**TxDOT Design-Build QAP: Lessons Learned and Development of a Three-Tiered Analysis Approach to Owner Verification**

Weng On Tam, Ph.D., P.E. (Corresponding Author)  
Professional Associate  
810 Hesters Crossing  
Suite 120, Round Rock, TX 78681  
Telephone: (512) 685-2913, Fax: (512) 685-2901  
E-mail: Weng.Tam@hdrinc.com

Gregory Cleveland, M.S.C.E., P.E.  
Materials Manager  
HDR Engineering, Inc.  
17111 Preston Road  
Suite 200, Dallas, Texas 75248  
Telephone: (972) 960-4400, Fax: (972) 960-4471  
E-mail: Gregory.Cleveland@hdrinc.com

J. Jeffrey Seiders, Jr., P.E.  
Director, Materials and Pavements Section  
Construction Division  
Texas Department of Transportation  
125 East 11th St.  
Austin, TX 78701-2483  
Telephone: (512) 506-5808, Fax: (512) 506-5812  
E-mail: jseider@dot.state.tx.us

Dennis Dvorak  
Pavement and Materials Engineer  
Federal Highway Administration  
4749 Lincoln Mall Drive Suite 600  
Matteson, IL 60443  
Ph: (708) 283-3542, Fax: (708) 283-3501  
E-mail: dennis.dvorak@dot.gov

Submitted for acceptance and publication at the 90th Annual Meeting of the Transportation Research Board

Original Submittal Date: August 1, 2010

Word Count = 5,641 (text, including Abstract 248) + 250 (1 Tables) + 1,500 (6 Figures)  
= 7,391 words
ABSTRACT

The Code of Federal Regulations for highways, specifically 23 CFR 637 Subpart B allows for the use of contractor quality control (QC) testing in the acceptance decision if validated by the owner agency’s verification testing and sampling. The SH 130 was the first design-build highway infrastructure project in Texas where contractor QC testing was used in the acceptance decision for all project-produced materials. A project-specific quality assurance program that addresses the Federal Highway Administration’s requirements was developed for the project. With the completion of the SH 130 and the 183A projects, TxDOT built upon lessons learned from those projects to develop a statewide quality assurance program for design-build projects.

An enhancement to the previous owner verification process is the new three-tiered approach. Level 1 is applied to the tests which are strong indicators of performance and provides the highest level of confidence in the contractor’s QC testing through the running of continuous F- and t-tests. Level 2 is applied to tests that are secondary indicators of performance through running quarterly independent verification on the contractor’s QC test results. Level 3 is applied to tests with extremely low test frequencies where independent verification cannot be meaningfully performed or tests on materials whose risk of failure does not affect the long-term performance of the facility past the contractual maintenance obligations.

While the previous design-build quality assurance programs served TxDOT well, this new approach is an enhancement that focuses verification efforts on tests that are better indicators of material performance.
INTRODUCTION

23 CFR 637B and FHWA Technical Advisory 6120.3

A revision of the Federal Highway Administration’s (FHWA) sampling and testing regulation titled “Quality Assurance Procedures for Construction” was published on June 29, 1995 as Title 23, Code of Federal Regulations, Part 637. This regulation permits the use of contractor QC test results in the acceptance decision “provided that adequate checks and balances are in place to protect the public investment (1, 2).” FHWA provided guidance and recommendations for the use and validation of contractor’s test results in the acceptance decision in FHWA Technical Advisory T 6120.3 (3).

Information contained in FHWA Technical Advisory T 6120.3 enhances earlier FHWA direction and stands as the most current guidance on this subject matter. More information on statistical procedures can be found in course material for NHI (National Highway Institute) Course Numbers 134042 and 134064 (4, 5), FHWA’s Evaluation of Procedures for Quality Assurance Specification (6), FHWA’s Optimal Procedures for Quality Assurance Specifications (7) and AASHTO’s Implementation Manual for Quality Assurance. A review of state construction quality assurance programs can be found in NCHRP Synthesis 346 (9) and a review of quality assurance in design-build projects can be found in NCHRP 376 (10).

