NCHRP RESEARCH REPORT 946: PROCEDURES AND GUIDELINES FOR VALIDATING CONTRACTOR TEST DATA

APPENDICES A–E

APPENDIX A. SURVEY OF STATE HIGHWAY AGENCIES

Introduction

Welcome to the NCHRP Project 10-100 Procedures and Guidelines for Validating Contractor Test Data survey.

If you have questions about the survey, please contact Adam Hand at (xxx) xxx-xxxx or by email at (xxxxxxxx@unr.edu).

Thank you for your participation in this study!

Please do NOT use your internet browser Back and Forward buttons during the survey. Please use the Back and Next button at the bottom of each survey page instead. If you used Back and Forward buttons on your browser by accident, please refresh the page by clicking the Refresh button on your browser to proceed with the survey.

Your Current Practice

*1. Please indicate which of the following statements best describes your current practice (Select one). **

- ○ The SHA uses Contractor test results as part of the acceptance decision for specific materials.
- ○ The SHA does not use Contractor test results as part of the acceptance decision for any material.

Page exit logic: Skip / Disqualify Logic IF: Question " 1. Please indicate which of the following statements best describes your current practice (Select one)." #2 is one of the following answers ("The SHA does not use Contractor test results as part of the acceptance decision for any material.") THEN: Show the following two questions and Jump to page 10 - Thank You! Flag response as complete**.**

2. Please indicate which of the following statements best describes your past and future use of Contractor test results as part of the acceptance decision (Select all that apply).

- ☐ The SHA has never used Contractor test results as part of the acceptance decision for any material.
- ☐ The SHA used Contractor test results as part of the acceptance decision for some materials in the past, but later dropped the program.
- ☐ The SHA has no plans in the future to use Contractor test results as part of the acceptance decision for any material.
- ☐ The SHA has future plans to use Contractor test results as part of the acceptance decision for material(s).

3. Who can the Research Team contact in your SHA for clarification or more information regarding the use of Contractor's test data in the acceptance decision?

Name: __________

Title: __________

Telephone: __________

Email: __________

Construction Material Tests

*1. Please indicate which of the following materials your SHA uses Contractor test data in a portion or all of the acceptance process. This includes test data on the finished product, such as smoothness (Select all that apply).**

- ☐ 1. Asphalt concrete mixture
- ☐ 2. Portland cement concrete mixture
- ☐ 3. Base or drainage aggregate
- ☐ 4. Subgrade or embankment soil
- ☐ 5. Reinforcing or structural steel
- ☐ 6. Other

Please specify "Other" in the text box below:

IF: Question " 1. Please indicate which of the following construction materials your SHA uses Contractor test data in the acceptance process..." Is one of the following answers ("Asphalt Concrete Mixture") **THEN:** Show the following questions**.**

Asphalt Concrete Mixture

1. What method does your SHA use to validate the Contractor's ***Asphalt Concrete Mixture*** *test data? (select best option) **

- 1. F and t test, independent samples
- 2. F and t test, split samples
- 3. Paired t-test, split samples
- 4. t-test, independent samples (analysis assumes similar variance in data sets)
- 5. average deviation (AD) or average absolute deviation (AAD)
- 6. Multi-laboratory precision value (acceptable deviation between test values)
- 7. Other

Please specify "Other" in the text box below:

2. What documents prescribe your SHA's current validation procedure for ***Asphalt Concrete Mixture****? (select all that apply) **

- 1. Standard Specification
- 2. Material/Construction Manual
- 3. Supplemental Specification or Special Provision

3. Please place a reference link(s) to the selected documents in the following text box.

4. Is your SHA willing to provide project level data (Contractor and SHA) used to validate Contractor test results for ***Asphalt Concrete Mixture*** *(Select one). **

- Yes

○ No

5. Does your SHA have any concerns with using AASHTO R 9: Acceptance Sampling Plans for Highway Construction and FHWA's 23 CFR 637B guidelines for validating Contractor's ***Asphalt Concrete Mixture*** *test data in the acceptance decision? (Select one) **

○ Yes

○ No

6. Does your SHA procedures for using Contractor's ***Asphalt Concrete Mixture*** *test data in the acceptance decision lead to project-level problems? (Select all that apply) **

☐ 1. No problems

☐ 2. Inadequate SHA staffing

☐ 3. Long test turn-around time

☐ 4. Availability of retesting procedures

☐ 5. Required amount of testing not conducted

☐ 6. Other

Please specify "Other" in the text box below:

7. When your SHA began to use or significantly changed how it uses Contractor's ***Asphalt Concrete Mixture*** *test data in the acceptance decision did it cause higher frequency of the following non-compliance actions? (Select all that apply) **

☐ 1. No change in frequency for non-compliance actions

☐ 2. Higher frequency of efforts to resolve test result differences between laboratories without dispute

☐ 3. Higher frequency of dispute

☐ 4. Higher frequency of work stoppages

☐ 5. Higher frequency of in-place material removal and replacement

☐ 6. Other

Please specify "Other" in the text box below:

8. Does your SHA anticipate changes in the use of Contractor's ***Asphalt Concrete Mixture*** *test data in the acceptance decision? (Give a brief description, the research team may contact you for more details).*

9. Who can the Research Team contact in your SHA for clarification or more information regarding the use of Contractor's Asphalt Concrete Mixture test data in the acceptance decision?

Name:

Title:

Telephone:

Email:

IF: Question " 1. Please indicate which of the following construction materials your SHA uses Contractor test data in the acceptance process..." Is one of the following answers ("Portland Cement Concrete Mixture") **THEN:** Show the following questions**.**

Portland Cement Concrete Mixture

1. What method does your SHA use to validate the Contractor's ***Portland Cement Concrete Mixture*** *test data? (select best option) **

- 1. F and t test, independent samples
- 2. F and t test, split samples
- 3. Paired t-test, split samples
- 4. t-test, independent samples (analysis assumes similar variance in data sets)
- 5. average deviation (AD) or average absolute deviation (AAD)
- 6. Multi-laboratory precision value (acceptable deviation between test values)
- 7. Other

Please specify "Other" in the text box below:

2. What documents prescribe your SHA's current validation procedure for ***Portland Cement Concrete Mixture****? (select all that apply) **

- 1. Standard Specification
- 2. Material/Construction Manual
- 3. Supplemental Specification or Special Provision

3. Please place a reference link(s) to the selected documents in the following text box.

4. Is your SHA willing to provide project level data (Contractor and SHA) used to validate Contractor test results for ***Portland Cement Concrete Mixture*** *(Select one). **

- Yes

○ No

5. Does your SHA have any concerns with using AASHTO R 9: Acceptance Sampling Plans for Highway Construction and FHWA's 23 CFR 637B guidelines for validating Contractor's ***Portland Cement Concrete Mixture*** *test data in the acceptance decision? (Select one) **

○ Yes

○ No

6. Does your SHA procedures for using Contractor's ***Portland Cement Concrete Mixture*** *test data in the acceptance decision lead to project-level problems? (Select all that apply) **

☐ 1. No problems

☐ 2. Inadequate SHA staffing

☐ 3. Long test turn-around time

☐ 4. Availability of retesting procedures

☐ 5. Required amount of testing not conducted

☐ 6. Other

Please specify "Other" in the text box below:

7. When your SHA began to use or significantly changed how it uses Contractor's ***Portland Cement Concrete Mixture*** *test data in the acceptance decision did it cause higher frequency of the following non-compliance actions? (Select all that apply) **

☐ 1. No change in frequency for non-compliance actions

☐ 2. Higher frequency of efforts to resolve test result differences between laboratories without dispute

☐ 3. Higher frequency of dispute

☐ 4. Higher frequency of work stoppages

☐ 5. Higher frequency of in-place material removal and replacement

☐ 6. Other

Please specify "Other" in the text box below:

8. Does your SHA anticipate changes in the use of Contractor's ***Portland cement concrete mixture*** *test data in the acceptance decision? (Give a brief description, the research team may contact you for more details).*

9. Who can the Research Team contact in your SHA for clarification or more information regarding the use of Contractor's Portland Cement Concrete Mixture test data in the acceptance decision?

Name:

Title:

Telephone:

Email:

IF: Question " 1. Please indicate which of the following construction materials your SHA uses Contractor test data in the acceptance process..." Is one of the following answers ("Base or drainage aggregate ") **THEN:** Show the following questions**.**

Base or drainage aggregate

1. What method does your SHA use to validate the Contractor's ***Base or drainage aggregate*** *test data? (select best option) **

- 1. F and t test, independent samples
- 2. F and t test, split samples
- 3. Paired t-test, split samples
- 4. t-test, independent samples (analysis assumes similar variance in data sets)
- 5. average deviation (AD) or average absolute deviation (AAD)
- 6. Multi-laboratory precision value (acceptable deviation between test values)
- 7. Other

Please specify "Other" in the text box below:

2. What documents prescribe your SHA's current validation procedure for ***Base or drainage aggregate****? (select all that apply) **

- 1. Standard Specification
- 2. Material/Construction Manual
- 3. Supplemental Specification or Special Provision

3. Please place a reference link(s) to the selected documents in the following text box.

4. Is your SHA willing to provide project level data (Contractor and SHA) used to validate Contractor test results for ***Base or drainage aggregate*** *(Select one). **

- Yes

○ No

5. Does your SHA have any concerns with using AASHTO R 9: Acceptance Sampling Plans for Highway Construction and FHWA's 23 CFR 637B guidelines for validating Contractor's ***Base or drainage aggregate*** *test data in the acceptance decision? (Select one) **

○ Yes

○ No

6. Does your SHA procedures for using Contractor's ***Base or drainage aggregate*** *test data in the acceptance decision lead to project-level problems? (Select all that apply) **

☐ 1. No problems

☐ 2. Inadequate SHA staffing

☐ 3. Long test turn-around time

☐ 4. Availability of retesting procedures

☐ 5. Required amount of testing not conducted

☐ 6. Other

Please specify "Other" in the text box below:

7. When your SHA began to use or significantly changed how it uses Contractor's ***Base or drainage aggregate*** *test data in the acceptance decision did it cause higher frequency of the following non-compliance actions? (Select all that apply) **

☐ 1. No change in frequency for non-compliance actions

☐ 2. Higher frequency of efforts to resolve test result differences between laboratories without dispute

☐ 3. Higher frequency of dispute

☐ 4. Higher frequency of work stoppages

☐ 5. Higher frequency of in-place material removal and replacement

☐ 6. Other

Please specify "Other" in the text box below:

8. Does your SHA anticipate changes in the use of Contractor's ***Base or drainage aggregate*** *test data in the acceptance decision? (Give a brief description, the research team may contact you for more details).*

9. Who can the Research Team contact in your SHA for clarification or more information regarding the use of Contractor's Base or drainage aggregate test data in the acceptance *decision?*

Name:

Title:

Telephone:

Email:

IF: Question " 1. Please indicate which of the following construction materials your SHA uses Contractor test data in the acceptance process..." Is one of the following answers ("Subgrade or embankment soil ") **THEN:** Show the following questions**.**

Subgrade or embankment soil

1. What method does your SHA use to validate the Contractor's ***Subgrade or embankment soil*** *test data? (select best option) **

- 1. F and t test, independent samples
- 2. F and t test, split samples
- 3. Paired t-test, split samples
- 4. t-test, independent samples (analysis assumes similar variance in data sets)
- 5. average deviation (AD) or average absolute deviation (AAD)
- 6. Multi-laboratory precision value (acceptable deviation between test values)
- 7. Other

Please specify "Other" in the text box below:

2. What documents prescribe your SHA's current validation procedure for ***Subgrade or embankment soil****? (select all that apply) **

- 1. Standard Specification
- 2. Material/Construction Manual
- 3. Supplemental Specification or Special Provision

3. Please place a reference link(s) to the selected documents in the following text box.

4. Is your SHA willing to provide project level data (Contractor and SHA) used to validate Contractor test results for ***Subgrade or embankment soil*** *(Select one). **

- Yes

○ No

5. Does your SHA have any concerns with using AASHTO R 9: Acceptance Sampling Plans for Highway Construction and FHWA's 23 CFR 637B guidelines for validating Contractor's ***Subgrade or embankment soil*** *test data in the acceptance decision? (Select one) **

○ Yes

○ No

6. Does your SHA procedures for using Contractor's ***Subgrade or embankment soil*** *test data in the acceptance decision lead to project-level problems? (Select all that apply) **

☐ 1. No problems

☐ 2. Inadequate SHA staffing

☐ 3. Long test turn-around time

☐ 4. Availability of retesting procedures

☐ 5. Required amount of testing not conducted

☐ 6. Other

Please specify "Other" in the text box below:

7. When your SHA began to use or significantly changed how it uses Contractor's ***Subgrade or embankment soil*** *test data in the acceptance decision did it cause higher frequency of the following non-compliance actions? (Select all that apply) **

☐ 1. No change in frequency for non-compliance actions

☐ 2. Higher frequency of efforts to resolve test result differences between laboratories without dispute

☐ 3. Higher frequency of dispute

☐ 4. Higher frequency of work stoppages

☐ 5. Higher frequency of in-place material removal and replacement

☐ 6. Other

Please specify "Other" in the text box below:

8. Does your SHA anticipate changes in the use of Contractor's **Subgrade or embankment soil** test data in the acceptance decision? (Give a brief description, the research team may contact you for more details).

9. Who can the Research Team contact in your SHA for clarification or more information regarding the use of Contractor's Subgrade or embankment soil test data in the acceptance decision?

