Mix Asphalt,” compared with the projects constructed under method specification item 340, “Hot Mix Asphaltic Concrete Pavement.” This research project was sponsored and initiated by the Department to address this very important issue.

In the first phase of the project, attempts were made to address existing problems by collecting technical information and performing numerical analyses, and by comparing projects built under the two sets of specifications. The study indicates that, statistically, there is no significant difference between the uniformity of the control parameters (air voids, asphalt content, gradation) of the two specifications. However, simple and direct comparison of statistical parameters, without any hypothesis testing, indicates less uniformity in the method specification projects, as compared with the QC/QA projects.

Evaluation of the current specification and the comments received from district personnel and contractors indicates problems with random sampling, control parameters, payment levels, and final quality of the product. Sampling of production and placement lots may not be truly random, given the possibilities for manipulating time and location of sampling. The payment levels are too wide on asphalt content and gradation, resulting in bonus payments for a mediocre product. Another significant problem with the payment method is that it is based on step function. Such a method has the potential to result in numerous problems. A new method is proposed to determine payments based on percent conforming material and on statistical concepts. Continuous function for pay factors is highly recommended for this purpose. Including other factors, such as voids in the mineral aggregate (VMA) and laboratory density, as pay factors should be seriously considered, insofar as the existing factors may not be sufficient to identify the true performance of the final product.

During phase two of the program, three main activities were conducted: a survey of other states regarding their methods of carrying out QC/QA specifications, a visual survey and field comparison of projects built under QC/QA and non-QC/QA specifications, and a brief analysis of the project costs.

Surveying a large number of the states that utilize QC/QA specifications indicated that all surveyed used asphalt content and in-place density as pay factors. However, in regard to other factors, they differed, using such parameters as gradation for specific sieves, laboratory density, and VMA. While the majority utilized a bonus/penalty approach (incentive/disincentive), a few included only penalties for poor-quality jobs (disincentive) and no bonus for high-quality jobs.

A visual survey of the constructed projects indicates that at this time, in general, QC/QA projects are as good as the non-QC/QA projects. Therefore, no conclusion could be drawn on distinct superiority or inferiority when comparing the two sets of specifications. It should be noted that the results of such comparisons may be influenced by the young age of the QC/QA specification projects versus non-QC/QA projects.

With respect to the project cost, the trend of the average bid price as a function of time indicates that starting in mid-1993 there has been approximately an 8 percent increase in the bid price of hot mix asphalt concrete. However, direct contact with district personnel indicates that there is no consistent pattern in decrease or increase of the cost. While some of the increase starting in 1993 could be associated with the start of implementing QC/QA specifications, a portion of such an increase can be attributed to the increase in the aggregate price.

CHAPTER 1
INTRODUCTION

1.1. General

Providing the general public with high-quality pavements at a reasonable cost is certainly the intent of any state highway agency (SHA). To this end, the transportation departments of individual states, along with the Federal Highway Administration (FHWA), have pursued through years an effort to find and utilize the best means of ensuring construction of high-quality pavements. Pavement construction specifications have gone through constant modifications to achieve the highest possible quality of finished product while maintaining reasonable costs. Within the last few years, a number of state highway agencies have moved toward statistically based quality control/quality assurance (QC/QA) specifications. The use of such specifications is growing rapidly and is gradually gaining wide acceptance within most state highway agencies.

For its part, the Texas Department of Transportation (TxDOT), one of the pioneers in seeking better ways of achieving better pavements, has implemented a new set of specifications in lieu of the method-type specifications. The framework for the new specification for production and placement of hot mix asphalt concrete was set in 1990. This specification was originally proposed under the title "Special Specification Item 3007, Quality Control/Quality Assurance of Hot Mix Asphalt." During 1993, a number of trial projects were built according to this QC/QA specification. Full implementation of specification item 3007 started in September 1994. It was later modified to some extent and was delivered under a new number: "Special Specification Item 3063" *(1)*, which was incorporated into construction jobs starting in March 1995. Based on the experience obtained within the first year of construction, special provisions were made to this specification and put into effect as of March 1996.

A number of pilot projects were built under QC/QA specification item 3063 before its full implementation beginning in March 1995. After constructing a number of hot mix asphalt pavements according to special specifications 3007 and 3063, concerns were expressed by some TxDOT personnel about the quality and cost of the constructed pavements. Questions were raised regarding the level of success of the new specifications and whether TxDOT had been able to reach its goals through implementing the new QC/QA specifications. Overall, the effectiveness of the new specifications was questioned and, as a result, the responsible authorities in the Department decided to investigate the effectiveness of the new specification compared with the method specification item 340.

In brief, an essential need was recognized to investigate the net effects (both encouraging and discouraging) on asphalt pavement quality and cost as a result of utilizing the new set of specifications. In this regard, a research project was sponsored by TxDOT and conducted by the Center for Transportation Research of The University of Texas at

Austin. The research, aimed at addressing these issues, began in September 1996 and ended in August 1997.

This report contains the final information, results, and findings for the research project conducted to evaluate the effectiveness of the QC/QA specifications for hot mix asphalt concrete. The following subjects are presented and discussed in this report.

- Results from interviews with personnel from TxDOT districts, as well as contractors, on the issue of effectiveness of the QC/QA specifications and the quality of the delivered product,
- Comparisons of projects built under non-QC/QA specifications and the various QC/QA specifications using statistical analysis of the collected data from a large number of projects evaluated in eight districts,
- Analysis of the current procedure for determination of pay factors,
- Recommendations to improve the specification and a new procedure for determination of pay factors,
- Results of surveying other states on their QC/QA specifications,
- Physical surveys of QC/QA and non-QC/QA projects, and
- Brief analysis of the cost effectiveness.

During the period of this research to evaluate special specification item 3063, "Quality Control/Quality Assurance of Hot Mix Asphalt," based in part on initial observations and input, TxDOT developed and initiated a new version of the QC/QA specification (special specification item 3022), under which a number of projects were built during 1997.

The major differences between special specification items 3022 and 3063 are:

- Clarification of intent, procedures, and responsibilities;
- Use of in-place and laboratory densities as pay factors, rather than in-place density, asphalt content, and gradation (deviations in percent passing 0.075 and 2 mm sieves);
- Use of a continuous pay factor function instead of a stepped function; and
- Quality assurance tests on which payments are based are performed by TxDOT instead of by the contractor.

The need for making these significant changes was recognized by TxDOT based on its experience with QC/QA special specification items 3007 and 3063.

Significant district and industry input was obtained through four regional meetings with TxDOT personnel and one meeting with statewide industry members held as part of this project. The research study was focused on evaluating the effectiveness of QC/QA specification 3063. No analysis or evaluation of special specification item 3022 was conducted during the course of this research program.

1.2. Different Specifications and Related Terminology

A construction specification should be practical to implement, and should be developed with the idea of achieving a high-quality result (constructed pavement) at a reasonable cost. As far as the quality of the final product is concerned, the level of responsibility of the state highway agency (i.e., the buyer of the product) and the contractor (i.e., the seller of the product) varies. This level of responsibility depends on the type and limitations set forth in the specification. The following terms are applied to different specifications:

- Method Specification
- Statistical QC/QA Specification
- End Result Specification
- Performance-Related Specification
- Performance-Based Specification
- Warranty Specification

The differences between some of these terms are clear and are applied to different types of specifications (for example, method specification versus performance-based specification). However, the differences between others are not so distinctive (for example, the difference between a performance-related specification and performance-based specification). In these cases, the terms very frequently are used interchangeably and, consequently, cannot always be distinguished.

In method specifications, the contractor is provided with specific details on the materials, design, and type and method of construction. In this way, the specifications are too restrictive to allow a contractor flexibility in making decisions about the design and/or process of the pavement construction. There is not enough incentive for the contractor to be innovative in improving the product quality.

The term *end result specification* is often used to refer to a specification in which certain parameters believed to influence performance are used as criteria to judge the quality of the product and to make the payment. The contractor is responsible for the quality of the control parameter (end result) based on which the payment is decided. As an example, deviation of such parameters as asphalt content, gradation, and air void from target values can be used as end result parameters. In such a specification, in contrast to method specifications, the contractor is left with more responsibility and latitude in using his ingenuity to improve the product quality. However, in an end result specification, the end may be defined at any of the following levels and stages:

Level 1) The end result will be the quality of the original materials and the deviations of some material parameters from certain control limits, as well as the quality of the compacted pavement. Parameters such as asphalt content and gradation deviations from target values, as well as air void levels of constructed pavements, are some examples of this kind of end result. In this case, it is believed that good control on the original materials and air void level will result in high-quality pavement. The limits on parameters for this case can be established based on historical data as well as on the relationship of the parameters with engineering properties of the compacted mixture.

Level 2) The end result will be the quality of the compacted material right after construction. In this case, it is believed that good controls on the material properties, and the method of construction in the beginning, will result in good performance in the long run. Such control requires obtaining samples of the prepared material, preparing compacted specimens, and testing those specimens for engineering properties. Deviation of the measured properties from certain criteria will be the basis for judging performance and making the payment. Obviously, it is crucial that the compacted samples be representative of the constructed pavements. It is necessary that tests be performed on the cores from the pavement. Also crucial is the need to define what properties are used for measurement and what are the acceptable limits and ranges for these properties.

Level 3) The end result will be the performance quality and developed distresses at the end of the design life based on predictions from reliable models. The results from these predictions, along with life-cycle cost analysis, will form the basis for the level of payment.

Level 4) Ideally, the end result will be at the end of the design life of the constructed pavement or overlay (i.e., how well the asset has delivered its service). In this case, the pavement or overlay quality at the end of its service life, based on a certain assessment, will be the end result.

As far as the quality of the end product is concerned, as an end result specification moves from level 1 to level 4, the responsibility of the agency is decreased and that of the contractor is increased. Existing specification item 3063 falls in the first category (level 1), while warranty specifications, in which the contractor carries the highest level of responsibility, belong to level 4 of an end result specification. In the case of a warranty specification, the contractor is ultimately responsible for acceptable performance of the pavement, and in this regard, he chooses the materials, design, and construction equipment and method. Thus, contractors are left with sufficient leverage and latitude for using their ingenuity and expertise to deliver a high-quality product.

Performance-related and performance-based specifications fall between the two extremes of method and warranty specifications, and correspond to the preceding levels 2 and 3. Some distinguish between the two levels by suggesting that a performance-related specification requires measurement of (and establishing limits on) properties that are not direct measures of performance, but are related to performance measures. Measurements of quality and quantity of original materials, or measurements of engineering properties of the compacted mixture, are one example.

A statistically based QC/QA specification applies to any specification in which statistical concepts and methods are incorporated into the quality assurance process. Statistical quality assurance (SQA) is part of a well-planned program in which quality is judged on the conformance of the results with established levels for certain parameters based on statistical concepts. Applying statistical concepts to quality control of paving materials has been widely covered in literature *(2, 3, 4, 5)*.

1.3. TxDOT Current QC/QA Specification

The current TxDOT specification item 3063 is a statistically based QC/QA specification. In this specification, decisions regarding the material selection, mix design, quality control, and quality assurance testing are left with the contractor, though the Department is still responsible for the quality of the final product. In regard to the level of responsibility, the contractor is given more flexibility than would be available under the traditional method specification. However, this level of responsibility is still considerably farther from the level in a performance-based or warranty specification. Payment to the contractor is based on deviations from target values on asphalt content, gradation, and air voids, with the idea that excessive deviations from these parameters will adversely affect the performance. Thus, there is no direct measurement or prediction of performance, and in this regard TxDOT is accepting responsibility.

In brief, there are a number of essential differences between this specification and the former method specification:

- The contractor takes part in conducting most of the laboratory tests.
- Results from quality assurance tests conducted by the contractor are used to determine specification compliance as well as payment levels.
- Verification testing by TxDOT is used to verify the accuracy of the contractor's test results.
- Referee testing by TxDOT is used to resolve differences between the contractor and the engineer's test results.
- Payment includes bonuses and penalties based on the test results.
- All sampling and testing is conducted by the personnel certified by the Materials and Tests Division.

The shift to the QC/QA specification that resulted in the preceding differences was driven by the need for transferring more responsibility to the contractor and reducing the required department manpower (while obtaining a high-quality product).

1.4. Historical Background

The move toward QC/QA specifications in highway construction is motivated by the desire to achieve the highest quality of the finished product while maintaining reasonable costs. Quality is judged by the accuracy and precision of selected properties of the finished product (gradation, asphalt content, and air voids) and also by the end result, which is satisfactory pavement performance. Accuracy is measured in terms of the proximity of average measured values to true values. Precision is measured in terms of variability of measured values. Because a QC/QA specification must communicate to the contractor in a clear and unambiguous manner exactly what is wanted, various statistical measures provide a practical and convenient way to describe the desired end result. In QC/QA specifications, basic statistical principles are used so that the contractor is responsible for controlling the construction process (quality control), while the specifying agency is responsible for judging the acceptability of the finished product (quality assurance).

Prior to the advent of QC/QA, the system utilized by TxDOT to construct asphalt concrete involved rigid control by a decentralized but highly qualified cadre of engineers and technicians. Essentially, TxDOT rented contractors, personnel, and equipment for asphalt concrete construction and largely accepted responsibility for the consequences. This approach resulted in a transportation system that was the envy of most highway agencies and established TxDOT engineering and technical professionals as being among the elite of their profession.

By the early 1980s, however, TxDOT began to experience a declining reserve of veteran engineering and technical professionals. It became increasingly difficult for TxDOT personnel to adequately perform their traditional function of rigorous job control.

The first efforts in QC/QA in Texas were pioneered by Burnett (*6*) in the early 1980s. While in the Odessa District, he developed a new method of specifying asphalt concrete construction. While not strictly a statistically based QC/QA specification, Burnett's specification differed remarkably from TxDOT's prior methods of controlling asphalt concrete construction. For the first time, TxDOT personnel relinquished some of their strict control of asphalt concrete construction, with contractors subjected to an evaluation of the "end result" of their work. In effect, contractors were, for the first time, more responsible for the final quality of their product. As might be expected, Burnett's specification was contentious, not only among those in the hot mix industry, but also among some in TxDOT as well.

While Burnett's specification is no longer used, his efforts had a profound effect on TxDOT and the hot mix industry in Texas. As evidence, the technical session of the Texas Hot Mix Asphalt Pavement Association's 1987 meeting was singularly devoted to statistically based QC/QA (*2*). For the first time, TxDOT and contractor personnel were jointly exposed to statistical quality control principles. A significant result of that meeting was that the TxDOT Materials and Tests Division began measuring the precision of its standard test methods, a key ingredient to the development of statistically based specifications.

By the early 1990s, TxDOT began concerted efforts to develop and implement a statistically based QC/QA specification for asphalt concrete construction. A TxDOT team was charged with bringing such a specification to fruition. This team mobilized experience within and outside of Texas on the issue of QC/QA. The final result of the team's efforts was a statistically based QC/QA specification that has been implemented by TxDOT. Not only did this group develop the written specification, their efforts also spawned many of the ancillary initiatives that were necessary for implementation of the specification.

For example, a key element of TxDOT's QC/QA specification was a systematic method of ensuring that TxDOT and contractor personnel were qualified to conduct QC/QA testing. This was accomplished by the development of a certification center supported by TxDOT and operated by the Texas Hot Mix Asphalt Pavement Association. This center is charged with evaluating and certifying the laboratory proficiency of TxDOT and industry personnel. By being "certified," these personnel are then qualified to perform testing on TxDOT projects. This center and TxDOT's approach have become a model for other states and industry groups. Most recently, the Colorado Department of Transportation and the Colorado Asphalt Pavement Association developed a similar system.

There has been much experience gained in the 3 to 4 years that TxDOT has used QC/QA principles. A clear benefit has been that hot mix contractors have taken charge of the quality of their product. Some TxDOT professionals have observed that QC/QA has forced the industry "to learn the technical aspects of their business." Contractors have learned principles of quality control and have developed laboratory facilities to measure quality. Implementation of QC/QA caused TxDOT to closely examine many of its test methods for clarity, effectiveness, and precision. Clearly, improved test methods have resulted. The sentiment of TxDOT and industry officials regarding QC/QA seems to be one of cautious optimism.

Even with these benefits, QC/QA remains to some TxDOT and industry personnel a contentious issue. A complaint among some TxDOT engineering professionals has been: "We awarded a bonus on a project, but it was not a quality pavement." At least in some cases data have suggested that contractors have systematically increased asphalt content as a means of facilitating compaction, with an attendant bonus paid for in-place density. Some contractors only reluctantly develop laboratory facilities and have complained of the cost of sending laboratory personnel to Austin to be certified.

1.5. Research Approach

A series of key activities was undertaken to achieve the goals of this research project. The first important issue was to investigate and identify possible problems associated with the existing QC/QA specification. In this regard, the project was carried out in two phases, as described below.

1.5.1. Phase One

1. Review of the QC/QA specifications (items 3007 and 3063)
2. Collection of existing documents on comments and concerns expressed by TxDOT and contractor personnel in regard to the QC/QA specification
3. Contact and interview with district personnel
4. Contact and interview with construction contractors

5. Contact with states that have been implementing QC/QA specifications
6. Collection of numerical data on field projects constructed under the QC/QA specification
7. Visual inspection of several projects at the time of construction

1.5.2. Phase Two

The second phase of the project included analysis of the collected information and data. Such analysis included studying the concerns and comments expressed by TxDOT and the contractor personnel, statistical analysis of the collected data, and comparing the results and pavement performance with those from the method specification (item 340).

Chapter 2 describes the activities and tasks conducted during the course of the research program. It also includes the information from interviews and contacts with TxDOT personnel, the contractor, and the states. Chapter 3 consists of analysis and comparison of data collected from projects constructed under different specifications. Chapter 4 contains information obtained from surveying projects. Suggested solutions and modifications are presented in Chapter 5. Finally, conclusions and recommendations are explained in Chapter 6. Specific comments made to the research team by TxDOT and contractors are presented in Appendix A. Examples of statistical analysis of the data are covered in Appendix B. Appendix C includes data obtained from visual surveys of the constructed projects.

CHAPTER 2
RESEARCH ACTIVITIES

2.1. General

The first step toward achieving the goals of the research project was identifying concerns and problems associated with the quality control/quality assurance (QC/QA) specification. In this regard, the following actions were undertaken during the first phase of the research:

- Collection of existing documents on comments and concerns expressed by TxDOT and contractor personnel in regard to the QC/QA specification
- Contact and interview with district personnel
- Contact and interview with construction contractors, producers, and suppliers
- Contact with states that have been implementing QC/QA specifications
- Collection of construction data for projects built under different specifications
- Statistical analysis of construction data from projects built under QC/QA and non-QC/QA specifications

The second phase of the program focused on the following activities:

- Survey of other states in regard to QC/QA specifications
- Visual survey of QC/QA and non-QC/QA projects
- A limited analysis of the cost effectiveness of QC/QA specifications

2.2. Collection of Existing Documents

Existing documents on QC/QA specification were obtained from the TxDOT audit office. The audit programs were performed from August 1995 to January 1996 in twenty of the twenty-five districts. Interviews were conducted with the Materials and Tests Division personnel, and in the districts with directors of construction, laboratory engineers/supervisors, and personnel from area offices. The general findings from these audit programs can be summarized as follows:

- A more uniform quality product is achieved through utilization of the QC/QA specification.
- Inspection by TxDOT personnel is reduced.
- The amount of testing conducted by Department personnel is reduced compared with the amount of testing prescribed in the previous specification.
- TxDOT personnel perform more verification tests than the minimum required by specification.

- There have been some cases where the projects constructed under QC/QA projects have failed, but they passed the specifications and the contractor has been paid a bonus for them.
- There is a large volume of paperwork associated with the new specification.
- The new specification is inappropriate for small jobs.
- There appears to be an inconsistency in terminology among the QC/QA specifications.

General recommendations suggested by personnel, based on the audit program, are as follows:

- Streamlining and standardizing the paperwork in an attempt to decrease the volume, and increase the accuracy of reporting the results and determining pay factors,
- Tightening the ranges for the specification parameters, and
- Using a pay factor of 1 for small jobs.

2.3. Meeting with District Personnel

2.3.1. The Need for Meetings

The researchers strongly believe that the people who are directly in contact with different aspects of the pavement construction are the ones who best understand the existing problems and know what is needed to improve the quality.

Initially it was thought that in the interest of obtaining a faster solution without duplicating previous efforts, information already obtained by TxDOT could be used as the basis for evaluating the QC/QA specification. Information provided by the Materials and Tests Division was to be reviewed, and recognized problems in both the QC/QA specification item 3063 and the original hot mix asphalt concrete (HMAC) specification item 340 were to be evaluated and catalogued. In an early organizational meeting with Project Director Richard Skopik, Project Coordinator David Head, Materials and Tests Bituminous Engineer Maghsoud Tahmoressi, and the research study team it became apparent that a more detailed and firsthand approach was needed before the true depth of any existing problems could be recognized and addressed.

A construction season had already ended after completion of the audit office interviews and before initiation of this research project. As mentioned before, as part of the research program there was a definite need for direct contact with the district personnel to obtain their opinions on the effectiveness of the QC/QA specification, considering the fact that a large number of new projects were built after the interviews.

2.3.2. Organizing Meetings

The project director (PD), working closely with the research team, arranged for the four planned regional meetings. The director of this research project played a key role in organizing and establishing these meetings. The meetings were held with personnel of different districts. District laboratory engineers and technicians, directors of construction and materials and tests divisions, and other authorities who have been implementing the QC/QA specifications participated and met with the project researchers. The dates of the meetings and the participating districts are indicated in the following table:

Meeting No.	Location	Date	Participating Districts
1	Tyler	9/30/96	Atlanta, Lufkin, Paris, Tyler
2	Corpus Christi	10/1/96	Corpus Christi, Houston, Laredo, Pharr San Antonio, Yoakum
3	Ft. Worth	10/7/96	Austin, Beaumont, Brownwood, Childress, Dallas, Waco, Wichita Falls, Fort Worth
4	Odessa	10/9/96	Abilene, Amarillo, El Paso, Lubbock, Odessa, San Angelo

2.3.3. General Comments

Many comments voiced at these meetings were similar to those presented in the documents received from the audit office. However, there were additional issues introduced that were based on experience with the QC/QA specification and on the construction of a larger number of projects. While there were many problems common to all regions of the state, some did appear to be regionally oriented. This was expected to some extent, owing to the many varied environmental conditions existing in the state. In addition, many of the comments or problems discussed dealt with factors outside the scope of this study; these will be included separately for the benefit of TxDOT.

In most cases, the personnel expressed dissatisfaction with specification item 3063, though a few comments indicated some improvements. In general, the expressed problems were from three different sources.

- Some problems encountered in carrying out the QC/QA specification can be attributed to the fact that the specification is relatively new, and with time and experience those problems will be resolved.

- A few problems exist mainly because the specification is not fully enforced. Improper or inadequate enforcement of a specification, however, can originate either from shortcomings of the specification itself or from insufficient experience of the personnel.

- There are problems that are considered fundamental shortcomings to the specification and are independent of the level of experience.

The detailed information obtained from the four regional meetings is presented in the appendix. The general concerns expressed at these meetings are summarized below.

2.3.3.1. Specification-Related Issues: Two general comments of merit made in all the regions were: (1) the specification as written was too complicated, sometimes causing different interpretations between TxDOT engineers; and (2) in many cases personnel, either commercial, contractor, or departmental, did not understand the interaction of the design, tests, and controls in obtaining a satisfactory pavement that performed as designed.

The comments related to the specifications included the following:

- Asphalt content could not be sufficiently controlled. The asphalt content was varied without redesigning the mix to achieve density.
- The quality of jobs of small quantities could not be controlled. Small quantity production often yields an unsatisfactory mix.
- Suggestions were made to remove option 1 for selection of lot size, and to use 2,000-ton lots.
- Use of additives is not controlled.
- Laboratory density needs to be used as a pay factor.
- JMF 1 and JMF 2 are confusing and it is probably better to remove JMF 1.
- There is insufficient or no control of aggregate stockpiles.
- Random selection points for sampling the pavement need to be exact. Proximity leaves wide options in the location for coring.
- The individual obtaining the cores is not required to be a certified technician.
- There is no control on consistency. Asphalt content may be on the high side of the allowable range on one day and on the low side the next day.
- No provisions are made for halting operations in inclement weather.
- Under the current specification the hot mix producer can produce a mix that qualifies for a bonus payment yet the paving contractor's placement results in a lesser quality. In brief, the state is paying more for construction jobs of the same quality or lower quality than for those built under item 340 specification.
- The built-in protection for the first and last days produced mixed benefits to the contractor and gave no guarantee that the mixture would be satisfactory.
- Ride quality measurements are inadequate.
- A contractor can use materials other than those used in the design of the project.
- Compaction control for shoulders needs to be redefined.
- The specification is not written clearly. In some cases, there is the possibility of multiple interpretations of the same subject. There are no clear guidelines.

2.3.3.2. Comments on Issues Not Directly Controlled by Specifications: While there was a significant number of comments related to the specifications, they dealt more with interpretation, experience, and possible improvements in these specifications.

- A positive result has been that the new specifications have required the contractors to obtain new equipment and to begin a certification program with their technical personnel.
- The certification program needs to be strengthened and possibly tied to a general indoctrination course on how the design, sampling, and tests interact.
- Some of the test procedures are not effective — for example, the stripping test. There have also been problems with the creep test, though it appears to be the best available at this time.
- TxDOT needs to test a minimum of one sample in four instead of one in twelve.
- The tremendous amount of paperwork required under the new specification restricts the effectiveness of the limited number of TxDOT personnel. Often the items required are received late and there is no check on the items covered.
- The Department is losing all of its knowledgeable technical people. This loss directly reflects the quality of the assurance portion of the new specification.
- There has been a mixed result from using commercial laboratories. Often the technician will arrive, take a sample, and depart. Test results are delivered on a schedule, but any knowledgeable observations at the plant that might have prevented problems with the mixture were lost.
- Problems are caused when the contractor, but not TxDOT, has the up-to-date equipment.
- There is a lack of guidelines for evaluating the contractor and the work.
- The contractor needs to test every sub-lot.
- Coarse matrix high binder (CMHB) material does not belong in a QC/QA specification at this time.
- Good contractors still provide a good product, but without inspection personnel on the scene there are too many loopholes presently in the specification.

2.3.4. Basic Problems

The specific problems of concern as put forward in these meetings can be summarized as follows:

- There are problems with sampling. Doubts were expressed as to whether sampling has been truly random.
- There are delays in reporting test results to the department of transportation; these delays can cause further subsequent delays in identifying possible problems that may need immediate remedial measures.

- Problems are associated with having various lot sizes and two lot choice options.
- The QC/QA specification is not appropriate for small jobs (small quantities) because it results in a cost escalation.
- Paperwork is tremendous and complicated.
- There are problems with paying bonuses based on the highest pay factor.
- There is insufficient control on stockpile quality.
- The ranges on pay parameters in the specification are too wide.
- Pavement shoulders are not handled properly for compaction and payment.

2.4. Meeting with Contractors, Producers, and Suppliers

A meeting was held on December 16, 1996, in Austin between the research team and hot mix producers and contractors working on Texas projects. The meeting was arranged through the office of the Texas Hot Mix Asphalt Pavement Association (THMAPA). Fifty-five individuals representing thirty-four producers, suppliers, and contractors attended the one-day meeting. Comments made at the meeting were both favorable and critical of the new QC/QA specification. Many of the questions or statements were very similar to those expressed by TxDOT personnel during the regional meetings. The following summarizes the comments made at the December 1996 meeting. At that time, it was already common knowledge that the QC/QA specification was being revised to accommodate some of the problems uncovered during initial use of the specification; some of the comments were clearly reacting to that knowledge.

- Why is gradation being eliminated as a pay factor?

- THMAPA understands that TxDOT will take over quality assurance (QA) and that probably the contractor's testing will double.

- Has there really been a significant number of failures? Little data are available and it appears that the data are skewed around the pay factor items.

- Is TxDOT really paying more for the product, even with the bonus? There are indications that the contractor may be including an anticipated bonus in his initial bid price.

- In-place densities are better now with the QC/QA specification than before with item 340.

- There is no longer the bid differential (5 percent or higher) between TxDOT and commercial projects because the contractor now has more control over his operation. There is still a 5 percent differential with Federal Aviation Administration (FAA) projects.

- Contractors now are doing more testing than TxDOT ever did.

- There is a perception that some contractors are using this specification to cheat in their operation. TxDOT could correct this under the specification.

- The contractors appreciate having control of the mix.

- It is not desirable to have job mix formula (JMF) 2 for a short run, followed by adjustment. We should go directly to production, even if it may be necessary to rework the design the next day.

