Highway Construction Quality Management in Oklahoma

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In 1989, the Oklahoma Department of Transportation (ODOT) initiated the use of statistically based quality assurance and quality control (QA-QC) specifications for their highway construction projects. To facilitate the transition from the "method" specifications to the QA-QC specifications, ODOT contracted with the school of civil engineering at Oklahoma State University to develop and conduct a series of training courses, or modules, that addressed the various aspects of construction methods, process control, and acceptance sampling and testing procedures. The progress of the ODOT construction quality managment program, the changes that took place in the original QA-QC specifications, and the reasons behind these changes are described. An assessment of the training program is presented.

Over the years, the Oklahoma Department of Transportation (ODOT) has evolved from a three-man agency, on a zero budget, whose primary mission was road inventory to a multimillion-dollar organization with diversified duties. Today ODOT is responsible for the construction, maintenance, and operation of more than 12,300 miles of highways and 6,800 bridges that compose Oklahoma's state highway system. As ODOT has grown, so have Oklahoma's needs for a safe and sound transportation network, which is critical to economic growth and quality of life. Toward this end, ODOT engineers have identified approximately 3,700 miles of highways and 260 bridges that are either deficient or inadequate to serve current traffic demand or future traffic. In addition, ODOT is committed to building 82 miles of new routes which are critically needed in urban areas. The estimated cost of highway construction work for the next 20 years exceeds $7.5 billion at today's prices, excluding routine maintenance and administrative costs.

Faced with significant expansion in the highway construction program and increasing concerns about the quality of highway and bridge construction, ODOT turned to quality assurance and quality control (QA-QC) specifications in 1989 after several years of careful study and consideration. The primary reason for the change was to improve construction quality by assigning the responsibility for quality control to the party that has actual control over the construction process—the contractor or material supplier. Another consideration was to overcome shortages of experienced inspection personnel; ODOT's inspection force has declined in size despite taking on increased responsibilities.

Hughes and Ahmed (*1*) provided an overview of ODOT's QA-QC special provisions for asphalt concrete pavement, portland cement concrete (PCC) pavement, structural concrete, embankments, and bases. In addition, the establishment of a training program for ODOT, contractor, and supplier personnel in QA-QC sampling, testing, and other related subjects was discussed. Like any preventive medicine, QA-QC specifications do not work if they are not used correctly. Used by the unskilled or with the wrong intent, QA-QC specifications will not help improve the quality of construction. The goals of the training program were twofold: (a) to alleviate the lack of understanding of, and the resistance to, the new specifications, and (b) to ensure to the extent possible uniformity in sampling and testing procedures among ODOT, contractor, and supplier personnel.

As anticipated from the beginning, development of QA-QC specifications has been an evolutionary process which will continue over the next several years. Unlike dealing with products on assembly lines, where the sources of variability can be substantially controlled, modern highway construction is a complex process. It involves a wide variety of types of materials, workmanship, and construction methods. Almost every project is different from the others.

The progress of the ODOT's construction quality management program, the changes that took place in the original special provisions, and the reasons behind these changes are described. A discussion and critique of the developments in the QA-QC training program is also presented.

CHANGES IN ODOT QA-QC SPECIFICATIONS

Refinement rather than innovation characterized developments in ODOT's QA-QC specifications within the past 18 months. Shortly after the implementation of these specifications in four projects, the quality of the constructed pavement improved remarkably. The key contributor to the quality improvement was the pay adjustment factors; nothing gets the contractor's attention more than withholding payment or cost of rework to correct deficiencies. Nevertheless, the pay adjustment factors have been one of ODOT's major concerns. The original numbers were based on measurements of quality characteristics that were collected from projects constructed according to the method specifications using biased sampling techniques. Other expressed concerns have to do with the relative magnitudes of the different components of variability (due to random variation in materials and processes, sampling techniques, or testing methods). Some contractors alleged that the allowable deviations were unrealistic. Whether these allegations were well founded or not, ODOT has become sensitive to potential claims. Merely tighting the allowable deviations without realism is an invitation to trouble.