Name:

Title:

Telephone:

Email:

IF: Question " 1. Please indicate which of the following construction materials your SHA uses Contractor test data in the acceptance process..." Is one of the following answers ("Reinforcing or structural steel ") **THEN:** Show the following questions**.**

Reinforcing or structural steel

1. What method does your SHA use to validate the Contractor's ***Reinforcing or structural steel*** *test data? (select best option) **

- 1. F and t test, independent samples
- 2. F and t test, split samples
- 3. Paired t-test, split samples
- 4. t-test, independent samples (analysis assumes similar variance in data sets)
- 5. average deviation (AD) or average absolute deviation (AAD)
- 6. Multi-laboratory precision value (acceptable deviation between test values)
- 7. Other

Please specify "Other" in the text box below:

2. What documents prescribe your SHA's current validation procedure for ***Reinforcing or structural steel****? (select all that apply) **

- 1. Standard Specification
- 2. Material/Construction Manual
- 3. Supplemental Specification or Special Provision

3. Please place a reference link(s) to the selected documents in the following text box.

4. Is your SHA willing to provide project level data (Contractor and SHA) used to validate Contractor test results for ***Reinforcing or structural steel*** *(Select one). **

- Yes

○ No

5. Does your SHA have any concerns with using AASHTO R 9: Acceptance Sampling Plans for Highway Construction and FHWA's 23 CFR 637B guidelines for validating Contractor's ***Reinforcing or structural steel*** *test data in the acceptance decision? (Select one) **

○ Yes

○ No

6. Does your SHA procedures for using Contractor's ***Reinforcing or structural steel*** *test data in the acceptance decision lead to project-level problems? (Select all that apply) **

☐ 1. No problems

☐ 2. Inadequate SHA staffing

☐ 3. Long test turn-around time

☐ 4. Availability of retesting procedures

☐ 5. Required amount of testing not conducted

☐ 6. Other

Please specify "Other" in the text box below:

7. When your SHA began to use or significantly changed how it uses Contractor's ***Reinforcing or structural steel*** *test data in the acceptance decision did it cause higher frequency of the following non-compliance actions? (Select all that apply) **

☐ 1. No change in frequency for non-compliance actions

☐ 2. Higher frequency of efforts to resolve test result differences between laboratories without dispute

☐ 3. Higher frequency of dispute

☐ 4. Higher frequency of work stoppages

☐ 5. Higher frequency of in-place material removal and replacement

☐ 6. Other

Please specify "Other" in the text box below:

8. Does your SHA anticipate changes in the use of Contractor's ***Reinforcing or structural steel*** *test data in the acceptance decision? (Give a brief description, the research team may contact you for more details).*

9. Who can the Research Team contact in your SHA for clarification or more information regarding the use of Contractor's Reinforcing or structural steel *test data in the acceptance decision?*

Name:

Title:

Telephone:

Email:

IF: Question " 1. Please indicate which of the following construction materials your SHA uses Contractor test data in the acceptance process..." Is one of the following answers ("Other Material(s): [other material name]") **THEN:** Show the following questions**.**

Other Material(s): [other material name]

1. What method does your SHA use to validate the Contractor's ***[other material name]*** *test data? (select best option) **

- 1. F and t test, independent samples
- 2. F and t test, split samples
- 3. Paired t-test, split samples
- 4. t-test, independent samples (analysis assumes similar variance in data sets)
- 5. average deviation (AD) or average absolute deviation (AAD)
- 6. Multi-laboratory precision value (acceptable deviation between test values)
- 7. Other

Please specify "Other" in the text box below:

2. What documents prescribe your SHA's current validation procedure for ***[other material name]****? (select all that apply) **

- 1. Standard Specification
- 2. Material/Construction Manual
- 3. Supplemental Specification or Special Provision

3. Please place a reference link(s) to the selected documents in the following text box.

4. Is your SHA willing to provide project level data (Contractor and SHA) used to validate Contractor test results for ***[other material name]*** *(Select one). **

- Yes

No

5. Does your SHA have any concerns with using AASHTO R 9: Acceptance Sampling Plans for Highway Construction and FHWA's 23 CFR 637B guidelines for validating Contractor's ***[other material name]*** *test data in the acceptance decision? (Select one) **

Yes

No

6. Does your SHA procedures for using Contractor's ***[other material name]*** *test data in the acceptance decision lead to project-level problems? (Select all that apply) **

1. No problems

2. Inadequate SHA staffing

3. Long test turn-around time

4. Availability of retesting procedures

5. Required amount of testing not conducted

6. Other

Please specify "Other" in the text box below:

7. When your SHA began to use or significantly changed how it uses Contractor's **[***other material name***]** *test data in the acceptance decision did it cause higher frequency of the following non-compliance actions? (Select all that apply) **

☐ 1. No change in frequency for non-compliance actions

☐ 2. Higher frequency of efforts to resolve test result differences between laboratories without dispute

☐ 3. Higher frequency of dispute

☐ 4. Higher frequency of work stoppages

☐ 5. Higher frequency of in-place material removal and replacement

☐ 6. Other

Please specify "Other" in the text box below:

8. Does your SHA anticipate changes in the use of Contractor's **[other material name]** *test data in the acceptance decision? (Give a brief description, the research team may contact you for more details).*

9. Who can the Research Team contact in your SHA for clarification or more information regarding the use of Contractor's **[***other material name***]** *test data in the acceptance decision?*

Name:

Title:

Telephone:

Email:

Thank You!

Thank you for taking our survey. Your response is very important to our industry.

APPENDIX B. RESULTS OF THE SHAS SURVEY

Twenty-nine SHAs completed the survey, with 79 percent (22 of the 28 SHAs) responding that they use Contractor test results as part of the acceptance procedure. Summary of the overall results and the asphalt concrete mixture results were presented in **Error! Reference source not found.**. In the following sections, details of the survey responses for other materials are presented.

B.1. Portland Cement Concrete Mixture

Eleven of the 14 SHAs that responded they use Contractor test results for acceptance of PCC mixture provided further detail about their process, Table B.1 summarizes the methods used in validating Contractor's PCC test results reported by SHAs, and Figure B.1 illustrates the same.

Table B.1. SHA Survey response to methods used to validate the Contractor test results for Portland Cement Concrete Mixture

–	What method does your SHA use to validate the Contractor's Portland Cement Concrete Mixture test data?	No. of Responses	%
1	*F*- and *t*-tests, independent samples	3	27.3
2	*F*- and *t*-tests, split samples	–	–
3	Paired *t*-test, split samples	–	–
4	*t*-test, independent samples (analysis assumes similar variance in data sets)	–	–
5	average deviation (AD) or average absolute deviation (AAD)	2	18.2
6	Multi-laboratory precision value (acceptable deviation between test values)	3	27.3
7	Other	3	27.3

–No data

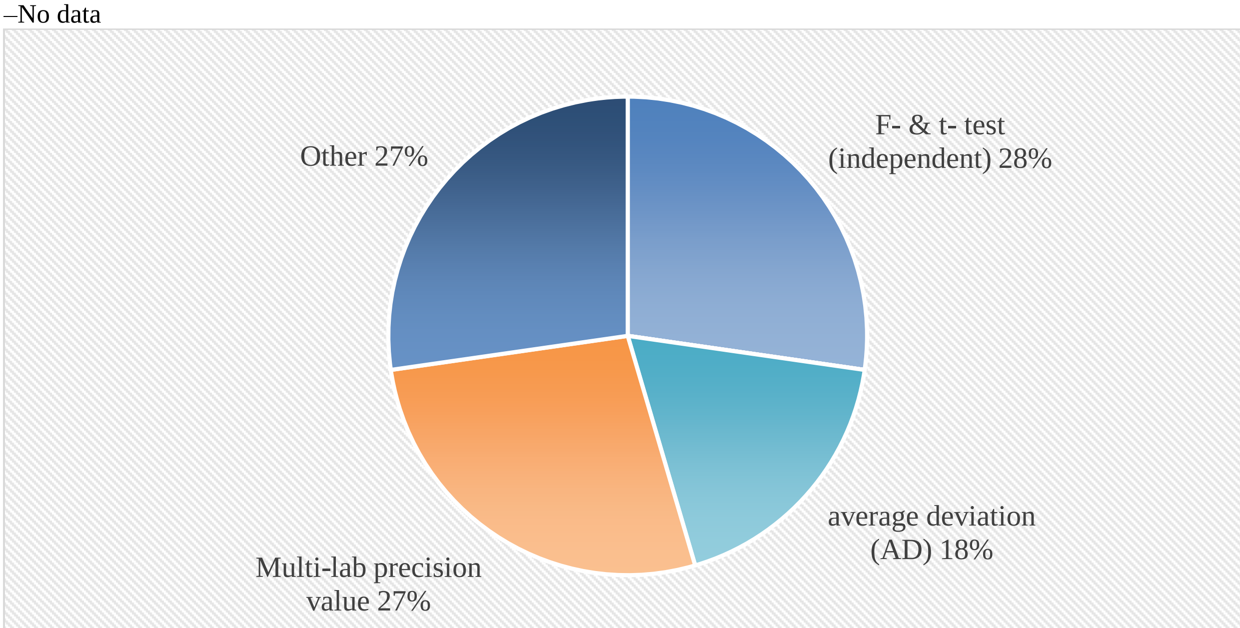

Figure B.1. SHA Responses on Acceptance Process for Portland Cement Concrete Mixture – November 2017.

Some of the SHAs responding they use another process include variations on the process listed above. The list of other processes is:

- Independent Assurance Parameters to Verify split samples.
- F and t independent samples for Design-Build projects. Operational tolerances on Design-Bid-Build projects.
- A tiered system based on statistical analysis of strength tests. Moving average with Department verification tests and split sample comparison tests.

The provisions for using Contractor test results are covered in standard specifications, material/construction manuals, and/or supplemental specifications. A majority of the SHAs responded the process is described in multiple documents.

Ten SHAs responded they had no concerns with their process and one SHA responded they did have concerns. Seven SHAs had no problems, three SHAs responded having a problem with adequate staffing, two SHAs have problems with retesting, one SHA has a problem with material not tested, and one SHA express other problems. The other issues are:

- Laboratory alignment.

The survey asked if the construction process was changed by the use of Contractor test results. The SHA responses are:

- 6 - no change.
- 4 - more time to resolve test differences.
- 1 - more disputes.
- 1 - more work stoppages.

Six SHAs responded they have no planned changes to their process and two SHAs do plan changes as listed below:

- We currently use compressive strength and thickness for pay factors. This will be expanded to included permeability, SAM number, and air content.
- Looking at different testing. May move to a performance related spec that includes pay factors. The SHA needs to move to a system that puts more weight on the QV test.

B.2. Base and Drainage Aggregate

Seven of the nine SHAs that responded they use Contractor test results for acceptance of base and drainage aggregate provided further detail about their process. Table B.2 summarizes the methods used in validating Contractor's base and drainage aggregate test results reported by SHAs, and Figure B.2 illustrates the same.

Table B.2. SHA Survey response to methods used to validate the Contractor test results for Base and Drainage Aggregate

–	What method does your SHA use to validate the Contractor's Base and Drainage Aggregate test data?	No. of Responses	%
1	*F*- and *t*-tests, independent samples	1	14.3
2	*F*- and *t*-test, split samples	–	–
3	Paired *t*-test, split samples	–	–
4	*t*-test, independent samples (analysis assumes similar variance in data sets)	–	–
5	average deviation (AD) or average absolute deviation (AAD)	1	14.3
6	Multi-laboratory precision value (acceptable deviation between test values)	2	28.6
7	Other	3	42.9

–No data

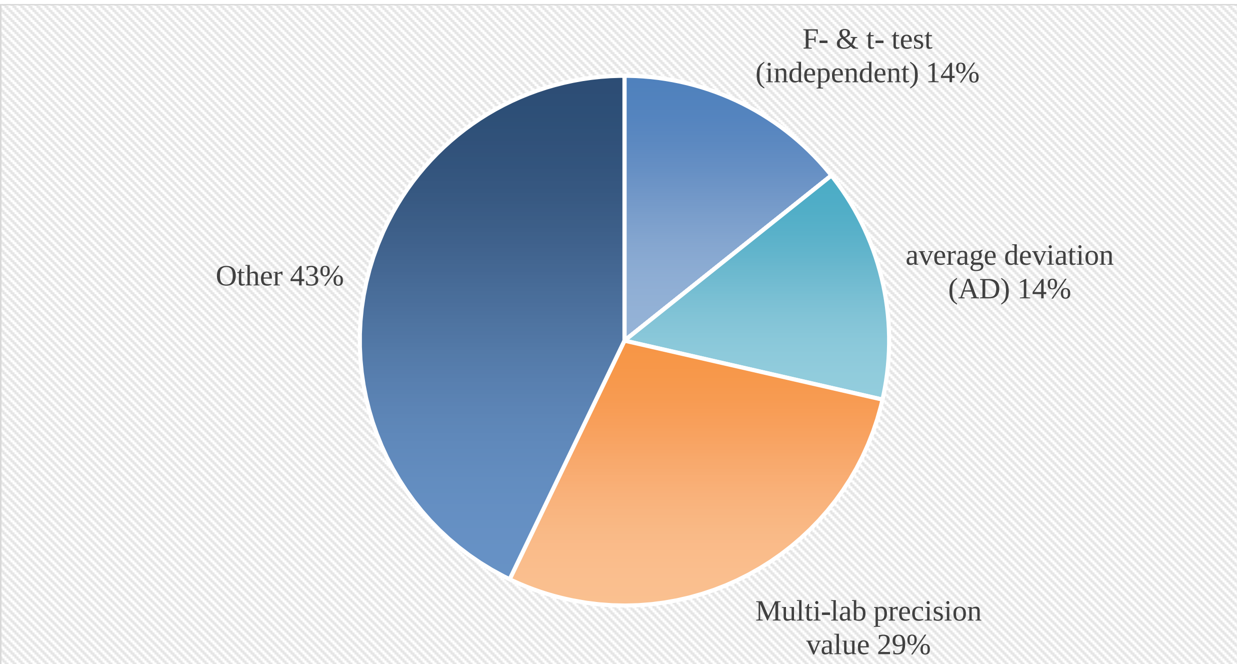

Figure B.2. SHA Responses on Acceptance Process for Base and Drainage Aggregate – November 2017.

Some of the SHAs responding they use another process include variations on the process listed above. The list of other processes is:

- Independent Assurance Parameters between QC and Verification split samples.
- *F*- and *t*- test for both independent and split samples.
- Direct comparison of the QC and Verification data.

The provisions for using Contractor test results are covered in standard specifications, material/construction manuals, and/or supplemental specifications. A majority of the SHAs responded the process is described in multiple documents.

Six SHAs responded they had no concerns with their process and one SHA responded they did have concerns. Four SHAs had no problems; one SHA responded having a problem with adequate staffing. Two SHAs had a problem with time to complete the testing; two SHAs had problems with retesting; one SHA had problems with not getting test results, and one SHA express other problems. The other issues are:

- Testing of material in stockpiles may not be representative of material that is place on project

The survey asked if the construction process was changed by the use of Contractor test results. The SHA responses are:

- 3 no change.
- 1 more time to resolve test differences.
- 1 more disputes.
- 1 more remove and replace.
- 2 other.