- TxDOT-certified personnel may not necessarily have sufficient knowledge of the specification; this situation can create control problems.

- There is apparently some resentment about the contractor having control of the work.

- Referee testing needs to be revised. Some do not want the Materials and Tests Division — and many do not want commercial laboratories — to do the testing.

- Rather than depend on the present skewed method, there is a need to develop a continuous curve for determining pay factors.

- Currently there is a 10-day waiting period for approval of a design. Should there be an additional 10-day period for the same design on another project?

- Under the QC/QA specification, what are the minimum requirements for detours?

- When there is a rut in the existing wheelpath overlaid with a 1 ½ inch mat, a core in the wheelpath indicates that density is not achieved.

- TxDOT administration stated that this was to be a uniform specification. It is not being interpreted this way across the state. The personnel need to be trained on this issue and the specification needs to be clarified.

- Will there be any binder testing in the revised specification?

- Will stone mastic asphalt (SMA) be included in the specification?

- Will coarse matrix high binder asphalt (CMHB) stay in the specification?

- The state must address personnel problems if QA is done by the state.

- Will there be calibration developed between the TxDOT press and the Superpave press?

- Can the Superpave design be included as an option?

- The bonus is still a sticking point. Maybe we could do away with it because some will continue to make it a part of the bid price.

- Consideration should be given to dropping the bonus from 5 percent to 2 percent.

2.5. Summary and Recommendations Based on Meetings

There is widespread concern among TxDOT district personnel across the state that, although the QC/QA specification is intended to yield a good product, this goal is not being achieved. The intent for the contractor to control his operation while TxDOT will use a limited number of personnel is good in theory but has been completely successful only in those cases where a good contractor has been involved — one who would provide a good product under any specification. There are too many areas in the specification that must be corrected, and TxDOT must put forth a major effort to upgrade the training of personnel involved in operations under this specification. Some of the items to be addressed are:

- Limits need to be placed on the amount of asphalt binder and the day-to-day allowable operational variation.
- Design must include actual materials delivered to the project.
- Recommendation that JMF 1and JMF 2 be combined.
- Be specific that a sub-lot shall be no more than 500 tons with a 2,000-ton lot.
- Shoulder placement controls should be the same as those for the main lanes.
- Random test location shall be specific and will not be known to the contractor until the actual time to sample.
- Remove the protection for the first and last day of production.
- The specification should address the need to control small quantities.
- Ride requirements in the specification are inadequate.
- Pay factors should be based on a continuous curve.
- Laboratory density should be included as a pay factor.
- Production voids in the mineral aggregate (VMA) should be used as a criterion in operational tolerances.
- The ranges of some pay parameters need to be tightened.
- Time and location of sampling should not be disclosed until the time of sampling, or DOT personnel should obtain the verification samples independent of quality assurance samples obtained by the contractor.

2.6. Survey Other States

This project was to include a survey of other states using QC/QA type specifications to determine whether a quality control plan was required to be submitted to the DOT for approval prior to construction. This task was accomplished in conjunction with a survey to obtain needed information for research study 0-1750, “Evaluate Items of Work That Could Be Performed Using an End Result Specification.” Twenty states cooperated in the study and responded directly to that question. Of those responding, eleven stated they did require submission of some form of a quality control plan. Several states initially required such a plan but dropped or ceased enforcement of the requirement when it was deemed meaningless or difficult to enforce, or when the use of the specifications had progressed to the phase where submission of a plan was no longer considered necessary. An additional state is investigating inclusion of such a requirement in its specifications. Five of the responding states indicated that they had no such requirements.

In reviewing the information and specifications furnished by the states canvassed, it was apparent that references to a “quality control plan” took many forms and, in fact, one state’s negative response to this question actually did include specific terms for acceptance testing by the contractor in its specifications. The control plan in most states was made a part of the construction and materials item, i.e., “Hot Mix Asphalt Pavements,” “Asphalt Concrete Pavement,” etc., while others have developed separate *quality control* and *quality acceptance items* that are referred to by like construction items, such as “Selected Material Base Course,” “Lime-Treated Base Course,” etc. Two states responded with manuals that had been developed for their QC/QA programs. California has developed a manual specifically for asphalt concrete that includes, along with pertinent California tests, detailed instructions on all phases of the program. Oregon’s manual for its quality assurance program is much simpler: It is limited to specifying for each item the requirements for control, verification, and independent assurance, leaving the details to each construction specification.

Examples of the types of wordings used:

I:

“Quality Control Testing: *Quality control of bituminous concrete is the responsibility of the Contractor. The Contractor shall maintain equipment and qualified personnel including at least one certified Bituminous Concrete Technician, and he shall perform all field sampling and testing necessary to determine the magnitude of the various properties governed by the Specification and shall maintain these properties within the limits of the Specification.”*

“Workable Quality Control Plan: *The Contractor, or Contractor-Producer, shall design a workable quality control plan, detailing the type and frequency of sampling and testing deemed necessary to measure and control the magnitude of the various properties of the bituminous concrete governed by these Specifications. This plan, prepared in accordance with MP 401.03.50 shall be submitted to the Engineer prior to production of material under this Specification.”*

The preceding section is quoted from the West Virginia DOT (*7*).

II:

"Contractor's Quality Control Plan. *Prior to initiation of work the contractor shall prepare a plan to ensure that acceptable quality can and will be obtained. The plan which is to be submitted to the Engineer at the pre-work conference shall cover all of the items discussed in Sections 411 and 708 of the Standard Specifications. However, the contractor must tailor the plan to meet specific needs of the project. Once accepted by the Engineer the plan becomes a part of the Contract and shall be enforced accordingly. Subsequent changes to the plan may be required by the Engineer in order to adjust to changes in the process or to correct problems in meeting Specification requirements."*

The preceding section is quoted from the Oklahoma DOT (*8*).

Surveying eleven of the states that utilize QC/QA specifications indicated that all use asphalt content and in-place density as pay factors. However, in regard to other factors, they differ and use parameters such as gradation for specific sieves, laboratory density, and the voids in the mineral aggregate (VMA, Table 2.1). While the majority utilizes the bonus/penalty approach (incentive/disincentive), a few include only penalties for poor-quality jobs and no bonus for high-quality jobs (disincentive, Table 2.2).

Table 2.1. Parameters Used for Determination of Pay Factors in Some States

State	AC	Gradation	In-Place Density	Lab-Compacted Density	VMA
Alabama	√		√	√	
Colorado	√	√	√		√
Georgia	√	√	√		
Iowa	√	√	√		
Kentucky	√		√	√	√
Michigan	√		√		√
Minnesota	√	√	√	√	
Missouri	√	√	√		√
Pennsylvania	√	√	√		
Virginia	√	√	√		√
Wisconsin	√	√	√	√	√

Table 2.2. Payment Type for Some of the States

State	Incentive	Disincentive	Payment Based on Tests Conducted by the
Alabama	√	√	Contractor
Colorado	√	√	State
Georgia		√	State
Iowa		√	Contractor
Kentucky	√	√	Contractor
Michigan	√	√	Contractor
Minnesota	√	√	Contractor
Missouri	√	√	State
Pennsylvania	√	√	State
Virginia	√	√	Contractor
Wisconsin	√	√	Contractor

2.7. Visual Inspection of the Projects

A physical survey was conducted on a number of projects built under QC/QA and non-QC/QA specifications. Attempts were made to inspect projects that would fit into a pair for a more meaningful and effective comparison. A pair of similar projects, in this regard, refers to projects that are as close as possible in terms of the following parameters:

- Materials used (asphalt and aggregate)
- Road location and structure
- Traffic level
- Climatic conditions
- Contractor and method of construction
- Year of construction

As expected, it was not possible to find "paired" projects satisfying the preceding criteria and differing only in the specification used for their construction. There were, however, a few cases in which the projects were similar; for example, projects built under the QC/QA and non-QC/QA specifications in the same year. Nevertheless, a number of projects were selected in eight districts and were visually surveyed and evaluated. A data collection sheet of the following format was used on the projects.

Data Collection Sheet:

District Surveying Date Survey Time

Road:

Year of Construction Mix Type

Specification Used Thickness

CONDITION SURVEY

Distress	**None**	**Slight**	**Moderate**	**Severe**	**Very Severe**
Rutting					
Fatigue Crack					
Thermal Crack					
Reflective Crack					
Longitudinal Crack					
Shoving					
Bleeding					
Segregation					

OVERALL RATING

	Excellent	Good	Average	Bad	Very Bad
Uniformity					
General Appearance					

Remarks:

In the survey, the quality was simply assessed visually. No physical measurements were used to quantify the distresses or the serviceability of the pavement. The highways surveyed are summarized and presented by district in Table 2.3.

While most of the non-QC/QA surveyed projects were constructed under item 340 of the Standard Specifications for Construction of Highways, Streets, and Bridges *(9)*, there were some that were built under item 3834. This item was a special provision that was developed by TxDOT to be used for construction before the 1993 standard specifications booklet was published. Practically, its content is the same as that presented in the 1993 specification item 340. In the same way, most of the QC/QA-surveyed projects were constructed according to item 3063. However, there were some that were constructed according to the earlier version of the QC/QA specification (i.e., item 3007).

Table 2.3. Districts and Roads Where Visual Surveys Took Place

Survey Date	District	Roads	Specification
8/7/97	El Paso	US 54, Fred Wilson Rd, Loop 375, Railroad Dr., FM 258	Non-QC/QC
		Airport Road, Loop 375, SH 20, FM 258	QC/QA
8/13/97	San Antonio	Huebner Rd., Highway 1604,IH 10, Wurzback Parkway	Non-QC/QC
		Eckert Rd, IH 10	QC/QA
8/14/97	Laredo	FM 1472,	Non-QC/QC
		Loop 20, IH 35, FM 1472,	QC/QA
8/14/97	Yoakum	US 77	Non-QC/QC
		FM 1685	QC/QA
8/15/97	Pharr	SH 100	Non-QC/QC
		SH 100	QC/QA
8/20/97	Tyler	SH 31 West, SH 64, Loop 323	Non-QC/QC
		SH 31 West, SH 274, Loop 323	QC/QA
8/21/97 9/5 & 9/10	Beaumont	SH 73, US96, SH 327	Non-QC/QC
		SH 73, IH-10, FM 1003, B90	QC/QA
8/21/97	Lufkin	US 59	Non-QC/QC
		US 59	QC/QA
8/22/97	Wichita Falls	Loop 473. FM 369	Non-QC/QC
		IH 44, Loop 473, US 281, SH 16	QC/QA

CHAPTER 3
QUANTITATIVE INFORMATION AND ANALYSIS OF DATA

3.1. General

An important part of the research program included collection and analysis of the numerical data obtained from projects constructed under the quality control/quality assurance (QC/QA) specification, and then comparing those with the results obtained from projects built under specification item 340. In this regard, efforts were made to obtain data on projects in different districts. Data from four sets of QC/QA projects were gathered. The first set included results from five pilot projects carried out under a QC/QA specification during 1993. The second set included a series of eleven projects obtained by the Texas Department of Transportation (TxDOT) audit office. The third one included the data obtained from construction and maintenance division of TxDOT for forty-four projects; the last set of data was obtained from the San Antonio District for twenty-one projects. The analysis reported here includes the second and third set of QC/QA projects (a total of fifty-five projects).

There was a need to obtain sufficient data for projects built under specification item 340 so the control parameters from the two specifications could be compared with each other. For this purpose, the extensive database that was developed in 1987 was used. A vast amount of data consisting of various details of construction under item 340 specification was included in this database. Data and corresponding analysis of that data were reported in a research report for project 0-1197 of the Center for Transportation Research of The University of Texas at Austin *(10)*. The control parameters for comparison of specifications included asphalt content, gradation, and air voids. Laboratory density data were also included in the analysis. The detailed results of the analysis are presented in Appendix B.

As part of the program, a brief comparison was also carried out between the costs of projects built under the two specifications.

3.2. Comparison of Similar Projects

Comparison of projects built under QC/QA specification with those under the 340 specification can be carried out using two approaches. One approach is a one-to-one comparison; that is, pairing projects (a QC/QA project and a non-QC/QA project) and comparing the results. The other approach is comparing a large number of projects of one specification with a large number of the other. A one-to-one comparison is meaningful only if there is enough knowledge and control on the variables from the two projects. The best situation for such a comparison is a case where a QC/QA project and a corresponding non-QC/QA project are built by the same contractor, with the same materials, and under the same environmental and traffic conditions. Obtaining similar projects of this nature was not possible in this study. However, such a comparison was previously carried out by TxDOT's Materials and Tests Division (MTD).

Analysis and comparison of six hot mix projects were reported by MTD *(11)*. Three projects were built under the method specification, and three were constructed according to the QC/QA specification. The projects were paired so that a QC/QA project could be compared with a method-specification project within the same district, constructed by the same contractor, and made with similar materials. The results of that study indicated that in every case, the measured parameters had less variability under the QC/QA specification as compared with the method specification. The parameters that were considered in this analysis included asphalt content, percent passing 2 mm sieve, percent passing 0.075 mm sieve, air voids, and laboratory densities.

3.2.1. Comparison of Control Parameters

Tables 3.1 through 3.5 indicate statistical results for the control parameters. For each case, four standard deviations are reported. Definitions for each are provided at the bottom of the table. Both QC/QA and non-QC/QA projects are included in Table 3.5. The non-QC/QA data are from TxDOT's 1987 construction projects *(10).* For all cases, the standard deviations for QC/QA projects are consistently lower than those for non-QC/QA projects, implying less variability in projects of the former compared with the latter. However, statistical T- and F-tests, as will be discussed later, indicate that in regard to variability in control parameters, there is not a significant difference between the QC/QA and non-QC/QA projects. The frequency histograms are presented in Figures 3.1 through 3.28.

Table 3.1. Mean and Standard Deviation for Asphalt Content Deviation (Percent)

	QC/QA Projects		Non-QC/QA Projects	
Statistics	Algebraic Difference	Absolute Difference	Algebraic Difference	Absolute Difference
Mean	0.02	0.15	0.02	0.19
S_o	0.21	0.15	0.26	0.18
S_m	0.18	0.14	0.14	0.09
S_p	0.17	0.12	0.23	0.16
S_a	0.14	0.10	0.21	0.15
No. of Data Points	1,369	1,369	1,632	1,631
No. of Projects	55	55	67	67

Table 3.2. Mean and Standard Deviation for Percent Passing 2 mm Sieve

	QC/QA Projects		Non-QC/QA Projects	
Statistics	Algebraic Difference	Absolute Difference	Algebraic Difference	Absolute Difference
Mean	0.05	1.56	-0.13	2.11
S_o	2.14	1.46	2.76	1.78
S_m	1.21	0.92	1.69	1.01
S_p	1.90	1.26	2.35	1.62
S_a	1.71	1.14	2.27	0.15
No. of Data Points	1,371	1,371	1,583	1,583
No. of Projects	55	55	67	67

Table 3.3. Mean and Standard Deviation for Percent Passing 0.075 mm Sieve

	QC/QA Projects		Non-QC/QA Projects	
Statistics	Algebraic Difference	Absolute Difference	Algebraic Difference	Absolute Difference
Mean	0.10	0.61	-0.72	1.30
S_o	0.86	0.61	1.41	0.89
S_m	0.67	0.46	1.14	0.61
S_p	0.61	0.45	0.86	0.71
S_a	0.54	0.41	0.79	0.64
No. of Data Points	1,375	1,375	1,583	1,583
No. of Projects	55	55	67	67

Table 3.4. Mean and Standard Deviation for In-Place Densities (Percent)

	QC/QA Projects	Non-QC/QA Projects
Statistics		
Mean	92.7	93.2
S_o	1.57	1.95
S_m	1.20	1.47
S_p	1.18	1.56
S_a	1.14	1.26
No. of Data Points	930	785
% > 96[1]	1.30	5.9
% < 91[2]	8.80	15.9

1: % > 96: Percent of projects with densities greater than 96 percent

2: % < 91: Percent of projects with densities smaller than 91 percent

Table 3.5. Mean and Standard Deviation for Laboratory Densities (Percent)

	QC/QA Projects	Non-QC/QA Projects
Statistics		
Mean	96.4	96.9
S_o	0.79	1.02
S_m	0.65	0.68
S_p	0.56	0.83
S_a	0.54	0.61
No. of Data Points	389	829

The terms used in the preceding tables are defined as follows:

- Mean: The mean value of all data points are considered together
- $S_{o:}$ The standard deviation when all data points are considered together
- $S_{m:}$ The standard deviation of the project means
- $S_{p:}$ The pooled standard deviation of the project means
- $S_{a:}$ The average of the standard deviations of all projects (average of all S_m'S)

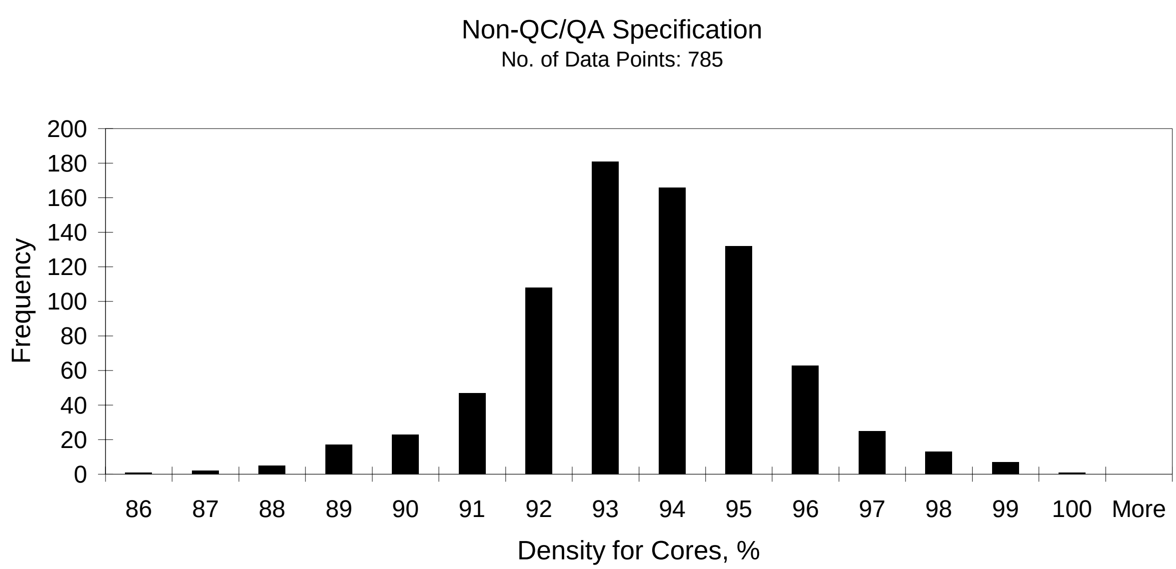

Figure 3.1. Frequency Distribution of Percent Densities for 1987 Construction Projects for All Data Points (Non-QC/QA Projects)

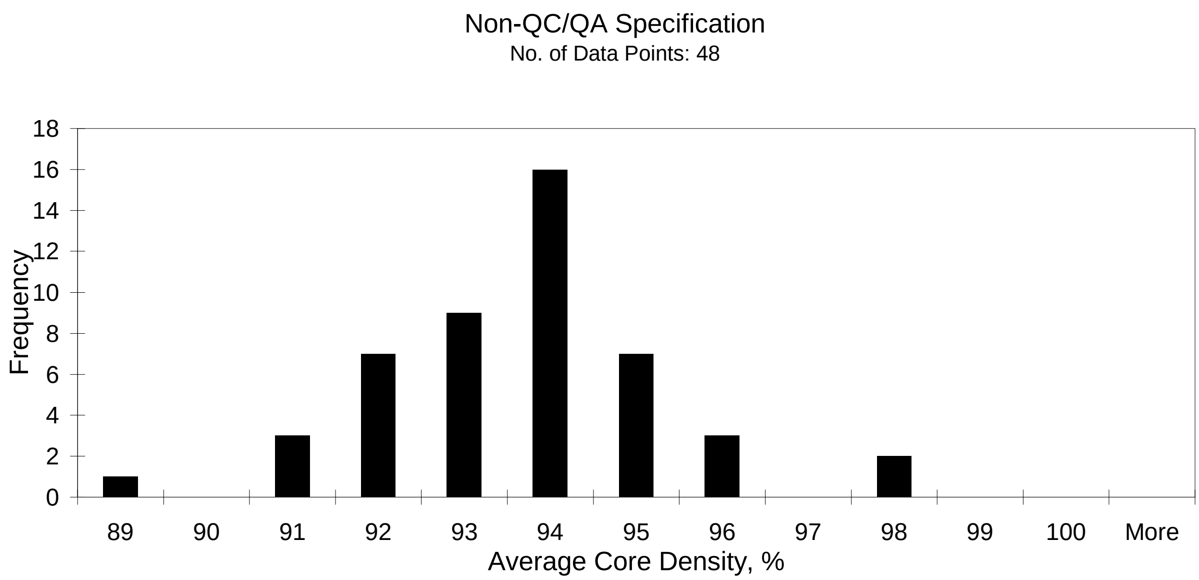

Figure 3.2. Frequency Distribution of Mean Percent Densities for 1987 Construction Projects (Non-QC/QA Projects)

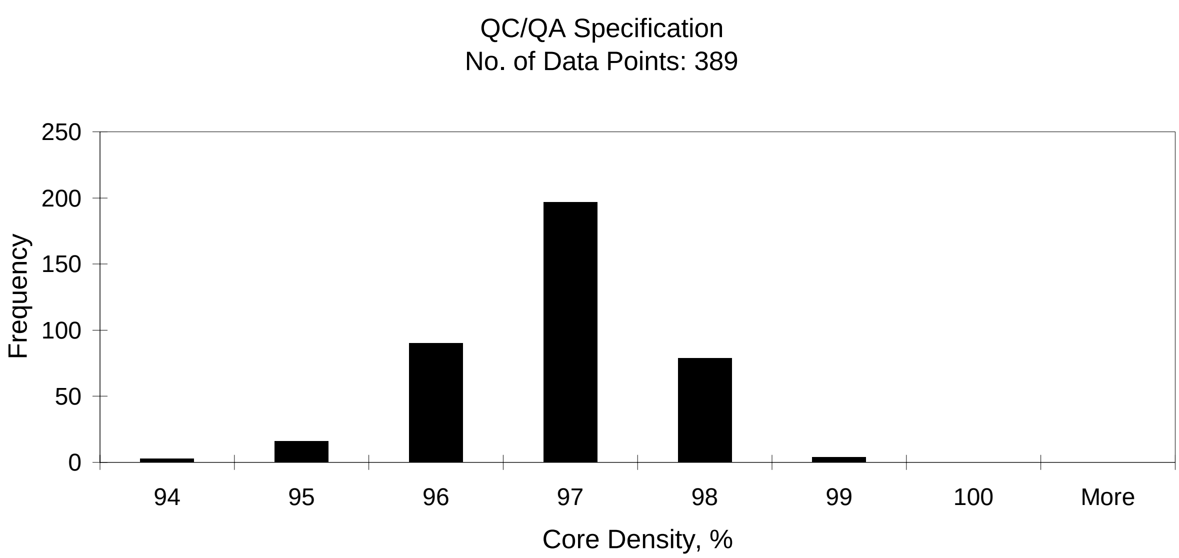

Figure 3.3. Frequency Distribution of Percent Densities for All Data Points (QC/QA Projects)

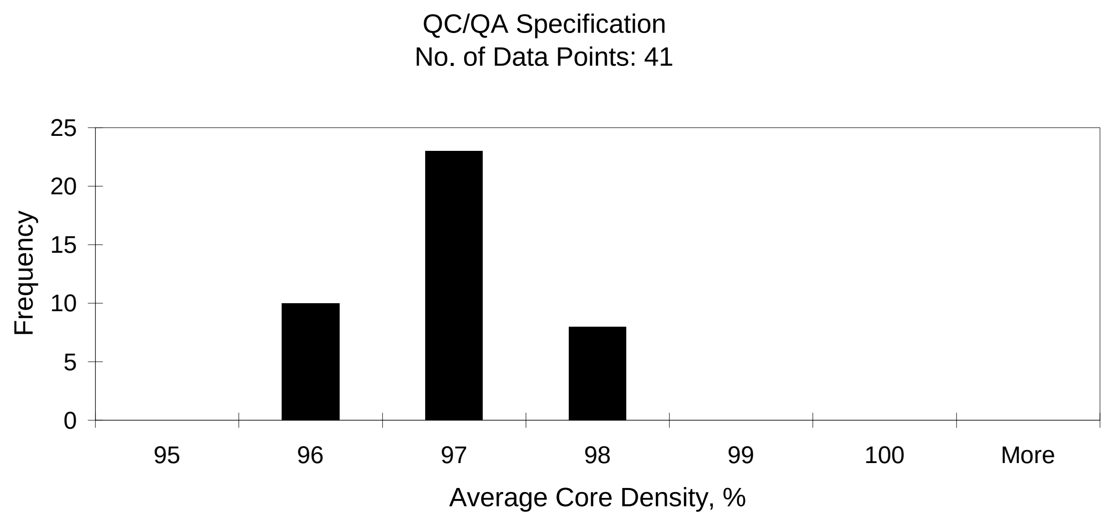

Figure 3.4. Frequency Distribution of Mean Percent Densities for QC/QA Projects

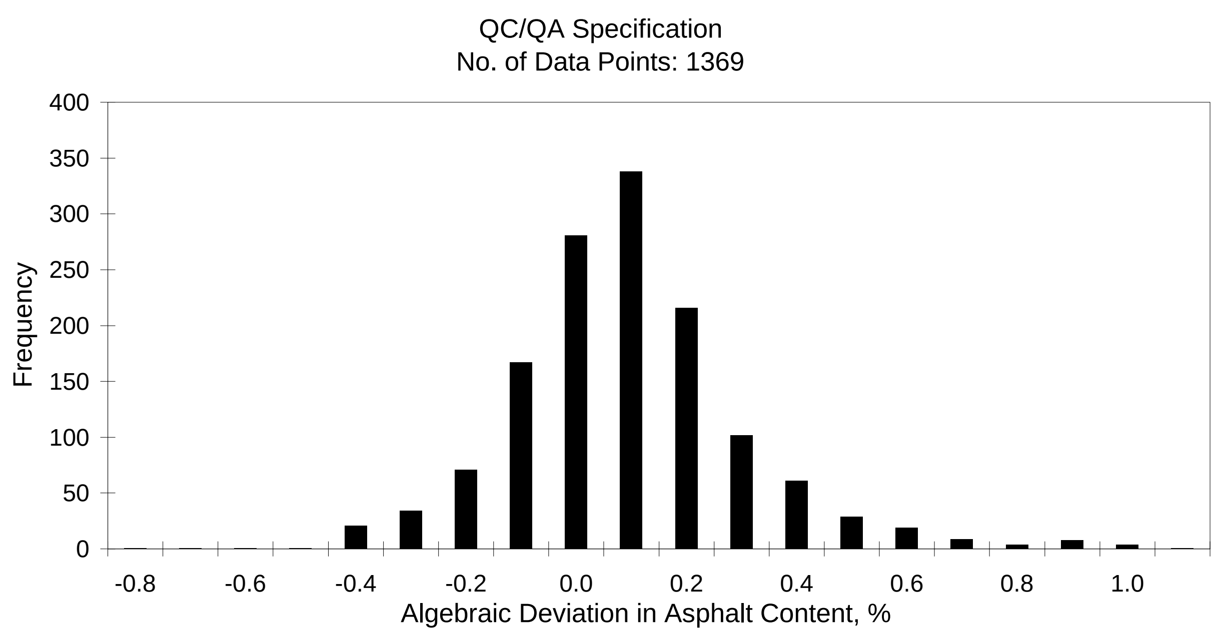

Figure 3.5. Frequency Distribution of Algebraic Difference between Design and Actual Asphalt Content for All Data Points (QC/QA Projects)