TxDOT Quality Assurance Program

As with all state highway agencies, TxDOT has a FHWA-approved quality assurance program for Federal-aid projects that it administers across the state. SH 130 Segments 1 through 4 (henceforth referred to as “SH 130”) in central Texas was the first highway infrastructure project in Texas where contractor quality control testing results were used as part of the acceptance decision for all project-produced materials. Per the CFR, TxDOT’s OV (owner verification) testing results served as the other part of the acceptance decision (11, 12). TxDOT and FHWA collaborated to develop the first quality assurance program (QAP) for such a project. The project-specific QAP includes requirements for process control, QC, OV, independent assurance (IA), and referee requirements and functions.

While the QAP encompassed several specific commitments, this paper will focus on the approach to OV. A companion paper being submitted along with this paper summarizes other lessons learned and enhancements to the quality assurance program for design-build projects.

Owner Verification on SH 130

On the SH 130 project, the F- and t-tests were used to statistically compare variances and means, respectively, of the OV and QC test results. At the beginning of the project, a five percent level of significance ($\alpha$) was selected to more easily identify differences since there was good collaboration between the OV and QC testing groups. The collaborative partnering included attempts to use the same model of testing equipment, discussing each step in each test method to unify the testing process, and initial split sample testing to align the testing equipment and personnel.

While the SH 130 project was underway, the 183A design-build project in Austin, Texas, ran concurrently and also provided good insight into the owner verification testing process. At the conclusion of these two projects, TxDOT contracted HDR Engineering, Inc. to work collaboratively with TxDOT and FHWA to extract the lessons learned from these two completed projects and develop a better approach to owner verification testing. Industry workshops were
conducted with TxDOT, FHWA, and participants on these two projects (owner verification firms, contractor’s independent quality control firms, and the contractors). After the initial industry meetings, the lessons learned were compiled and the SH 130 data was reviewed to determine if a better approach to owner verification could be developed. The result of this effort is the development of TxDOT’s statewide Quality Assurance Program for Design-Build Projects with an Optional 15-year Capital Maintenance Agreement (13, henceforth referred to as TxDOT DB QAP). Additional work was later completed to work out details of the new analysis approach, trial runs with previously collected SH 130 data were performed, and corresponding modifications to TxDOT’s I2MS software system (originally developed to support the SH 130 owner verification work) to support the new owner verification approach. TxDOT’s DB QAP has been approved by the FHWA for statewide use of design-build projects.

The following discussion on the three-tiered approach utilizes screen captures from I2MS because the essence of this new approach is automated and graphically represented in the system.

THREE-TIERED APPROACH TO OWNER VERIFICATION TESTING

Lessons Learned

On the SH 130 project, the contractor QC testing frequency was established using TxDOT’s applicable Guide Schedule for Testing and Sampling at that time. The OV test frequency was established at a minimum of ten percent of the contractor’s QC testing frequency with a higher initial testing frequency. The higher initial testing frequency is to establish initial confidence in the QC test results and the minimum ten percent regular testing frequency is based on generally accepted industry practice (7). This testing frequency applied to all tests performed by the QC testing firm. Owner verification was performed using statistical validation (F- and t-tests) on all analysis categories. Each analysis category represents a unique combination of “material or product” (e.g. a given Portland cement concrete mix) and test method (e.g. compressive strength). For example, the compressive strength and air content tests on Mix ABC would be considered two different analysis categories. Similarly, the compressive strength of Mix ABC and the compressive strength of Mix DEF could be considered two analysis categories. Taking into account the different Portland cement concrete mixes, hot mix asphalt mixes, and the various types of bound and unbound material use on the project, there were a few hundred analysis categories that required validation during the peak-production year.

During each quarter, TxDOT’s Materials Manager would use ad-hoc tools in an attempt to proactively manage the validation process. The results of the owner verification efforts were then reported to FHWA quarterly. However, not much could be done after the report was completed at the end of the quarter to address previously completed tests if the non-validation happened before the end of the quarter and the ad-hoc tools were not able to detect the non-validating outcome.