Two SHAs responded with other issues as listed below:

- Difficult to track. Non-compliance issues handled on job. Issues not tracked.
- Does not apply to their process.

One SHA responded they have no planned changes to their process and no SHAs plan changes.

B.3. Subgrade and Embankment

Six of the nine SHAs that responded they use Contractor test results for acceptance of subgrade and embankment provided further detail about their process. Table B.3 summarizes the methods used in validating Contractor's asphalt concrete test results reported by SHAs, and Figure B.3 illustrates the same.

Table B.3. SHA Survey response to methods used to validate the Contractor test results for Subgrade and Embankment

–	What method does your SHA use to validate the Contractor's Subgrade and Embankment test data?	No. of Responses	%
1	*F*- and *t*-tests, independent samples	1	16.7
2	*F*- and *t*-tests, split samples	–	–
3	Paired *t*-test, split samples	–	–
4	*t*-test, independent samples (analysis assumes similar variance in data sets)	–	–
5	average deviation (AD) or average absolute deviation (AAD)	1	16.7
6	Multi-laboratory precision value (acceptable deviation between test values)	1	16.7
7	Other	3	50.0

–No data

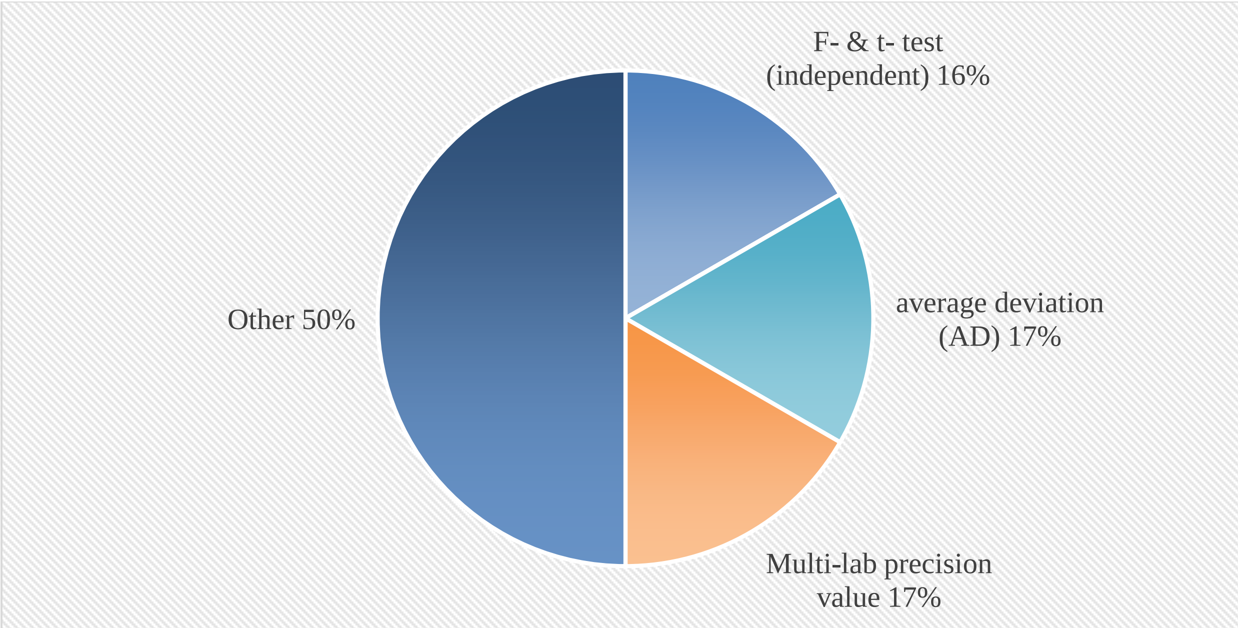

Figure B.3. SHA Responses on Acceptance Process for Subgrade and Embankment – November 2017.

Some of the SHAs responding they use another process include variations on the process listed above. The list of other processes is:

- Independent Assurance Parameters on QC and Verification split samples.
- No testing of subgrades.
- Direct Comparison of QC and Verification data.

The provisions for using Contractor test results are covered in standard specifications, material/construction manuals, and/or supplemental specifications. Some of the SHAs responded the process is described in multiple documents.

Three SHAs responded they had no concerns with their process and three SHAs responded they did have concerns. Four SHAs had no problems; One SHA responded having a problem with adequate staffing; one SHA has a problem with time to complete the testing; one SHA has problems with getting test performed, and one SHA express other problems. The other issues are:

- Test results from one location may not be representative of all of the material placed

The survey asked if the construction process was changed by the use of Contractor test results. The SHA responses are:

- 5 no change
- 1 other

One SHA responded with other issues as listed below:

- Difficult to track. Non-compliance issues handled on job. Issues not tracked.

Three SHAs responded they have no planned changes to their process and one SHA does plan changes as listed below:

- Would like to see some improvements in earthwork specs.

B.4. Reinforcing and Structural Steel

One of the four SHAs that responded they use Contractor test results for acceptance of reinforcing and structural steel provided further detail about their process indicating other process. The SHA responding they use another process is listed below.

- Verification of testing by witnessing and small sample tests

The provisions for using Contractor test results were not given.
The SHA responded they had no concerns with their process and responded having a problem with adequate staffing.
The survey asked if the construction process was changed by the use of Contractor test results. The SHA responses are:

- 1 more time to resolve test differences.
- 1 more disputes.
- 1 more work stoppages.

The SHA responded they have no planned changes to their process.

B.5. Other Materials

The survey asked the SHAs to list other materials not covered by the previous categories. Four SHAs responded with the following materials or construction items:

- Pavement smoothness.
- Asphalt compaction.
- Cement treated base.
- Design-Build projects will allow Contractor based acceptance on all materials.

No critical material categories appeared from this list. No details for each item are given.

B.6. Survey Observations

The responses to this survey lead to the following observations:

- Asphalt concrete mixture is the most common highway construction material that the SHAs use Contractor test results as part of the acceptance process.
- Portland cement concrete, base aggregate, and subgrade are the next most common materials that use Contractor test results.
- There is no dominant method used to validate the Contractor test results. *F*- and *t*-tests, average deviation, and multiple laboratory difference (or a variation on these methods) were all commonly used.
- A majority of SHAs have no concerns about their validation process and identified no problems with their current process. A common problem for some SHAs was having adequate staffing to perform the validation.

A majority of SHAs had no change in their sampling and testing program due to the use of Contractor test results as part of their acceptance program.

APPENDIX C. NUMERICAL SIMULATIONS

As discussed in **Error! Reference source not found.** “**Error! Reference source not found.**,” the primary purpose of “**Error! Reference source not found.**” was to inform the process of identifying validation procedures worthy of consideration as recommended practice. The list of the procedures (or tests) identified is presented in Table C.1. A shortlist of tests was developed categorizing tests based on function. Table C.2 summarizes the shortlisted hypothesis tests, Table C.3 the shortlisted analysis of variance tests, and Table C.4 the shortlisted normality tests.

Table C.1. Procedures (tests) Identified during “Error! Reference source not found.**”**

Test	Also Known As	Comments
D2S limits	–	1 on 1 comparison (tests method variability only)
$\bar{X} \pm CR$	–	Low power range test
equal variance *t*-test	Student's *t*-test	mean comparison
unequal variance *t*-test	Welch's, Satterthwaite's	mean comparison
paired *t*-test	–	mean comparison
Ansari-Bradley test	–	non-parametric
Mann-Whitney	Wilcoxon test, Mann–Whitney U, (MWW)	non-parametric
Fligner-Killeen test	–	non-parametric
F-test	–	variance comparison
Levene’s test	–	variance comparison
Bartlett's test	–	variance comparison
Friedman's test	–	variance comparison
Kruskal-Wallis test	–	variance comparison
Kolmogorov-Smirnov test	–	mean comparison
Anderson-Darling test	–	Normality
Shapiro-Wilk test	–	Normality
Permutation test	–	randomization
bootstrap-based test	–	randomization

–No data

Table C.2. Tests recommended for further evaluation – Hypothesis Testing

Test	Compares	Abbreviation
equal variance *t*-test “Student *t*-test”	mean	t-test
unequal variance *t*-test “Welch's *t*-test”	mean	UV-t-test
paired *t*-test	mean	p-t-test
Mann-Whitney	median	U-test
Kolmogorov-Smirnov two sample test	distribution	ks-test

Table C.3. Tests recommended for further evaluation – Analysis of Variance

Test	Compares	Abbreviation
F-test	variance	f-test
Ansari-Bradley test	variance	Ansari-Bradley
Levene’s test	variance	Levene
Modified Levene’s test	variance	Modified Levene
Bartlett's test	variance	Bartlett

Table C.4. Tests recommended for further evaluation – Normality Test

Test	Type
Anderson-Darling test	Normality
Shapiro-Wilk test	Normality
Lilliefors test “Kolmogorov-Smirnov normality test”	Normality

Normal Distribution data sets

The process used in evaluating the tests was discussed in Section **Error! Reference source not found.** and is illustrated in Figure C.1. The “success rate” of each test was then evaluated by calculating the ratio of the number of hypothesis test results with a value of 0 “Pass” to the total number of iterations:

$$\text{Success Rate (\%)}=\frac{N_{H_0}}{N_T}\times 100$$

Where N_{H_0} is the number of hypothesis test results with a value of 0 and N_T is the total number of iterations.

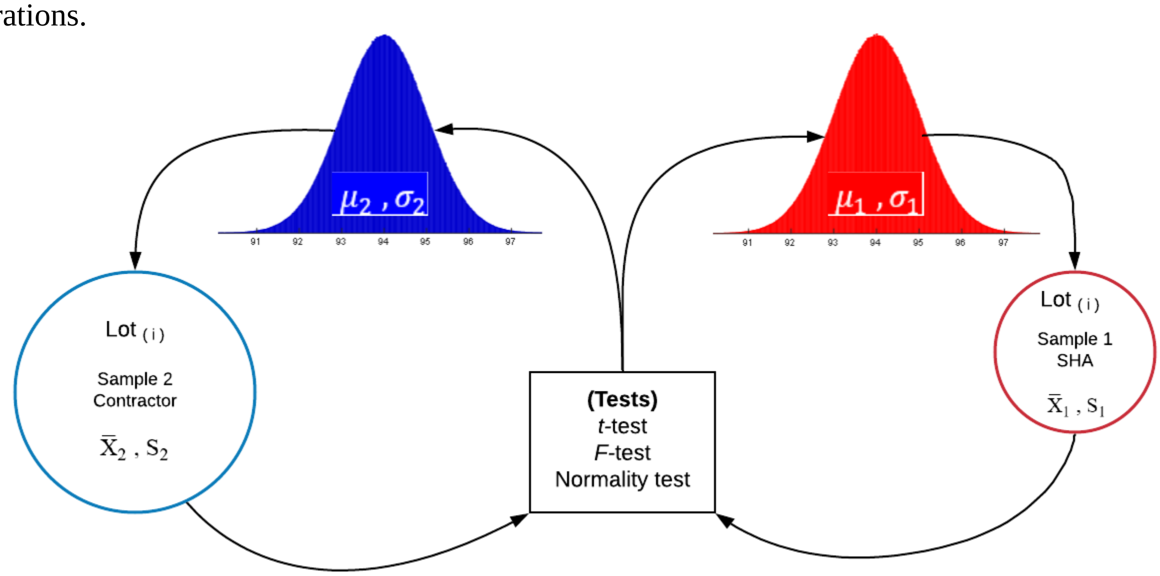

Figure C.1. Numerical Simulations Flow Chart, Normal Distribution.

For each AQC, four different scenarios of distributions were examined using this iterative process. Figure C.2 shows an illustration of the four scenarios considered for in-place density when μ_1 was 94.0 percent and σ_1 was 1.0 percent, as an example. In the first scenario, the mean of the SHA distribution, μ_1, and standard deviation, σ_1, were equal to the mean of the Contractor distribution, μ_2, and standard deviation, σ_2 ($\mu_1 = \mu_2$ and $\sigma_1 = \sigma_2$). The two distributions appear on top of each other in Figure C.2. In this case, the *t*-test hypothesis test result is expected to be zero since the means of the two samples were equal ($\bar{X}_1 = \bar{X}_2$ and $S_1 = S_2$). The other three scenarios considered are also illustrated in Figure C.2. In the second scenario, the mean of the SHA distribution, μ_1, was equal to the mean of the Contractor distribution, μ_2, but the standard deviations were not equal ($\mu_1 = \mu_2$ and $\sigma_1 \neq \sigma_2$). In the third scenario, the mean of the SHA distribution, μ_1, was not equal to the mean of the Contractor distribution, μ_2, but the standard deviations were equal ($\mu_1 \neq \mu_2$ and $\sigma_1 = \sigma_2$). In the fourth scenario, the mean of the SHA distribution, μ_1, and standard deviation, σ_1, were not equal to the mean of the Contractor distribution, μ_2, and standard deviation, σ_2 ($\mu_1 \neq \mu_2$ and $\sigma_1 \neq \sigma_2$).