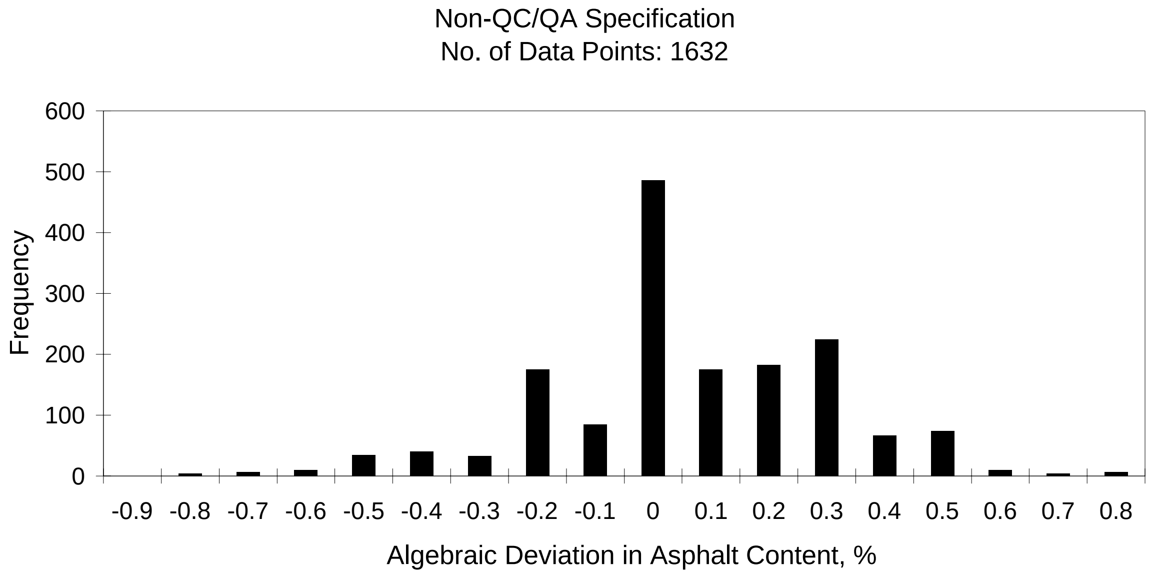

Figure 3.6. Frequency Distribution of Algebraic Difference between Design and Actual Asphalt Content for All Data Points (Non-QC/QA Projects)

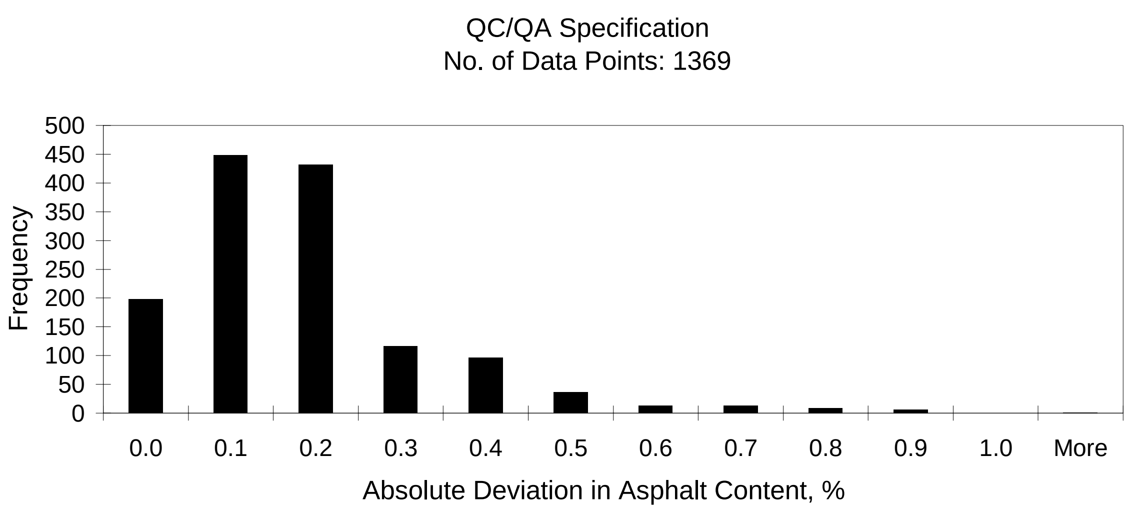

Figure 3.7. Frequency Distribution of Absolute Deviation between Design and Actual Asphalt Content for All Data points (QC/QA Projects)

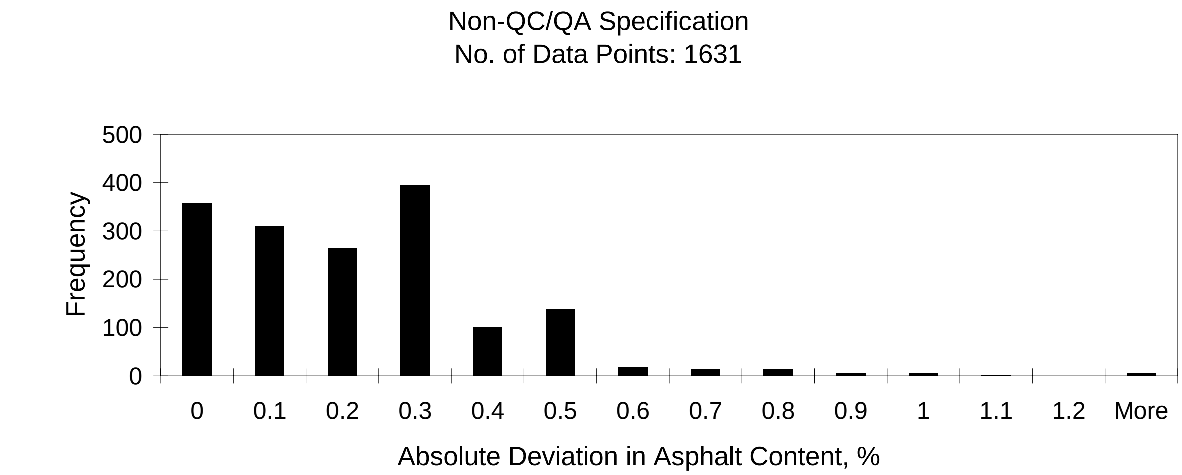

Figure 3.8. Frequency Distribution of Absolute Deviation between Design and Actual Asphalt Content for All Data points (Non-QC/QA Projects)

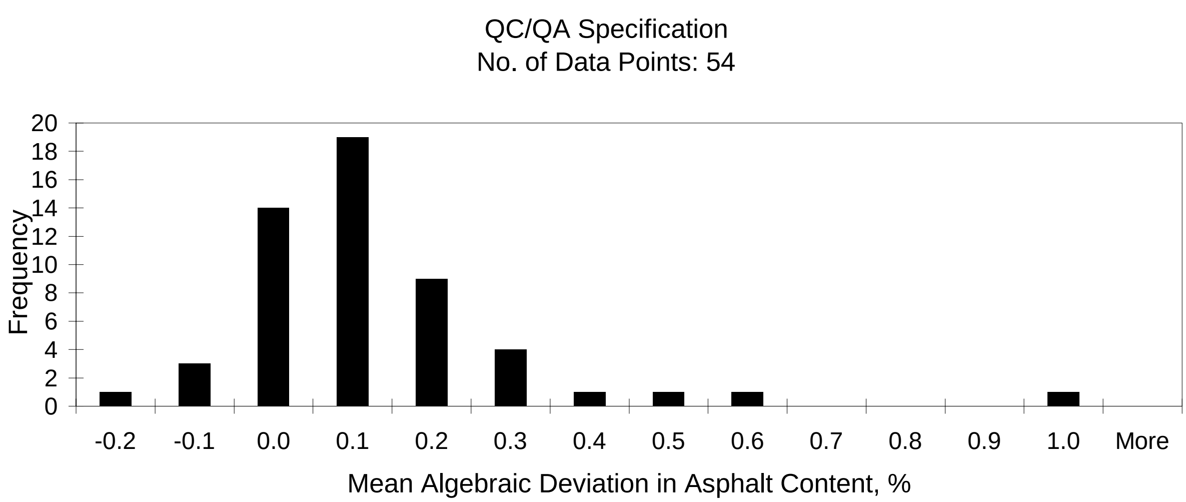

Figure 3.9. Frequency Distribution of Mean Algebraic Asphalt Content Deviation for QC/QA Projects

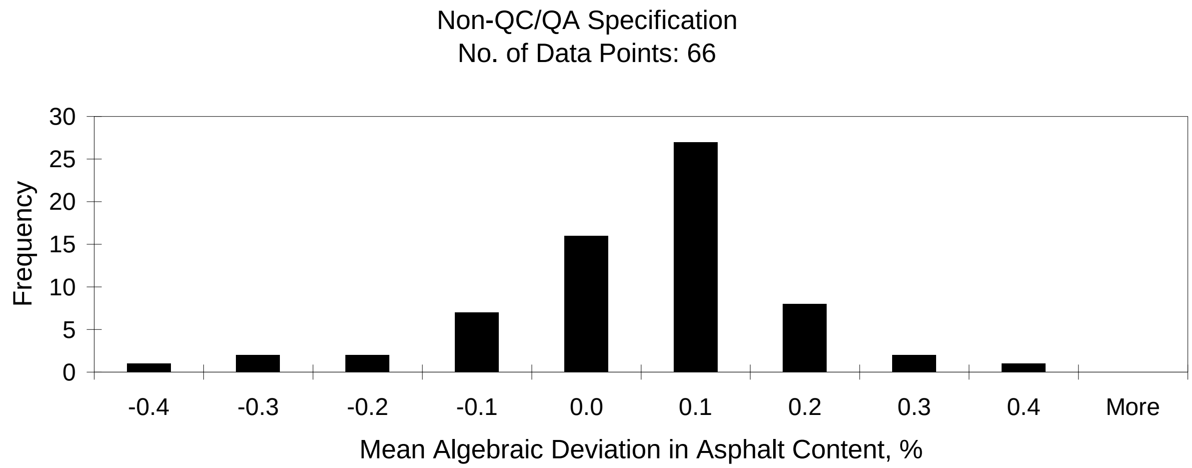

Figure 3.10. Frequency Distribution of Mean Algebraic Asphalt Content Deviation for Non-QC/QA Projects

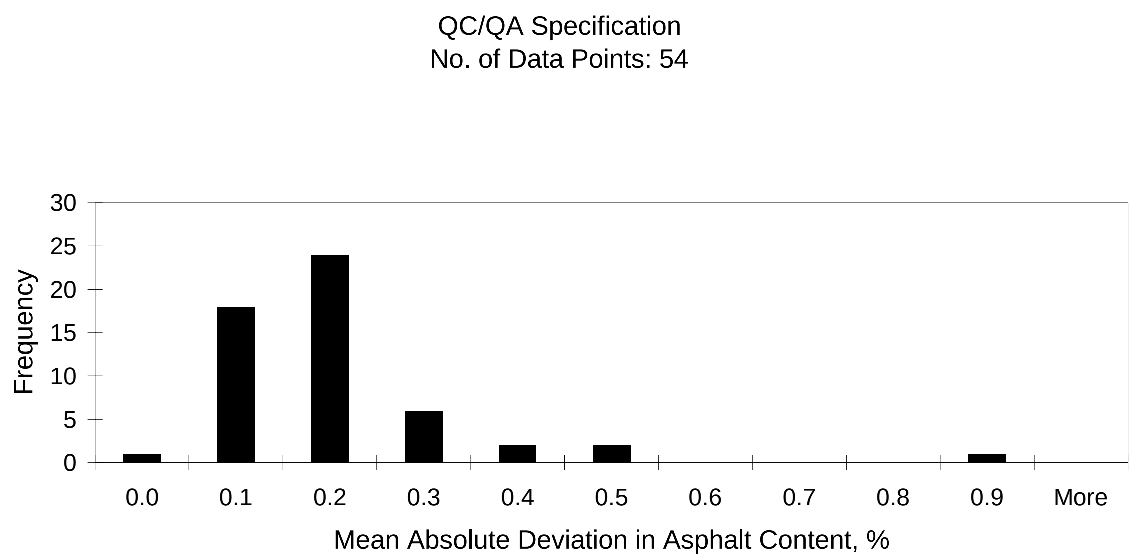

Figure 3.11. Frequency Distribution of Mean Absolute Asphalt Content Deviation for QC/QA Projects

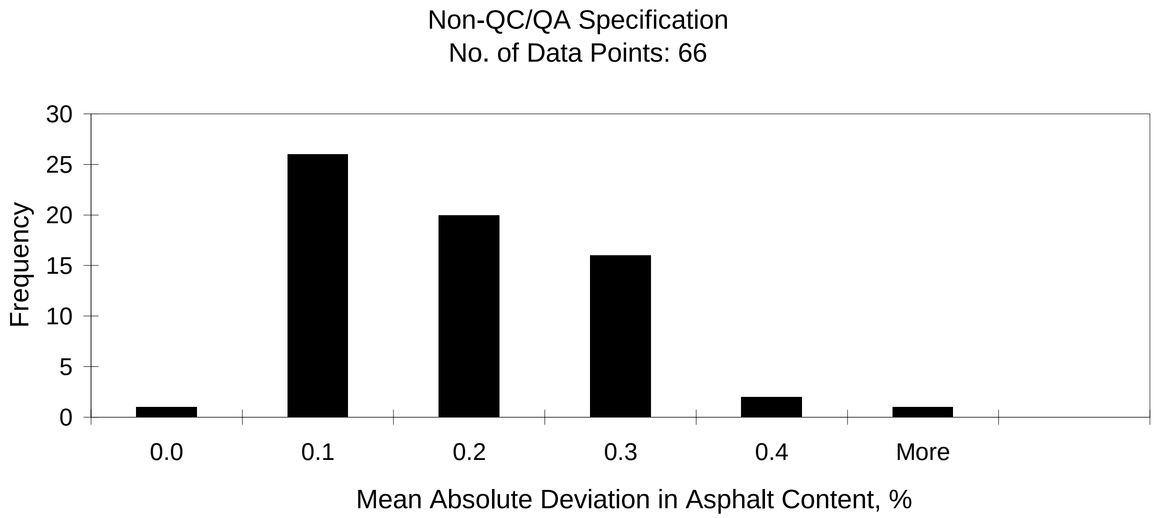

Figure 3.12. Frequency Distribution of Mean Absolute Asphalt Content Deviation for Non-QC/QA Projects

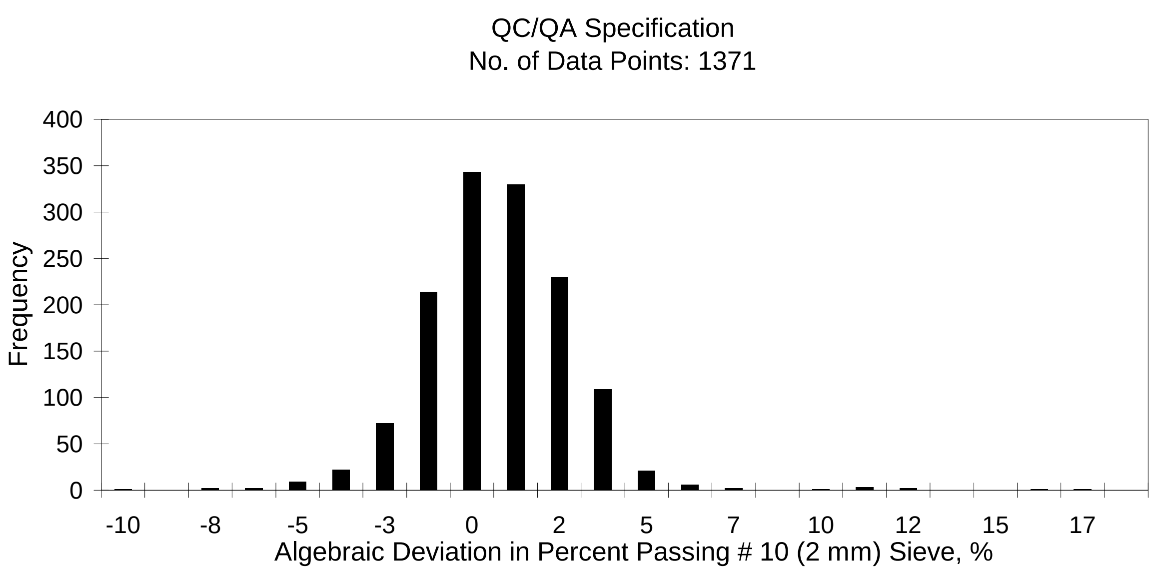

Figure 3.13. Frequency Distribution of Algebraic Deviation in Percent Passing 2 mm Sieve for All Data Points (QC/QA Projects)

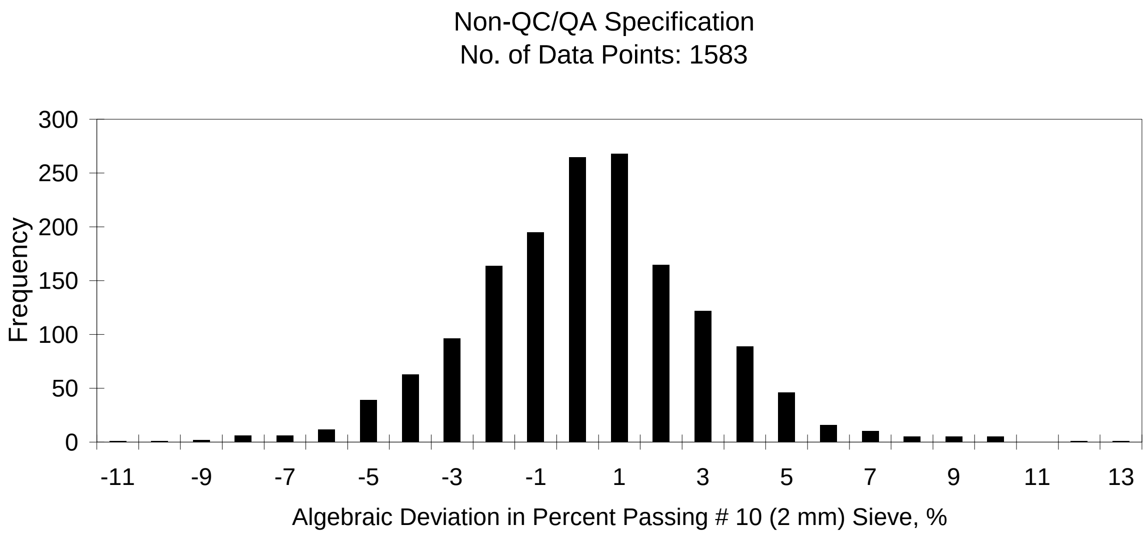

Figure 3.14. Frequency Distribution of Algebraic Deviation in Percent Passing 2 mm Sieve for All Data Points (Non-QC/QA Projects)

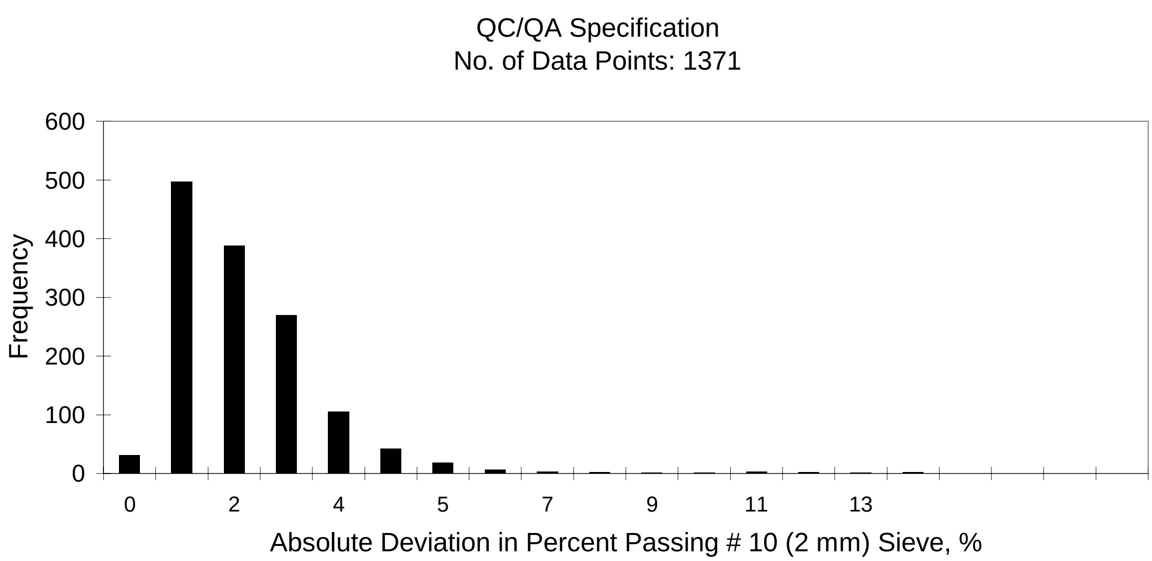

Figure 3.15. Frequency Distribution of Absolute Deviation in Percent Passing 2 mm Sieve for All Data Points (QC/QA Projects)

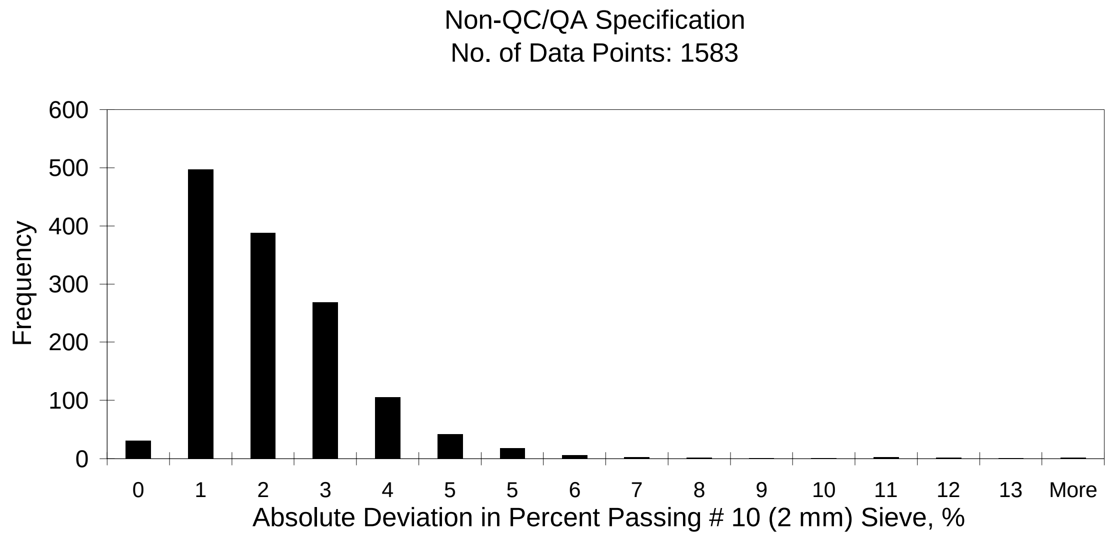

Figure 3.16. Frequency Distribution of Absolute Deviation in Percent Passing 2 mm Sieve for All Data Points (Non-QC/QA Projects)

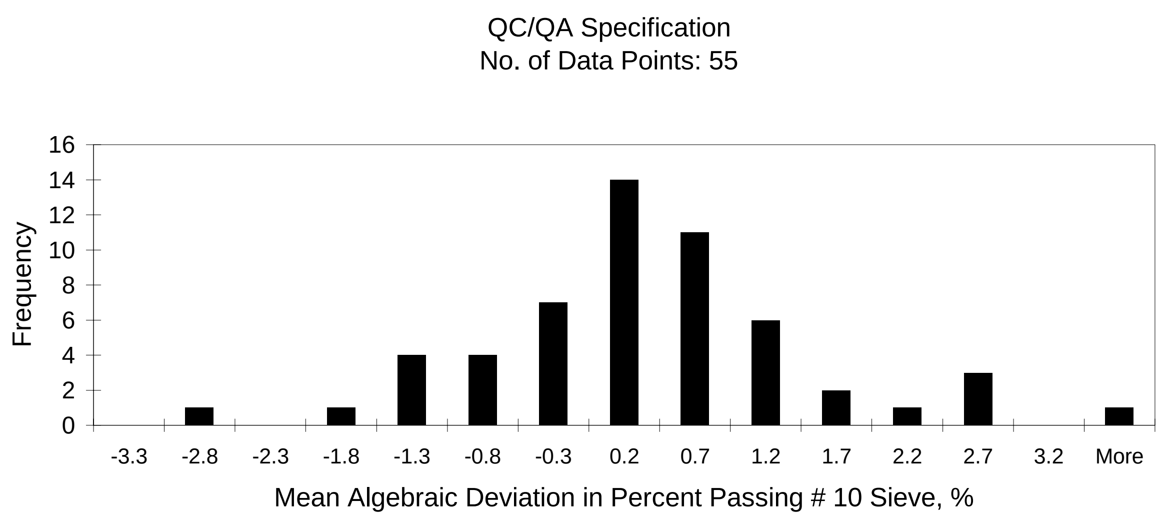

Figure 3.17. Frequency Distribution of Mean Algebraic Deviation in Percent Passing 2 mm Sieve for QC/QA Projects

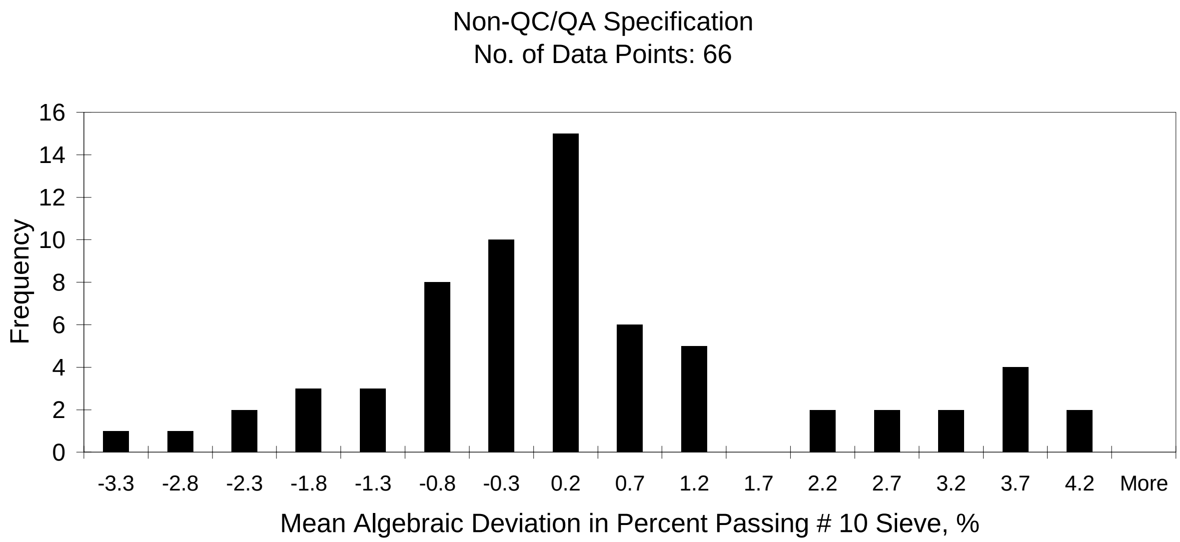

Figure 3.18. Frequency Distribution of Mean Algebraic Deviation in Percent Passing 2 mm Sieve for Non-QC/QA Projects

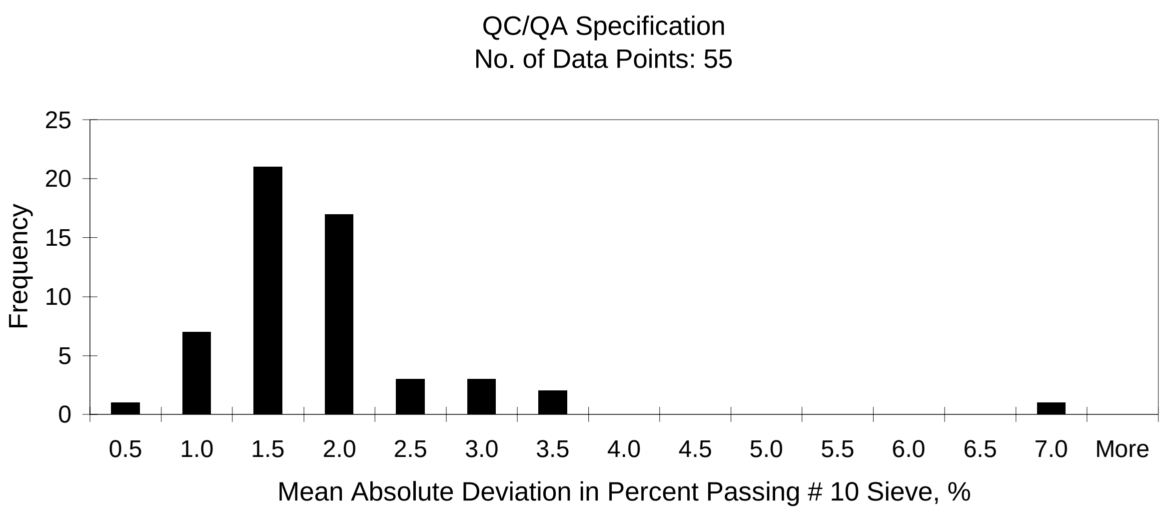

Figure 3.19. Frequency Distribution of Mean Absolute Deviation in Percent Passing 2 mm Sieve for QC/QA Projects