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The special provisions for asphalt concrete pavements and PCC pavements have been revised several times in coordination with all interested parties, including ODOT, industry associations, and FHWA. Most of the revisions relate to the allowable deviations from prescribed standards in the pay adjustment tables. A concensus was seldom reached, but there was an understanding of the reasons for the changes. The revisions reflect compromises between designers who generally believe that the allowable deviations are too loose and contractors who obviously want them looser. As ODOT engineers gain information from ongoing QA–QC projects, their data base is improved and the level of confidence is enhanced. The number of contracts that include QA–QC specifications has increased from 4 in 1989 to 13 in 1990, and ODOT has been gearing up in its independent sampling and testing efforts. To lessen the period of uncertainty, ODOT has sponsored an applied research project aimed at studying the components of variability of asphalt concrete and PCC pavement construction. Although the study deals with highway and bridge construction in Oklahoma, the results should be of interest to others who are experiencing similar problems. Meanwhile, until the findings of this study become available, ODOT will rely on the information it gathers as it goes.

Recognition of the gray areas of construction quality extends beyond acknowledging that materials vary. Quality of the construction process is equally difficult to pinpoint. In this light, ODOT has broadened the ranges of acceptance. For example, the original QA–QC specifications required the removal of a lot of bituminous concrete with an average of four test results of less than 92 percent of maximum theoretical density, whereas a lot with exactly 92 percent was acceptable with a 90 percent pay factor. As shown in Table 1, the latest

TABLE 1 PAY ADJUSTMENT FACTORS FOR ROADWAY DESIGN

Pay Factor	1 Test	2 Tests	3 Tests	4 Tests*
	ORIGINAL VERSION			
	Average of Deviations From Target Without Signs			
1.00	0.00-2.00	0.00-1.41	0.00-1.15	0.00-1.00
0.98	2.01-2.40	1.42-1.70	1.16-1.39	1.01-1.20
0.95	2.41-3.00	1.71-2.12	1.40-1.73	1.21-1.50
0.90	3.01-4.00	2.13-2.83	1.74-2.31	1.51-2.00
Unacceptable:**				
	Over 4.00	Over 2.83	Over 2.31	Over 2.00
Target:				
	94% of Maximum Theoretical Density (Core or Nuclear)			
	LATEST VERSION			
	Average of Deviations From Target Considering Signs			
1.00	(+)4.00-(-)2.00	(+)2.83-(-)1.41	(+)2.31-(-)1.15	(+)2.00-(-)1.00
0.99	(-)2.01-(-)2.60	(-)1.42-(-)1.84	(-)1.16-(-)1.50	(-)1.01-(-)1.30
0.98	(-)2.61-(-)3.20	(-)1.85-(-)2.26	(-)1.51-(-)1.85	(-)1.31-(-)1.60
0.96	(-)3.21-(-)3.80	(-)2.27-(-)2.69	(-)1.86-(-)2.19	(-)1.61-(-)1.90
0.93	(-)3.81-(-)4.40	(-)2.70-(-)3.11	(-)2.20-(-)2.54	(-)1.91-(-)2.20
0.89	(-)4.41-(-)5.00	(-)3.12-(-)3.54	(-)2.55-(-)2.89	(-)2.21-(-)2.50
0.84	(-)5.01-(-)5.60	(-)3.55-(-)3.96	(-)2.90-(-)3.23	(-)2.51-(-)2.80
0.78	(-)5.61-(-)6.20	(-)3.97-(-)4.38	(-)3.24-(-)3.58	(-)2.81-(-)3.10
0.70	(-)6.21-(-)6.80	(-)4.39-(-)4.81	(-)3.59-(-)3.93	(-)3.11-(-)3.40
0.60	(-)6.81-(-)7.40	(-)4.82-(-)5.23	(-)3.94-(-)4.27	(-)3.41-(-)3.70
0.50	(-)7.41-(-)8.00	(-)5.24-(-)5.66	(-)4.28-(-)4.62	(-)3.71-(-)4.00
unacceptable:**				
	Over (-)8.00	Over (-)5.66	Over (-)4.62	Over (-)4.00
	Over (+)4.00	Over (+)2.83	Over (+)2.31	Over (+)2.00
Target:				
	94% of Maximum Theoretical Density (Core or Nuclear)			

* If more than four tests are conducted, the allowable deviations will be determined by dividing the allowable deviations for one test by the square root of the number of tests actually conducted.