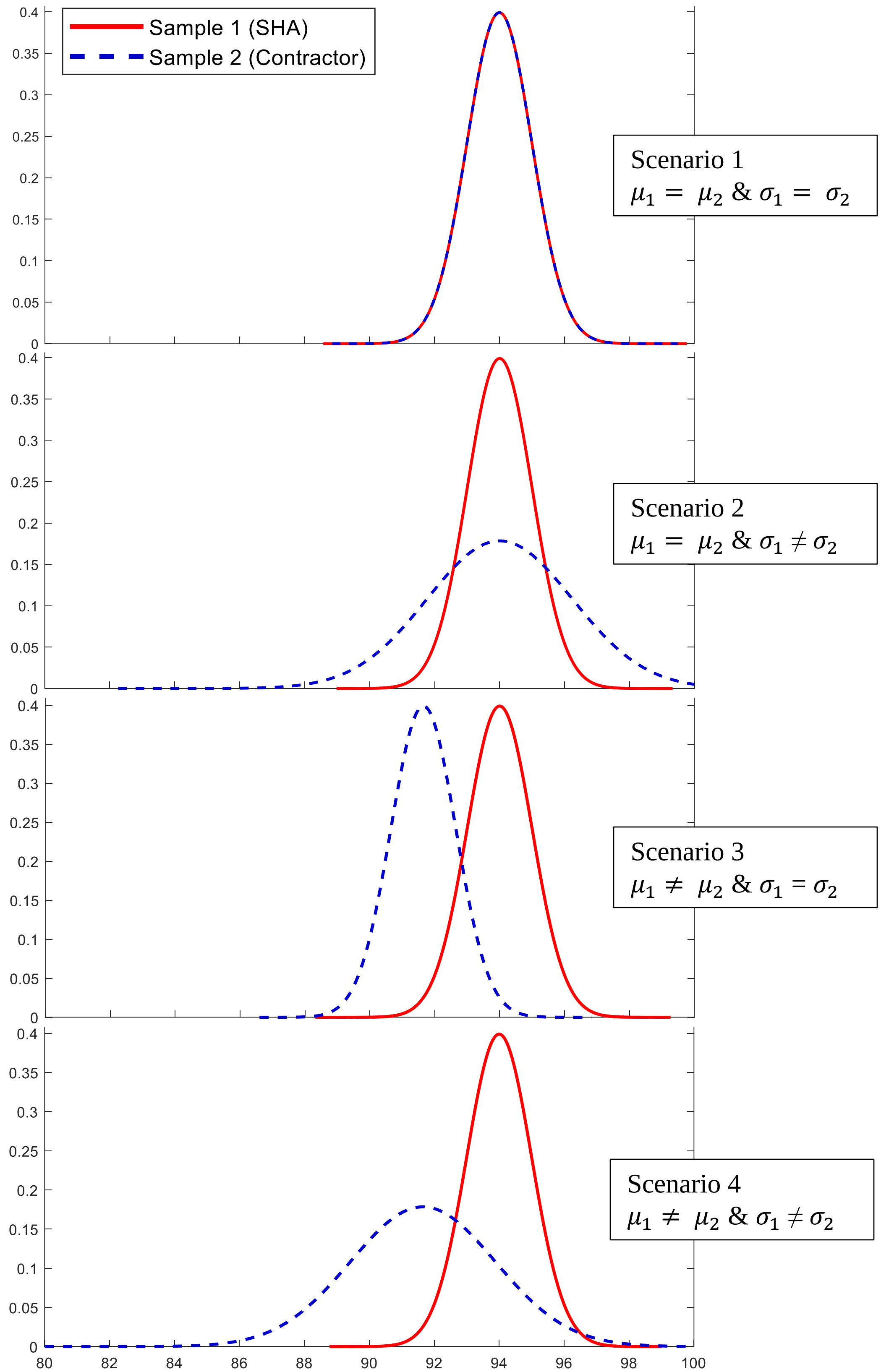
Sample 1 (SHA)
Sample 2 (Contractor)
Scenario 1
$\mu_1 = \mu_2$ & $\sigma_1 = \sigma_2$
Scenario 2
$\mu_1 = \mu_2$ & $\sigma_1 \neq \sigma_2$
Scenario 3
$\mu_1 \neq \mu_2$ & $\sigma_1 = \sigma_2$
Scenario 4
$\mu_1 \neq \mu_2$ & $\sigma_1 \neq \sigma_2$
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
80
82
84
86
88
90
92
94
96
98
100

Figure C.2. Numerical Simulations Distribution Scenarios for In-Place Density.

MATLAB codes were developed to run the iterative process and the output data was exported in MS Excel spreadsheets for further analysis. The advantage of using MATLAB in the iterative process was the ready to use functions available in MATLAB library with detailed documentation on function application. The following are some examples of the ready to use MATLAB functions:

- The MATLAB function `normrnd` generates random numbers following a normal distribution, with a known mean, a known standard deviation, and a known number of samples.
- The MATLAB `ttest2` function was used to perform the equal variance two-sample *t*-test. The function compares SHA (sample 1) and Contractor (sample 2) data returning a test decision for H_o that the SHA (sample 1) and Contractor (sample 2) data come from independent random samples from normal distributions with equal means and equal but unknown variances, using the two-sample *t*-test. H_a is that the SHA (sample 1) and Contractor (sample 2) data come from populations with unequal means. The hypothesis result is 1 if the test rejects H_o at the selected α, and 0 otherwise.
- The two-sample Kolmogorov-Smirnov test was performed using the MATLAB `kstest2` function. The function compares SHA (sample 1) and Contractor (sample 2) data and returns a test decision for H_o that the data in SHA (sample 1) and Contractor (sample 2) come from the same continuous distribution, using the two-sample Kolmogorov-Smirnov test. H_a is that the SHA (sample 1) and Contractor (sample 2) data come from different continuous distributions. The hypothesis result is 1 if the test rejects H_o at the selected α, and 0 otherwise.

The MATLAB codes developed to run the iterative process and the output spreadsheets are all provided as a complementary part of this research report in a form of electronic database.

Non-Parametric, Skewed distributions

For the skewed datasets a similar process to the one explained in Section **Error! Reference source not found.** "**Error! Reference source not found.**" and Section 0 was used. However, the first challenge was generating a realistic skewed distribution for construction materials AQCs. When typical skewed distribution types were used, such as Gamma and Beta distributions, unrealistic ranges were observed for typical construction materials AQCs. Using in-place density as an example with a mean of 94.0 percent, a Gamma distribution results in a range of values from 40 to 160 as illustrated in Figure C.3. Therefore, a different technique was used to develop more realistic skewed distributions for construction materials AQCs.

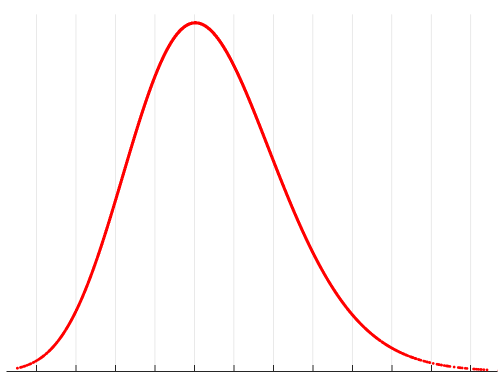

Figure C.3. Generating Skewed Distribution Using Gamma Function.

To generate a skewed distribution with a controlled mean and a reasonable range two normal distributions were combined to form a skewed distribution. Figure C.4 illustrates the process used in generating skewed distributions. The first step in the process was generating a normal distribution with a known mean, μ_1, and a known standard deviation, σ_1, illustrated by the gray dotted line in Figure C.4 (normal distribution 1). The next step was generating a second normal distribution with a known mean, μ_2, and a known standard deviation, σ_2, where

$$\mu_2 = \mu_1 - \sigma_1 \quad and \quad \sigma_2 = \frac{\sigma_1}{2}$$

The second normal distribution is illustrated by a gray dashed line in Figure C.4. The combined distributions result in a right skewed distribution illustrated by a solid red line in Figure C.4. In this example, μ_1 = 94.0 and σ_1 = 1.0, hence μ_2 = 93.0 and σ_2 = 0.5. This skewed distribution represents the SHA sample (sample 1).

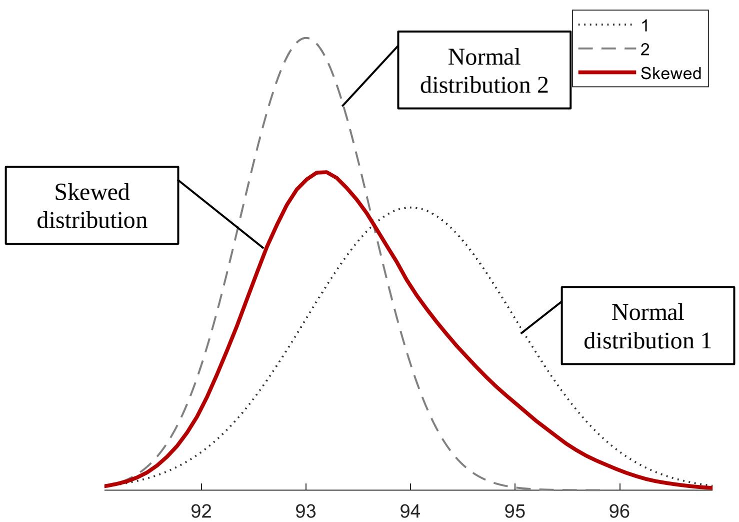

Figure C.4. Generating Skewed Distribution.

The same steps were followed to generate a second skewed distribution representing the Contractor sample (sample 2). The distribution is illustrated by the red skewed distribution to the left half of Figure C.5, while the SHA sample (sample 1) is illustrated by a blue skewed distribution to the right half of Figure C.5. The same iterative process explained in Section **Error! Reference source not found.** titled “**Error! Reference source not found.**” was used to evaluate the success rate of the tests listed in Table C.2 through Table C.4.

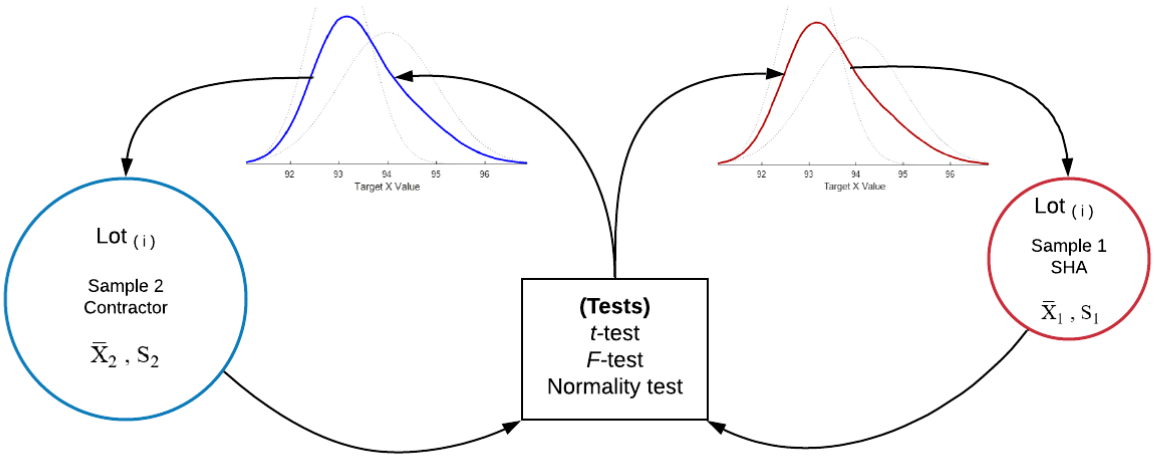

Figure C.5. Numerical Simulations Flow Chart, Skewed Distribution.

Non-Parametric, Bimodal distributions

For the bimodal datasets a similar evaluation process to the one explained under Section **Error! Reference source not found.** "**Error! Reference source not found.**" was used. No readily available function for a bimodal distribution was found to generate distributions with realistic ranges observed for typical construction materials AQCs. To generate bimodal distributions with ranges representative of typical construction materials AQCs, a technique analogous to that followed to generate the skewed distributions was used. Two normal distributions were generated and combined to form a bimodal distribution. Figure C.6 illustrates the process of generating a bimodal distribution. The first step in the process was generating a normal distribution with a known mean, μ_1, and a known standard deviation, σ_1, illustrated by the gray dotted line in Figure C.6. The next step was generating a second
normal distribution with a known mean, μ_2, and a known standard deviation, σ_2, where

$$\mu_2 = \mu_1 - 3 \times \sigma_1 \quad and \quad \sigma_2 = 0.8 \times \sigma_1$$

The second normal distribution is illustrated by a gray dashed line in Figure C.6. The combined distributions result in a right skewed distribution illustrated by a blue line in Figure C.6. In this example μ_1 = 94.0 and σ_1 = 0.5, hence μ_2 = 92.5 and σ_2 = 0.4. This bimodal distribution represents the SHA sample (sample 1).

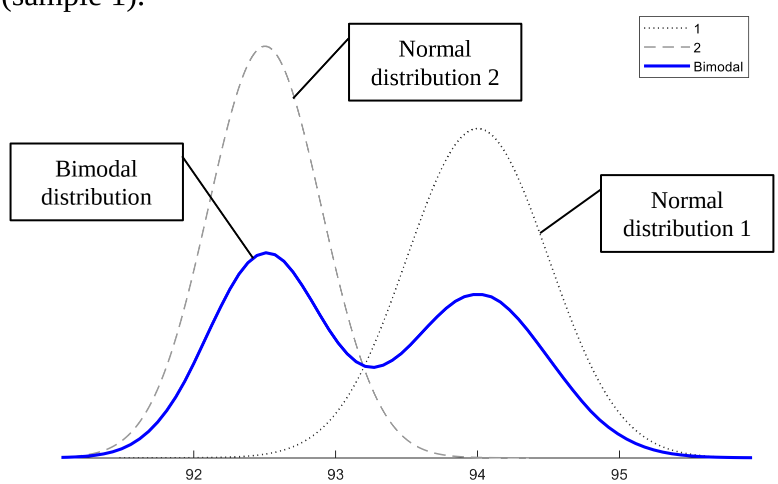

Figure C.6. Generating Bimodal Distribution.

The SHA sample (sample 1) is also illustrated by a blue bimodal distribution to the right half of Figure C.7. Similar steps were followed to generate a second bimodal distribution representing the Contractor sample (sample 2). This distribution is illustrated by the red bimodal distribution to the left half of Figure C.7. The same iterative process explained in Section **Error! Reference source not found.** titled "**Error! Reference source not found.**" was used to evaluate the success rate of the tests listed in Table C.2 through Table C.4.