As the project progressed, TxDOT and FHWA noticed that there were a number of analysis categories where statistical differences were observed, but the actual difference in the test results were not materially different (e.g. a 0.4 percent difference in percent compaction between the means of the OV and QC populations) nor would they adversely impact the performance of the material being accepted. In most cases, both the OV and QC populations comfortably exceeded the specification requirements (e.g. exceeding the percent compaction requirement by three percent or more). However, investigations into the non-validations were conducted and both the OV and QC firms were found to be performing properly. After
significant review, TxDOT and FHWA determined that the level of significance used in the F- and t-tests should be decreased to one percent because the statistical differences were not materially significant. A level of significance of one percent was consistent with practices around the country (7, 9, 14). This change significantly reduced the effort spent investigating materially insignificant differences for those materials which significantly exceeded specification requirements. While this change reduced unnecessary non-validation investigations, TxDOT’s Materials Manager was not well equipped to proactively monitor the level of validation on the project across all the analysis categories. There was also the question of whether the OV approach could be improved based on the lessons learned from these projects. The three-tiered approach presented in this paper is a result of reviewing data from the two completed projects and working collaboratively with FHWA to develop a better approach to owner verification.

**Development of the Three-Tiered Approach**

The development of TxDOT’s three-tiered approach is based on very practical lessons learned from previous projects and national guidance provided by FHWA. In addition to regulations and guidance previously mentioned, opportunities for improvement from FHWA’s quality assurance stewardship reviews were also incorporated (17). Such improvements include using a rolling comparison of QC and OV test results and limiting the OV sample population to between 20 and 30 test results. A limited study on the benefits and limitations on how the three-tiered approach would have impacted the SH 130 project was evaluated. This served as the basis for the parameters recommended for use in the continuous analysis. An extensive research study to perform robust risk analyses and determine the optimal values for each parameter in the continuous analysis was not included in the scope of the developmental work.

The fundamental principle behind the three-tiered approach is to assign the appropriate level of resources to monitor and evaluate each analysis category based on TxDOT’s residual risk after the Developer (a term used by TxDOT for a design-builder or concessionaire) has completed construction and fulfilled its maintenance obligations. In general, the higher the residual risk for the performance of the material after the Developer’s maintenance obligations expire, the higher the level of monitoring and verification. For example, concrete on a bridge structure is typically designed and constructed to perform over a service life significantly longer than 15 years (length of optional maintenance agreement on TxDOT design-build projects) and so TxDOT’s has significant residual risk after the 15-year capital maintenance agreement. Similarly, the stronger the relationship between the material property being tested and the material’s performance, the higher the level of monitoring and verification required. For example, the compressive strength of concrete is a significantly better indicator of performance than the concrete slump. Therefore compressive strength of concrete calls for Level 1 analysis while concrete slump does not.

Table 1 shows the first page of the default analysis category table contained in the TxDOT DB QAP (16). This table was developed using the required test methods contained in TxDOT’s Guide Schedule of Sampling and Testing (15). A default level of analysis (1, 2 or 3) was assigned to each test for each analysis category (a combination of “material or product” and test method). Level 1 has the highest residual risk to TxDOT and/or a strong correlation to the performance of the material being tested. It should be noted that Level 1 analysis categories require a sufficiently high testing frequency in order to have sufficiently powerful statistical analyses.
Table 1: Example Analysis Categories for Owner Verification