** Unless otherwise directed by the Engineer, products testing in this range are unacceptable, and shall be removed and replaced at no additional cost to the Department.

specifications establish 90 percent density and 50 percent pay factor as the lower limits.

Another key change was in the procedure of determining the combined pay factor (CPF). Originally, the CPF was computed as the product of the individual pay adjustment factors for the different quality characteristics used for acceptance purposes. When few characteristics were out of specifications, even slightly, the resulting pay adjustment could be excessive. To remedy this situation and to show contractors evidence of support, the latest version of the specifications uses a weighted average procedure to compute the CPF. Many designers believe this procedure goes too far in the other direction. As QA–QC specifications mature, ODOT should be able to formulate a CPF that is fair to both contractors and ODOT.

Although changes in the procedures for determining the CPF greatly affect pay adjustments, perhaps the greatest impact on quality will result from the new requirements concerning plant start-up and control strip methods. The latest specifications provide for extensive trial and error work on temporary or less critical areas, such as detours, before construction begins on the mainline facilities. This is a common sense approach that was used when ODOT had adequate numbers of inspection personnel. In recent years, however, the tendency has been for the contractors to begin full-scale operations with very little preparatory effort. Often when this happens, a significant portion of the project is completed before the necessary QC measures are established. In addition to providing for production and placement trial procedures, the new QA–QC specifications also require calibration of both contractor and ODOT test procedures. This requirement should not only lessen the number of disputes but also enhance the quality of the final product.

Because the quality of highway construction depends on the skills and training of the individuals involved, the latest version of the QA–QC specifications requires that contractor personnel who perform QC testing should receive the same training as ODOT employees who perform similar work. Some contractors operating under QA–QC specifications relied on consultants to perform the necessary QC activities; others established their own QC teams and test facilities. To ensure the level of personnel qualifications, ODOT is considering the certification of personnel employed by ODOT, contractors, and consultants who are assigned to inspection, sampling, and testing. ODOT is exploring in-house certification programs as well as certification by nationally recognized organizations such as the National Institute for Certification in Engineering Technologies or the American Concrete Institute.

Other changes to the QA–QC specifications, such as the addition of Treatment of Outliers and Referee Testing, simply formalized existing ODOT procedures. These additions were especially helpful to contractors unfamiliar with ODOT policies.

Among the problems that are likely to remain unsolved for some time is the lack of rapid and reliable test methods. This problem presents a major bottleneck in the process of implementing QA–QC specifications in Oklahoma and in other states. Accurate and quick test results are needed by the contractor's QC technicians in modifying the construction process on a timely basis and by ODOT employees in the acceptance process. Table 2 summarizes the findings of a recent study by a TRB task force concerning research and development needs in highway construction engineering and management (*2*). Of the 16 highest-priority research and development needs, the development of more effective, rapid test methods has been ranked third by representatives from the highway construction industry including state and federal highway agencies, contractors, universities, and consultants. Undoubtedly, these test methods will be developed soon; nevertheless, they will need to be used with as much skill as those existing today.

QA–QC TRAINING PROGRAM

One of the prime concerns of the highway construction industry today has to do with the industry's most valuable asset, quality personnel. A recent study of staffing considerations in highway construction projects has concluded, among other things, that given adequate design plans and specifications, the quality of highway construction depends on the training and motivation of the individuals involved (*3*). In another recent study (*2*), it has been found that personnel-related issues represent more than 25 percent of the 16 top-priority needs identified by highway agencies and contractors.