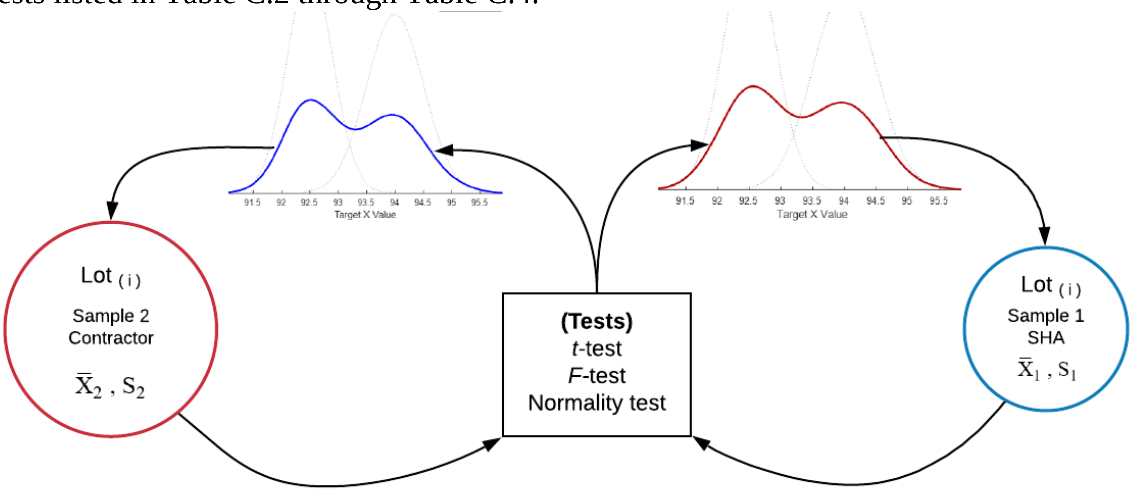

Figure C.7. Numerical Simulations Flow Chart, Bimodal Distribution.

Numerical Simulations Findings

The statistical tests presented in Section **Error! Reference source not found.** were evaluated using numerical simulations to quantify risks and qualify acceptable tests. Multiple distribution types and construction material AQCs were considered, as summarized in **Error! Reference source not found.** and **Error! Reference source not found.** of **Error! Reference source not found.**. The results of the numerical simulations follow organized by data distribution type.

Normal Distribution results

For each AQC, four different scenarios of distributions were examined using this iterative process. Figure C.2 shows an illustration of the four scenarios considered:

- Scenario 1, SHA distribution mean, μ_1, and standard deviation, σ_1, equal Contractor distribution mean, μ_2, and standard deviation, σ_2 ($\mu_1 = \mu_2$ and $\sigma_1 = \sigma_2$).
- Scenario 2, SHA distribution mean, μ_1, equal Contractor distribution mean, μ_2, but the standard deviations were not equal ($\mu_1 = \mu_2$ and $\sigma_1 \neq \sigma_2$).
- Scenario 3, SHA distribution mean, μ_1, was not equal to Contractor distribution mean, μ_2, but the standard deviations were equal ($\mu_1 \neq \mu_2$ and $\sigma_1 = \sigma_2$).
- Scenario 4, SHA distribution mean, μ_1, and standard deviation, σ_1, were not equal to Contractor distribution mean, μ_2, and standard deviation, σ_2 ($\mu_1 \neq \mu_2$ and $\sigma_1 \neq \sigma_2$).

Hypothesis Tests

Figure C.8 shows the numerical simulation results for a set of hypothesis tests under scenario 1. The success rate of the different tests is shown on the y-axis as a function of SHA sample CV1. Since the representative values of AQCs selected had a wide range of target means and standard deviations, the CV, the ratio of the standard deviation to the mean, was the most suitable parameter to compare the test results. **Error! Reference source not found.** of **Error! Reference source not found.** shows the AQCs selected and the corresponding CV values. Under scenario 1, the tests are expected to perform at a success rate of 95 percent or above, which is represented by the horizontal dotted line in Figure C.8. The values presented in Figure C.8 are for the SHA sample size of 7, while the Contractor sample size varied from sample size of 7 (equal sample size) up to sample size of 70 (SHA sample size × 10). The Contractor sample sizes considered were 7, 14, 21, 28, 35, 42, 49, 56, 63, and 70. The hypothesis tests in this case performed at the expected threshold of 95 percent. Figure C.9 shows similar results for scenario 2 where the sample means were equal while the standard deviations were unequal ($\mu_1 = \mu_2$ and $\sigma_1 \neq \sigma_2$).

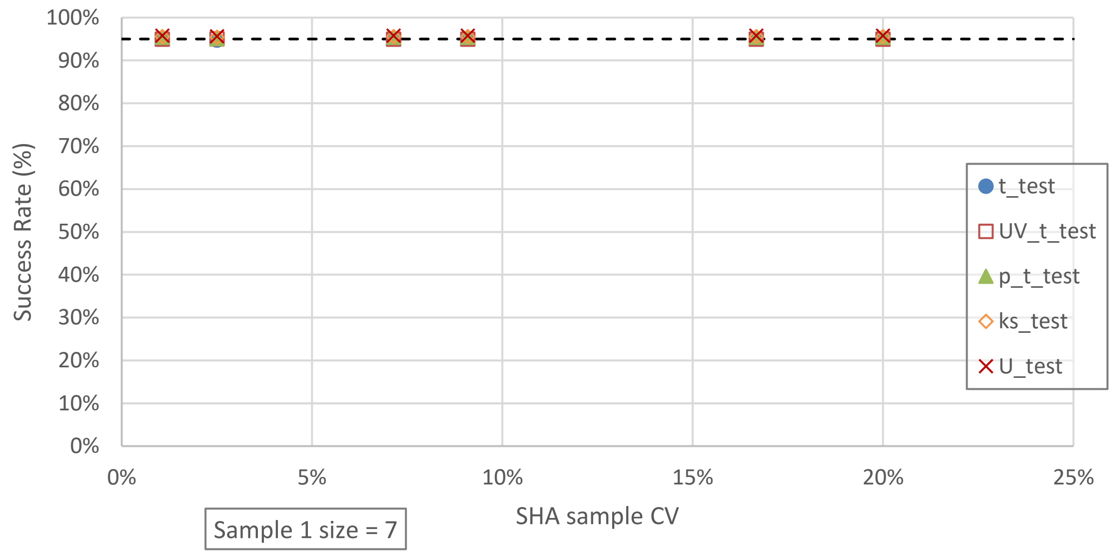

Figure C.8. Numerical Simulations Results – Equal Means and Equal Standard Deviations.

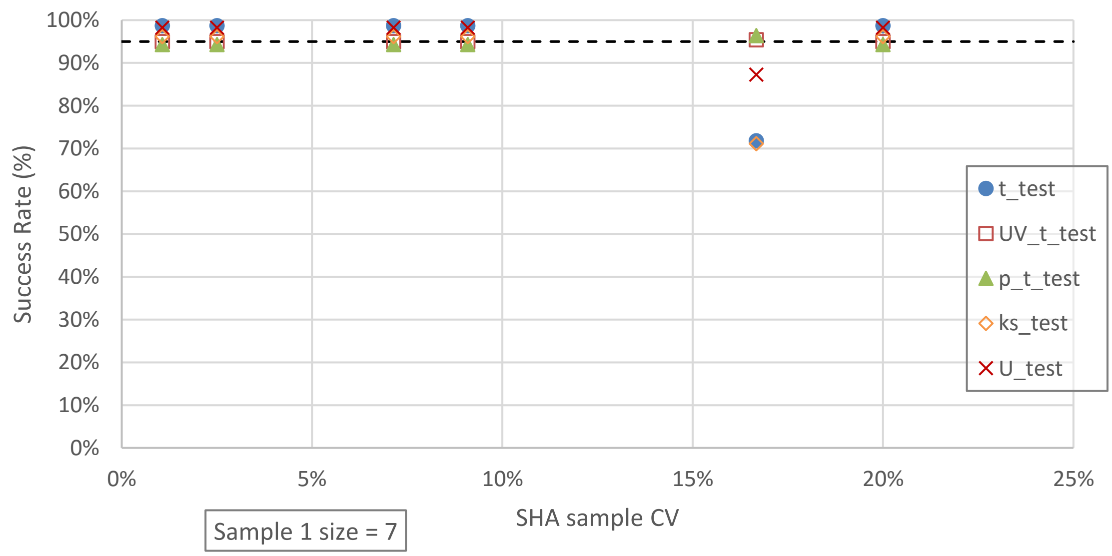

Figure C.9. Numerical Simulations Results – Equal Means and Unequal Standard Deviations.

Figure C.10 shows a similar set of results for hypothesis tests under scenario 3 where the sample means were unequal while the standard deviations were equal ($\mu_1 \neq \mu_2$ and $\sigma_1 = \sigma_2$). Under scenario 3, the tests are expected to perform at a success rate of 5 percent or below, which is represented by the horizontal dotted line in Figure C.10 and Figure C.11. The hypothesis tests in this case did not perform at the expected threshold of five percent. However, the hypothesis tests performed better as the CV1 value got smaller. By comparison the *t*-test performed best, followed by the unequal variance *t*-test and Mann-Whitney test. Figure C.11 shows similar results for scenario 4 where the sample means and the standard deviations were unequal ($\mu_1 \neq \mu_2$ and $\sigma_1 \neq \sigma_2$).

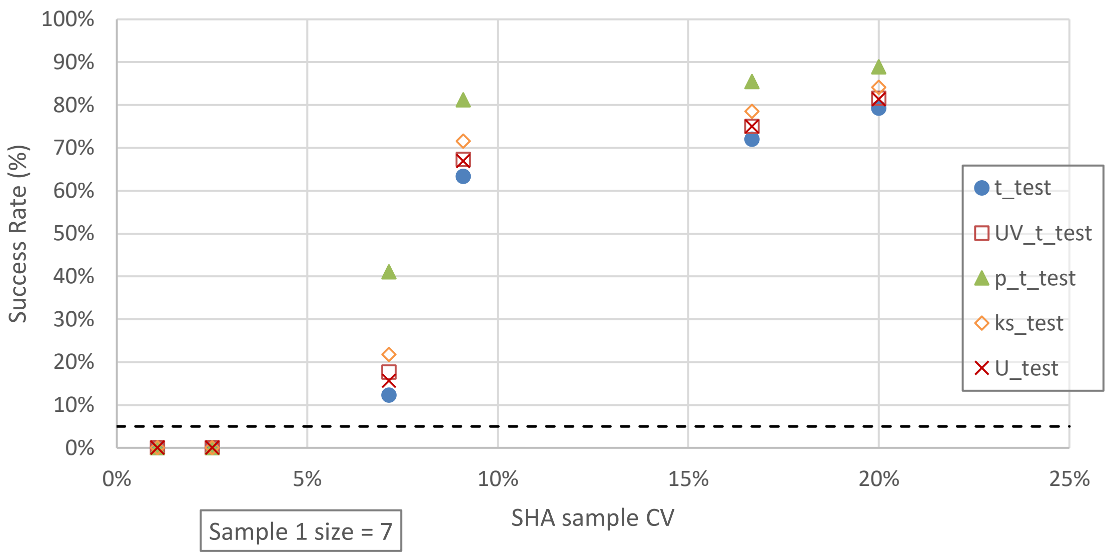

Figure C.10. Numerical Simulations Results – Unequal Means and Equal Standard Deviations.

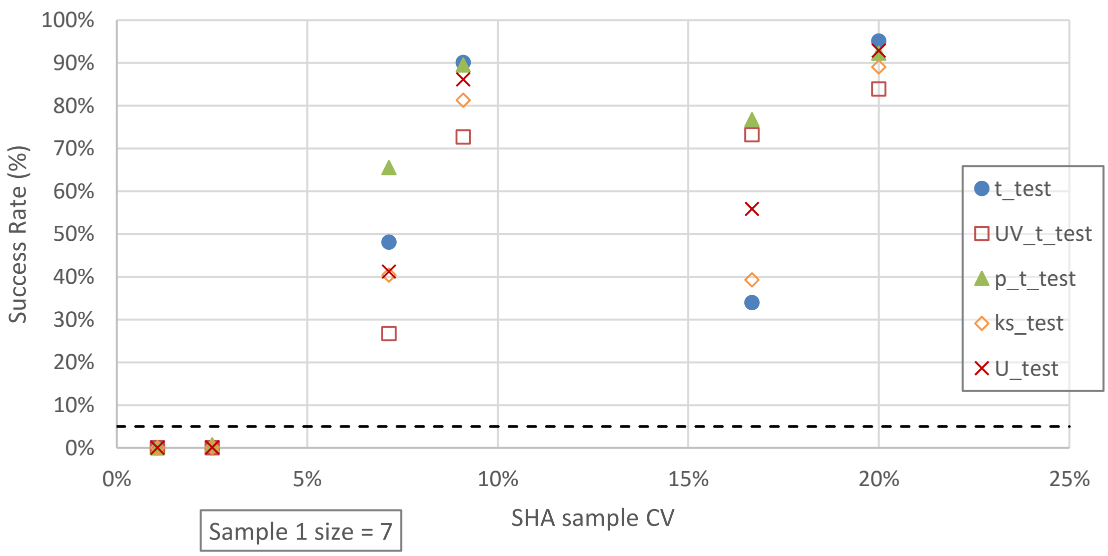

Figure C.11. Numerical Simulations Results – Unequal Means and Unequal Standard Deviations.

Variance Tests

Figure C.12 shows the numerical simulation results for a set of variance tests under scenario 1 where the sample means and standard deviations were equal ($\mu_1 = \mu_2$ and $\sigma_1 = \sigma_2$). The success rate of the tests is shown on the y-axis as a function of SHA sample CV1. Under scenario 1, the tests are expected to perform at a success rate of 95 percent or above, which is represented by the horizontal dotted line in Figure C.12. The values presented in Figure C.12 are for the SHA sample size of 7, while the Contractor sample size varied from 7 (equal sample size) up to a sample size of 70 (SHA sample size × 10). The variance tests in this case performed at the expected threshold of 95 percent. Figure C.13 shows similar results for scenario 3 where the sample means were unequal while the standard deviations were equal ($\mu_1 \neq \mu_2$ and $\sigma_1 = \sigma_2$), except for the Ansari-Bradley test since it requires that the samples have equal medians.