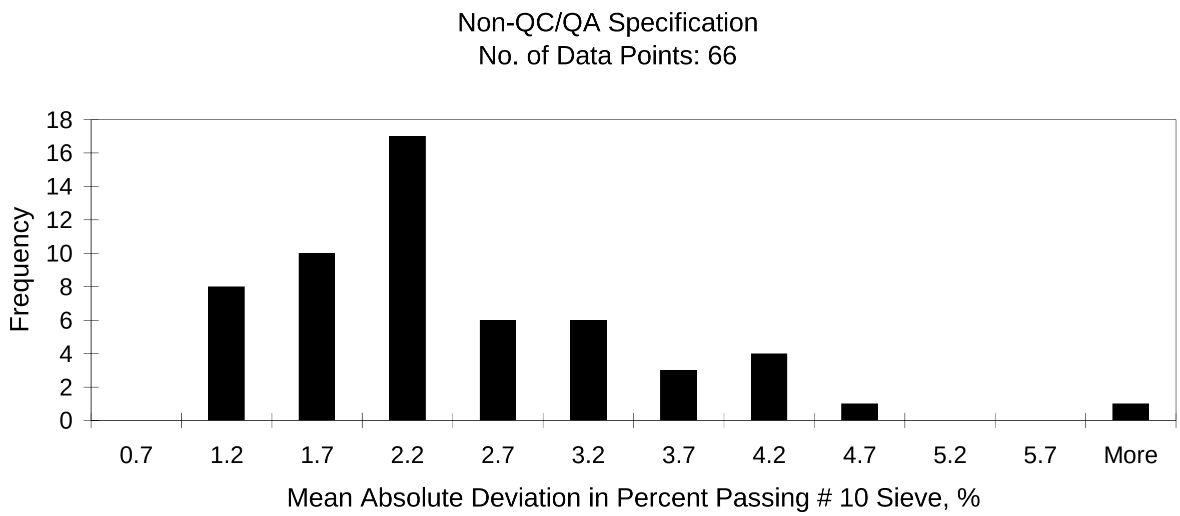

Figure 3.20. Frequency Distribution of Mean Absolute Deviation in Percent Passing 2 mm Sieve for Non-QC/QA Projects

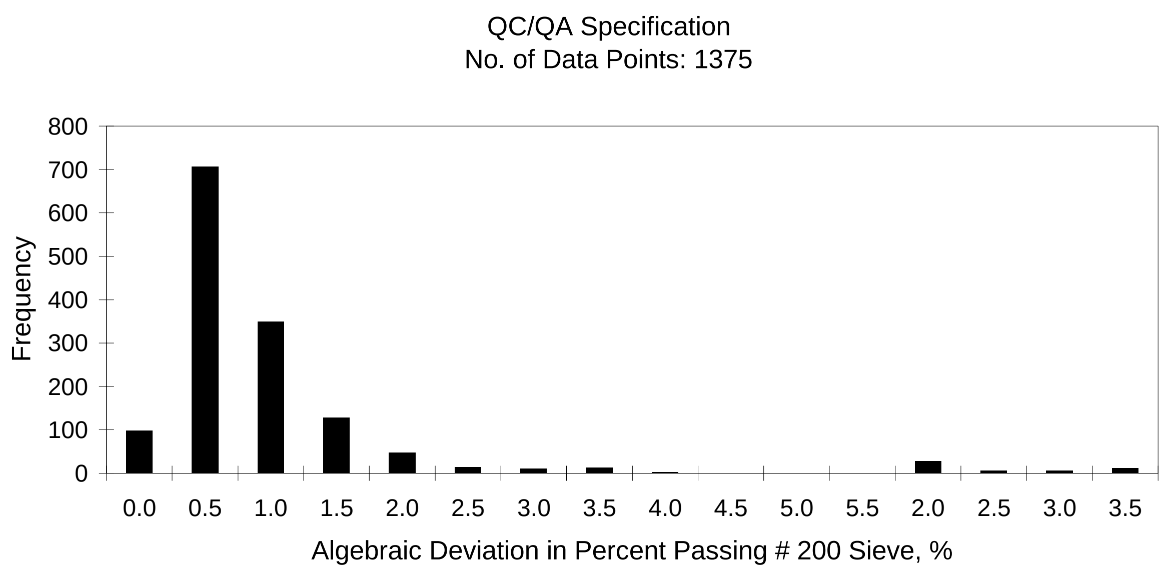

Figure 3.21. Frequency Distribution of Algebraic Deviation in Percent Passing 0.075 mm Sieve for All Data Points (QC/QA Projects)

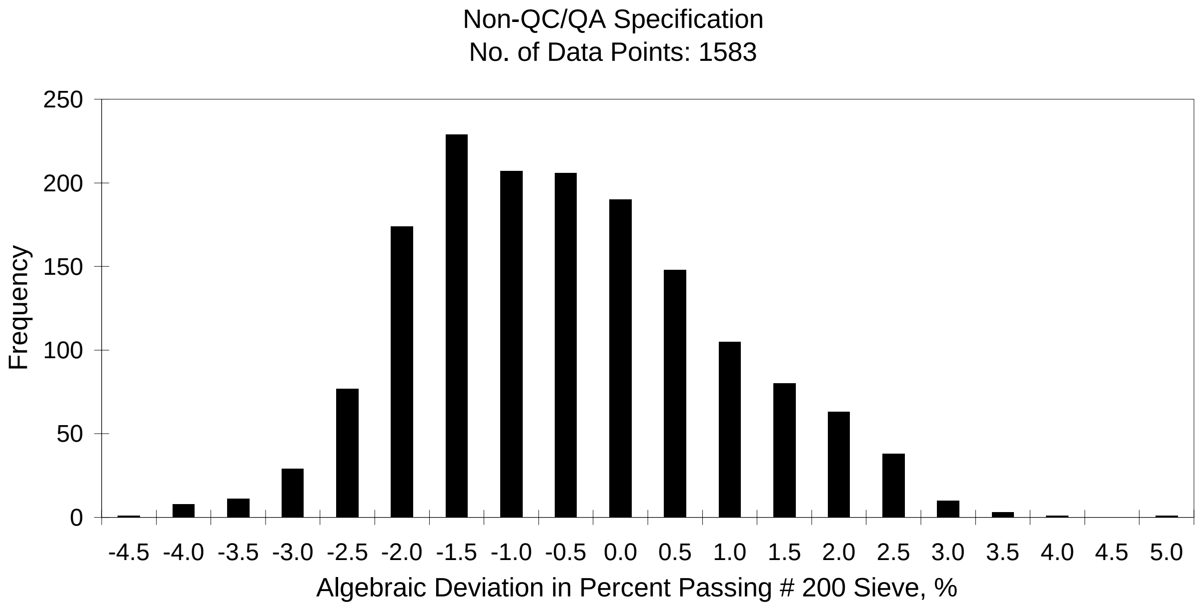

Figure 3.22. Frequency Distribution of Algebraic Deviation in Percent Passing 0.075 mm Sieve for All Data Points (Non-QC/QA Projects)

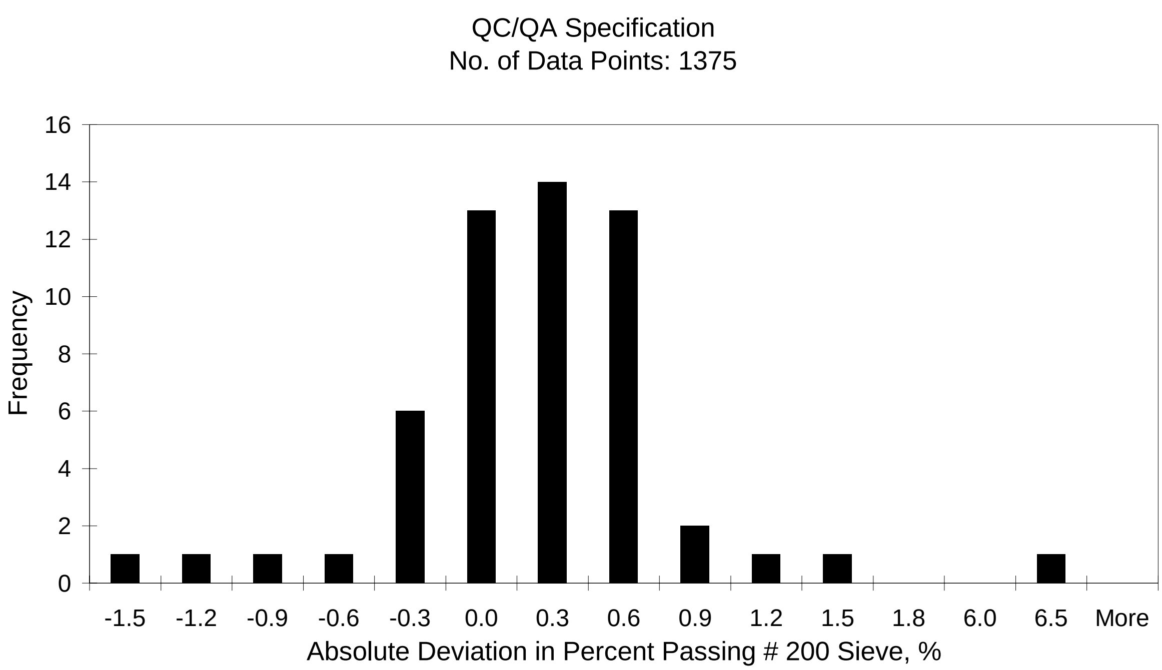

Figure 3.23. Frequency Distribution of Absolute Deviation in Percent Passing 0.075 mm Sieve for All Data Points

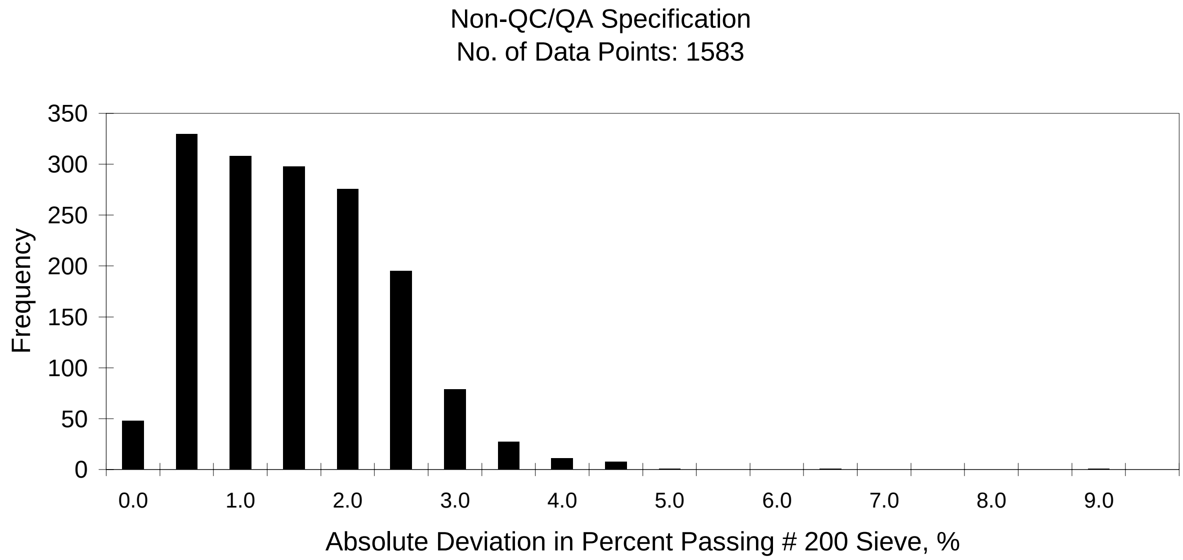

Figure 3.24. Frequency Distribution of Absolute Deviation in Percent Passing 0.075 mm Sieve for All Data Points (Non-QC/QA Projects)

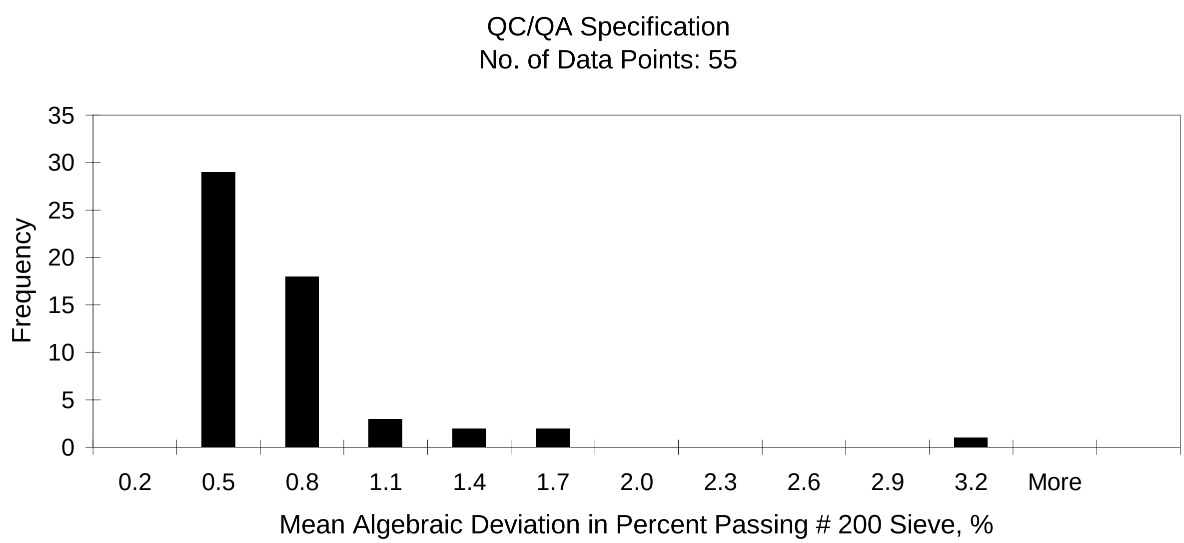

Figure 3.25. Frequency Distribution of Mean Algebraic Deviation in Percent Passing 0.075 mm Sieve for QC/QA Projects

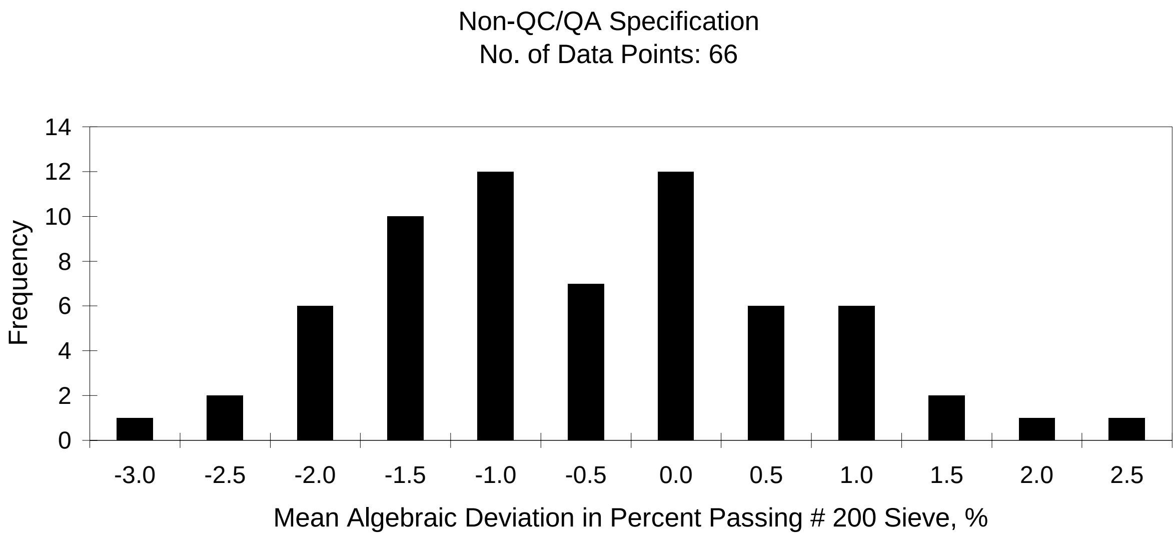

Figure 3.26. Frequency Distribution of Mean Algebraic Deviation in Percent Passing 0.075 mm Sieve for Non-QC/QA Projects

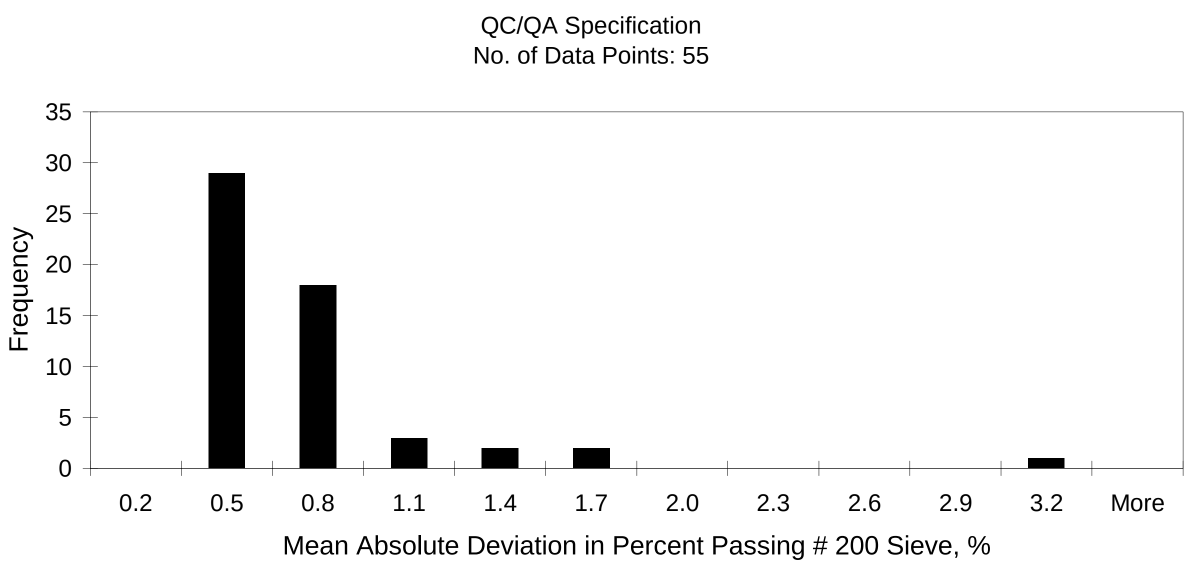

Figure 3.27. Frequency Distribution of Mean Absolute Deviation in Percent Passing 0.075 mm Sieve for QC/QA Projects

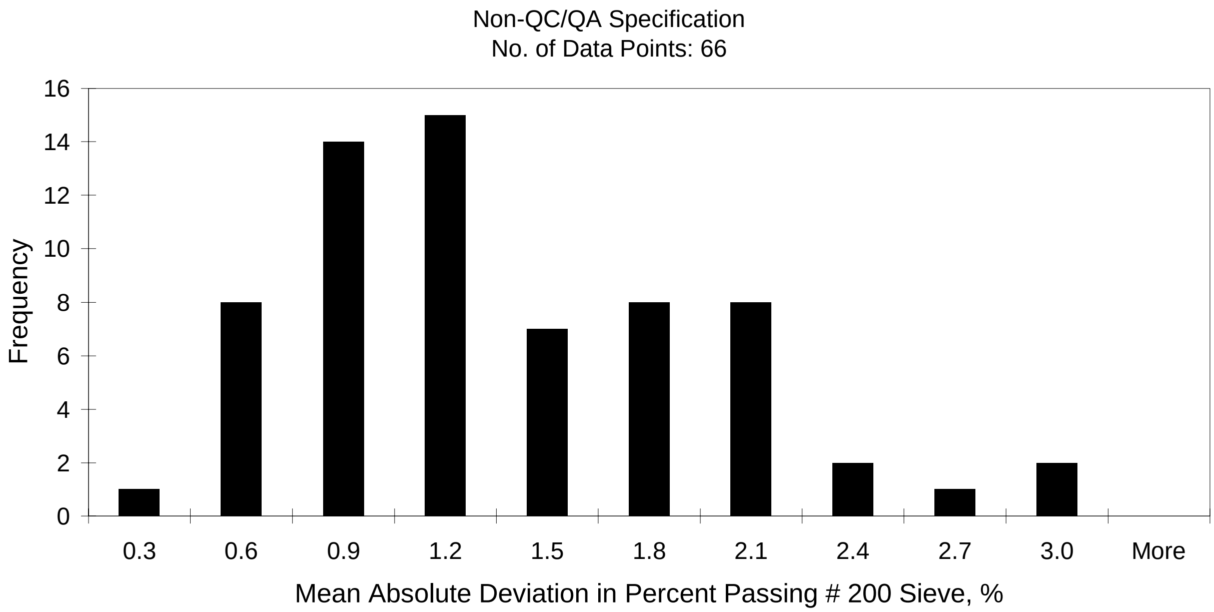

Figure 3.28. Frequency Distribution of Mean Absolute Deviation in Percent Passing 0.075 mm Sieve for Non-QC/QA Projects

For air voids, the histogram corresponding to the non-QC/QA projects follows the pattern of a normal distribution very closely. However, the plot of the air voids for QC/QA projects indicates a large concentration of results in the middle. The plot does not follow the typical pattern of a normal distribution. The reason for such a trend is not clear because one expects to observe a close to normal distribution for a large number of air void values. One interesting observation is that about 6 percent of densities exceed 96 percent under the item 340 specification, whereas only 1.3 percent of densities under QC/QA specification are larger than 96 percent (Table 3.4). In a similar comparison, for densities less than 91 percent, approximately 16 percent of projects under non-QC/QA specification fall below 91 percent, compared to 9 percent under the QC/QA specification. It must be noted that densities below 91 percent and over 96 percent cover the ranges for which reduced pay factors (less than one) are applied.

For asphalt content, i.e., the percent passing the 2 mm sieve and the percent passing the 0.075 mm sieve, the algebraic deviations follow a close to normal distribution, while the absolute deviations do not.

3.3. Statistical Tests and Analysis

3.3.1. Assumptions

The algebraic differences of the parameters under consideration (percent asphalt content, percent passing 2 mm and 0.075 mm sieves) display normal distributions, as do the distributions of the data points of laboratory densities and air voids. On the other hand, the data used in this research are assumed to be independent. In this case, the foundation for the use of T-test and F-test holds true.

3.3.2. Selection of T-Test and F-Test

The T-test is used in this report to test whether there is a statistically significant difference between the means of the parameters of specification item 3063 (Quality Control/Quality Assurance, QC/QA) and item 340 (method specification). The F-test is used to test the statistical differences in the variances of parameters.

The QC/QA specification and method specification were not implemented concurrently. Therefore, the data collected on control parameters for QC/QA specification belong to younger pavements, as compared with the data collected for the non-QC/QA specification. In addition, the data were not for similar projects under both specifications. Therefore, statistical models such as factorial design, block design, and Latin squares cannot be used to test the differences between two specifications; the T-test and F-test can, however, be used. The T-test and F-test usually provide a robust test on the parameters as long as the degree of freedom of data is sufficiently large.

3.3.3. T -Test with Unequal Population Variances

It has been shown that if the distributions of two samples are not too far from normal distribution and/or the two sample variances are not too different from one another, then the T-test works reasonably well. However, if the variances of the two samples are very different from one another, then the T-test with unequal population variances (in Eq 1) should be used in order to prevent erroneous test conclusions. In this research, the population variances of QC/QA and non-QC/QA projects are unknown. Therefore, it would be better to use equation (1) as the test model.

$$T \text{ statistic: } t = \frac{\bar{x} - \bar{y} - \Delta}{\sqrt{\frac{S_1^2}{m} + \frac{S_2^2}{n}}} \qquad \text{(Eq 1)}$$

$$\text{Degree of Freedom } df = \frac{\left(\frac{S_1^2}{m} + \frac{S_2^2}{n}\right)^2}{\frac{\left(S_1^2/m\right)^2}{m-1} + \frac{\left(S_2^2/n\right)^2}{n-1}} \qquad \text{(Eq 2)}$$

Ho: $\mu_1 = \mu_2$

Ha: $\mu_1 \neq \mu_2$

Rejection region for *Ho* at risk level α : either $t \leq t_{-\alpha/2,\ df}$ *or* $t \geq t_{\alpha/2,\ df}$

where

m	=	the number of data for population 1 (QC/QA)
n	=	the number of data for population 2 (non-QC/QA)
$\bar{x}$	=	the mean of data for population 1
$\bar{y}$	=	the mean of data for population 2
Δ	=	the difference between the true population means (assumed to be zero)

Equations (1) and (2) are used in this research to conduct hypothesis tests in order to determine if there is a significant difference in the means of the parameters under observation between QC/QA and non-QC/QA projects.

3.3.5. F -Test

The F-test is used in this study to test the difference between population variances for reasons similar to those of the T-test. The F-statistic is listed in equation (3).

$$\text{F-statistic: } f = \frac{s_1^2}{s_2^2} \qquad \text{(Eq 3)}$$

Ho: $\sigma_1^2 = \sigma_2^2$

Ha: $\sigma_1^2 \neq \sigma_2^2$

Rejection region for H_o at risk level α : either $f \leq F_{1-\alpha/2,\ m-1,\ n-1}$ *or* $f \geq F_{\alpha/2,\ m-1,\ n-1}$

3.3.5. Results from Statistical Analysis

The summary of results for testing significant differences between the parameters under observation is shown in Tables 3.6, 3.7, and 3.8. Parameters include algebraic differences in percent AC, percent passing 2 mm sieve, percent passing 0.075 mm sieve, percent laboratory densities, and percent air voids. All data points for each parameter are used to obtain the indicated results in Table 3.6. The means and standard deviations of project means are used to obtain the results presented in Table 3.7, and pooled standard deviations of all projects for results in Table 3.8. The risk level α is considered 5 percent in drawing conclusions shown in these tables.

Table 3.6. Results Based on the Means and Standard Deviations of All Data Points (S_o)

	Significant Difference in Mean	*T* - Statistic	*T* - Critical	Significant Difference in Variance	*F* - Statistic	*F* - Critical
AC %	No	-0.93	1.96	No	0.67	1.29
#10 S.	Yes	1.97	1.96	No	0.60	1.28
#200 S.	Yes	19.42	1.96	No	0.37	1.28
Lab Den.	Yes	-10.78	1.96	No	0.59	1.00
Air Void	No	1.88	1.96	No	0.17	1.00

Table 3.7. Results Based on the Means and Standard Deviations of Project Means (S_m)

	Significant Difference in Mean	*T* - Statistic	*T* - Critical	Significant Difference in Variance	*F* - Statistic	*F* - Critical
AC %	No	0.11	1.98	Yes	1.77	1.71
# 10 S.	No	-0.25	1.98	No	0.50	1.70
# 200 S.	Yes	5.25	1.98	No	0.32	1.70
Lab Den.	No	0.74	1.98	No	0.00	1.70
Air Void	No	0.27	1.99	No	0.66	1.64

Table 3.8. Statistical Results Based on the Pooled Standard Deviations of All Projects (S_p)

	Significant Difference in Mean	*T* - Statistic	*T* - Critical	Significant Difference in Variance	*F* – Statistic	*F* - Critical
AC %	No	-0.11	1.98	No	1.07	1.70
# 10 S.	No	0.75	1.98	No	0.44	1.70
# 200 S.	Yes	4.01	1.98	No	0.21	1.70
Lab Den.	Yes	-2.42	1.98	No	0.63	1.70
Air Void	No	1.42	1.99	No	0.82	1.77

The results shown in Tables 3.6 through 3.8 indicate that there is not a significant difference between variances for different control parameters when comparing QC/QA and non-QC/QA projects (with the exception of asphalt content deviation when mean values of projects are used, as shown in Table 3.7). This implies that from a statistical point of view, there is no difference between uniformity of projects built under QC/QA and non-QC/QA specifications. However, as mentioned before, if purely numerical values are considered, less variability is observed for QC/QA projects.

Table 3.8 indicates that the means for laboratory density and percent passing the 0.075 mm sieve are statistically different for QC/QA and non-QC/QA projects. The means for other parameters do not differ under the two specifications. The means for laboratory densities are expected to be different because in non-QC/QA projects laboratory densities were mostly targeted at 97 percent, whereas for most QC/QA projects, they were around 96 percent. However, for percent passing the 0.075 mm sieve, the results indicate that there is a better control to follow the target value for QC/QA projects compared to non-QC/QA projects.