QA–QC Training Modules

The QA–QC training program established by Oklahoma State University (OSU) consists of 5-day training modules in aggregates, asphalt materials, asphalt paving, concrete materials, concrete construction, and soil mechanics. In addition, the program includes a 2-day course in statistical methods of QA–QC which is tailored to highway construction. The aggregate module is a recommended prerequisite for the asphalt materials, concrete materials, and soils modules. It is recommended, but not required, that students attend the aggregates and materials modules before attending the asphalt paving and concrete construction modules.

The first module, aggregates, was offered the week of February 6, 1989. Since then, 32 of the 5-day modules and 9 of the 2-day modules have been conducted. A total of 1,004 students had received more than 31,300 student-hours of training as of March 31, 1990. Some individuals attended several modules and are counted more than once. The breakout of individuals by training modules is shown in Table 3.

Because the aggregates module is a recommended prerequisite for three other modules and ODOT wanted some flexibility by having a pool of qualified employees to select from for future training, the aggregates module was offered much more frequently than the others. All of the modules except statistics are hands-on and laboratory-oriented; they must be taught on the OSU campus in a special classroom-laboratory complex which is provided for exclusive use for the QA–QC training. The attendance for the laboratory modules is generally limited to 24 students (six, four-person lab teams), but occasional exceptions are made to accommodate special requirements. (Because the statistics module requires only a classroom facility and audio-visual equipment, different arrangements were made for the conduct of this course; it is discussed separately.)

TABLE 2 HIGHEST PRIORITY RESEARCH AND DEVELOPMENT NEEDS IN CONSTRUCTION ENGINEERING AND MANAGEMENT (*2*)

Priority	Problem Title
1	Performance-Based Specifications for Highway Construction
2	Construction Claims and Their Resolution
3	Development of More Effective Rapid Test Methods and Procedures
4	Constructability Review
5	Improving the Quality of Work on Highway Projects
6	Alternative Methods to Facilitate Timely Reconstruction
7	Responsibilities for Quality Management
8	Effectiveness of the Disadvantaged Business Enterprises (DBE) Program
9	Evaluating the Effects of Specifications and Other Contract Requirements on Staffing
10	Retaining Quality Professional and Technical Personnel
11	Constructability and Operability of Pavement Drainage Systems
12	Certification Programs for Construction Engineering Technicians
13	Rut Resistance Asphalt Concrete Pavements and Overlays
14	Management Skills for Construction Personnel
15	Recruiting Qualified Highway construction Engineering Personnel
16	Optimizing the Use of Consultant vs. In-House Staff for the Design and Construction of Public Works

At the conclusion of each of the six laboratory modules, students are given a 2- to 3-hour written examination. It is an open-book examination with objective-type questions on the various test methods conducted during the course. Some of the questions require data manipulation and plotting of test results. Table 4 summarizes the results of the examinations to date. As expected, the first module in the sequence, aggregates, has the highest failure rate. This course identifies students with reading problems, attitude problems, and other factors contributing to unsatisfactory performance.

In the early planning stages of the training modules it was anticipated that some attendees might not have the basic mathematics skills that are necessary to manipulate the sampling and test data and to solve the rudimentary equations associated with mix design. A test of basic mathematics skills was designed and administered by the state's extensive vocational-technical network. All students except those with proof of having taken a college algebra course were required to take and pass this basic mathematics course before enrolling in the training module. The passing rate for those who have

TABLE 3 TRAINING MODULE ATTENDANCE

INSTRUCTION MODULE	TIMES OFFERED	No. OF PARTICIPANTS		
		ODOT	CONTRACTOR	TOTAL
Aggregates	12	163	118	281
Concrete Materials	6	103	25	128
Concrete Construction	1	19	16	35
Asphalt Materials	5	64	53	117
Asphalt Paving	3	42	41	83
Soils	5	66	35	101
Statistics	9	220	39	259
Totals	41	677	327	1004

TABLE 4 PERCENT OF STUDENTS FAILING

INSTRUCTION MODULE	PERSONNEL		
	ODOT	Contractor/Other	Overall
Aggregates	11.0% (18)	14.5% (15)	11.75% (33)
Asphalt Materials	0%	0%	0%
Concrete Materials	2.0% (2)	4.2% (1)	2.3% (3)
Soils	3.1% (2)	20.6% (6)	7.9% (8)
Asphalt Paving	0%	2.5% (1)	1.2% (1)
Concrete Construction	11.0% (2)	0%	8.0% (2)
Overall	5.5%	10.8%	6.4% (47)