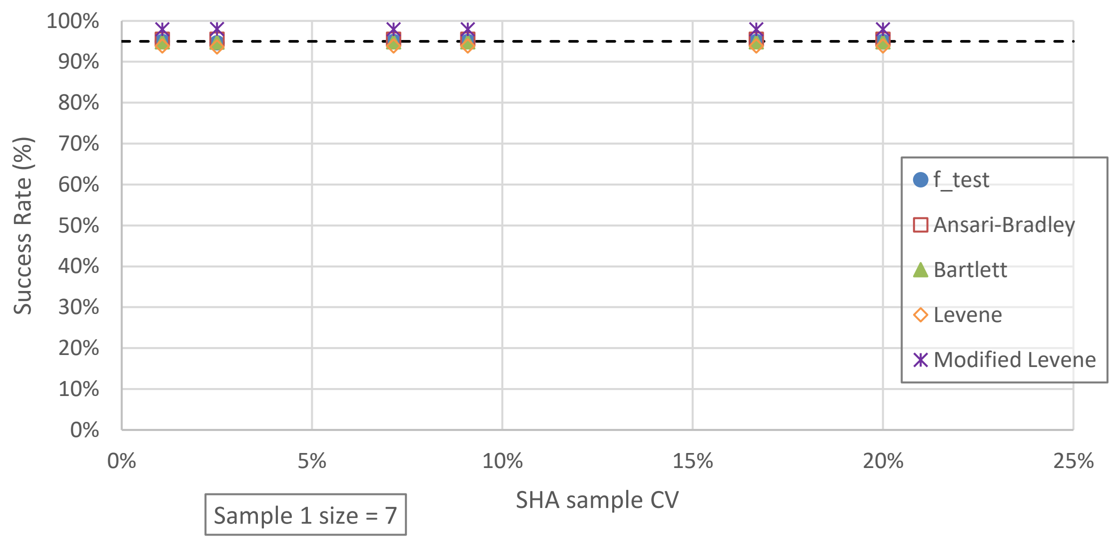

Figure C.12. Numerical Simulations Results – Equal Means and Equal Standard Deviations.

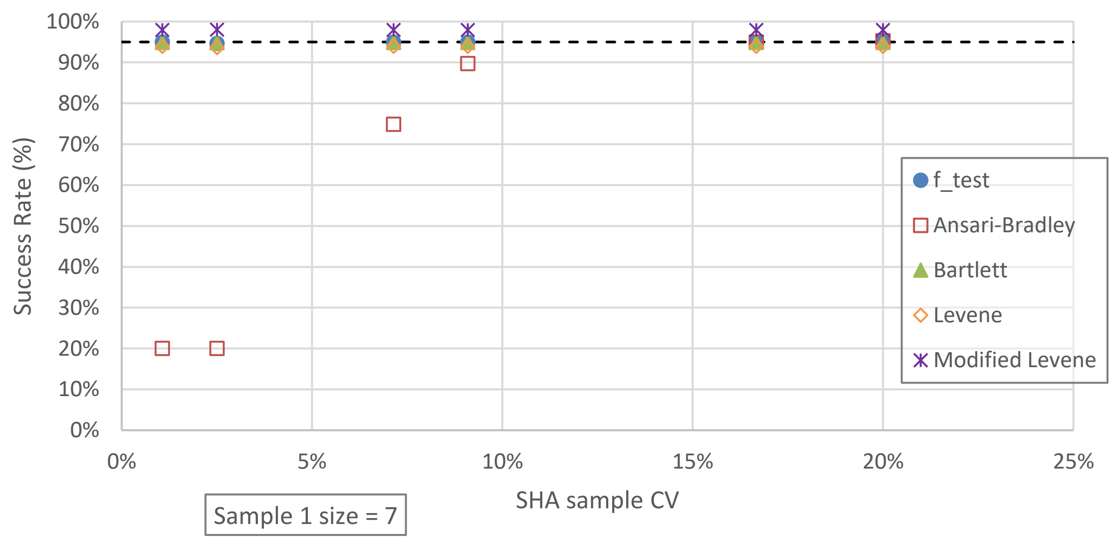

Figure C.13. Numerical Simulations Results – Unequal Means and Equal Standard Deviations.

Figure C.14 shows a similar set of results for variance tests under scenario 2 where the sample means were equal while the standard deviations were unequal ($\mu_1 = \mu_2$ and $\sigma_1 \neq \sigma_2$). Under scenario 2, the tests are expected to perform at a success rate of five percent or below, which is represented by the horizontal dotted line in Figure C.14 and Figure C.15. All of the variance tests in this case performed at the expected threshold of five percent. However, by comparison, the *F*-test had the best performance followed by the Ansari-Bradley test, Levene's test and Bartlett's test. Figure C.15 shows similar results for scenario 4 where the sample means and the standard deviations were unequal ($\mu_1 \neq \mu_2$ and $\sigma_1 \neq \sigma_2$). The Ansari-Bradley test performance was inconsistent in scenario 4 since it requires that the samples have equal medians.

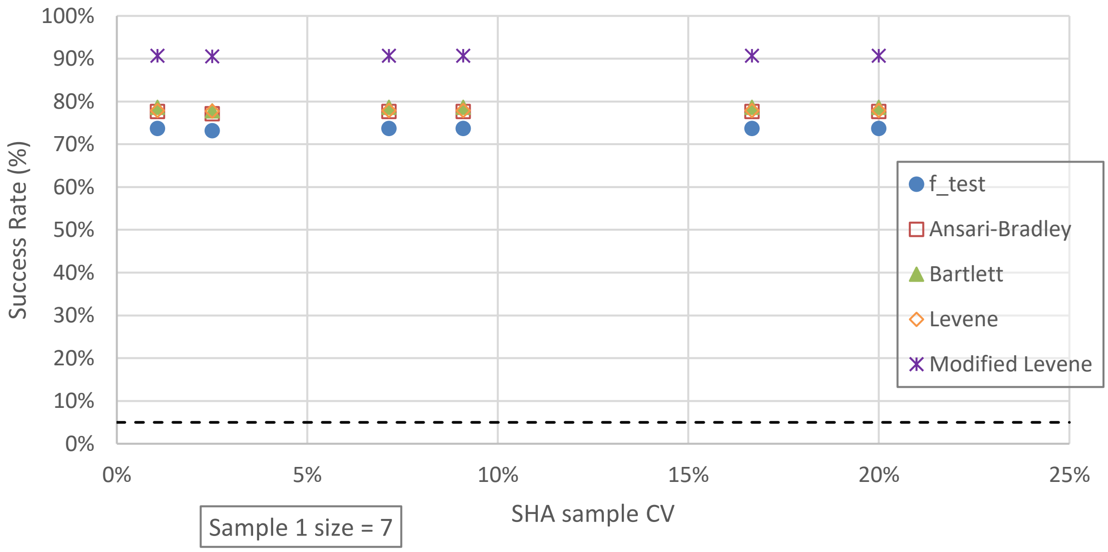

Figure C.14. Numerical Simulations Results – Equal Means and Unequal Standard Deviations.

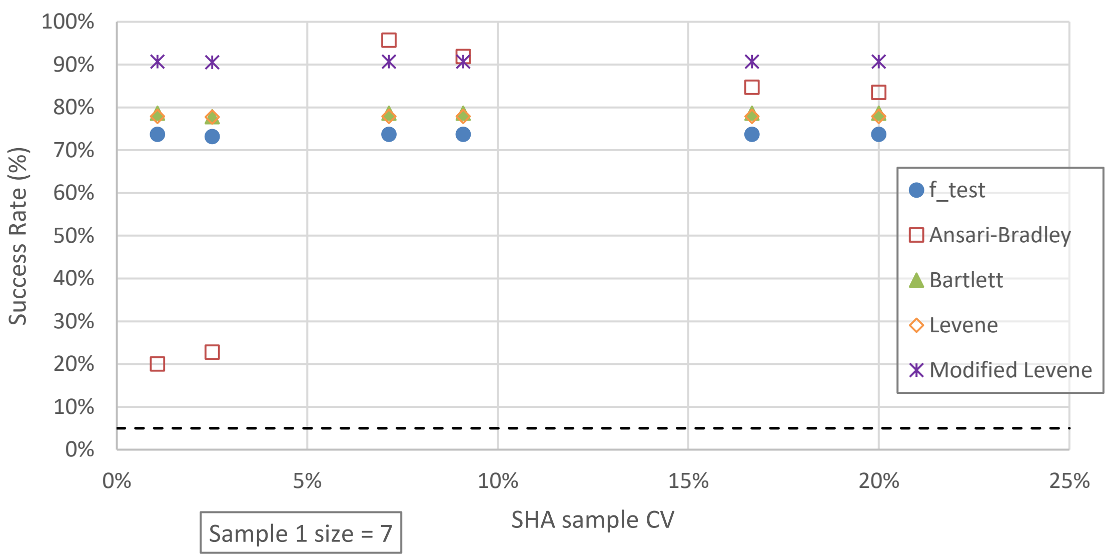

Figure C.15. Numerical Simulations Results – Unequal Means and Unequal Standard Deviations.

<u>*Non-Parametric, Skewed distributions results*</u>

Hypothesis Tests

Figure C.16 shows the numerical simulation results for a set of hypothesis tests under scenario 1 where the sample means and standard deviations were equal ($\mu_1 = \mu_2$ and $\sigma_1 = \sigma_2$). The success rate of the tests is shown on the y-axis as a function of SHA sample CV1. Under scenario 1, the tests are expected to perform at a success rate of 95 percent or above, which is represented by the horizontal dotted line in Figure C.16. The values presented in Figure C.16 are for the SHA sample size of 7, while the Contractor sample sizes varied from 7 (equal sample size) to 70 samples (SHA sample size × 10). The Contractor sample sizes considered were 7, 14, 21, 28, 35, 42, 49, 56, 63, and 70. The hypothesis tests in this case performed at the expected threshold of 95 percent, except for the paired *t*-test. Figure C.17 shows the results for scenario 2 where the sample means were equal while the standard deviations were unequal ($\mu_1 = \mu_2$ and $\sigma_1 \neq \sigma_2$), and a similar trend is observed for all of the tests except for the Kolmogorov-Smirnov two sample test, where the performance of the test slightly deteriorated.

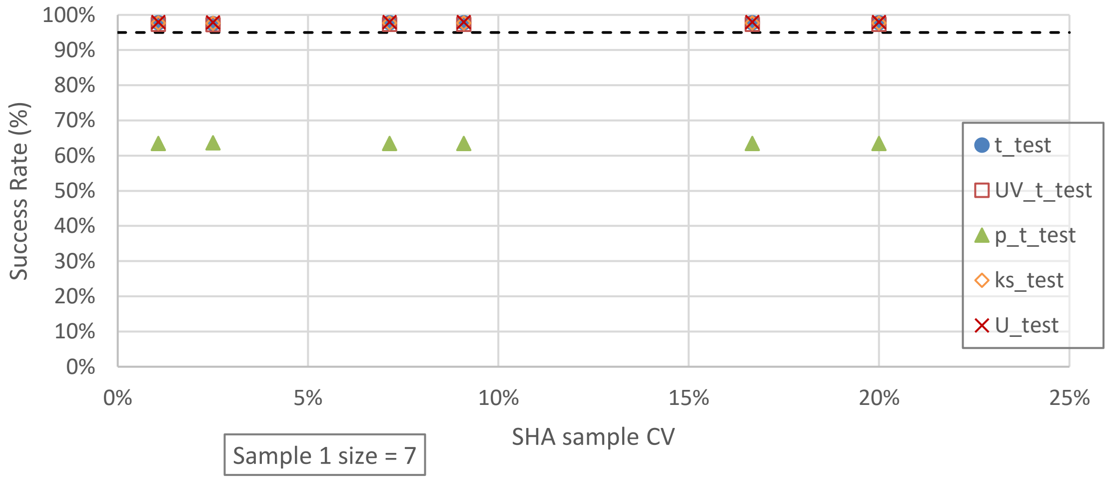

Figure C.16. Numerical Simulations Results – Equal Means and Equal Standard Deviations.

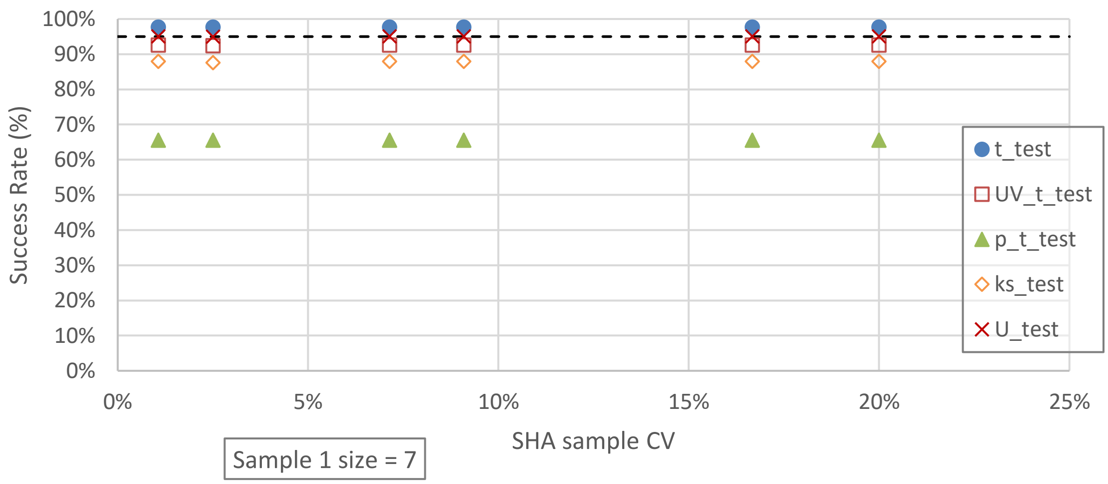

Figure C.17. Numerical Simulations Results – Equal Means and Unequal Standard Deviations.

Figure C.18 shows a similar set of results for hypothesis tests under scenario 3 where the sample means were unequal while the standard deviations were equal ($\mu_1 \neq \mu_2$ and $\sigma_1 = \sigma_2$). Under scenario 3, the tests are expected to perform at a success rate of five percent or below, which is represented by the horizontal dotted line in Figure C.18 and Figure C.19. The hypothesis tests in this case did not perform at the expected threshold of five percent. However, the hypothesis tests performed better as the CV1 value got smaller. By comparison the *t*-test had the best performance followed by the Mann-Whitney test. Figure C.19 shows results for scenario 4 where the sample means and the standard deviations were unequal ($\mu_1 \neq \mu_2$ and $\sigma_1 \neq \sigma_2$). By comparison, the Kolmogorov-Smirnov two sample test had the best performance followed by the unequal variance *t*-test.