<table>
<thead>
<tr>
<th>Levels for Analysis</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMBANKMENTS, SUBGRADES, BACKFILL, AND BASE COURSES</td>
<td>Liquid Limit</td>
<td>Tex:104-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Plasticity Index</td>
<td>Tex:106-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Linear Shrinkage</td>
<td>Tex:107-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Gradation</td>
<td>Tex:110-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moisture/Density</td>
<td>Tex:114-E</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>In-Place Density</td>
<td>Tex:115-E</td>
<td>1</td>
</tr>
<tr>
<td>RETAINING WALL (NON-SELECT BACKFILL)</td>
<td>Liquid Limit</td>
<td>Tex:104-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Plasticity Index</td>
<td>Tex:106-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Linear Shrinkage</td>
<td>Tex:107-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Gradation</td>
<td>Tex:110-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moisture/Density</td>
<td>Tex:114-E</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>In-Place Density</td>
<td>Tex:115-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Gradation</td>
<td>Tex:110-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Resistivity</td>
<td>Tex:128-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>Tex:126-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Soundness</td>
<td>Tex:411-A</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>In-Place Density</td>
<td>Tex:115-E</td>
<td>1</td>
</tr>
<tr>
<td>RETAINING WALL (SELECT BACKFILL)</td>
<td>Liquid Limit</td>
<td>Tex:104-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Plasticity Index</td>
<td>Tex:106-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Linear Shrinkage</td>
<td>Tex:107-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Gradation</td>
<td>Tex:110-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moisture/Density</td>
<td>Tex:113-E</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Wet Ball Mill</td>
<td>Tex:116-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Triaxial</td>
<td>Tex:117-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>In-Place Density</td>
<td>Tex:115-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Moisture Content</td>
<td>Tex:106-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>Tex:140-E</td>
<td>1</td>
</tr>
<tr>
<td>UNTREATED BASE COURSES</td>
<td>Liquid Limit</td>
<td>Tex:104-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Plasticity Index</td>
<td>Tex:106-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Linear Shrinkage</td>
<td>Tex:107-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Gradation</td>
<td>Tex:110-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moisture/Density</td>
<td>Tex:115-E</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Wet Ball Mill</td>
<td>Tex:116-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Triaxial</td>
<td>Tex:117-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>In-Place Density</td>
<td>Tex:115-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Moisture Content</td>
<td>Tex:103-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moisture</td>
<td>Tex:144-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>Tex:150-E</td>
<td>1</td>
</tr>
<tr>
<td>TREATED SUBGRADE AND BASE COURSES</td>
<td>Liquid Limit</td>
<td>Tex:104-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Plasticity Index</td>
<td>Tex:106-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Linear Shrinkage</td>
<td>Tex:107-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Gradation</td>
<td>Tex:110-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moisture/Density</td>
<td>Tex:115-E</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Wet Ball Mill</td>
<td>Tex:116-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Triaxial</td>
<td>Tex:117-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>In-Place Density</td>
<td>Tex:115-E</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Moisture Content</td>
<td>Tex:103-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moisture</td>
<td>Tex:144-E</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>Tex:150-E</td>
<td>1</td>
</tr>
</tbody>
</table>

While there are default levels set for each analysis category, each project has its own unique conditions that may warrant project-specific modifications to the default levels of analysis for some material categories. The risk workshop will evaluate project-specific contractual framework and conditions (e.g. soil conditions, past performance of project elements in the area, etc.) For example, TxDOT’s DB QAP assumes an optional 15-year capital maintenance agreement. If a design-build project does not have a capital maintenance agreement and maintenance of the project is the owner agency’s responsibility upon final acceptance, the owner’s residual risk is higher and the default levels may be lowered to increase the level of oversight and verification TxDOT requires each project team to conduct a risk workshop with FHWA to evaluate any unique project-specific conditions. Based on the results of this workshop, the levels of analysis for each analysis category will be established for the project.

**Level 1 – Continuous Analysis of Tests Directly Related to Performance**

Level 1 provides for continuous analysis for those analysis categories which are strong indicators of performance. Examples include compressive strength for hydraulic cement concrete, percent soil compaction for embankment, and percent asphalt content for hot-mix asphalt concrete. The QC testing frequency is in compliance with TxDOT’s *Guide Schedule of...*
**Sampling and Testing** (16) and the OV testing frequency should be a minimum of ten percent of the QC testing frequency. F- and t-tests are performed on these material categories on a continuous basis with the addition of each OV test result. The p-values (from the F- and t-tests) are reported for each analysis and tracked over time. This new approach enables TxDOT to efficiently monitor the validation status of each analysis category daily in “real time” and allows for more timely action to address non-validation.

When using the F- and t-tests for owner verification, the objective is to maximize the OV sample size (which should be smaller than the QC sample size) so as to have a sufficiently powerful analysis while capping the maximum sample OV sample size so as to limit the detection of materially insignificant statistical differences. For example, there were statistical non-validation scenarios on SH 130 where both the OV and QC samples populations significantly exceeded the specification requirement and the difference in the means was smaller than TxDOT’s split-sample tolerance for that test method. In the continuous analysis approach, the OV sample population increases as additional OV test results are reported; up to a maximum of 25 OV test results or a maximum time period of 90 days. In addition, the maximum number of OV test results was established to limit the detection of materially insignificant (from a material performance standpoint) statistical differences. The maximum time period of 90 days was also established to limit the inclusion of different sample populations into one analysis. For example, aggregate base from a given quarry may have different properties based the location and depth from which material is being excavated. Not including a time limit on the time period for which test results are included in the F- and t-tests may lead to the inclusion tests results no longer representative (or from the same sample population) of the current production run.