CHAPTER 4
SURVEY OF PROJECTS

4.1. Survey of Projects

A visual survey of the constructed projects generally indicated that QC/QA projects are in as good a condition as the non-QC/QA projects. However, no general conclusion could be drawn on distinct superiority or inferiority when comparing the two sets of specifications. Because no exact matching pairs could be found, in the case of the few very close pairs (for example, SH 100 in the Pharr District, SH 73 in Beaumont, and FM 258 in El Paso), the quality of the constructed pavements was essentially equal for pavements constructed under both specifications.

Both the QC/QA specification and the non-QC/QA specification yielded projects that were in good or excellent shape (Appendix C). Average or low-quality pavements were also observed under old and new specifications. It was not easy to judge which specification had a higher percentage of better pavements when compared with the other.

It is important to realize that some of the physical problems found in the most recent pavements exist mainly because of the inadequacy of the design or of the poor quality of the materials used. These problems are not directly due to deficiencies in specifications. For example, the very severe rutting and shoving observed on Loop 20 at the intersection with IH-35 in Laredo less than 2 years after construction exist simply because conventional mixes and designs used at this intersection are not adequate to prevent distresses regardless of what construction specifications are used. There is considerable heavy truck traffic at this intersection, and pavement temperature at peak summer times is extremely high. However, some other problems are directly related to the quality of construction. An example is Wurzbach Road at the intersection with Bandera Highway in San Antonio, where the overlay contained too high a binder content and there was an immediate need to remove and replace it with a new overlay. This problem cannot be attributed to the specification that requires performing sufficient tests to ensure the mixture meets the required criteria.

4.2. A Look at the Projects' Costs

One of the concerns of TxDOT, in regard to the QC/QA specifications, has been whether implementing these specifications has increased the cost of production and placement of hot mix asphalt. If the answer is yes, can the higher cost be justified by a better quality of the pavement under QC/QA specifications?

The cost of hot mix asphalt (HMA) varies considerably throughout the state. Even within the same district, the cost of constructing hot mix asphalt varies within a wide range. The cost of HMA depends on many factors, including the cost of the original materials, use of modifier, and the distance the material needs to be hauled. Aggregate is one of the most important factors in determination of the cost. In areas where local sources of quality aggregate are abundant, the cost can be considerably lower than that in areas where the aggregate has to be transported from distant quarries. Transportation and trucking can greatly boost the cost of the delivered aggregate. If, for example, a certain type of crushed stone costs about $4.10 per ton at the quarry, this price can be easily doubled and tripled for delivering it 10 to 80 kilometers away. Therefore, it is not surprising to see a wide range in cost and bid prices of HMA throughout the state. The typical range of bid prices reported within the state varies from the low twenties to the high thirties (in dollars). While the average bid price has been higher for most of the districts after implementing QC/QA specifications, some have reported 5 to 10 percent lower bid prices in recent years. Part of this lower price may be attributed to higher competition among contractors in certain areas. However, studying a number of projects built under QC/QA specification indicates that, on average, TxDOT pays approximately a 2 percent bonus on the HMA projects with implementation of specification item 3063. The following table indicates the average pay factor and the corresponding standard deviation for the pay parameters. These results are obtained based on the analysis of forty-five projects built under QC/QA specifications from 1993 through 1996.

Table 4.1. Average Pay Factors under QC/QA Specification for a Number of Sub-lots

Pay Parameters	0.075 mm Sieve	2 mm Sieve	Asphalt Content	In-Place Air Voids
Number of Sub-lots Surveyed	61	61	61	61
Average P.F.	1.03	1.00	1.03	1.00
Std. Dev. for P.F.	0.02	0.03	0.05	0.03

The table indicates that the average pay factor for asphalt content and percent passing the 0.075 mm sieve is 1.03, whereas an average pay factor of 1.00 is obtained for in-place air voids and percent passing the 2 mm sieve. The average pay factor being higher than one for asphalt content and 0.075 mm sieves implies that a change is needed to ensure that a bonus will be paid for a tighter range of deviations from these two parameters. The reason behind this problem is explained in section 5.3.3 of Chapter 5. Section 5.7 in Chapter 5 describes a procedure that can resolve this problem.

Figure 4.1 shows the trend of the average bid price as a function of time for production and placement of HMA for the period between 1992 through 1997. This average is obtained based on the data for all the districts in the state. The average bid price for the period before July 1993 is slightly over $27. There is a sudden jump in price starting in August 1993. The average bid price remains relatively high, around $30 for the period from August 1993 through June 1995, when a drop in the price is observed. Beyond June 1995, the average price remains around $28.50.

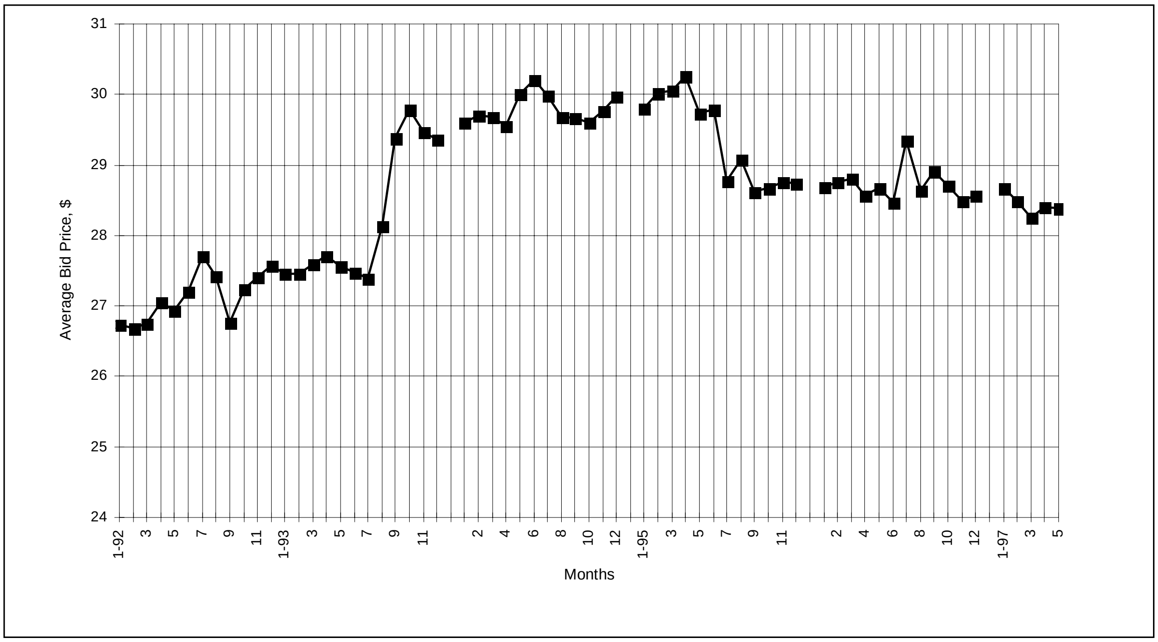

Figure 4.1. The Average Bid Price for Production and Placement of Hot mix Asphalt as a Function of Time (Courtesy of Construction and Maintenance Division, Texas Department of Transportation)

It is reasonable to believe that the 8 percent higher price for the 2-year period from August 1993 through June 1995 compared with previous years was associated with initiation of QC/QA projects that required the contractors to purchase new equipment, hire certified technicians, or have their technicians trained and certified. However, a portion of this increase can be attributed to the increase in the aggregate price (Figure 4.2). After the first 2 years of the QC/QA specification, during which time new equipment and procedures were somewhat established, a gradual decrease in bid price was observed, so that during the spring of 1997, the average bid price was just about 4 percent higher than that for the period before 1993. If the average 2 percent bonus is also added, it can be concluded that, on average, the production/placement of HMA has increased by almost 6 percent over the last 2 years, as compared with the years before 1993.

Considering the increase in the cost of aggregate and an average higher cost for asphalt cement (Figures 4.2 and 4.3), respectively, during recent years it can be concluded that the move toward new QC/QA specifications has not increased the cost of hot mix asphalt compared with the years prior to 1993. Figure 4.2 shows how the price of the aggregate for hot mix asphalt has changed during the last 10 years. The graph represents the price at the quarry for one of the local sources of crushed stone. The average price for the years 1995, 1996, and 1997 is about \$4.41/ton, whereas the average price for all the years before 1993 is about \$3.88/ton. Therefore, there is an increase of about 14 percent that can definitely contribute to the increase in the cost of hot mix asphalt. Figure 4.3 shows the cost of asphalt cement (AC-20) for a number of years for one major U.S. city. The average price for the years 1995, 1996, and 1997 is about $118 per ton, which is almost 3 percent higher than the average cost of $114 dollars per ton for the years 1987 through 1993 (excluding 1992). Thus, the higher cost of original materials has contributed to the higher cost of hot mix asphalt for the years after 1995, compared to the years before 1993.

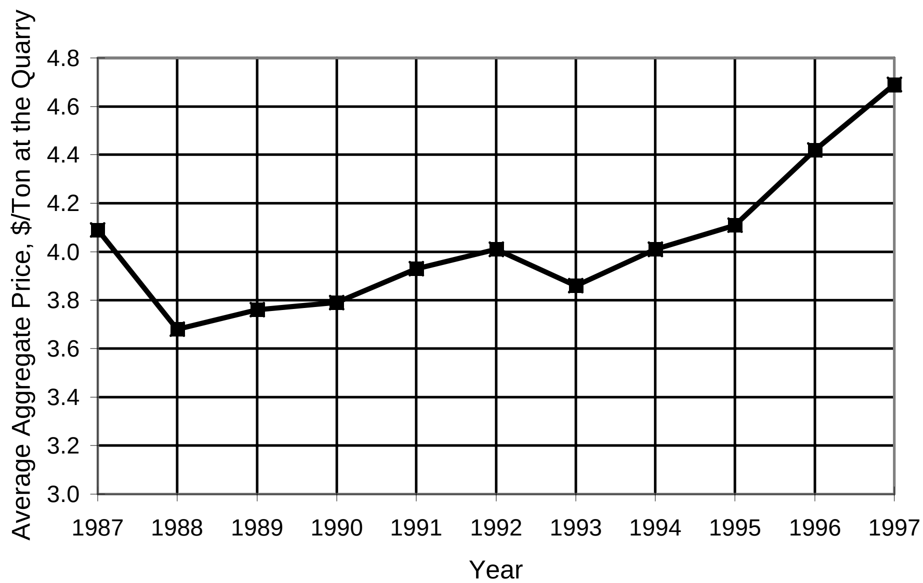

Figure 4.2. The Price of Crushed Aggregate Used in Hot Mix Asphalt Obtained from One of the Aggregate Producers in Texas

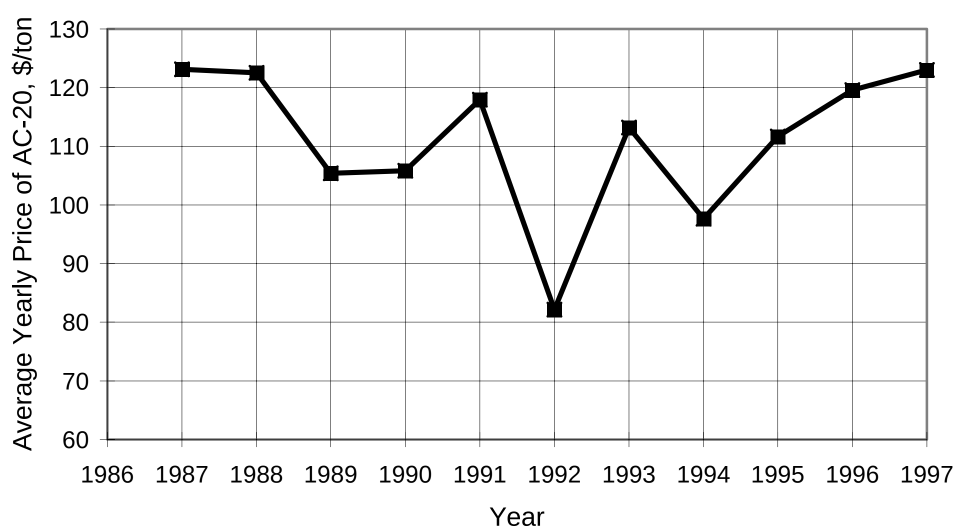

Figure 4.3. Average Cost of Asphalt Cement (AC-20) for a major U.S. City (Source: ENR)

CHAPTER 5
SUGGESTED MODIFICATIONS

5.1. General

The move toward a quality control/quality assurance (QC/QA) specification is definitely a step forward. States that have already started with a QC/QA specification have shown no tendency to return to method specifications; rather, they continue to develop and improve their QC/QA specifications. In this regard, the Texas Department of Transportation (TxDOT) has certainly taken encouraging steps. While the fundamentals are reasonable within the current QC/QA specification, there are some shortcomings that need to be addressed and resolved.

The recommendations outlined in this chapter are made based on the information obtained from TxDOT and from the construction industry as discussed in Chapter 2, and on the data obtained to date presented and analyzed in Chapter 3.

5.2. Sampling

The QC/QA specification relies on the laws of probability and statistics for fairness. Accordingly, it is essential that we ensure randomness of sampling. Random sampling is a method of sampling in which every piece within the population has an equal opportunity to appear in the sample. In this regard, the time and location of sampling should not be disclosed until the time of sampling. It is recommended that the engineer be responsible for establishing the random sampling plan. It is also recommended that the frequency of sampling be increased; that is, six rather than four samples should be taken for each lot. However, only four of the six will be used for testing, and the remaining two will be retained for possible use. This higher frequency helps in better controlling product uniformity.

5.3. Pay Factors

5.3.1. Continuous Versus Stepped Pay Schedule

There is certainly a definite need to change the pay schedule from a step-wise type to a continuous form. This latter type has a distinct advantage over the former. In a stepped pay schedule, there are cases when the true level of the work is closer to a boundary (where the pay factor moves up or down to the next step). An estimate of the quality of the product may fall on either side of this boundary primarily because of chance. There could be a substantial difference in the amount of pay, depending on which side of the boundary the estimate lies. Such a situation may lead to disputes over precision of measurements, round-off rules, and so forth.

Under a stepped function, a tendency may exist to manipulate the measured value to force it on one side of the boundary for higher or lower pay. This may be the reason why measured air voids of cores from constructed QC/QA projects have such a high concentration of values on one side of the boundary. Out of 930 values for percent densities from QC/QA projects, there are only four values equal to 90.9, whereas there are thirty-two values equal to 91.1. Based on random selection, the number of percent densities equal to 90.9 is expected to be approximately equal to the number of densities equal to 91.9. For the existing stepped pay schedule, the pay factors are equal to 1 and 0.95 for percent densities of 91.1 and 90.9, respectively. It is clear how the use of a continuous function can resolve this problem.

5.3.2. Determination of Pay Levels

An important issue in the development of the pay schedule is the determination of appropriate pay levels for various levels of quality. Various methods have been proposed for this purpose. A rational approach is relating the level of payment to the predicted performance of the pavement and to the cost of maintaining and repairing the pavement in the future. This method is considered a *liquidated damage* approach. Examples can be found in several publications. The following formula has been developed for determination of pay factor based on the expected life of the pavement *(12):*

$$PF = 100\left[\ (1 + C_0 (R^{L_d} - R^{L_e}) / C_p (1 - R^{L_0})\ \right]$$

where

PF	=	pay factor (percent)
C_p	=	present unit cost of pavement (bid item only)
C_0	=	present unit cost of overlay
L_d	=	design life of pavement
L_e	=	expected life of pavement
R	=	$(1 + R_{inf}/100)/(1+R_{int}/100)$
R_{inf}	=	annual inflation rate (percent)
R_{int}	=	annual interest rate (percent)

Another simple procedure, taking advantage of mean and standard deviation and presented by Afferton et al. *(12)*, is the use of quality index *Q* defined as follows:

$$\frac{\bar{\bar{X}} - L}{S}$$

where

Q	=	quality index
X	=	the sample mean

S = sample standard deviation

L = specification limit

The payment is determined based on the magnitude of *Q*. Such an approach is useful for a one-sided case (i.e., single limit specification, such as for the thickness of the pavement). For a double-limit specification, one having both lower and upper limits, a more general approach should be used. Any method used in this regard must be statistically sound and must address both variability and deviations from target values. Engineering judgment is used to determine limits for each parameter, beyond which the material is considered defective. Based on a certain sampling plan and these limits, the measured deviations from target values and the magnitude of variability for each parameter can be used to determine what percent of the material is defective. Payments can be established based on the level of defect. As an incentive, a bonus may be applied to the material and workmanship with very little percent defective (excellent quality), and a penalty must be applied to the material and workmanship with a high percentage of defective material (poor quality). For implementation of this concept, a logical relationship needs to be developed between the quality level and payment. An example of such a relationship is proposed as *(12)*:

$$PF = 102 - 0.2PD$$

where

PF = pay factor

PD = percent defective

For this case, when 10 percent of the product is defective, payment will be 100 percent. For less defective material, a bonus is paid; and for a material more than 10 percent defective, a penalty will be applied. When PD=100 (maximum value for percent defective), a pay factor of 82 percent is obtained from this equation. However, this will be a high level of payment for 100 percent defective material. Most state highway agencies tend to reject the material completely if it is more than a certain percent defective (for example, 80 percent). Therefore, such an equation is proper for an acceptable level of percent defective.

5.3.3. Pay Factors According to Specification 3063

In the specification item 3063, the concept of mean absolute deviation (MAD) is used to determine the level of payment. MAD is calculated based on four measurements for each production or placement lot. The parameters for which MAD is calculated and payments are based include asphalt content, gradation (percent passing 2 mm sieve and percent passing 0.075 mm sieve), and placement air voids. Payments are determined based on the magnitude of MAD for each parameter from the target values.

The advantage of using means of absolute values versus means of algebraic values is that in the case of the former, the deviation from target values is better captured. For example, we assume that for a certain project the target asphalt content is 5 percent, and the four sample measurements are 4.7, 4.7, 5.3, and 5.3 percent for one of the lots, and are 4.9, 4.9, 5.1, and 5.1 for another lot. Obviously, the second lot is of a better quality based on this sampling (less variability). If algebraic values are used, the mean deviation in either case will be zero, whereas if absolute deviations are used the mean absolute deviation will be 0.3 for the first lot and 0.1 for the second lot. Therefore, mean absolute deviation better presents quality of the material in regard to deviations from target values. However, the problem with mean absolute deviation is that it does not always adequately indicate the level of uniformity of the product. Consider the same example. In one of the lots, the results from asphalt content measurements are 4.7, 4.8, 5.2, and 5.3 percent. In the other lot, the values are 5.2, 5.2, 5.3, and 5.3 percent. For both cases MAD is 0.25. However, it is clear that there is less variation in the second lot even though both lots have the same range of deviations from target values. Therefore, using MAD alone to determine pay factors may not be adequate. An extra measure, such as standard deviation, is required to distinguish between lots with the same mean absolute deviations but different levels of uniformity.

5.4. Acceptance Sampling Plan

5.4.1 An Alternative Approach to Mean Absolute Deviation

A logical approach is to include both the mean and the standard deviation. As mentioned before, a stepped function is used for determination of pay factors in specification item 3063. An example of pay schedule based on step function is shown in Figure 5.1. This example represents payments for asphalt content deviation as outlined in specification 3063. A pay factor of 1.00 applies to a mean absolute deviation of 0.30 in percent asphalt content, while a pay factor of 0.95 applies to a deviation of 0.31. There is only a difference of 0.01 percent between the two. Our testing procedures and equipment do not have the capability of measuring asphalt content within 0.01 percent accuracy. Therefore, from a testing point of view, there is no difference between a deviation of 0.30 and 0.31 in percent asphalt content. On the other hand, one could hardly argue that a deviation of 0.31 in asphalt content has a more detrimental effect on performance than a deviation of 0.30. Considering this argument, 5 percent difference in pay factor is difficult to justify.

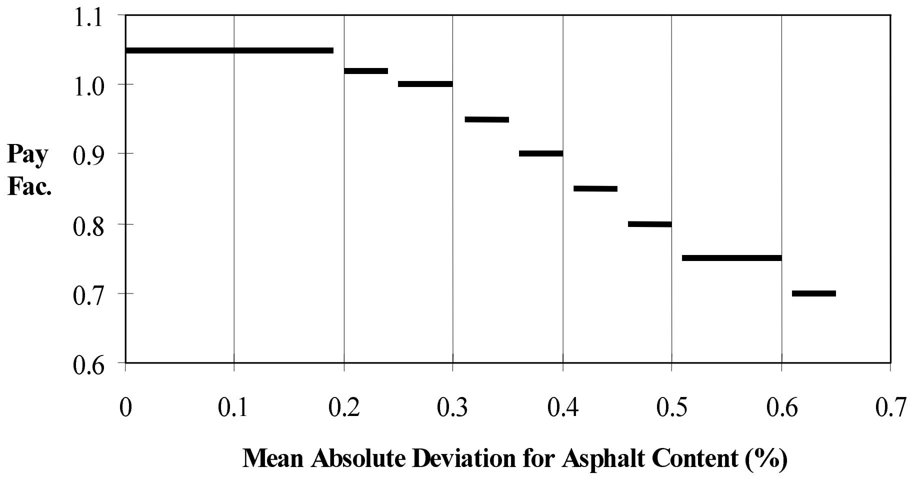

Figure 5.1. Pay Factor Determined Based on a Stepped Function

The use of a continuous pay factor eliminates such a problem because under a continuous function practically the same pay factor is delivered whether mean absolute deviation is 0.3 or 0.31.

5.4.2. Acceptable Sampling Plan and Quality Levels

An important part of any statistical quality control/quality assurance process is a logical acceptance sampling plan. Since continuous control of the whole product is not feasible, a good acceptance sampling plan is necessary to exert effective pressure for quality improvement. As part of the plan, the decision needs to be made on the size of the lot, and on the frequency and size of sampling and testing. The agency's risk in accepting material of poor quality and the contractor's risk in having good material rejected depend on the size of the sampling. As the size of the sample becomes smaller, the risks for the agency and contractor increase. In a good sampling plan, these risks are balanced and kept at a reasonably low level.

In an acceptance sampling plan, it is necessary to decide on a maximum percent defective that is considered acceptable. This "acceptable quality level" is abbreviated as AQL. The value selected for AQL depends on the seriousness of the consequences. Obviously, for serious defects with serious consequences, a relatively low AQL value should be used. The selection of AQL is primarily based on engineering judgment. Along with AQL, there is RQL, which is defined as the level below which the quality of the product is unacceptable. The RQL is also referred to as "the limiting quality level," "the unacceptable quality level," or "lot tolerance percent defective." In some cases, the quality of the delivered product is not as good as AQL (and, hence, qualified for full payment), but not as poor as RQL (hence, completely rejected and removed). This region between the AQL and RQL is referred to as the *indifference zone*, and has a corresponding pay factor of less than 1.

A more appropriate term for percent defective is *percent nonconforming*, implying the percent of the material that is not within the limits of acceptance. The percent of material within limits of acceptance is referred to as *percent within limits* (PWL) or *percent conforming.* Percent defective and percent within limits are complements and add up to 100 percent (PD+PWL = 100%).

5.4.3. Operating Characteristics Curve

Development of an operating characteristics curve (OC curve) is an essential step of the acceptance sampling plan. On such a curve, probability of acceptance of the product is shown on the ordinate and the percent defective is presented on the abscissa. Based on such a curve, it will be possible to know in advance if the acceptance procedure will function as intended. This curve helps to determine the risk levels to the agency and the contractor, and can be used to determine if the selected AQL and RQL provide reasonably low risks. The operating characteristics curve is developed using the information on the expected mean and standard deviation for the desired parameter, the specification limits on defective material, and the sample size for each lot. An example of an OC curve is shown in Figure 5.2. This curve has been developed for density of laboratory specimens using a sample size of four, and a mean and standard deviation of 96 and 0.65, respectively (using historical data).

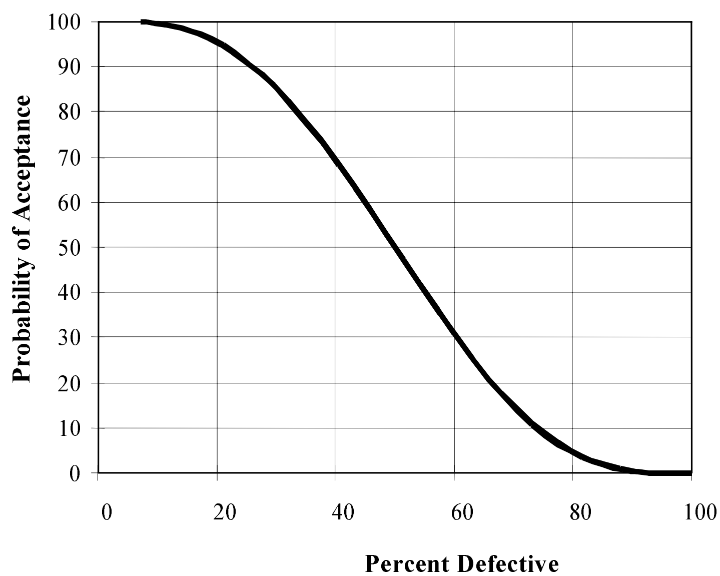

Figure 5.2. A Sample Operating Characteristics Curve

The acceptance sampling requires randomness, i.e., each piece in the lot is assumed to have an equal chance to be selected in the sample.

5.5. Selection of Pay Parameters

In the QC/QA specification 3063, the controlling parameters for payment are asphalt content, percent passing 2 mm and 0.075 mm sieves, and placement air voids. Payment is determined based on deviations from target values for these parameters. As expressed during interviews, some district personnel were in favor of including the laboratory density as a pay parameter. The assumption was that considerable information can be obtained on the quality of the mixture based on the density of plant mix laboratory-compacted specimens. A study needs to be carried out to determine the relationship between the effect of variations in the quality and quantity of the asphalt and aggregates on the density of the laboratory-compacted specimens. A study of this nature can be carried out in the form of a sensitivity analysis based on a statistical experiment design. In general, the most crucial parameters affecting performance need to be considered as pay factor parameters.

5.6. Proposed Method for Acceptance Sampling and Payment Determination

Based on the preceding discussion on the acceptance sampling plan, the following procedure is proposed:

Once the pay parameters are established, the following steps can be followed to determine the quality and the level of payment.

1. For any parameter, establish the limits beyond which the product is considered defective and unacceptable. Assuming a normal distribution of deviations from target values for the parameter of interest (for example, asphalt content), the lower and upper limits of acceptance will be established. The area outside these limits indicates the limiting (unacceptable) quality level.

2. The operating characteristics curve (OC) is developed for the product.

3. Establish the acceptable quality level (AQL). This is the maximum percent defectiveness at which the product will be completely accepted at a pay factor of at least 1. This level is determined based on the OC curve, the degree of criticality, the desired risk levels, and the associated probabilities of acceptance. It is recommended that 95 percent probability of acceptance be used at AQL for typical control parameters in hot mix asphalt concrete (HMAC). Evaluating typical OC curves for a sample size of four indicates that, at this probability, AQL will be about 20 percent. An AQL of 20 percent implies that a lot with at most 20 percent defectiveness will be paid at a pay factor of 1 or more.

4. Establish the unacceptable quality level (RQL) as explained above. This is the minimum percent defect for which the product will be completely rejected. It is recommended that a 20 percent probability of acceptance be used at RQL for typical control parameters in HMAC. Evaluating typical OC curves for a sample size of four

indicates that, at this probability, RQL will be about 80 percent. An acceptable quality level of 80 percent implies that a lot with at least 80 percent defectiveness will be completely rejected with no payment.

5. As mentioned before, there is the possibility that the product will be more defective than the level established as AQL, but not defective enough to be completely rejected. Such material, lying in the zone between AQL and RQL, will be paid at a reduced rate depending on the level of defect. In other words, a pay factor of less than 1 and larger than zero will be applied to the lot if the percent defective lies between AQL and RQL.

An example is provided to illustrate how the suggested method of establishing defectiveness and payment can be applied. For this example, it is assumed that density of laboratory-compacted specimens is one of the parameters considered for determination of payment. It is assumed that a laboratory density of 96 percent is the optimum desired level. Based on historical data, the pooled standard deviation for this parameter is selected as 0.65 percent. It is also reasonably assumed that this parameter follows a normal distribution. Upper and lower acceptance limits (UAL and LAL, respectively) are considered as the following:

$$UAL = \mu + zs$$

$$LAL = \mu - zs$$

where

μ = mean laboratory density (96%)

s = standard deviation

z = normalized operator determined based on the area under the normal curve equivalent to percent within limits

Based on the given information, the normal distribution and the associated OC curve for a sample size of four (n=4) are illustrated in Figure 5.2. The OC curve indicates that if AQL is accepted at 96 percent and RQL at 20 percent, then the associated probabilities of acceptance for these two cases will be 15 and 80 percent of defective material, respectively.