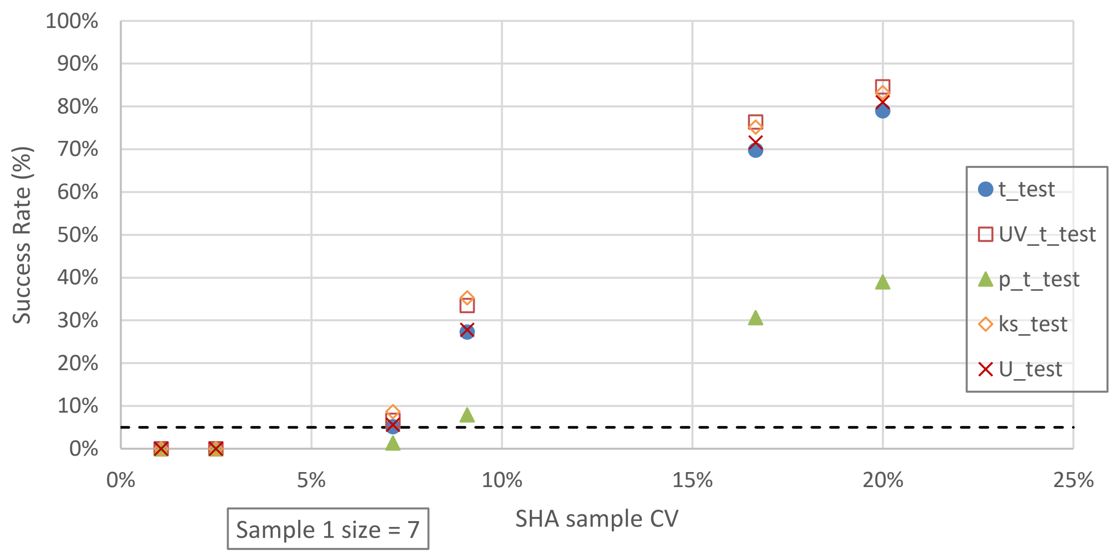

Figure C.18. Numerical Simulations Results – Unequal Means and Equal Standard Deviations.

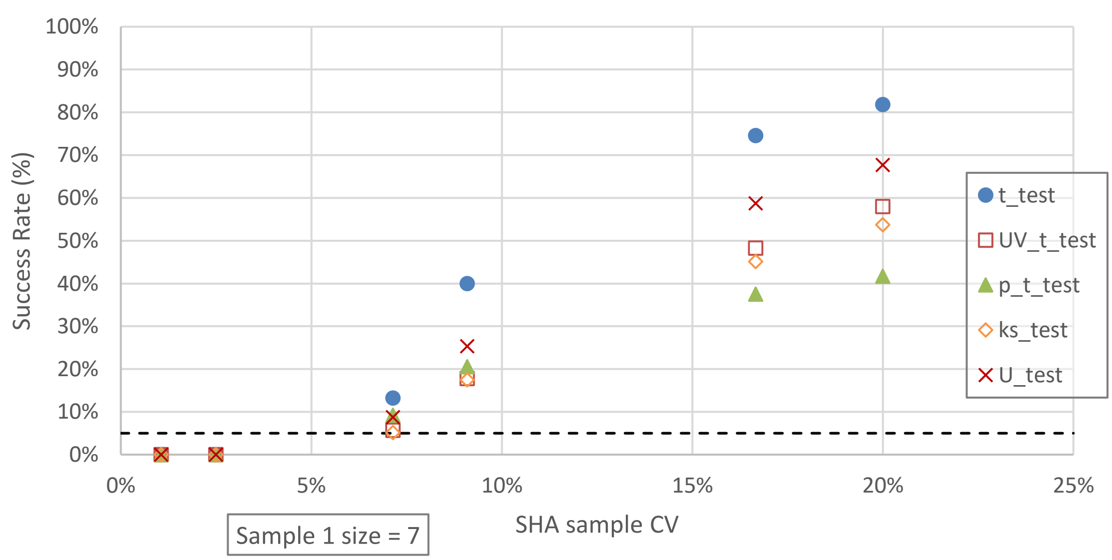

Figure C.19. Numerical Simulations Results – Unequal Means and Unequal Standard Deviations.

Variance Tests

Figure C.20 shows the numerical simulation results for a set of variance tests under scenario 1 where the sample means and standard deviations were equal ($\mu_1 = \mu_2$ and $\sigma_1 = \sigma_2$). The success rate of the tests is shown on the y-axis as a function of SHA sample CV1. Under scenario 1, the tests are expected to perform at a success rate of 95 percent or above, which is represented by the horizontal dotted line in Figure C.20. The values presented in Figure C.20 are for the SHA sample size of 7 samples, while the Contractor sample size varied from 7 samples (equal sample size) up to 70 samples (SHA sample size × 10). The variance tests in this case performed at the expected threshold of 95 percent. Figure C.21 shows similar results for scenario 3 where the sample means were unequal while the standard deviations were equal ($\mu_1 \neq \mu_2$ and $\sigma_1 = \sigma_2$), except for the Ansari-Bradley test since it requires that the samples have equal medians.

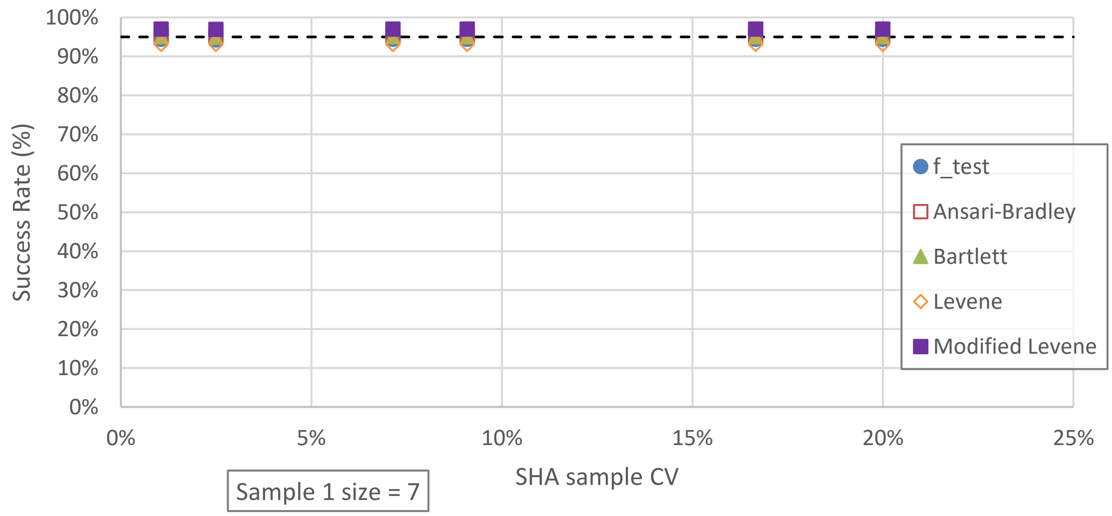

Figure C.20. Numerical Simulations Results – Equal Means and Equal Standard Deviations.

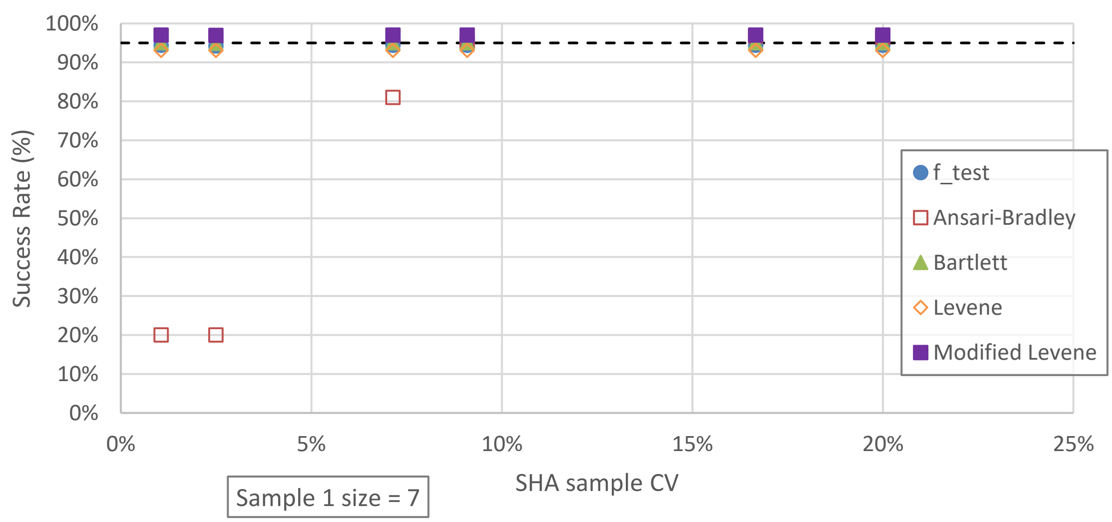

Figure C.21. Numerical Simulations Results – Unequal Means and Equal Standard Deviations.

Figure C.22 shows a similar set of results for variance tests under scenario 2 where the sample means were equal while the standard deviations were unequal ($\mu_1 = \mu_2$ and $\sigma_1 \neq \sigma_2$). Under scenario 2, the tests are expected to perform at a success rate of five percent or below, which is represented by the horizontal dotted line in Figure C.22 and Figure C.23. The variance tests in this case did not perform at the expected threshold of five percent. By comparison, the *F*-test performed the best followed by the Ansari-Bradley test, Levene's test and Bartlett's test. Figure C.23 shows similar results for scenario 4 where the sample means and the standard deviations were unequal ($\mu_1 \neq \mu_2$ and $\sigma_1 \neq \sigma_2$).

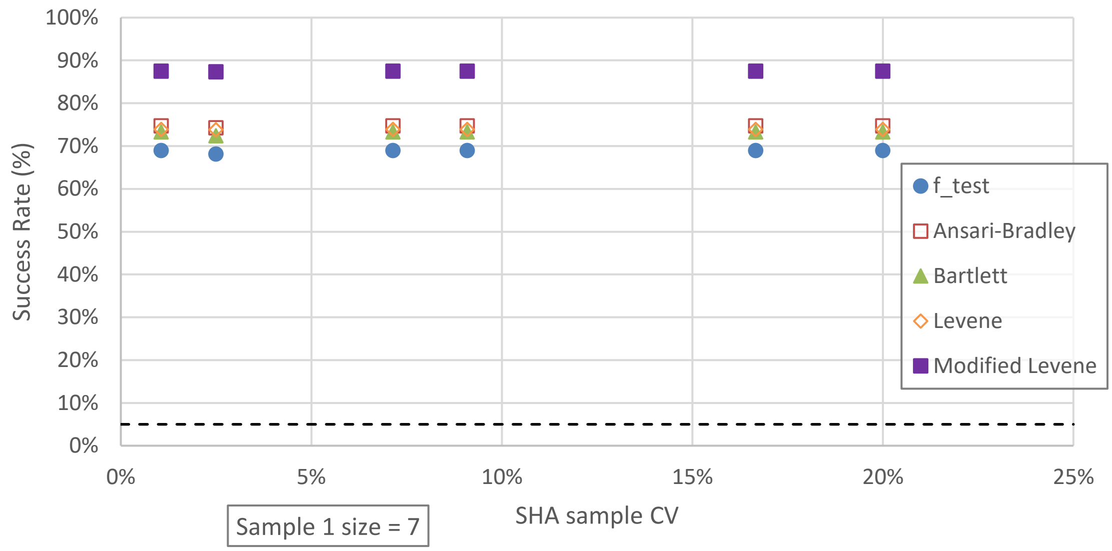

Figure C.22. Numerical Simulations Results – Equal Means and Unequal Standard Deviations.

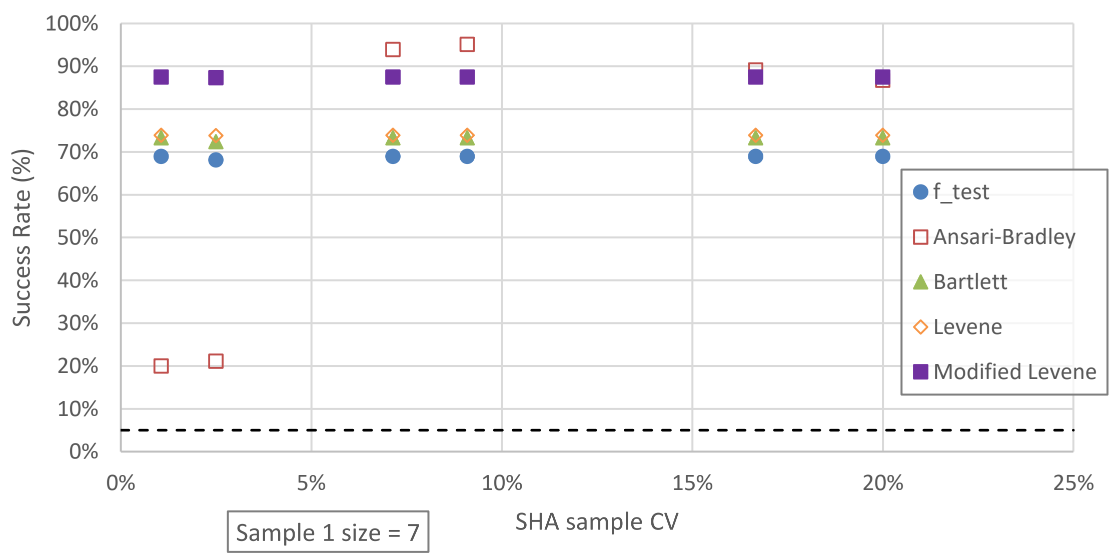

Figure C.23. Numerical Simulations Results – Unequal Means and Unequal Standard Deviations.

<u>*Non-Parametric, Bimodal distributions results*</u>

Hypothesis Tests

Figure C.24 shows the numerical simulation results for a set of hypothesis tests under scenario 1 where the sample means and standard deviations were equal ($\mu_1 = \mu_2$ and $\sigma_1 = \sigma_2$). The success rate of the tests is shown on the y-axis as a function of SHA sample CV1. Under scenario 1, the tests are expected to perform at a success rate of 95 percent or above, which is represented by the horizontal dotted line in Figure C.24. The values presented in Figure C.24 are for the SHA sample size of 7, while the Contractor sample sizes varied from 7 (equal sample size) to 70 samples (SHA sample size × 10). The Contractor sample sizes considered were 7, 14, 21, 28, 35, 42, 49, 56, 63, and 70. The hypothesis tests in this case performed at the expected threshold of 95 percent except for the paired *t*-test. Figure C.25 shows the results for scenario 2 where the sample means were equal while the standard deviations were unequal ($\mu_1 = \mu_2$ and $\sigma_1 \neq \sigma_2$), the tests performed similar to scenario 1.