At the end of each day, I2MS searches for any new OV test results approved that day and will automatically trigger a new analysis in that analysis category. New OV tests are those test results considered to have been submitted for the first time, corrected or revised. Each continuous analysis is based on the following criteria:

1. If there are fewer than 25 OV test results in the past 90 days, the analysis will cover the past 90 days. All OV and QC samples in that date range are selected and used in the F- and t-tests.
2. If there are more than 25 OV test results in the past 90 days, the analysis will cover the date range from the date of the 25th most recent OV test result to the current date. All OV and QC samples in that date range are selected and used in the F- and t-tests.
3. If there are newly approved tests beyond the past 90 days, the analysis will cover the date range from that oldest unanalyzed test result to the current date. All OV and QC samples in that date range are selected and used in the F- and t-tests.

Figure 1 provides an illustration of the continuous analysis concept. A fictitious OV testing frequency that is higher than recommended is presented to fit the illustration into one figure. On Day 1, there are seven QC tests and four OV tests. When the results for Day 1 are approved, the Analysis 1 is performed and the p-values for F- and t-tests are reported. A p-value higher than the specified level of significance for that material category indicates that there is no statistically significant difference (i.e. the null hypothesis in the F- or t-test is rejected) between OV and QC test results. Conversely, a p-value lower than the specified level of significance for that material category indicates that there is a statistically significant difference (i.e. the null hypothesis in the F- or t-test is rejected) between OV and QC test results. On Day...
2, there are three additional OV tests results and seven additional QC test results reported. Analysis 2 is performed with the cumulative number of 14 QC test results and 7 OV test results. The number of OV test results in each subsequent analysis continues to increase until Day 9 when the maximum number of 25 OV test results is exceeded. At that juncture, the first four OV test results and the first seven QC test results from Day 1 are excluded and Analysis 9 is performed on 25 OV test results (maximum number allowed) and 55 QC test results. The 55 QC test results are based on the QC tests performed in the same date range as the 25 OV tests. Similarly, on Day 110, there are test results that were reported more than 90 days ago. When the 90-day threshold is exceeded, those test results are excluded from Analysis 16 which as a result is performed with 11 OV test results and 27 QC test results. As new OV test results are added to the analysis, older OV results are excluded. This method of data capture and analysis provides a “real time” view of the current status of validation on material from the same statistical population.

![Figure 1: Example Continuous Analysis Algorithm](image)

Figure 2 is a screen capture from I2MS dashboard for Level 1 analyses. In this I2MS user interface, TxDOT’s Materials Manager can monitor the status of verification for Level 1 analysis categories and record any action taken. Each line represents an analysis run for a given analysis category. Green numbers represent F- and t-test p-values for analyses where the OV test results validate the QC test results at the specified level of significance and red numbers represent analyses that do not validate. Default levels of significance for each material category can be found in the TxDOT DB QAP. These levels of significance were developed based on

---

**Figure 1: Example Continuous Analysis Algorithm**

Figure 2 is a screen capture from I2MS dashboard for Level 1 analyses. In this I2MS user interface, TxDOT’s Materials Manager can monitor the status of verification for Level 1 analysis categories and record any action taken. Each line represents an analysis run for a given analysis category. Green numbers represent F- and t-test p-values for analyses where the OV test results validate the QC test results at the specified level of significance and red numbers represent analyses that do not validate. Default levels of significance for each material category can be found in the TxDOT DB QAP. These levels of significance were developed based on
practical experience on the SH 130 project data and are consistent with practices around the country.

Figure 2: Screen Capture Showing Example I2MS Continuous Analyses Dashboard

The arrows to the left of the p-values indicate the trending of the moving F- and t- test analyses. Green upward arrows indicate a positive validation trend (increasing confidence in validation) and red downward arrows indicate a negative validation trend (decreasing confidence in validation). The number of arrows indicates how many times the analysis has moved in that direction with a maximum of three arrows representing three or more movements in that direction. For example, a red number with one red downward arrow indicates that the material category is not validating and the last analysis indicated a decrease in the level of validation. I2MS enables TxDOT to evaluate these Level 1 tests practically in “real time” and take the
necessary actions to proactively manage the project and minimize non-validation. The “details” button at the right of the screen allows TxDOT’s Materials Manager to record comments on the current analysis, view historical F- and t-test analysis results and comments, view a plot of the QC and OV tests results against the date of each test, and view specific test identification information (sample date, tested by, material code, etc.) for each test in the analysis.