To encourage production of high quality, a bonus of up to 5 percent is considered for material less than 15 percent defective. A pay factor of 1 is used for percent defective between 15 and 20. Payment is linearly reduced from 1 as percent defective increases from 20 to 80 percent. For lots with material more than 80 percent defective, a very high penalty or zero payment is applied. This payment method is illustrated in Figure 5.3. The figure is applicable to any control parameter, including asphalt content, percent passing sieves 0.075 and 2 mm, and air voids. Two attributes are required for each parameter to determine the pay factor: the mean and the standard deviation.

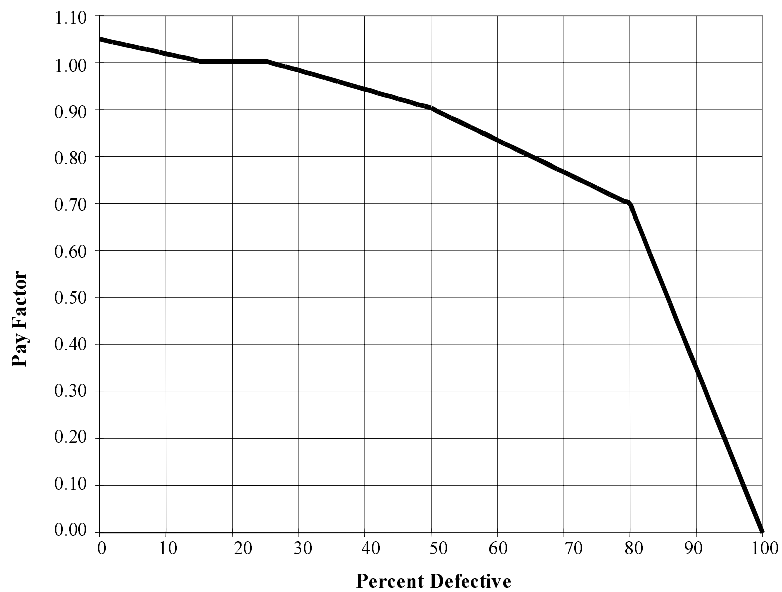

Figure 5.3. Example of a Continuous Pay Factor Based on Percent Defective

5.7. Evaluation of Current Pay Factors with Respect to Percent Defective

One of the major concerns expressed by Department personnel was that ranges on parameters seem to be too wide for determination of payments. For example, there is a 5 percent bonus if the mean absolute deviation from target asphalt content is less than 0.2 percent. An evaluation was performed to indicate how these payments are related to the percent defective. Thus, for each set of four sub-lots (one lot), mean and standard deviation, percent defective, and mean absolute deviation were calculated. The corresponding pay factors were determined based on the procedure outlined in the existing specification item 3063, as well as based on the suggested procedure explained above. The pooled standard deviations reported in Chapter 3 were used in establishing OC curve and determination of percent defective. Comparison was made for all four pay parameters: asphalt content, percent passing 2 mm sieve, percent passing 0.075 mm sieve, and air voids. The results for real projects constructed under item 3063 are shown in Tables 5.1 through 5.4. In many cases, the suggested pay factor is very close to the existing one. However, there are cases where, according to the current method, the same pay factor is used even though percent defective may be considerably different. This problem is avoided through the suggested method.

An example is payment for asphalt content, as shown in Table 5.3. The table indicates the pay factors based on the asphalt content mean absolute deviation for some of the constructed projects. It can be seen that two different lots with the same mean absolute deviation of 0.18 have been paid based on a factor of 1.05 (see the existing pay factor in the table). However, the first lot has been very uniform with a standard deviation of 0.05 (resulting in percent defectiveness of less than 1 percent), whereas the second lot with a standard deviation of 0.17 (13 percent defectiveness) has not been as uniform as the former. If the concept of percent defectiveness is taken into account, the payment for the former will be 1.05 and payment for the latter will be 1.01 (see the suggested pay factor in the table). There are sixty-nine lots presented in the table. The average existing pay factor for these lots is 1.03, whereas the average suggested pay factor for the lots is 1.00.

Table 5.1. Comparison of Pay Factors between Item 3063 and Suggested Method for Asphalt Content

Algebraic AC % Diff. Mean	Algebraic AC % Diff. Std	Abs AC % Diff. Mean	Abs AC % Diff. Std	Percent Defective	Suggested Pay Factor	Existing Pay Factor
0.03	0.05	0.03	0.05	0.00	1.05	1.05
0.13	0.04	0.13	0.04	0.00	1.05	1.05
-0.04	0.08	0.05	0.05	0.20	1.05	1.05
0.05	0.13	0.10	0.08	1.40	1.05	1.05
-0.07	0.10	0.08	0.09	1.20	1.05	1.05
-0.18	0.05	0.18	0.05	0.00	1.05	1.05
0.22	0.05	0.22	0.05	0.20	1.05	1.02
0.15	0.09	0.15	0.09	1.70	1.05	1.05
-0.18	0.05	0.18	0.05	0.60	1.05	1.05
0.23	0.05	0.23	0.05	0.20	1.05	1.02
0.14	0.15	0.15	0.14	1.40	1.05	1.05
-0.21	0.03	0.21	0.03	0.60	1.05	1.02
-0.10	0.08	0.10	0.08	0.20	1.05	1.05
-0.03	0.16	0.13	0.07	5.00	1.04	1.05
-0.08	0.11	0.09	0.09	2.00	1.04	1.05
-0.13	0.10	0.13	0.10	4.00	1.04	1.05
0.15	0.10	0.15	0.10	3.00	1.04	1.05
-0.12	0.09	0.12	0.09	2.60	1.04	1.05
0.16	0.10	0.16	0.10	3.00	1.04	1.05
-0.13	0.13	0.13	0.13	8.90	1.03	1.05
-0.20	0.08	0.20	0.08	6.00	1.03	1.02
0.06	0.17	0.15	0.08	6.00	1.03	1.05
0.00	0.14	0.10	0.08	9.00	1.03	1.05
-0.15	0.13	0.15	0.13	9.00	1.03	1.05
0.01	0.17	0.17	0.09	5.00	1.03	1.05
-0.15	0.13	0.15	0.13	8.90	1.03	1.05
0.14	0.15	0.15	0.14	6.00	1.03	1.05
0.05	0.18	0.15	0.09	7.00	1.03	1.05
0.05	0.13	0.10	0.08	8.50	1.03	1.05
-0.20	0.08	0.20	0.08	6.00	1.03	1.02
-0.05	0.19	0.15	0.10	9.40	1.02	1.05
-0.22	0.06	0.22	0.06	11.00	1.02	1.02
0.10	0.18	0.15	0.13	10.00	1.02	1.05
0.15	0.17	0.15	0.17	13.00	1.01	1.05
-0.05	0.21	0.15	0.13	13.00	1.01	1.05
0.18	0.17	0.18	0.17	13.40	1.01	1.05
0.25	0.10	0.25	0.10	18.50	1.00	1.00
0.18	0.19	0.23	0.10	17.00	1.00	1.02
0.20	0.14	0.20	0.14	16.00	1.00	1.02
0.14	0.23	0.19	0.18	18.00	1.00	1.05
0.18	0.19	0.23	0.10	16.50	1.00	1.02
0.20	0.14	0.20	0.14	16.00	1.00	1.02
0.14	0.23	0.19	0.18	18.00	1.00	1.05
0.12	0.18	0.19	0.08	10.00	1.00	1.05
-0.10	0.23	0.20	0.11	19.00	1.00	1.02
-0.19	0.16	0.19	0.16	22.00	1.00	1.05
0.20	0.18	0.20	0.18	22.00	1.00	1.02
0.20	0.15	0.20	0.15	18.00	1.00	1.02
0.20	0.14	0.20	0.14	16.00	1.00	1.02
-0.05	0.31	0.20	0.22	29.00	0.99	1.02
0.18	0.28	0.23	0.22	29.00	0.99	1.02
0.09	0.33	0.27	0.14	32.00	0.98	1.00
0.22	0.25	0.22	0.25	31.00	0.98	1.02
-0.28	0.05	0.28	0.05	31.00	0.98	1.00
-0.08	0.33	0.28	0.13	34.00	0.97	1.00
0.65	0.24	0.65	0.24	36.00	0.96	0.70
-0.30	0.08	0.30	0.08	38.00	0.96	1.00
0.07	0.46	0.29	0.33	47.00	0.92	1.00
0.07	0.46	0.29	0.33	47.00	0.92	1.00
0.15	0.50	0.30	0.40	52.00	0.89	1.00
0.40	0.14	0.40	0.14	67.00	0.79	0.90

Table 5.2. Comparison of Pay Factors between Item 3063 and Suggested Method for Air Voids

Algebraic Air Voids Mean	Algebraic Air Voids Std	Percent Defective	Suggested Pay Factor	Existing Pay Factor
6.45	0.86	0.20	1.05	1.02
7.25	0.73	1.40	1.05	1.00
6.30	0.28	0.00	1.05	1.02
7.50	0.42	0.00	1.05	1.00
7.40	0.14	0.00	1.05	1.00
6.48	0.73	0.00	1.05	1.02
6.45	0.13	0.00	1.05	1.02
5.60	0.67	0.00	1.05	1.05
7.00	0.37	0.00	1.05	1.00
7.35	0.68	0.90	1.05	1.00
6.48	1.04	1.00	1.05	1.02
7.00	0.00	0.00	1.05	1.00
7.53	0.62	1.00	1.05	1.00
5.75	0.79	0.00	1.05	1.05
7.15	0.93	2.60	1.04	1.00
7.13	0.98	3.30	1.04	1.00
6.53	1.32	3.70	1.04	1.02
6.83	1.10	3.40	1.04	1.02
8.48	0.22	3.40	1.04	1.00
6.48	1.41	4.90	1.04	1.02
5.83	1.44	4.00	1.04	1.05
6.75	1.22	4.00	1.04	1.02
7.33	0.90	3.70	1.04	1.00
5.83	1.44	4.00	1.04	1.05
6.40	1.54	7.00	1.03	1.02
6.88	1.23	5.20	1.03	1.02
7.93	0.69	7.30	1.03	1.00
7.78	0.82	11.00	1.02	1.00
6.55	1.83	12.00	1.02	1.02
6.50	1.69	9.40	1.02	1.02
6.58	1.72	11.00	1.02	1.02
6.58	1.72	11.00	1.02	1.02
7.78	1.63	27.00	1.00	1.00
8.35	1.03	28.00	1.00	1.00
8.53	0.65	27.00	1.00	1.00
7.20	2.29	27.00	1.00	1.00
8.20	0.91	26.00	1.00	1.00
7.98	1.09	23.00	1.00	1.00
8.13	1.05	22.00	1.00	1.00
7.78	1.47	25.00	1.00	1.00
7.93	1.16	19.00	1.00	1.00
8.43	0.62	26.00	1.00	1.00
8.53	0.71	29.00	0.99	1.00
8.38	0.83	32.00	0.98	1.00
8.08	1.65	31.00	0.98	1.00
8.18	1.31	32.30	0.98	1.00
8.55	1.03	35.00	0.97	1.00
8.18	1.46	34.00	0.97	1.00
5.43	3.62	37.00	0.96	1.05
8.58	1.22	43.00	0.93	1.00
8.88	0.10	50.00	0.90	1.00
8.88	0.75	50.00	0.90	1.00
9.73	1.69	68.00	0.78	0.90
9.95	1.85	71.00	0.77	0.90
9.20	0.70	72.00	0.76	0.95
9.75	1.24	74.00	0.74	0.90
9.80	1.33	77.40	0.72	0.90
8.98	0.22	82.00	0.66	1.00
9.45	0.53	87.00	0.45	0.95

Table 5.3. Comparison of Pay Factors between Item 3063 and Suggested Method for Percent Passing 75-micron Sieve (Difference between Design and Extraction)

Algebraic 75-µ Mean	Algebraic 75-µ Std. Dev.	Absolute 75-µ Mean	Absolute 75-µ Std. Dev.	Percent Defective	Suggested Pay Factor	Existing Pay Factor
-0.18	0.22	0.23	0.15	0.00	1.05	1.05
-0.18	0.15	0.18	0.15	0.00	1.05	1.05
-0.15	0.13	0.15	0.13	0.00	1.05	1.05
0.03	0.29	0.18	0.21	0.00	1.05	1.05
-0.23	0.17	0.23	0.17	0.00	1.05	1.05
0.23	0.25	0.28	0.17	0.00	1.05	1.05
0.33	0.22	0.28	0.15	0.00	1.05	1.05
0.68	0.13	0.68	0.13	0.00	1.05	1.02
-0.40	0.12	0.40	0.12	0.00	1.05	1.05
-0.25	0.19	0.25	0.19	0.00	1.05	1.05
-0.65	0.13	0.65	0.13	0.00	1.05	1.02
0.18	0.17	0.18	0.17	0.00	1.05	1.05
-0.30	0.23	0.30	0.23	0.10	1.05	1.05
-0.25	0.31	0.30	0.24	0.20	1.05	1.05
-0.20	0.37	0.30	0.26	0.70	1.05	1.05
0.88	0.19	0.88	0.19	0.90	1.05	1.02
-0.33	0.30	0.33	0.30	1.00	1.05	1.05
-0.28	0.30	0.28	0.30	1.00	1.05	1.05
-0.53	0.22	0.53	0.22	1.10	1.05	1.02
-0.40	0.34	0.40	0.34	2.00	1.05	1.05
0.00	0.54	0.35	0.35	3.00	1.04	1.05
-0.10	0.47	0.30	0.34	3.00	1.04	1.05
0.05	0.51	0.40	0.22	2.20	1.04	1.05
0.58	0.33	0.58	0.33	2.50	1.04	1.02
-0.85	0.17	0.85	0.17	3.90	1.04	1.02
0.88	0.26	0.88	0.26	4.30	1.04	1.02
0.60	0.27	0.60	0.27	3.60	1.04	1.02
0.35	0.59	0.40	0.55	8.00	1.03	1.05
-0.35	0.45	0.50	0.18	6.00	1.03	1.05
-0.45	0.44	0.45	0.44	5.60	1.03	1.05
0.15	0.65	0.55	0.21	7.60	1.03	1.02
-0.68	0.24	0.68	0.24	11.00	1.02	1.02
-0.75	0.24	0.75	0.24	10.50	1.02	1.02
-0.43	0.56	0.58	0.34	11.00	1.02	1.02
-0.48	0.39	0.48	0.39	10.00	1.02	1.05
0.80	0.36	0.80	0.36	11.00	1.02	1.02
0.68	0.61	0.68	0.61	15.00	1.01	1.02
1.00	0.22	1.00	0.22	13.00	1.01	1.00
0.20	1.02	0.65	0.73	25.00	1.00	1.02
0.78	0.52	0.78	0.52	19.50	1.00	1.02
0.25	0.83	0.70	0.36	16.00	1.00	1.02
0.43	0.90	0.88	0.19	22.00	1.00	1.02
0.38	0.98	0.83	0.50	26.00	1.00	1.02
1.10	0.50	1.10	0.50	31.00	0.98	1.00
1.10	0.50	1.10	0.50	31.00	0.98	1.00
1.00	0.63	1.00	0.63	35.00	0.97	1.00
1.00	0.63	1.00	0.63	35.00	0.97	1.00
-0.68	0.79	0.88	0.46	36.00	0.96	1.02
1.08	0.67	1.08	0.67	36.00	0.96	1.00
1.32	0.14	1.32	0.14	37.00	0.96	1.00
0.98	0.79	0.98	0.79	38.00	0.95	1.00
0.95	1.01	1.05	0.87	42.00	0.94	1.00
1.26	0.75	1.26	0.75	48.00	0.92	1.00
-0.80	1.24	0.85	1.19	45.00	0.92	1.02
-0.80	1.24	0.85	1.19	45.00	0.92	1.02
1.25	0.88	1.25	0.88	48.00	0.91	1.00
1.25	0.88	1.25	0.88	48.00	0.91	1.00
0.80	2.10	1.30	1.74	60.00	0.84	1.00
1.40	0.42	1.40	0.42	64.00	0.81	1.00
1.45	0.25	1.45	0.25	73.00	0.75	1.00
1.45	0.25	1.45	0.25	73.00	0.75	1.00

Table 5.4. Comparison of Pay Factors between Item 3063 and Suggested Method for Percent Passing 2-mm Sieve (Difference between Design and Extraction)

Algebraic 2-mm Mean	Algebraic 2-mm Std. Dev.	Absolute 2-mm Mean	Absolute 2-mm Std. Dev.	Percent Defective	Suggested Pay Factor	Existing Pay Factor
1.60	0.71	1.60	0.71	0.10	1.05	1.02
0.15	1.16	1.00	0.22	0.00	1.05	1.02
0.95	1.16	1.15	0.89	0.80	1.05	1.02
0.10	0.48	0.40	0.16	0.00	1.05	1.05
1.00	0.50	1.00	0.50	0.00	1.05	1.02
0.55	0.97	0.80	0.71	0.00	1.05	1.05
1.73	0.53	1.73	0.53	0.00	1.05	1.02
0.10	1.06	0.80	0.54	0.00	1.05	1.05
-0.07	1.25	1.03	0.41	0.40	1.05	1.02
1.03	0.52	1.03	0.52	0.00	1.05	1.02
2.00	0.94	2.00	0.94	2.80	1.04	1.00
-2.68	0.45	2.68	0.45	3.70	1.04	1.00
1.30	1.17	1.50	0.80	2.00	1.04	1.02
-2.68	0.45	2.68	0.45	4.00	1.04	1.00
1.23	1.35	1.58	0.71	3.80	1.04	1.02
-1.55	1.00	1.55	1.00	2.00	1.04	1.02
1.98	1.02	1.98	1.02	4.00	1.04	1.00
2.65	0.60	2.65	0.60	5.00	1.04	1.00
1.58	0.22	1.58	0.22	2.80	1.04	1.02
-1.23	1.50	1.48	1.16	7.00	1.03	1.02
-0.65	1.86	1.10	1.56	7.50	1.03	1.02
0.48	2.02	1.58	1.03	0.00	1.03	1.02
1.55	1.38	1.55	1.38	5.60	1.03	1.02
1.85	1.11	1.85	1.11	5.30	1.03	1.02
0.60	1.89	1.20	1.47	6.00	1.03	1.02
2.23	1.01	2.23	1.01	8.30	1.03	1.00
-2.05	0.93	2.05	0.93	6.60	1.03	1.00
2.45	0.56	2.45	0.56	11.00	1.02	1.00
1.80	2.17	2.40	1.17	11.00	1.02	1.00
1.48	1.67	1.58	1.54	11.00	1.02	1.02
2.60	0.95	2.60	0.95	10.00	1.02	1.00
-1.65	1.41	1.65	1.41	10.00	1.02	1.02
0.85	2.36	2.10	0.82	15.00	1.01	1.00
-1.58	1.81	1.93	1.28	14.00	1.01	1.00
-1.53	2.25	1.78	1.99	20.00	1.00	1.02
1.43	2.63	1.98	2.10	23.00	1.00	1.00
2.18	2.11	2.18	2.11	23.00	1.00	1.00
1.80	2.17	2.40	1.17	19.00	1.00	1.00
-0.43	2.69	2.13	1.21	19.00	1.00	1.00
2.63	1.24	2.63	1.24	21.00	1.00	1.00
2.53	1.80	2.58	1.71	25.00	1.00	1.00
1.43	2.63	1.98	2.10	23.00	1.00	1.00
2.18	2.11	2.18	2.11	23.00	1.00	1.00
2.63	1.24	2.63	1.24	21.10	1.00	1.00
-1.08	2.47	2.33	0.68	19.00	1.00	1.00
-2.13	1.56	2.13	1.56	18.50	1.00	1.00
-1.55	2.46	1.90	2.10	22.50	1.00	1.02
2.40	1.59	2.40	1.59	19.00	1.00	1.00
-0.60	2.47	1.85	1.42	17.00	1.00	1.02
-2.58	1.16	2.58	1.16	19.00	1.00	1.00
1.83	1.90	1.88	1.84	17.00	1.00	1.02
-2.78	1.52	2.78	1.52	30.00	0.99	1.00
1.88	0.68	1.88	0.68	28.00	0.99	1.02
1.10	3.35	3.00	0.93	30.00	0.98	1.00
-2.63	2.38	2.63	2.38	37.00	0.96	1.00
3.34	1.10	3.34	1.10	36.00	0.96	0.95
-2.95	2.94	3.65	1.58	43.00	0.93	0.95
-3.28	3.54	4.18	1.90	50.00	0.90	0.90
3.68	1.54	3.68	1.54	50.00	0.90	0.95
-3.08	4.71	3.08	4.71	54.00	0.88	0.95
-3.83	0.99	3.83	0.99	66.00	0.80	0.95

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

A number of important findings were developed as a result of the activities pursued under this research program. This chapter summarizes the project's findings and corresponding conclusions.

Based on the received comments, projects built under specification item 3063 have not been of a higher quality, compared with the projects built under method specification.

Comparison of construction data obtained from quality control/quality assurance (QC/QA) projects with those from non-QC/QA projects indicates that the first group (QC/QA) had consistently smaller standard deviations on all parameters compared with the second group (non-QC/QA). This implies less variability in QC/QA projects. However, a statistical analysis of the data indicates that this difference is not significant.

Based on the percent of nonconforming material, as discussed in Chapter 5, pay factors are too high for asphalt content and percent passing the 0.075 mm sieve.

A general conclusion voiced at each of the regional meetings was that many of the commercial and contractor's technical personnel, and in some instances Department personnel, were unaware or unsure about how the design, sampling, and testing interfaced to yield a final acceptable product.

In general, visual survey of the constructed projects and statistical analysis of the collected construction information indicated there was no distinct superiority or inferiority when comparing the two sets of specifications and, in general, QC/QA projects are as good as the non-QC/QA projects. The young age of the QC/QA specification projects may have influenced this comparison. However, general comments received from the districts' personnel imply that projects built under specification item 3063 have not been of a higher quality, and sometimes not even of the same quality, compared with projects built under a method specification.

In general, the quality of pavements constructed under QC/QA specifications has been similar to that of pavements constructed under method specifications; however, there have been problems associated with sampling and pay factors. The use of a stepped pay function in specification item 3063, rather than a continuous one, has raised questions regarding the quality of the collected data and the fairness of payments. The move towards a continuous function, adapted in specification item 3022, has been a significant improvement over previous QC/QA specifications.

The general trend of the bid price of the hot mix asphalt as a function of time indicates about an 8 percent increase for the period between August 1993 and June 1995, compared with the period before August 1993. The average bid price is approximately 4 percent higher after June 1995, compared with the period before implementing the QC/QA specification. However, a major part of this increase is due to the increase in the cost of materials.

6.2. Recommendations

After collecting valuable information from district personnel and contractors, the research team initiated modifications to the specification and provided feedback and comments to the Texas Department of Transportation (TxDOT) Materials and Tests Division so they could be used as guidelines in their efforts to rewrite QC/QA specifications. These recommendations included subjects such as pay factors, control parameters, the wording in the specification, and random sampling.

It is highly recommended that continuous pay factors be used instead of stepped pay factors. It is also recommended that payments be decided based on percent conforming or percent defective material, rather than on mean absolute deviations (MAD) because of the shortcomings of the MAD procedure. The procedure outlined in Chapter 5 is proposed for this purpose.

It is important that efforts be made to ensure proper random sampling. At this point, there is no assurance that sampling is truly random, and there is no assurance that test results are from sampled specimens. Appropriate and clear guidelines are essential in this respect.

It is recommended that different options for lot size be eliminated and only one option, preferably one similar to option 2 of item 3063, be utilized. In a similar manner, it is recommended that JMF 1 and JMF 2 be modified to form a single job mix formula (JMF).

All the hot mix asphalt concrete (HMAC) produced and placed should be subjected to the same requirements, including the first and last days of production and paved shoulders.

The specification should clearly address the problems of controlling small quantities.

A form of quality control plan should be made a part of the QC/QA specifications developed by TxDOT. There are a number of usable forms that may be used as a guide, two of which are illustrated in the body of this report. As an aid, a manual or guide on the interpretation and use of QC/QA specifications can be prepared to provide needed information to all personnel involved in the design, use, and control of construction performed under these types of specifications. There are guides available from National Cooperative Highway Research Program (NCHRP) projects and information from other states to help in this regard. Because TxDOT is implementing QC/QA specifications in different items of construction (i.e., asphalt, portland cement, and concrete), it is recommended that short courses be conducted to aid with implementation of the specifications utilizing the manuals recommended above.

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APPENDIX A

DETAILED COMMENTS FROM DISTRICT MEETINGS

WITH DISTRICT PERSONNEL AND CONTRACTORS

RESEARCH PROJECT 0-1721
CANVAS OF QC/QA PROBLEMS

CONSTRUCTION REVIEWS
MEETINGS WITH DISTRICT PERSONNEL

TYLER: SEPTEMBER 30, 1996
DISTRICTS: TYLER, ATLANTA, PARIS, LUFKIN

TYLER:

- Special specifications 3007 and 3063 are good in theory, but they do not necessarily yield a good product.
- A warranty specification is recommended.
- The asphalt mixture is generally OK when the plant has its own laboratory, but not good when a commercial lab is used.
- Their experience has been that when the density is greater than 98.0 a bonus is paid, but the result is a fat pavement. The district often suspects the use of a pencil on test results.
- The specification is much too complicated.
- Small quantities should require samples.
- A QC/QA specification doesn't provide for removal of a substandard mixture.
- Item 340 is preferred since there has been no apparent improvement and there is less control than before. Item 340 had fewer problems with definition.
- Although there have been some good jobs with QC/QA spec, even some better than with item 340, it mainly depended on the contractor and plant.
- The project was almost over before problems surfaced. There was a general loss of control.
- It is recommended that Option 1 be removed and 2,000-ton lots be used.
- There have been cases of no improved quality though bonuses were paid.
- There is no control on the asphalt content of the mix that has allowed the use of asphalt to achieve density.
- There is no control on small quantities. Better control of the mixture was experienced under item 340.
- One project of the CMHB design was tried with the QC/QA specifications. This resulted in an unsatisfactory project.
- Good plants still produce good products.
- There have been cases of the plant producing a mixture way too hot, but the mix was not rejected.
- A multiple increase in paperwork has occurred that is often received late and still gives no check on quality.
- A clarification of the tolerances on JMF-1 laboratory density is needed.
- A requirement to remold at optimum design instead of accepting interpolation is necessary.
- Maintenance requisitions and SMAs still use item 340.
- Five hundred tons are classified as a small quantity, but a lot of 1,000 tons is the smallest lot. What is the control for the in-between amounts?
- A recommendation is to take one sample every 500 tons and a 2,000-ton lot. Cores should be taken where the material from which the plant sample was taken went down

ATLANTA:

- The district lab verifies JMF-1 instead of the area office labs.
- Some contractors have a gyratory press that differs from that used by TxDOT.
- They are not getting split samples from the contractor.
- Contractor is not running gradations for each design verification, but instead uses shortcuts and the district does not get the same design.
- JMF-1 is for checking equipment and methods but there is no formal method for checking equipment.
- The contractor often questions JMF-1 and wants to go directly to JMF-2 where he can run until production evens out.
- Aggregate is not controlled.
- When lime is required, plant is often not putting it in.
- Recommend 5 years on technician certification.
- Need warranty specifications.
- There is a question: Is 3063 a bridge between 340 and a true end-result specification?
- Experience so far appears that more manpower is spent on 3063 than on 340.
- The contractor is getting almost the total 5 percent bonus.
- With this specification there may not be a worry in the long term, but presently they are not getting quality and do not see where quality has been promoted.
- There is no evidence of the contractor performing quality control, but it appears, instead, that the use of the pencil is encouraged.
- There is no control on additives; plus slow verification is received from Materials and Tests Division.
- Contractor never shuts himself down when tests require it.
- There has not been a job in 2 years where latex was used.
- They were getting bids of $30 on item 340, now $42 on item 3063 for equal or poorer product. (It would probably be the same now for 340.)
- The district has experienced one job where all records, etc., were perfect but still had to shut the project down for uncoated aggregates.

PARIS:

- There are no guidelines to evaluate the contractor and the work.
- They have been paying 105 percent for projects that are not performing, which includes raveling within 1 year.
- Plant lab results were generally satisfactory, but those from commercial labs were poor.
- There appears to be poor control on all parts of the project: design, construction, quality of materials, and so on.
- Although the designs meet the specification, many are not good but harsh and sometimes the contractor adds asphalt to meet density. In some cases up to 1/2 of the mix is fine aggregate.
- HMA-certified labs cannot produce acceptable designs and HMA school graduates are not qualified to control mixes and production.
- It usually takes 2–3 designs before getting an acceptable one.