(n) = number failing

taken the basic mathematics test is 73 percent. Those who cannot pass this test are provided the opportunity to attend a remedial mathematics course offered by the vocational-technical network. Even having passed the mathematics skills test, beginning with the first module taught, some students had difficulty with the simple algebraic equations and ratios and proportions necessary to combine aggregates to meet gradation specifications. Because many students were incapable of grasping the material, several special tutoring sessions were held in the evening following the initial exposure to these procedures.

The number of students who do not possess the necessary mathematics skills appeared to grow as time went on. The problem was finally identified and traced to two sources. First, the basic mathematics test was found to be inadequate in that it did not have enough questions in the area where the problem existed. Second, the questions on the basic mathematics test had not been changed, and eventually the answers were passed among the employees of the various organizations.

To remedy this situation, the test has been modified to place more emphasis on algebraic equations, ratios, and proportions. In addition, new questions are used each time the test is conducted. These changes were implemented only 3 months ago, so insufficient time has elapsed to determine whether the problem has been resolved.

Of the 47 students who have failed one or more of the modules to date, none failed solely because of the mathematics skills problem. Surprisingly, the single predominant cause of failure was the lacking of reading comprehension skills by a substantial number of emplyees from all participating organizations. Although to a much lesser degree, the second highest cause of failure appeared to be lack of motivation or interest. Lack of education or personal intelligence was a minor contributing factor with very few, if any, failing because of inability to grasp the material.

The lack of reading skills by such a substantial number of students was totally unanticipated. The problem was not recognized immediately, and the initial failures were associated with other causes. In the fourth or fifth month of the program, a technician from a metropolitan agency attended the aggregate module. He appeared to be very knowledgeable of the testing and sampling procedures and was the obvious leader of his laboratory group. He showed no problem in working with the data, plotting results, or following proper technical procedures. He impressed all of the instructors with his enthusiasm and interest. When the final examination was graded, however, he scored 42 (passing is 75 of 100 possible). Because of the irrelevance of his responses, it was obvious that he did not understand the questions.

The technician's supervisor was contacted and informed of the instructors' suspicions. He quietly looked into the matter and later reported a startling discovery: the individual had difficulty in both reading and writing. During the day, on the job, he memorized the events that took place, and in the evening his wife wrote his daily logs and reports.

After this experience, all of the failing examinations were reexamined; it is suspected that at least half of those failing the examination did so because of a lack of reading comprehension. ODOT is being encouraged to require a reading comprehension test for all employees planning to attend the QA–QC training. Because technical specifications are written at about the 10th grade reading level, this would be the minimum passing level of the test. Students who do not achieve this level would be given the opportunity to participate in a reading improvement program. If ODOT accepts this recommendation, all attendees would then be required to pass the reading comprehension test, which, like the basic mathematics test, would be administered by the state vocational-technical network.

Statistical Methods Module

The statistical methods module was developed to familiarize ODOT and contractor personnel with the key statistical concepts and methods needed for the effective implementation of QA–QC specifications. The topics covered in this course include stratified random sampling techniques based on lots and sublots; sources and measures of variability; effect of sample size on the variability in sample averages; basics of the normal distribution; control charts for sample average and range; and the ASTM procedure for dealing with outlying test results (ASTM E178-80). The selection of course content was based on a proposed course duration of 3 days. However, before the first session, ODOT requested that the material be reduced and that the course be conducted over a 2-day period. This was accomplished, and nine sessions have been held to date. However, the one complaint received consistently is that too much material is being presented in too short a period.

Because this module does not involve laboratory work, it is presented at each of ODOT's eight division headquarters and at the ODOT state headquarters. Contractor personnel in the geographical area also attend these sessions. The first session is offered on a Friday. At the end of the day, an 18-page homework assignment is distributed. The problems are worked during the following week and mailed by the ODOT supervisor and the individual contractors to OSU where they are corrected without being assigned a grade. On the following Friday, 2 weeks after the first session, the second day of instruction is conducted. The homework papers are passed out and discussed at the beginning of the session before new material is presented.