For analyses that indicate validation and less than three downward trending arrows, each new analysis will be displayed for one day in the “current analysis” tab before being moved to the “historical analysis” tab automatically at the end of the day. For analyses that do not show validation or have three downward trending arrows, each analysis will require a comment from the Materials Manager (responsible for owner verification). This comment is to acknowledge the trend and/or record any action taken to address the results of this analysis prior to it being moved to the “historical analyses” tab.

Figure 3: Screen Capture Showing Example I2MS Sample Continuous Analysis Report
Figure 3 shows a report that can be generated to visualize the validation (p-value) trend for a given analysis category. This is an example of the Level 1 report for a concrete mix. A red line indicates that the F- and t- tests are performed at level of significance ($\alpha$) of 0.025 or 2.5 percent. The blue dashed trend line shows the p-value for F-test which has consistently been above the red $\alpha$ line indicating verification of the QC test results. The yellow solid line shows the p-value for the t-test which has steadily increased from below the red $\alpha$ line. This trend indicates that this analysis category is now validating though it started out not validating. The obscured comments showed how TxDOT’s Materials Manager noticed the non-validation and took steps to address the issue. This is an example of how knowledge of the status of validation can help identify trends in non-validation in “real time” (rather than at the end of each quarter) and take necessary investigative steps to potentially avoid non-validation or bring the analysis category into validation more quickly.

**Level 2 – Quarterly Independent Verification of Tests Indirectly Related to Performance**

Level 2 provides independent verification for those materials which are secondary indicators of performance. An example is the slump test for hydraulic cement concrete. The QC testing frequency is required to be in compliance with TxDOT’s *Guide Schedule of Sampling and Testing* (16) and the OV testing frequency should be a minimum of once per quarter. Figure 4 provides a Level 2 analyses screen capture from the I2MS dashboard. Using this I2MS user interface, the TxDOT’s Materials Manager can monitor the status of verification for Level 2 analysis categories and record any action taken.

![Figure 4: Screen Capture Showing Example I2MS Independent Verification Dashboard](image-url)

TRB 2011 Annual Meeting  
Paper revised from original submittal.
The “details” button at the right of the screen allows TxDOT’s Materials Manager to record comments on the current analysis, view historical independent verification results and comments, view a plot of the QC and OV tests results against the date of each test, and view specific test identification information (sample date, tested by, material code, etc.) for each test in the analysis. Each independent verification analysis category will appear on the “current analysis” tab when the first QC test result in that category is approved for analysis. Each analysis category that appears on the “current analysis” tab will remain on that tab until a review of the QC and OV test results is performed and TxDOT’s Materials Manager determines if the QC test results are “verified” or “not verified” by the OV test results. TxDOT’s Materials Manager is responsible for addressing any analysis that results in a “not verified” status. When the analysis is addressed, it will be moved from the “current analyses” tab to the to the “historical analyses” tab.

Figure 5 shows a report that can be generated to graphically represent QC and OV data trends and show the comments recorded by TxDOT’s Materials Manager. This figure represents an example of the Level 2 report for the hydraulic cement slump of a concrete mix. The obscured comments showed how TxDOT’s Materials Manager comments that justified his decision that the OV test results verified the QC test results.

Level 2 validation is based on the application of engineering judgment to determine whether the QC and OV test results represent the same material.
Level 3 – Observation Verification of Low Frequency and Miscellaneous Tests

Level 3 provides observation verification for those materials which only require very few QC tests for compliance with TxDOT’s *Guide Schedule of Sampling and Testing* (14) or tests on materials whose risk of failure does not affect the long-term performance of the facility past the contractual maintenance obligations. An example is the acid insoluble test (Tex-612-J) for fine aggregate in hydraulic cement for concrete pavements which has a frequency of once per project per source. Another example is the entrained air test (Tex-416-A) for non-structural (miscellaneous) concrete riprap where risk of failure does not affect the long-term performance of the facility past the contractual maintenance obligations. Under the Level 3 approach, OV does not perform tests but observes the QC test performance for equipment and procedural compliance with the test procedure. The frequency of this testing is a minimum of once per project per test method or periodically as determined by TxDOT’s Materials Manager. For Level 3, the OV representative observing the QC technician performing the test enters his observation findings into I2MS for record keeping purposes.