LUFKIN:

- The concept of QC/QA is not being met. It is probably too late to revert to item 340 but, if not, it must be fixed with TxDOT controls.
- Wording of the specification is confusing, which is causing different interpretation w/in TxDOT.
- The specification doesn't exclude RAP.
- TxDOT people are gradually losing HMAC knowledge and expertise, making TxDOT less qualified to challenge the contractor.
- Belt sampling is not representative.
- Fewer tests are being run by the contractor.
- Preference is for the aggregate analysis to be by previous pass/retain format.
- Laboratory density needs to be a factor.
- Specification as written allows the use of concrete sand.
- Need a better stripping test. Methods 530 and 531 are not adequate.
- Need to review test procedures, some are too complicated. Stripping is one of these based on individual review.
- It is difficult to interpret "operational tolerances."
- In Option 1 vs. Option 2, there may be a long delay before completion of a lot. There is nothing in the computer program from the Materials and Tests Division to show date placed, ticket numbers, etc.
- There needs to be a deadline on furnishing test results (24 hours?).
- There are a large number of forms for every lot.
- One of the projects in the district is coming up. It was not clear who is responsible. The Paris District paid to remove and then paid to replace.
- There may be an advantage for a PC modem connection from plant to area engineer's office.
- Why must the specification be so complicated?
- Why should there be a requirement on recertification on the profilograph when it is not used?
- Penalty in the ride specification is not severe enough to insure a good job. The specification is too complicated. An inspector did better with the straight edge.
- Need to remove the allowance for different size lots.
- Recommend putting teeth into specification for contractor's failure to notify the engineers of changes by letter.
- Contractor-owned RAP not allowed.
- Need wording in the specification to allow rejection of the mix when over-asphalted or over-temped by contractor.

CORPUS CHRISTI: OCTOBER 2, 1996
DISTRICTS: CORPUS CHRISTI, LAREDO, PHARR, YOAKUM, SAN ANTONIO, HOUSTON

CORPUS CHRISTI:

- The district is just starting to use this specification. There has been a problem with the generation of random numbers and getting them to the contractor. Apparently the district hands them to the contractor at the beginning of a lot.
- TxDOT tells the contractor where to sample.
- The district cannot tell if an antistripping agent has been added to the mix or not when it is required.
- When problems occur with the mat tearing, etc., they will be missed unless caught as it is being placed.
- Need a printout to catch any changes.
- There is no control between sample points.
- Hot mix contractors with their own personnel seem to have more trouble. Commercial labs tend to stay in the middle.
- The inspector has to use the numbers on the gage for antistrip addition, but there is no way to verify.
- Still get good quality construction from a good contractor regardless whether item 340 or item 3063 is used.
- QC/QA can work only by using quality materials, but there seems to be no way to verify or control this quality.
- Plant inspectors need to know more about how a plant operates to be able to understand what is happening during production.
- Item 340 had language to control stockpiles, etc.
- Need language in this specification to assure that stockpiles contain the materials used for design.
- With the allowable time frame to bring in cores, extended delays are possible and results can be out for several tons placed without the engineer knowing.
- Bonus on one item can allow maximum on the project.
- The district has had only a small amount, which was on a ramp, removed.
- There is not a time line on design; a project had the design verified a year ago and no HMAC placed yet. Need a means to provide for reverification.
- There is more paperwork required than before with 340.
- Construction and MAT need to change to programs used in the field.
- Department jumped into this spec before training and furnishing field personnel with computers.

HOUSTON:

- Asphalt is supposed to be put into mix on “auto” setting but “manual” is used instead.
- More trouble with roadside plants, not so much with permanent commercial plants.
- Can take all the samples TxDOT wants but the pay factor samples are locked.
- Do we need an end result specification?
- Experience so far with using item 3063: contractors have purchased new equipment, etc., which has been an improvement.
- Bad part is loss of experienced inspection personnel. Now field personnel don’t know plant, operation, don’t understand VMA, etc.
- Agree that CMHB doesn’t belong in QC/QA spec.

YOAKUM:

- A sampling program is being developed in the state headed by Paul Krugler to overcome the problems of knowing in advance the sampling points.
- No one has ever taught interpretation— tests, software, etc., but not interpretation. Understanding how to run the test does not guarantee knowledge of spec.
- Too soon to really know if better pavement is being produced. Need to evaluate whole structure when looking at a failure rather than just the pavement.
- JMF changing for every lot can allow bonus when some sub-lots are out.
- Option 1: Some have merely samples, labeling them P&R.
- Now putting general notes back into everything for placement unless otherwise directed by the engineer.
- No miscellaneous placement.
- Random selection point for sampling pavement needs to be exact. Close proximity leaves wide option. Person taking cores not now required to be certified tech.
- Would like ride spec on everything.
- District holds a preplacement meeting 2 months in advance, requiring design at that time.
- Need language to address stockpile problems.

LAREDO:

- No consistency or uniformity in the amount of asphalt added: one day on the high side, next on the low side.
- Presently random sampling.
- Paying a lot bonus, sometimes as much as 6 months later.
- Cannot stop contractor from laying in bad weather; have pictures of mix going down in the rain. Couldn't shut them down because District says let them run.
- Problems can be with interpretation of specification instead of always with the spec.
- Need to have only one option. Recommend eliminating Option 1.
- Regional workshops indicated projects did not have the people on the road, particularly the contractor's personnel.
- Current Form 404 conflicts with QC/QA. New form doesn't have room, no date of production. Having to hand calculate placement. Paperwork too complicated.

SAN ANTONIO:

- May have bought more consistency with the commercial plants.
- No way to tell if better performance is there just because all tests were run and apparently w/in spec.
- Problems with mix design: with one supplier contractor getting 1 percent lower and TxDOT getting 1 percent higher; verification of VMA, getting 1 percent lower density; contractor is adding more material than does TxDOT to get a 2.00-inch specimen for Hveem.
- When will CMHB be implemented into QC/QA? CMHB doesn't belong in QC/QA specification.
- Variations in asphalt content of 0.8% in design in a current project.
- Starting to require computers and programs as part of project-required equipment.
- Consider using thin-layer nuclear device for in-place density.
- There are still cases of undertaking item 340 and QC/QA projects at the same time because of pre-existing contracts.

PHARR:

- There is nothing in the specification about when ride specification is run.
- Also do not believe that CMHB belongs in QC/QA specification.

FORT WORTH: OCTOBER 7, 1996
DISTRICTS: FORT WORTH, WACO, DALLAS, BROWNWOOD, CHILDRESS, AUSTIN, BEAUMONT, TYLER, MAT (Chico)

CHILDRESS:

- The department does not have the necessary control anticipated.
- Flushing problems on project; contractor changed target values rather than correcting problem.
- Getting bad rides on the projects.
- The contractor cannot be forced to change when still w/in specification limits.
- There are problems verifying designs on all mixes: Contractor using Rainhardt press and lab using TxDOT.
- Have removed Type A base material.

FORT WORTH:

- With bad mix, contractor has replied to request for verification of design.
- Have removed some Type C mix.
- Control charts not filled out until job was over.
- Special provision out on 3063 that requires target-molded lab density and correlation of lab gyratory presses. Presently evaluating this special.
- MAT preparing a training course on this specification to take to districts. Need a guidance document.
- Independent sampling and testing. Federal Register requires this. Krugler and Epps working on this.
- Need to have professional software developed to replace the MAT version.
- MAT plans to present training for qualification (to include contractor's personnel).

WACO:

- Removed some mix for ride quality in spots.
- Had contractor use TxDOT equipment in verifying design.
- Most experience suggests that problems are due to sloppy work.
- Asphalt content as much as 1 percent off. Commercial lab had long delay in getting design.
- Nothing in spec prohibits where sample is taken and can take more than prescribed number.
- Bad contractor improved to mediocre w/penalties from bad work.
- Good contractor has slipped in some cases, getting bonus but not as good as previous work.
- Good support from their district administration.
- Will always have inconsistencies unless there is an inspector on site willing to stand up and enforce the specification.
- Need to make specification more clear and tighten meaning; need to identify inconsistencies or irregularities (segregation, bleeding, etc.).
- Good contractor's operation does not change going from 340 to 3063.
- Specification written with the idea that all have the motivation to provide a good product.
- Asphalt content is increased to get density. Common to keep rerunning nuclear density until getting the density desired.
- Arguments on technician's ability to run density.
- Contractor sometimes runs several samples to get the answer wanted.
- Have a plan note that all shoulders are handled just like the main lanes.
- Had to stop the contractors from using the small quantity games.
- Need to do away with the protected mix in first and last day's production. Protection for the first-day's production mix only benefits the bad contractor.

- Experimented with taking production samples at the road site; believe the best location is just behind the lay-down machine. They have an inspector on the job.
- Preconstruction conferences have helped, even with poorer contractors. Some were preproduction meetings and predesign.
- Don't pay on asphalt content, pay on lab density and mold every sub-lot.
- Time in reporting is a problem. Need to set up a tracking document. The allowed time is presently excessive. Should shut down if more than two days.
- Software program: Some area engineers are beginning to see benefits, but need to be sure contractor uses them.

DALLAS:

- Contractor not that familiar with design process, not knowledgeable about specification. No experience.
- Specification ties the hands of the engineer. The penalty is too soft. Been told by the top administration down: hands off; the result is the engineer's experience is not used as input.
- Would like to take samples where the engineer wants to designate.
- TxDOT people also need to be educated on specification. Need consistency.
- Have observed mix laid in the rain — young, inexperienced inspector allowed it; it came up later and TxDOT wound up paying for it twice.
- Small projects do not fit QC/QA specification. Do not use for maintenance.
- JMF-1 looks good, but then JMF-2 does look like the same design.
- No one monitoring stockpiles for segregation, etc.
- Some TxDOT labs have equipment out of specification and some operate out of spec; need to look at own operation. (Who's responsible?)

BROWNWOOD:

- A current CMHB project was getting a bad job within the specification; had to go out of the specification to get a workable mix.
- Seeing areas in specification where contractor is playing games.
- JMF-2: worked three days to get a sample.
- Ran seven samples to get a sample to obtain bonus: was successful.
- Borderline mixes are common.
- Often contractor will run two samples that are out, then one in.
- TxDOT should have to deal with contractor only.
- Need to stiffen up requirements for ride quality. Present sporadic stops/starts detrimental to ride.
- What is benefit of 3063?
- Problem with minus 200 in CMHB in special provision; can't go below 6 percent; need range to be 5–10 percent instead of 6–10 percent.
- Need to be able to identify mixing and compacting temperature for modified asphalts (ACs).
- Problems in using profilograph: reading charts, etc.

Materials and Tests Division, CHICO Office:

- Every design has too high asphalt for all products.
- Supply four different districts and each will interpret spec differently.
- No requirement for limiting minus 10, etc., in stockpiles.
- Getting inferior product between samples.
- Problems with RAP in base courses.
- How will the Krugler data fit into this study?
- Most commercial lab technicians do not know about different plants or what happens in them; need instruction or certification on spec (Level IA).

AUSTIN:

- Problems with the contractor specifying production as small quantities.
- Eliminate Option 1.

BEAUMONT:

- No communication between contractor and TxDOT.
- Confusion in interpretation of spec.
- Confusion between operational tolerances and tolerances between contractor results and TxDOT results (Tables 3 and 4).
- Small contractors claim they can't bid because of added expense (equipment, certification, etc.).
- Paying more for equal or lesser quality.
- Not all people have gone to certification school.
- Getting highest pay factor when only one is high and others are barely above 1.0.

TYLER:

- Referee test: District and MAT agreed but TxDOT still paid because of misinterpretation by TxDOT of Table 4.
- Need to streamline and simplify.

ODESSA: OCTOBER 9, 1996
DISTRICTS: ODESSA, EL PASO, ABILENE, SAN ANGELO, LUBBOCK, AMARILLO

ODESSA:

- Believe we're getting our money's worth for the most part. Some glitches but contractors are taking more interest and are playing a more active role.
- Not doing the job for ride quality.
- District went heavily with CMHB and the jury is still out on effectiveness. QC/QA and CMHB are two new changes in the production of HMAC at the same time.
- Segregation of aggregate is not quantifiable in QC/QA spec.
- No compaction control on shoulders if laid together with main lanes. Plan note: Shoulders separate with density control.
- Improvement with special provisions 001 and 002.
- In the early days, commercial labs were not successful.
- Specifications not tight enough and getting maximum bonus on asphalt when other points are marginal to 1.00.
- Contractor trying but no control.
- Beneficial to have inspector in plant.
- Ride specification not tight enough (minimum bonus might be partial reason for contractor not giving proper attention to it). TxDOT won't remove because compounds the roughness.
- Thin overlays: How thick before applying the ride spec? Can be bad and still get bonus; question the use of the profilograph — SI may be better.
- Certification not rigorous enough; anyone can make I-A and II-A without really knowing how to perform. (Other districts disagreed.)

LUBBOCK:

- Shoulders and main lanes have same controls.
- Specification drove the need for contractors to acquire new equipment.
- Going to use baghouse fines for CMHB.
- Know contractor is using pencil on verification tests but cannot catch because Table 4 values are too wide. No way to catch under present spec.
- Only know of one person in state decertified, and then only because he admitted improper action.
- Getting contractors to run each sub-lot. So far they have agreed although spec does not require. Attempts to get this wording into the spec have failed in the spec development committee.
- Hands are tied because of contractors on committee blocking changes.
- Needed changes wouldn't necessarily cost more.
- Need to put some methods back into specification; if this is to become an end result spec, okay, but change spec to reflect.
- Specification based on trust but contractors have been caught acting out of spec purposely.
- Recommend testing sample 1 in 4 instead of 1 in 12.
- Sampling and tests must be done independently.
- Will now send in referee samples to Austin for independent test.
- Requires more people than 340.
- Computer program can hurt because of time element. It allows manipulations to be performed rapidly and immediately.
- Major problem with creep.

LUBBOCK: (cont.)

- Contractor can use materials other than those designated for the project.
- TxDOT needs to run as many tests as the contractor runs.
- Need to have penalty of some sort when the ride is not satisfactory, but TxDOT won't remove because it would increase the damage.
- Question the certification program as now run by the TX Hot Mix Assn.
- Not having any problems with small quantities.
- Need to have same quality requirements for aggregates for Type C and CMHB (soundness, sand equivalent, mineral filler, screenings).
- Uniform quality statement is meaningless.
- Need to get paperwork in by specific date or shutdown.
- Computer spreadsheet required January 1, 1997.
- Problem with asphalt breaking up in coring; don't test it going through plant. Has 12-14 pen.

ABILENE:

- Under 340, failing stability: rerun and shutdown or modify design. Now need three in a row before can shut down job.
- Now planning to get closely involved with all phases; need to provide for this in specification.
- Creep is best test now but still not enough to give consistent values; need something better.
- Asphalt tolerances on wrong database, too wide.
- What do you do when mix is not very good or out? Need to modify spec to pay on TxDOT test results.
- Make clear in spec that operational problems can be corrected when found to exist.
- First days of production, contractor has to test but can be first days of production or lot 1.
- Need uniform checklist for preconstruction conference.

SAN ANGELO:

- Eliminate bonus.
- Overall penalties compensated by bonus then wound up with field change that often pays for penalty items.

AMARILLO:

- Specification too wide, allows bonus.
- Change JMF constantly, lab density OK but cores fail.
- Need to set a reasonable size lot.
- Eliminate Option 1. (All agree.)
- Do not allow extended period for report of test results (2 days maximum).

EL PASO:

- Specification should require state inspector where contractor is required to have one.

MEETINGS WITH CONSTRUCTION PERSONNEL
AUSTIN: DECEMBER 16, 1996

- Why is gradation being eliminated as a pay factor? Asphalt will probably remain.
- THMAPA understands that TxDOT will take over Q/A and that probably the contractor's testing will double.
- Have there really been a significant number of failures? There are little data available and it appears that the data are skewed around the pay factor items.
- Is TxDOT really paying more for the product, even with the bonus? There are indications that the contractor may be taking an anticipated bonus into his initial bid price.
- In-place densities are better now with the QC/QA specification than before with item 340.
- There is no longer the differential (5 percent or higher) between TxDOT and commercial projects since the contractor now has more control over his operation. There is still a 5 percent differential with FAA projects.
- Contractors now are doing more testing than TxDOT ever did.
- There is a perception that some contractors are using this specification to cheat in their operation. TxDOT could correct this under the specification.
- The state may be realizing more of a savings they are getting from the bonus worked into the bid price and the contractor doing more of the project testing.
- Appreciate having the control of the mix and this benefits even their commercial work.
- Do not like JMF 2 for a short run, then adjust. Should go directly to production, even if it is necessary to rework the design the next day.
- Will TxDOT people running tests be there full time of operation?
- TxDOT-certified people do not necessarily know anything about the specification, which creates control problems.
- There is apparently some resentment at times about the contractor having control of the work.
- Would prefer reworking the referee testing. Some do not want MAT and many do not want commercial laboratories to do the testing.
- Need to develop a continuous curve for determining pay factors rather than use the present skewed method.
- Why is the bonus maximum for plants 1.05 and only 1.03 for the road?
- Currently there is a 10-day waiting period for approval of a design. Should there be an additional 10-day period for the same design on another project?
- Under the QC/QA specification, what are the minimum requirements for detours?
- When there is a rut in the existing wheelpath overlaid with a 1 ½ inch mat, a core in the wheelpath will not achieve density.
- TxDOT administration stated that this was to be a uniform specification. It is not being interpreted this way over the state. Need to train personnel and clean up the specification.
- Will there be any binder testing in the revised specification?
- Will SMA be included in the specification?
- Will CMHB stay in the specification?
- The pay scale for the main lanes differs from that for the shoulders. These are made to average in some districts.
- State must address personnel problems if quality assurance is done by the state.
- Will there be a calibration developed between the TxDOT press and the Superpave press?
- How about having the Superpave design as an option?
- The bonus is still a sticking point; could do away with it since some will continue to make it a part of the bid price.
- Consider dropping the bonus from 5 percent to 2 percent.

APPENDIX B

EXAMPLES OF STATISTICAL ANALYSIS OF THE CONSTRUCTION DATA FROM PROJECTS OF SPECIFICATION ITEM 3063 (QC/QA) AND PROJECTS OF SPECIFICATION ITEM 341

HYPOTHESIS TEST

Comparing the Mean of Average Algebraic Deviations in Asphalt Content (Extracted – Design) for QC/QA Projects by T – Test

H_0: AC1 avg = AC2 avg

No. of Treatments: I = 2 Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment X $avg_{I.}$	Variance of the I - th Treatment S^2_I
1 (QC/QA)	54	0.03	0.03
2 (NON-QC/QA)	66	0.03	0.02
Total No. of Data J = Sum of J_I	120		
Grand Mean:		0.03	

T Statistic = $(X\ avg_{1.} - X\ avg_{2.}) / \mathrm{Sqrt}(S^2_1 / J_1 + S^2_2 / J_2)$ = 0.11

Degrees of Freedom (DF) = $(S^2_1 / J_1 + S^2_2 / J_2) \wedge 2 /$
$[(S^2_1 / J_1) \wedge 2 / (J_1 - 1) + (S^2_2 / J_2) \wedge 2 / (J_2 - 1)]$
= 97

$T_{DF,\ 0.025}$ = 1.99

Hence, H_0:AC1 avg = AC2 avg is not rejected at risk level 0.05, where
AC1 avg is calculated as the mean of average deviations in asphalt content for QC/QA projects;
AC2 avg is calculated as the mean of average deviations in asphalt content for NON-QC/QA projects;
There is no significant difference between the mean of average algebraic deviations in AC % for QC/QA and that for NON-QC/QA projects.

HYPOTHESIS TEST

Comparing the Mean of Average Algebraic Deviations in Asphalt Content (Extracted – Design) for QC/QA Projects with Those for NON-QC/QA Projects by Single Factor ANOVA

H_0: AC1 avg = AC2 avg

No. of Treatments: I = 2 | Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment X $avg_{I.}$	Variance of the I - th Treatment S^2_I	Mean Square of Treatment MSTr	Mean Square of Error MSE
1 (QC/QA)	54	0.03	0.03	0.00	0.03
2 (NON-QC/QA)	66	0.03	0.02		
Total No. of Data J = Sum of J_I	120				
Grand Mean:		0.03			

F Statistic = MSTr / MSE = 0.03

DF 1 = I - 1 = 1 ; DF 2 = Sum of (J_I - 1) = 118

$F_{DF\ 1,\ DF\ 2,\ 0.025}$ = 5.16

Hence, H_0:AC1 avg = AC2 avg is not rejected at risk level 0.05, where
AC1 avg is calculated as the mean of average deviations in asphalt content for QC/QA projects;
AC2 avg is calculated as the mean of average deviations in asphalt content for NON-QC/QA projects;
There is no significant difference between the mean of average algebraic deviations in AC % for QC/QA and that for NON-QC/QA projects.

HYPOTHESIS TEST

Comparing the Variance of Average Algebraic Deviations in Asphalt Content (Extracted – Design) for QC/QA Projects with That for NON-QC/QA Projects by F – Text

H_0: AC1 Variance = AC2 Variance

No. of Treatments: I = 2 Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment X $avg_{I.}$	Variance of the I - th Treatment S^2_I
1 (QC/QA)	54	0.03	0.03
2 (NON-QC/QA)	66	0.03	0.02
Total No. of Data J = Sum of J_I	120		
Grand Mean:		0.03	

F Statistic = S^2_1 / S^2_2 = 1.77

$F_{J1-1, J2-1, 0.025}$ = 1.71

Hence, H_0: AC1 Variance = AC2 Variance is rejected at risk level 0.05, where
AC1 Variance is the variance of the average deviations in asphalt content for QC/QA projects;
AC2 Variance is the variance of the average deviations in asphalt content for NON-QC/QA projects;
There is a significant difference between the variance of cc in AC %
for QC/QA and that for NON-QC/QA projects.

HYPOTHESIS TEST

Comparing the Mean of Average Algebraic Deviations in % Passing # 200 Sieve (Extracted – Design) for QC/QA Projects with Those for NON-QC/QA Projects by T – Test

H_0: S200 avg1 = S200 avg2

No. of Treatments: I = 2 Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment $X\ avg_{I.}$	Variance of the I - th Treatment S^2_I
1 (QC/QA)	55	0.12	0.45
2 (NON-QC/QA)	66	-0.77	1.30
Total No. of Data J = Sum of J_I	121		
Grand Mean:		-0.36	

T Statistic = $(X\ avg_{1.} - X\ avg_{2.}) / \mathrm{Sqrt} (S^2_1 / J_1 + S^2_2 / J_2)$ = 5.34

Degrees of Freedom (DF) = $(S^2_1 / J_1 + S^2_2 / J_2) \wedge 2 /$

$[(S^2_1 / J_1) \wedge 2 / (J_1 - 1) + (S^2_2 / J_2) \wedge 2 / (J_2 - 1)]$

= 108

$T_{DF,\ 0.025}$ = 1.98

Hence, H_0:S200 avg1 = S200 avg2 is rejected at risk level 0.05, where
S200 avg1 is calculated as the mean of average deviations in # 200 Sieve for QC/QA projects;
S200 avg2 is calculated as the mean of average deviations in # 200 Sieve for NON-QC/QA projects;
There is a significant difference between the mean of average algebraic deviations in # 200 sieve for QC/QA and that for NON-QC/QA projects.

HYPOTHESIS TEST

Comparing the Mean of Average Algebraic Deviations in % Passing # 200 Sieve (Extracted – Design) for QC/QA Projects with Those for NON-QC/QA Projects by Single Factor ANOVA

H_0: S200 avg1 = S200 avg2

No. of Treatments: I = 2 Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment $X\ avg_{I}.$	Variance of the I - th Treatment S^2_I	Mean Square of Treatment MSTr	Mean Square of Error MSE
1 (QC/QA)	55	0.12	0.45	48.29	0.87
2 (NON-QC/QA)	66	-0.77	1.30		
Total No. of Data J = Sum of J_I	121				
Grand Mean:		-0.36			

F Statistic = MSTr / MSE = 55.49

DF 1 = I - 1 = 1 ; DF 2 = Sum of (J_I - 1) = 119

$F_{DF\ 1,\ DF\ 2,\ 0.025}$ = 5.15

Hence, H_0: S200avg 1 = S200avg 2 is rejected at risk level 0.05, where
S200 avg1 is calculated as the mean of average deviations in # 200 Sieve for QC/QA projects;
S200 avg2 is calculated as the mean of average deviations in # 200 Sieve for NON-QC/QA projects;
There is a significant difference between the mean of average algebraic deviations in # 200 sieve for QC/QA and that for NON-QC/QA projects.

HYPOTHESIS TEST

Comparing the Variance of Average Algebraic Deviations in % Passing # 200 Sieve (Extracted – Design) for QC/QA Projects with That for NON-QC/QA Projects by F – Test

H_0: S200 Variance1 = S200 Variance2

No. of Treatments: I = 2 | Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment X avg_{I} .	Variance of the I - th Treatment S^2_I
1 (QC/QA)	55	0.12	0.45
2 (NON-QC/QA)	66	-0.77	1.30
Total No. of Data J = Sum of J_I	121		
Grand Mean:		-0.36	

F Statistic = S^2_1 / S^2_2 = 0.34

$F_{J1-1, J2-1, 0.025}$ = 1.70

Hence, H_0: S200 Variance1 = S200 Variance2 is not rejected at risk level 0.05, where
S200 Variance1 is the variance of the average deviations in # 200 sieve for QC/QA projects;
S200 Variance2 is the variance of the average deviations in # 200 sieve for NON-QC/QA projects;
There is no significant difference between the variance of average algebraic deviations in % passing # 200 sieve for QC/QA and that for NON-QC/QA projects.

HYPOTHESIS TEST

Comparing the Mean of Lab Density Averages
for QC/QA Projects with That for NON-QC/QA Projects by T – Test

H_0: LabDensity avg1 = LabDensity avg2

No. of Treatments: I = 2 Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment $X\ avg_{I.}$	Variance of the I - th Treatment S^2_I
1 (QC/QA)	41	96.51	0.26
2 (NON QC/QA)	57	95.25	164.46
Total No. of Data J = Sum of J_I	98		
Grand Mean:		95.77	

T Statistic = $(X\ avg_{1.} - X\ avg_{2.}) / Sqrt (S^2_1 / J_1 + S^2_2 / J_2)$ = 0.74

Degrees of Freedom (DF) = $(S^2_1 / J_1 + S^2_2 / J_2) ^\wedge 2 /$
$[(S^2_1 / J_1) ^\wedge 2 / (J_1 - 1) + (S^2_2 / J_2) ^\wedge 2 / (J_2 - 1)]$
= 56

$T_{DF,\ 0.025}$ = 1.98

Hence, H_0:LabDensity1 = LabDensity2 is not rejected at risk level 0.05, where
LabDensity1 is the mean of lab density averages for QC/QA projects;
LabDensity2 is the mean of lab density averages for NON-QC/QA projects.
There is no significant difference between the mean of lab density averages for QC/QA and that for NON-QC/QA.

HYPOTHESIS TEST

Comparing the Mean of Lab Density Averages
for QC/QA Projects with That for NON-QC/QA Projects by Single Factor ANOVA

H_0: LabDensity avg1 = LabDensity avg2

No. of Treatments: I =		2		Risk Level Alpha =	0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment X avg $_I$.	Variance of the I - th Treatment S^2_I	Mean Square of Treatment MSTr	Mean Square of Error MSE
1 (QC/QA)	41	96.51	0.26	79.86	82.36
2 (NON QC/QA)	57	95.25	164.46		
Total No. of Data J = Sum of J_I	98				
Grand Mean:		95.77			

F Statistic = MSTr / MSE = 0.97

DF 1 = I - 1 = 1 ; DF 2 = Sum of (J_I - 1) = 96

$F_{DF 1, DF 2, 0.025}$ = 5.15

Hence, H_0: LabDensity avg1 = LabDensity avg2 is not rejected at risk level 0.05, where
LabDensity1 is the mean of lab density averages for QC/QA projects;
LabDensity2 is the mean of lab density averages for NON-QC/QA projects.
There is no significant difference between the mean of lab density averages for QC/QA and that for NON-QC/QA.