At the end of the second day, another homework assignment is given to the students. A solution sheet is left at the division office where students can correct their own work, or the supervisor may choose to correct all papers. No pass/fail examination is given because of the shortage of time.

TRAINING PROGRAM EVALUATION

On the first morning of each module, students are given a critique sheet and asked to complete it and turn it in with their final examination on the fifth day. A sample critique sheet is shown in Figure 1. Based on these responses and other comments passed on to the instructors, a number of changes have been made in the course content, in the way the laboratories are conducted, and in teaching personnel.

A number of interesting things have been learned from the students' response. Students do not like videotapes of testing procedures. Tapes had been used to explain the test methods prior to the laboratory sessions in two of the training modules. These videotapes have been replaced with live demonstrations by the instructors.

The attendees have a strong preference for the hands-on laboratory instruction rather than formal lectures. In coor-

COURSE EVALUATION
QUALITY ASSURANCE-QUALITY CONTROL TRAINING PROGRAM

Course ____________ Date ____________
Name ____________ Employer ____________

1. Based upon information available to you, is this course about what you expected?

   A. Yes, exactly B. Yes, to a large extent
   C. Yes, to some extent D. No, not at all

2. Was the course material presented in a manner that was easy for you to understand?

   A. Excellent B. Very Good C. Good D. Poor E. Very Poor

3. Do you feel that the material presented will be useful in your work?

   A. Greatly B. Helpful C. A little D. Not at all

4. How do you rate the printed materials used in conjunction with the course?

   A. Excellent B. Very Good C. Good D. Poor E. Very Poor

5. How would you rate the instructors?

Name	Excellent	Very Good	Good	Poor	Very Poor
____	____	____	____	____	____
____	____	____	____	____	____
____	____	____	____	____	____

6. What did you like best about the course?

7. What did you like least about the course?

8. Overall, how would you rate this course?

   A. Excellent B. Very Good C. Good D. Poor E. Very Poor

9. Are you interested in receiving additional information on the following training modules?

   Aggregates Concrete Materials
   Asphalt Materials Concrete Construction
   Asphalt Paving Soils
   Statistical Methods

10. Please provide additional comments on ways we can improve this training module.

FIGURE 1 Course evaluation form.

dination with ODOT, the Oklahoma Asphalt Paving Association, and the Association of Oklahoma General Contractors, several of the modules have been revised by eliminating background lecture material and increasing the laboratory time, which allows for repetition of many of the sampling and test procedures. Additional laboratory equipment has been added to reduce the waiting time in the laboratory, and extra safety precautions have been implemented.

Initially it was anticipated that the students would consider site visits a waste of time, so these visits were minimized in the curriculum. However, the first visit to an automated asphalt plant was so well received that additional site visits have been added to the curriculum of both the asphalt paving and the concrete construction modules. The student reaction to these field visits remains very positive even though some of the sites are more than 70 miles away and require travel over the lunch period.

Other changes to the course content include the addition of 2-hour seminars on the final day to end the course. Both the asphalt paving and the concrete construction modules have added this feature. The panels comprise two high-ranking ODOT officials, two experienced general managers of construction firms, and a representative of a materials supplier. The panel is moderated by an OSU civil engineering faculty member. Each panel member is allowed 5 minutes to address what he or she feels are the most pressing issues related to the specific industry and with implementing the performance specification. For the next hour and a half, the students address questions to the panel members. This has proven to be lively, interesting, and informative, and in some instances, debates have ensued. This feature has been enthusiastically received by the students.

CONCLUSIONS

"Slow and steady" best describes the progress of the ODOT program for construction quality management within the past 18 months. Quality assurance and quality control, two of the buzzwords last year, have gained acceptance within the construction industry in Oklahoma. Of the key developments that took place, two are particularly worth noting: realism and training.

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