![Screen Capture Showing Example I2MS Observation Verification Dashboard](image)

*Figure 6: Screen Capture Showing Example I2MS Observation Verification Dashboard*
Figure 6 is a screen capture from I2MS dashboard for Level 3 observations. Using this I2MS user interface, TxDOT’s Materials Manager can monitor record observations of the QC test performance. The “comment” button at the right of the screen allows TxDOT’s Materials Manager to record comments on the current observation. Each observation category will appear on the “current observation” tab when the first QC test result in that category is approved. Each analysis category on the “current observation” tab will remain on that tab until an observation is recorded. When the observation is recorded, it will be moved from the “current observation” tab to the “historical observation” tab.

Level 3 contains a similar report to that of Levels 1 and 2 but is not shown due to space limitations.

**APPLICABILITY TO TXDOT CONCESSION PROJECTS**

TxDOT’s design-build projects generally included a 15-year optional capital maintenance agreement. TxDOT’s concession (design-build-finance-operate-maintain) projects include 50 years of operations and maintenance (capital and routine). Since TxDOT’s residual risk is different for the two project delivery methods, a table containing default levels of analysis has been established for concession projects. The SH 130 Segments 5 and 6 quality assurance program contains an example of the concession levels of analysis (18). The significantly longer Developer maintenance responsibilities on concession projects greatly reduce TxDOT’s overall residual risk. As a result, some test methods are assigned higher default levels of analysis in the default concession table. A risk assessment workshop is conducted for each concession project to discuss and evaluate project-specific risks and opportunities associated with specific contract requirements, project funding sources, and project-specific materials issues. The default levels of analysis for a specific project are adjusted based on this risk assessment workshop.

**APPLICABILITY TO OTHER PROJECTS**

TxDOT’s quality assurance program approach was developed for projects greater than approximately $200 million which utilize contractor results in the acceptance decision. However many of the engineering procedures and software processes are applicable to smaller projects. Examples of such procedures and processes include clearly defining roles and responsibilities, tiered approach to validating QC test results, defined dispute resolution and reporting requirements, data entry and workflow with controlled vocabulary lists, technician qualification and its verification, searching and graphing data for review, and automated statistical calculations. These practices are part of an efficient validation approach that reduces errors and improves the accuracy of data and data analyses through automation.

While analysis parameters for the three-tiered verification approach have been established for larger projects, the principle of assigning resources to monitor and evaluate each analysis category based on the owner agency’s residual risk for failure of a particular element is universally applicable and provides for more efficiency in the validation process. For smaller projects with fewer or less frequent tests, the level of analysis (1, 2, or 3) for a given analysis category may have to be adjusted or the parameters by which the Level 1 analysis is performed may have to be adjusted based on project-specific conditions. These parameters can be reviewed and adjusted during a project-specific risk workshop.
SUMMARY AND CONCLUSIONS

The SH 130 and 183A projects were the first design-build highway infrastructure project in Texas where contractor QC testing was used in the acceptance decision for all project-produced materials. A project-specific quality assurance program that addresses the FHWA’s requirements was developed for each project and the projects were successfully completed. TxDOT built upon the lessons learned to develop a statewide quality assurance program for design-build projects which has been approved by FHWA for use on applicable projects around Texas.

An enhancement to the previous owner verification process is the development of a three-tiered approach. Level 1 is applied to the tests which are strong indicators of performance and provides the highest level of confidence in the contractor’s QC testing through the running of continuous F- and t-tests. Level 2 is applied to tests that are secondary indicators of performance through independent quarterly verification on the contractor’s QC testing. Level 3 is applied to tests with extremely low test frequencies where independent verification cannot be meaningfully performed or tests on materials whose risk of failure does not affect the long-term performance of the facility past the contractual maintenance obligations.

The three-tiered approach presented herein is a result of lessons learned on two completed design-build projects. As additional experience is gained from ongoing design-build and concession projects, TxDOT will continue to incorporate new lessons learned and refine the owner verification process.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Paul Bowen, Corwin Anderegg, Mike Watry and John Bellamy who worked diligently on the project. The authors are grateful for the collaboration with Jim Travis (FHWA), Darren Hazlett (TxDOT), and David Belser (TxDOT) as well as the constructive comments from Dr. Jim Burati.

REFERENCES