HYPOTHESIS TEST

Comparing the Variance of Lab Density Averages
for QC/QA and That for NON-QC/QA Projects by F – Test

No. of Treatments: I = 2 Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment $X\ avg_{I.}$	Variance of the I - th Treatment S^2_I
1 (QC/QA)	41	96.51	0.26
2 (NON-QC/QA)	57	95.25	164.46
Total No. of Data J = Sum of J_I	98		
Grand Mean:		95.77	

F Statistic = $S^2{}_1 / S^2{}_2$ = 0.00

$F_{J1-1,\,J2-1,\,0.025}$ = 1.70

Hence, H_0: LabDensity Variance1 = LabDensity Variance2 is not rejected at risk level 0.05, where
LabDensity Variance1 is the variance of lab density averages for QC/QA projects;
LabDensity Variance2 is the variance of lab density averages for NON-QC/QA projects;
There is no significant difference between the variance of lab density averages
for QC/QA and that for NON-QC/QA projects.

HYPOTHESIS TEST

Comparing the Mean of Air Void Averages
for QC/QA Projects with That for NON-QC/QA Projects by T – Test

H_0: AirVoid avg1 = AirVoid avg2

No. of Treatments: I = 2   Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment $X\ avg_{I.}$	Variance of the I - th Treatment S^2_I
1 (QC/QA)	50	6.96	1.63
2 (NON-QC/QA)	48	6.88	2.47
Total No. of Data J = Sum of J_I	98		
Grand Mean:		6.92	

T Statistic = $(X\ avg_{1.} - X\ avg_{2.}) / Sqrt (S^2_1 / J_1 + S^2_2 / J_2)$ = 0.27

Degrees of Freedom (DF) = $(S^2_1 / J_1 + S^2_2 / J_2) ^\wedge 2 /$
$[(S^2_1 / J_1) ^\wedge 2 / (J_1 - 1) + (S^2_2 / J_2) ^\wedge 2 / (J_2 - 1)]$
= 90

$T_{DF, 0.025}$ = 1.99

Hence, H_0: AirVoid avg1 = AirVoid avg2 is not rejected at risk level 0.05, where
AirVoid1 is the mean of air void averages for QC/QA projects;
AirVoid2 is the mean of air void averages for NON-QC/QA projects.
There is no significant difference between the mean of air void averages for QC/QA and that for NON-QC/QA.

HYPOTHESIS TEST

Comparing the Mean of Air Void Averages
for QC/QA Projects with That for NON-QC/QA Projects by Single Factor ANOVA

H_0: LabDensity avg1 = LabDensity avg2

No. of Treatments: I = 2 Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment $X\ avg_{I}.$	Variance of the I - th Treatment S^2_I	Mean Square of Treatment MSTr	Mean Square of Error MSE
1 (QC/QA)	50	6.96	1.63	0.29	2.05
2 (NON-QC/QA)	48	6.88	2.47		
Total No. of Data J = Sum of J_I	98				
Grand Mean:		6.92			

F Statistic = MSTr / MSE = 0.14

DF 1 = I - 1 = 1 ; DF 2 = Sum of (J_I - 1) = 96

$F_{DF\ 1,\ DF\ 2,\ 0.025}$ = 5.22

Hence, H_0: AirVoid avg1 = AirVoid avg2 is not rejected at risk level 0.05, where
AirVoid1 is the mean of air void averages for QC/QA projects;
AirVoid2 is the mean of air void averages for NON-QC/QA projects.
There is no significant difference between the mean of air void averages for QC/QA and that for NON-QC/QA.

HYPOTHESIS TEST

Comparing the Variance of Air Void Averages for QC/QA and
That for NON-QC/QA by F – Test

H_0: AirVoid Variance1 = AirVoid Variance2

No. of Treatments: I = 2 Risk Level Alpha = 0.05

Treatment I	No. of Data for Treatment I J_I	Mean of the I - th Treatment $X\ avg_{I.}$	Variance of the I - th Treatment S^2_I
1 (QC/QA)	50	6.96	1.63
2 (NON-QC/QA)	48	6.88	2.47
Total No. of Data J = Sum of J_I	98		
Grand Mean:		6.92	

F Statistic = S^2_1 / S^2_2 = 0.66

$F_{J1-1,\ J2-1,\ 0.025}$ = 1.64

Hence, H_0: AirVoid Variance1 = AirVoid Variance2 is not rejected at risk level 0.05, where
AirVoid Variance1 is the variance of air void averages for QC/QA projects;
AirVoid Variance2 is the variance of air void averages for NON-QC/QA projects;
There is no significant difference between the variance of air void averages for QC/QA and that for NON-QC/QA.

APPENDIX C

DATA FROM VISUAL SURVEY OF QC/QA AND NON-QC/QA PROJECTS

Table C.1. Summary of Results from Visual Survey of Constructed Projects

(See Tables C.2 and C.3 for Guide to Location of Roads and Guide to Abbreviations, Respectively)

No.	District	Road	Mix Type	Thick mm	Spec. Used	Const. Year	Survey Date	Rut	Fatig. Crack	Therm Crack	Refl. Crack	Long. Crack	Shov.	Bleed.	Segr.	Unifor	General Appear.
1	Beaumont	SH 73	C	50	340	92	8/21	1	0	0	1	0	0	0	1	4	4
2		SH 73	D	50	QC/QA	94/95	8/21	1	0	0	0	0	0	1	2	3	3
3		US 96	C	38	340	93/94	9/5	0	1	0	1	0	0	1	1	4	4
4		IH 10	C	50	QC/QA	96	9/10	1	1	0	0	0	1	0	1	4	4
5		B 90	C	38	QC/QA	94	9/10	1	1	0	2	1	0	0	0	4	4
6		US 96	C	62	3834	94	9/5	0	0	0	0	0	0	0	1	5	5
7		FM 1003	C	38	QC/QA	93/94	9/5	0	0	0	0	0	0	0	1	5	5
8		SH 327	C	38	3834	94	9/5	0	0	0	0	0	0	0	1	5	5
9	El Paso	US 54	D	38	340	87	8/7	1	0	2	0	2	0	0	1	4	3
10		Fred Wilson	N/A	38	340	89	8/7	2	0	0	2	2	0	0	1	3	3
11		Airport Rd.	C	38	QC/QA	94	8/7	2	3	0	0	0	3	0	1	3	2
12		Loop 375	C	38	QC/QA	N/A	8/7	1	0	0	0	0	0	0	2	3	4
13		Rail Road Dr.	D	38	340	85	8/7	0	0	0	0	3	0	0	2	3	4
14		SH 20	D	38	QC/QA	93	8/7	1	0	0	0	3	0	0	1	4	5
15		FM 258	D	38	340	87	8/7	0	0	0	0	0	0	0	1	4	4
16		FM 258	D	38	QC/QA	94/95	8/7	0	0	0	0	0	0	0	1	4	4
17		Loop 375	D	38	340	90	8/7	1	0	0	2	3	0	0	1	4	4
18	Laredo	Loop 20	D	75	QC/QA	94	8/14	4	1	0	0	1	4	2	1	3	1
19		IH 35	D	75	QC/QA	93	8/14	2	0	0	0	0	0	2	2	3	3
20		FM 1472, 1	D	50	3834	94	8/14	2	0	0	0	0	0	2	1	3	4
21		FM 1472, 2	D	50	3834	94	8/14	1	0	0	0	0	0	1	1	4	4
22		FM 1472, 3	D	50	QC/QA	94	8/14	1	0	0	0	0	0	1	1	4	4
23	Lufkin	US 59, 1	C	38	340	92	8/21	1	0	0	4	0	0	0	1	4	3
24		US 59, 2	C	38	QC/QA	93	8/21	1	0	0	0	2	0	0	1	3	3
25		US 59, 3	Sup. Pav	N/A	QC/QA	96	8/21	0	0	0	0	0	0	0	0	4	4
26		US 59, 4	D	38	340	94	8/21	1	0	0	2	2	0	0	1	4	3
27		US 59, 5	D	38	QC/QA	95	8/21	2	0	0	2	2	0	0	0	3	4
28	Pharr	SH 100, 1	D	38	3778	92	8/15	1	0	0	0	2	0	0	1	4	4
29		SH 100, 2	D	38	3834	93	8/15	1	0	0	0	2	0	0	1	4	3
30		SH 100, 3	D	38	QC/QA	94	8/15	1	0	0	0	0	0	0	1	4	4
31		SH 100, 4	D	38	340	90	8/15	2	0	0	0	2	0	0	1	4	3

Table C.1. Summary of Results from Visual Survey of Constructed Projects, Continued
(See Tables C.2 and C.3 for Guide to Location of Roads and Guide to Abbreviations, Respectively)

No.	District	Road	Mix Type	Thick mm	Spec. Used	Const. Year	Survey Date	Rut	Fat. Crack	Therm Crack	Refl. Crack	Long. Crack	Shov.	Bleed.	Segr.	Unifor.	General Appear.
32	San Antonio	Eckert	CMHB-C	50	QC/QA	96	8/13	0	0	0	0	0	0	0	1	4	4
33		Eckert	Sup. Pav	50	QC/QA	96	8/13	0	0	0	0	0	0	0	1	4	4
34		Huebner	D	38	340	95/96	8/13	0	0	0	0	0	0	0	0	4	4
35		HW 1604	CMHB-C	N/A	340	93	8/13	1	0	0	0	0	0	0	0	4	4
36		HW 1604	Sup	N/A	340	93	8/13	0	0	0	0	0	0	0	0	4	4
37		IH 10	CMHB-C	N/A	340	94	8/13	0	0	0	0	0	0	0	1	3	4
38		Wurzbach	D	N/A	340	96	8/13	0	0	0	0	0	0	0	2	3	4
39	Tyler	SH 31, 1	Sup/19c	50	QC/QA	97	8/20	0	0	0	0	0	0	0	1	4	5
40		SH 31, 2	Sup/19f	38	340	97	8/20	0	0	0	0	0	0	0	2	4	4
41		SH 31, 3	C	215	340	89	8/20	0	0	0	0 & 4	0	0	0	1	4	4
42		FM 274	C	N/A	QC/QA	95	8/20	0	0	0	0	0	0	0	1	3	3
43		Loop 323	C	50	QC/QA	96	8/20	0	0	0	0	0	0	1	2	2	2
44		SH 64	C	38	340	94/95	8/20	1	0	0	0	0	0	0	2	3	3
45		Loop 323	C	N/A	340	89	8/20	2	0	0	0	1	3	2	2	3	2
46	Wichita Falls	IH 44	CMHB-C	38	QC/QA	96	8/22	1	0	0	0	0	0	0	1	3	4
47		Loop 473, 1	D	38	QC/QA	93	8/22	1	0	0	2	2	0	0	1	4	4
48		Loop 473, 2	D	38	QC/QA	92	8/22	1	0	0	0	0	0	0	1	4	4
49		Loop 473, 3	D	38	340	81/82	8/22	0	0	0	3	3	0	0	1	3	3
50		US 281	D	N/A	QC/QA	93	8/22	1	0	0	3	3	0	0	1	4	4
51		SH 16, 1	D	<25	QC/QA	95	8/22	1	0	2	3	3	0	0	1	3	3
52		SH 16, 2	D	38	QC/QA	97	8/22	0	0	0	0	0	0	0	3	3	3
53		FM 369	D	38	340	90	8/22	2	0	2	3	3	0	0	1	3	3
54	Yoakum	US 77	C	N/A	340	96	8/14	1	0	0	0	0	0	0	1	4	4
55		FM 1685	C	38	QC/QA	96	8/14	0	0	0	0	0	0	2	1	4	4

Table C.2. Location of Surveyed Roads Presented in Table C.1.

No.	District	Road Location
1	Beaumont	SH 73, Westbound (about 500 m west of Tayler Vayon Bridge)
2		SH 73, Westbound
3		US 96 (Lumberton)
4		IH-10 (Winnie)
5		B 90 (Green Ave.)
6		US 96 (Hardin County)
7		FM 1003 (Honey Island)
8		SH 327
9	El Paso	US 54 (north of McCombs, towards New Mexico state line), Northbound
10		Fred Wilson Road (eastbound, 1000 m east of Railroad Drive)
11		Airport Road (southbound, between Biggs Field and Airways Blvd.)
12		Loop 375 (southbound, south of Montana)
13		Railroad Drive (between Fred Wilson Rd. and Honda Pass)
14		SH 20 (between Loop 375 and FM 1110)
15		FM 258 (between Socorro Rd. and Glorietta Rd.)
16		FM 258 (between Glorietta Rd. and San Elizario Rd.)
17		Loop 375 (southbound, between IH-10 and International Bridge)
18	Laredo	Loop 20 (at intersection with IH35, both sides)
19		IH35, Northbound (one mile north of Loop 20, mileage mark reads at 8)
20		FM 1472 (between FM 3464 and Killiam Blvd.)
21		FM 1472, Southbound (towards Laredo)
22		FM 1472, Southbound (towards Laredo)
23	Lufkin	US 59, Southbound
24		US 59, Northbound
25		US 59, Southbound
26		US 59 (at Loop 287)
27		US 59 (at Loop 287)
28	Pharr	SH 100
29		SH 100
30		SH 100
31		SH 100
32	San Antonio	Eckert
33		Eckert
34		Huebner
35		HW 1604
36		HW 1604
37		IH 10
38		Wurzbach
39	Tyler	SH 31, Westbound
40		SH 31, Westbound
41		SH 31 (between Malakoff and Athens)
42		FM 274 (at Trinidad)
43		Loop 323 (at US 69)
44		SH 64 before US 259
45		Loop 323 before FM 14

Table C.2. Location of Surveyed Roads Presented in Table C.1, Continued

46	Wichita Falls	IH 44, Northbound
47		Loop 473 (southbound and northbound, between Christine and FM 369).
48		Loop 473 (30th St. to Christine)
49		Loop 473 (from 30th street to US 287).
50		US 281, North (starting from FM 1954 for 5 km)
51		SH 16, 1
52		SH 16 (between Young county line and south of Highway 114)
53		FM 369 (between US 281 and Rhea Rd., south of district office)
54	Yoakum	US 77 at Victoria (starting approximately 2 km north of Loop 463 for a length of 4 km)
55		FM 1685 (starting west of US 59 for approximately 6 km)

Table C.3. Guide for Abbreviations and Rankings

Abbreviations	**Full Term**	**Distress Ranking Table**		
Spec.	Specification	None	0	
Const.	Construction	Slight	1	
Rut	Rutting	Moderate	2	
Fatig.	Fatigue Cracking	Severe	3	
Therm	Thermal Cracking	Very Severe	4	
Refl.	Reflective Cracking			
Long.	Longitudinal Cracking	**Quality Ranking Table for**		
Shov.	Shoving	**Uniformity and Appearance**		
Bled.	Bleeding	Excellent	5	
Seg.	Segregation	Good	4	
Unif.	Uniformity	Average	3	
Appear.	Appearance	Bad	2	
N/A	Not Available	Very Bad	1	

REMARKS FROM VISUAL SURVEY FOR PROJECTS PRESENTED IN TABLE C.1.

District **Beaumont** Surveying Date **8/21/97** Survey Time **11:46 P.M.**
Road: **SH 73, Westbound (about 500 meters west of Tayler Vayon Bridge)**
Year of Construction **1992** Mix Type: **C** Specification **non-QC/QA (item 340)**

Remarks: Reflective cracks are at shoulders and about 30 feet apart, possibly due to shrinkage of soil cement base.

District **Beaumont** Surveying Date **8/21/97** Survey Time **12:08 P.M.**
Road: **SH 73, Westbound**
Year of Construction **1994-95** Mix Type: **D** Specification **QC/QA**

Remarks: Truck-to-truck segregation is noticed.

District **Beaumont** Surveying Date **9/5/97** Survey Time **12:15 p.m.**
Road: **US 96 (Lumberton)**
Year of Construction **1993 & 94** Mix Type: **C** Specification **non-QC/QA (item 340)**

Remarks: Transverse cracks were about 1-meter long and about 25 meters apart.

District **El Paso** Surveying Date **8/7/97** Survey Time **9:00 A.M.**
Road **US 54 (north of McCombs, towards New Mexico state line), Northbound**
Year of Construction **1987** Mix Type: **D** Specification **non-QC/QA (Item 340)**

Remarks: This has been a new HMA over a flexible base; average ADT of 2,500.

District **El Paso** Surveying Date **8/7/97** Survey Time **10:10 A.M.**
Road **Fred Wilson Road (eastbound, 1,000 meters east of Railroad Drive)**
Year of Construction **1989 ?** Specification **non-QC/QA (item 340)**

Remarks: The road has very heavy traffic with lots of 18-wheeler trucks.

District **El Paso**
Surveying Date **8/7/97**
Survey Time **11:15 A.M.**
Road **Airport Road (southbound, between Biggs Field and Airways Blvd.)**
Year of Construction **1994** Mix Type: **C** Specification **QC/QA**

Remarks: The surveyed section is very close to intersection. The high-shoving lane with severe depression under the wheelpath is heavily loaded with 18-wheeler trucks that tend to make a left turn at the intersection. The HMA has been heavily shoved to the side. Fatigue and longitudinal cracking has developed under the depressed section.

District **El Paso** Surveying Date **8/7/97** Survey Time **11:50 A.M.**
Road **Loop 375 (southbound, south of Montana)**
Year of Construction Mix Type: **C** Specification **QC/QA**

Remarks: Segregation is observed in the middle of the mat.

District **El Paso** Surveying Date **8/7/97** Survey Time **10:40 A.M.**
Road **Railroad Drive (between Fred Wilson Rd. and Honda Pass)**
Year of Construction **1985** Mix Type: **D** Specification **non-QC/QA (item 340)**

Remarks: Longitudinal cracks at the joint, as well as longitudinal crack in the middle of passing lane possibly owing to settlement. Road susceptible to water accumulation.

District **El Paso** Surveying Date **8/7/97** Survey Time **1:05 P.M.**
Road **SH 20 (between Loop 375 and FM 1110)**
Year of Construction **1993** Mix Type: **D** Specification **QC/QA**

Remarks: Road in very good shape. ADT is about 21,000 around Loop 375 and SH 20 and is about 4,500 around SH 20 and FM 1110.

District **El Paso** Surveying Date **8/7/97** Survey Time **2:28 P.M.**
Road: **FM 258 (between Socorro Rd. and Glorietta Rd.)**
Year of Construction **1987** Mix Type: **D** Specification **non-QC/QA (item 340)**

Remarks: This two-lane road has an ADT of about 10,900 to 13,800.

District **El Paso** Surveying Date **8/7/97** Survey Time **2:40 P.M.**
Road **FM 258 (between Glorietta Rd. and San Elizario Rd.)**
Year of Construction **1994-95** Mix Type: **D** Specification **QC/QA**

Remarks: ADT is about 6,000 to 7,000. The two sections under QC/QA and non-QC/QA specifications looked very similar.

District **El Paso** Surveying Date **8/7/97** Survey Time **1:30 P.M.**
Road **Loop 375 (Southbound, between IH-10 and International Bridge)**
Year of Construction **1990** Mix Type: **D** Specification **non-QC/QA (item 340)**

Remarks: Severe longitudinal cracks at construction joints (side and middle).

District **Laredo** Surveying Date **8/14/97** Survey Time: **9:40 A.M.**
Road: **Loop 20 (at intersection with IH35, both sides)**
Year of Construction **December, 1994** Mix Type: **D** Specification Used **QC/QA**

Remarks: The problem exists mainly at the intersection where there is slow traffic and a very large number of heavy trucks.

District **Laredo** Surveying Date **8/14/97** Survey Time: **10:40 A.M.**
Road: **FM 1472, Southbound (towards Laredo)**
Year of Construction **1994** Mix Type: **D** Specification **QC/QA**

Remarks: Conditions were nearly the same on this road for both QC/QA and non-QC/QA roads.

District **Lufkin** Surveying Date **8/21/97** Survey Time **3:30 P.M.**
Road: **US 59, Southbound**
Year of Construction **1992** Mix Type: **C** Specification **non-QC/QA (item 340)**

Remarks: The overlay is built over an old concrete pavement. In one area, because of concrete blow-up, surface heaving is noticed.

District **Lufkin** Surveying Date **8/21/97** Survey Time **4:11 P.M.**
Road: **US 59, Northbound**
Year of Construction **1993** Mix Type: **C** Specification **QC/QA (Pilot Project)**

Remarks: A series of short longitudinal cracks are noticeable. Loss of aggregate between wheelpath is observed. The mix has more than 15 percent field sand.

District **Lufkin** Surveying Date **8/21/97** Survey Time **4:30 P.M.**
Road: **US 59, Southbound**
Year of Construction **1996 (18 months old at the time of this survey)**
Specification Used **QC/QA** Mix Type: **Superpave**

Remarks: The pavement in general looks very good to excellent.

District **Lufkin** Surveying Date **8/21/97** Survey Time **5:45 P.M.**
Road: **US 59 (at Loop 287)**
Year of Construction **1994 (fall)** Mix Type: **D** Specification **non-QC/QA**

Remarks: A number of overlays have been placed on top of the 4-inch full asphalt concrete on the top of black base.

District **Lufkin** Surveying Date **8/21/97** Survey Time **5:50 P.M.**
Road: **US 59 (at Loop 287)**
Year of Construction **1995 (April)** Mix Type: **D** Specification **QC/QA (item 3007)**

Remarks: Longitudinal cracks are noticed in the wheelpath. Possible reason is reflection of cracks from the bottom up.

District **Pharr** Surveying Date **8/15/97** Survey Time: **10:15 A.M.**
Road: **SH 100**
Year of Construction **1992** Mix Type: **D** Specification **non-QC/QA (item 3778)**

Remarks: Slight loss of fines in wheelpath. At a small section, severe fatigue and longitudinal cracks with moderate rutting. However, this problem was localized.

District **Pharr** Surveying Date **8/15/97** Survey Time: **11:04 A.M.**
Road: **SH 100**
Year of Construction **1994** Mix Type: **D** Specification **QC/QA (item 3007)**

Remarks: Slight loss of fines in wheelpath. At a small section, severe fatigue and longitudinal cracks with moderate rutting. However, this problem was localized.

District **Pharr** Surveying Date **8/15/97** Survey Time: **11:18 A.M.**
Road: **SH 100**
Year of Construction **1990** Mix Type: Specification Used **non-QC/QA (item 340)**

Remarks: Loss of fines and slight rutting are noticeable.

District **San Antonio** Surveying Date **8/13/97** Survey Time **1:50 P.M.**
Road: **Eckert Rd.**
Year of Construction **1996** Mix Type: **CMHB-C & Superpave** Specification **QC/QA**

Remarks: Both CMHB-C and Superpave sections have good appearance. This is new construction on top of 230 mm of blackbase.

District **San Antonio** Surveying Date **8/13/97** Survey Time: **2:30 P.M.**
Road: **Highway 1604**
Year of Construction **1993 ?** Mix Type: **CMHB** Specification **non-QC/QA**

Remarks: Some loss of surface aggregate at spots.

District **San Antonio** Surveying Date **8/13/97** Survey Time: **2:30 P.M.**
Road: **Highway 1604**
Year of Construction **1993 ?** Mix Type: **Superpave**
Specification Used **non-QC/QA** Thickness **mm**

Remarks: Noticeable longitudinal joint.

District **San Antonio** Surveying Date **8/13/97** Survey Time: **3:00 P.M.**
Road: **IH 10**
Year of Construction **1994** Mix Type: **CMHB-C** Specification **non-QC/QA**

Remarks: Some segregation at the center.

District **San Antonio** Surveying Date **8/13/97** Survey Time: **3:35 P.M.**
Road: **Wurzbach Parkway**
Year of Construction **1996** Mix Type: **D** Specification **non-QC/QA (item 340)**

Remarks: One of the latest jobs constructed under specification item 340.

District **Tyler** Surveying Date **8/20/97** Survey Time: **9:07 A.M.**
Road: **Highway 31 West**
Year of Construction **1997** Mix Type: **Superpave-19 mm, coarse** Specification Used **QC/QA**

Remarks: Aggregate: 30 percent crushed granite and 35 percent basalt. Asphalt: AC-30P (PG70-22).

District: **Tyler** Surveying Date **8/20/97** Survey Time: **9:16 A.M.**
Road: **31 Westbound**
Year of Construction **1997** Mix Type: **Superpave-19 mm- fine** Specification **non-QC/QA (item 340)**

Remarks: Loss of fines and slight segregation are noticeable.

District **Tyler** Surveying Date **8/20/97** Survey Time: **10:30 A.M.**
Road: **SH 31 (between Malakoff and Athens)**
Year of Construction **1989** Mix Type: **C** Specification **non-QC/QA (item 340)**

Remarks: Westbound lanes with reflective cracking are built over an old concrete pavement, whereas the eastbound lanes with no cracking are constructed over soil-cement base.

District **Tyler** Surveying Date **8/20/97** Survey Time: **10:46 A.M.**
Road: **FM 274 (at Trinidad)**
Year of Construction **1995** Mix Type: **C** Specification **QC/QA**

Remarks: Loss of fines and raveling. The old seal has been milled and overlaid.

District: **Tyler** Surveying Date **8/20/97** Survey Time: **1:30 P.M.**
Road: **Loop 323 (at US 69)**
Year of Construction **1996 (fall)** Mix Type: **C** Specification **QC/QA**

Remarks: Loss of fines and slight rutting are noticeable.

District **Tyler** Surveying Date **8/20/97** Survey Time: **2:30 P.M.**
Road: **SH 64 before US 259**
Year of Construction **1994-95** Mix Type: **C** Specification **non-QC/QA (item 340)**

Remarks: Loss of fines and raveling.

District **Wichita Falls** Surveying Date **8/22/97** Survey Time **10:50 A.M.**
Road: **IH 44, Northbound**
Year of Construction **1996** Mix Type: **CMHB-C** Specification Used **QC/QA**

Remarks: Loss of fines at the surface is noticeable. Road has an ADT of about 20,000. The overlay is over a 38-mm, 8-year-old HMA that lies over 200-mm thick concrete (CRCP). The bumps are noticeable. It appears to be the result of lay-down machine. The ride is not smooth. Truckload-to-truckload segregation is noticed.

District **Wichita Falls** Surveying Date **8/22/97** Survey Time **11:15 A.M.**
Road: **Loop 473 (Southbound and Northbound, between Christine and FM 369)**
Year of Construction **1993** Mix Type: **D** Specification Used **QC/QA**

Remarks: Noticeable longitudinal and transverse cracks (possibly from reflection).

District **Wichita Falls** Surveying Date **8/22/97** Survey Time **11:26 A.M.**
Road: **Loop 473 (30th St. to Christine)**
Year of Construction **1992** Mix Type: **D** Specification **QC/QA**

Remarks: The pavement looks good to excellent.

District **Wichita Falls** Surveying Date **8/22/97** Survey Time **11:35 A.M.**
Road: **Loop 473 (from 30th Street to US 287)**
Year of Construction **1981-2** Mix Type: **D** Specification Used **non-QC/QA (item 340)**

Remarks: Cracks have created large blocks. The pavement has an average-to-good appearance.

District **Wichita Falls** Surveying Date **8/22/97** Survey Time **11:40 A.M.**
Road: **US 281, North (starting from FM 1954 for 5 kilometers)**
Year of Construction **1993** Mix Type: **D** Specification **QC/QA**

Remarks: The pavement looks good to excellent.

District **Wichita Falls** Surveying Date **8/22/97** Survey Time **12:15 P.M.**
Road: **Highway 16**
Year of Construction **1995** Mix Type: **D** Specification **QC/QA**

Remarks: The overlay is treated with fog seal. Loss of fines is noticed at the surface. Thermal cracks are transverse.

District **Wichita Falls** Surveying Date **8/22/97** Survey Time **12:20 A.M.**
Road: **SH 16 (between Young County Line and South of Highway 114)**
Year of Construction **1997 (May)** Mix Type: **D** Specification **QC/QA**

Remarks: Roller marks and segregation are very noticeable.

District **Wichita Falls** Surveying Date **8/22/97** Survey Time **1:09 P.M.**
Road: **FM 369 (between US 281 and Rhea Rd., South of district office)**
Year of Construction **1990** Mix Type: Specification **non-QC/QA (item 340)**

Remarks: Other than severe cracking, the pavement looks good to average. It appears that the black base had been badly stripped and cracked before overlaying. Screed marks are noticeable. At the surface severe longitudinal and transverse cracks are noticed. These cracks have been fixed.

District **Yoakum** Surveying Date **8/14/97** Survey Time: **3:41 A.M.**
Road: **US 77 at Victoria (starting approximately 2 km north of loop 463 for a length of 4 km)**
Year of Construction **1996 (March through May)** Mix Type: **C** Specification **non-QC/QA (item 340)**

Remarks: One of the last QC/QA jobs. The mix looks good.