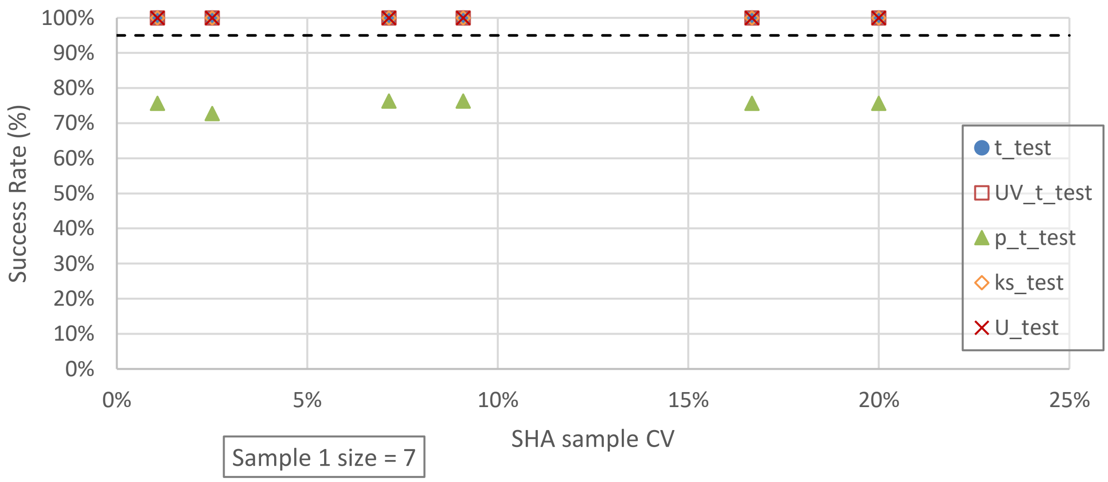

Figure C.24. Numerical Simulations Results – Equal Means and Equal Standard Deviations.

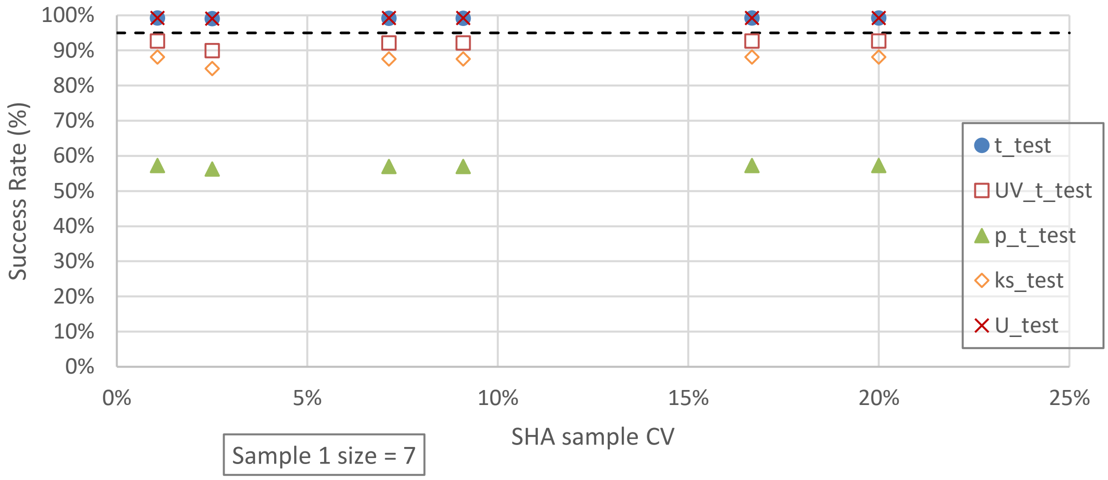

Figure C.25. Numerical Simulations Results – Equal Means and Unequal Standard Deviations.

Figure C.26 shows a similar set of results for hypothesis tests under scenario 3 where the sample means were unequal while the standard deviations were equal ($\mu_1 \neq \mu_2$ and $\sigma_1 = \sigma_2$). Under scenario 3, the tests are expected to perform at a success rate of five percent or below, which is represented by the horizontal dotted line in Figure C.26 and Figure C.27. The hypothesis tests in this case did not perform at the expected threshold of five percent. However, the hypothesis tests performed better as the CV1 value got smaller. By comparison, the *t*-test had the best performance followed by the Mann-Whitney test. Figure C.27 shows results for scenario 4 where the sample means and the standard deviations were unequal ($\mu_1 \neq \mu_2$ and $\sigma_1 \neq \sigma_2$). The unequal variance *t*-test had the best performance followed by the Kolmogorov-Smirnov sample test.

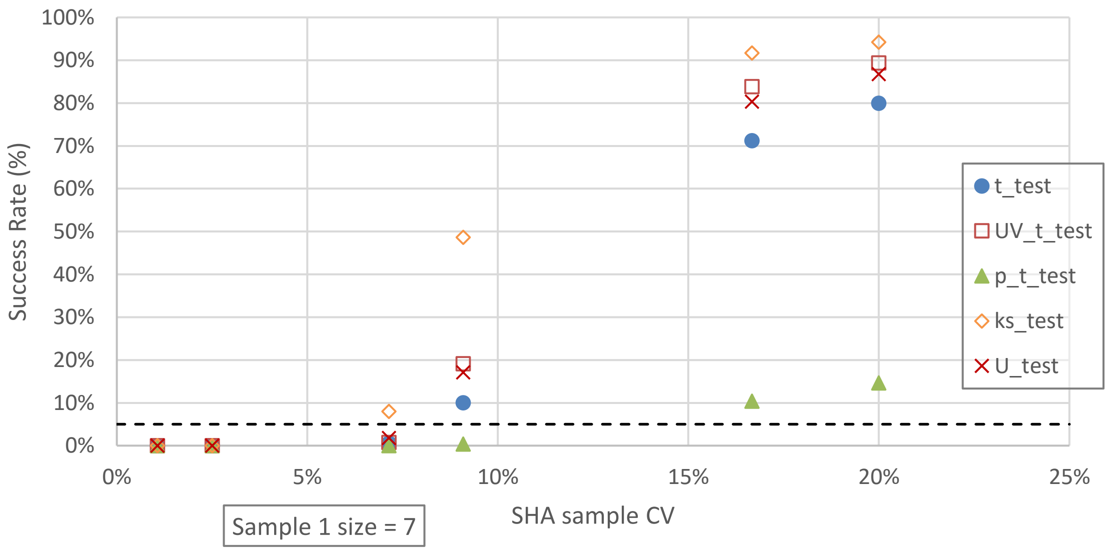

Figure C.26. Numerical Simulations Results – Unequal Means and Equal Standard Deviations.

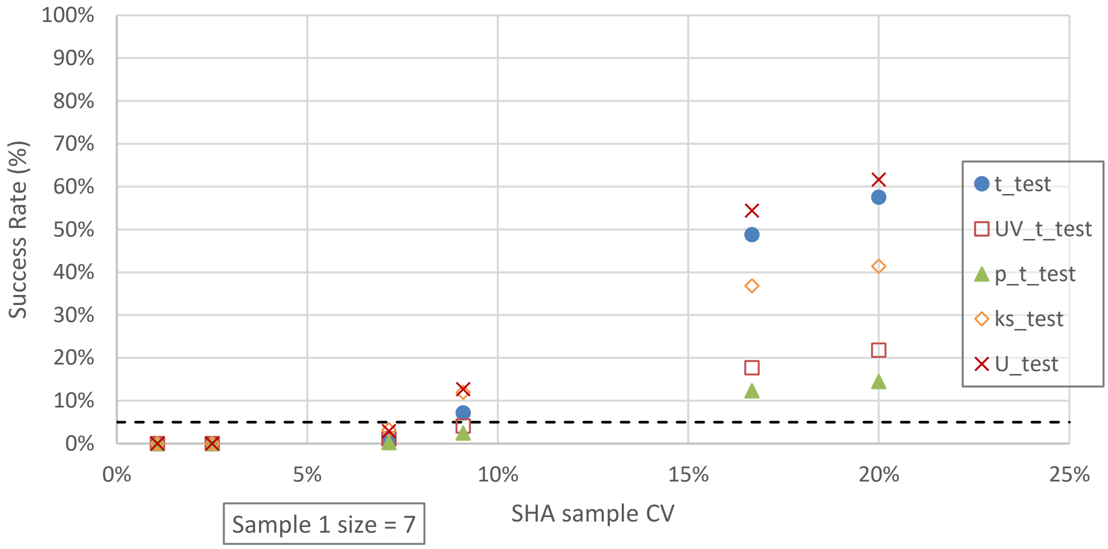

Figure C.27. Numerical Simulations Results – Unequal Means and Unequal Standard Deviations.

Variance Tests

Figure C.28 shows the numerical simulation results for a set of variance tests under scenario 1 where the sample means and standard deviations were equal ($\mu_1 = \mu_2$ and $\sigma_1 = \sigma_2$). The success rate of the tests is shown on the y-axis as a function of SHA sample CV1. Under scenario 1, the tests are expected to perform at a success rate of 95 percent or above, which is represented by the horizontal dotted line in Figure C.28. The values presented in Figure C.28 are for the SHA sample size of 7, while the Contractor sample sizes varied from 7 (equal sample size) to 70 samples (SHA sample size × 10). The variance tests in this case performed at the expected threshold of 95 percent. Figure C.29 shows similar results for scenario 3 where the sample means were unequal while the standard deviations were equal ($\mu_1 \neq \mu_2$ and $\sigma_1 = \sigma_2$), except for the Ansari-Bradley test since it requires that the samples have equal medians.

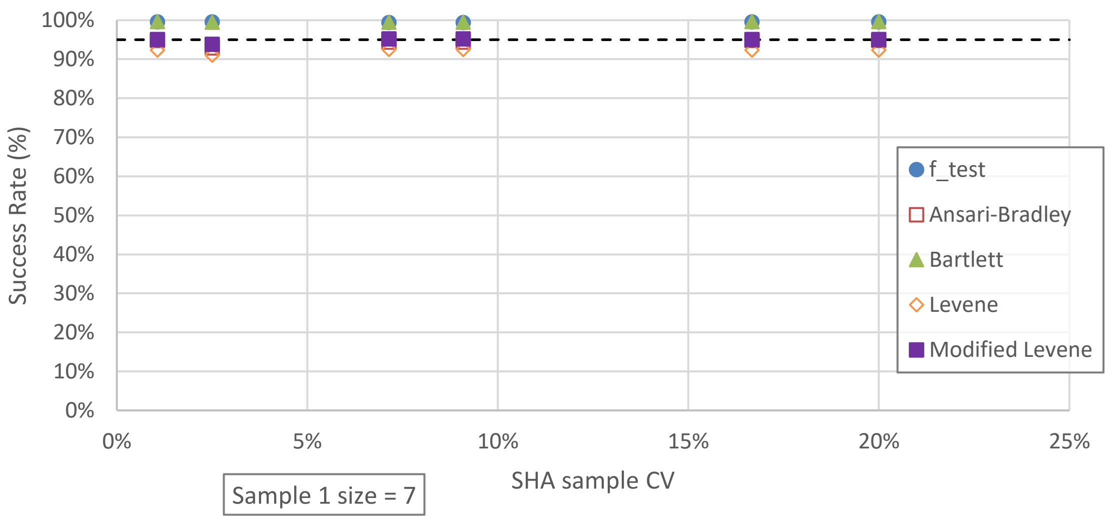

Figure C.28. Numerical Simulations Results – Equal Means and Equal Standard Deviations.

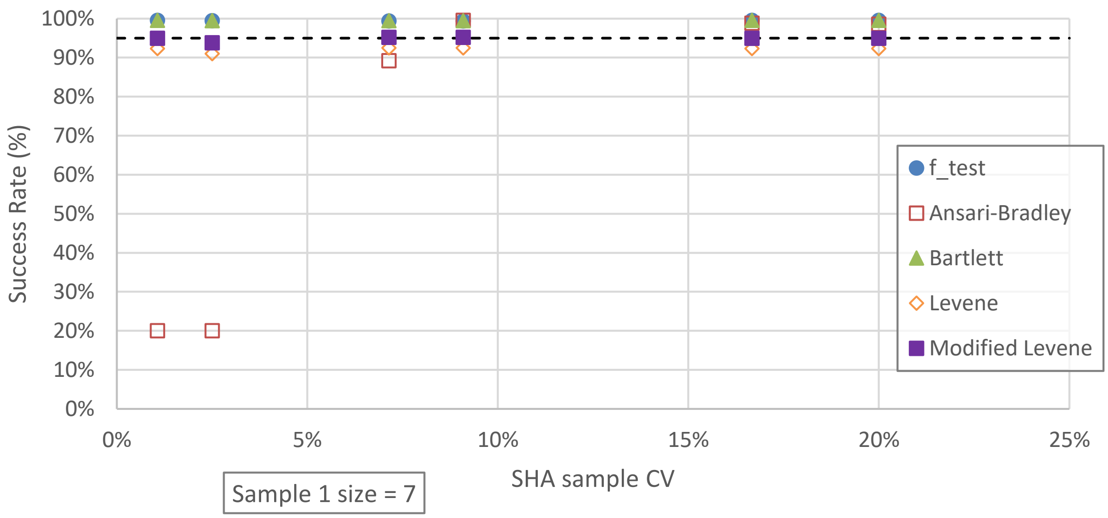

Figure C.29. Numerical Simulations Results – Unequal Means and Equal Standard Deviations.

Figure C.30 shows a similar set of results for variance tests under scenario 2 where the sample means were equal while the standard deviations were unequal ($\mu_1 = \mu_2$ and $\sigma_1 \neq \sigma_2$). Under scenario 2, the tests are expected to perform at a success rate of five percent or below, which is represented by the horizontal dotted line in Figure C.30 and Figure C.31. The variance tests in this case did not perform at the expected threshold of five percent. By comparison, Levene's test had the best performance followed by the Ansari-Bradley test. Figure C.31 shows similar results for scenario 4 where the sample means and the standard deviations were unequal ($\mu_1 \neq \mu_2$ and $\sigma_1 \neq \sigma_2$). The Ansari-Bradley test performance was inconsistent in scenario 4 since it requires that the samples have equal medians.

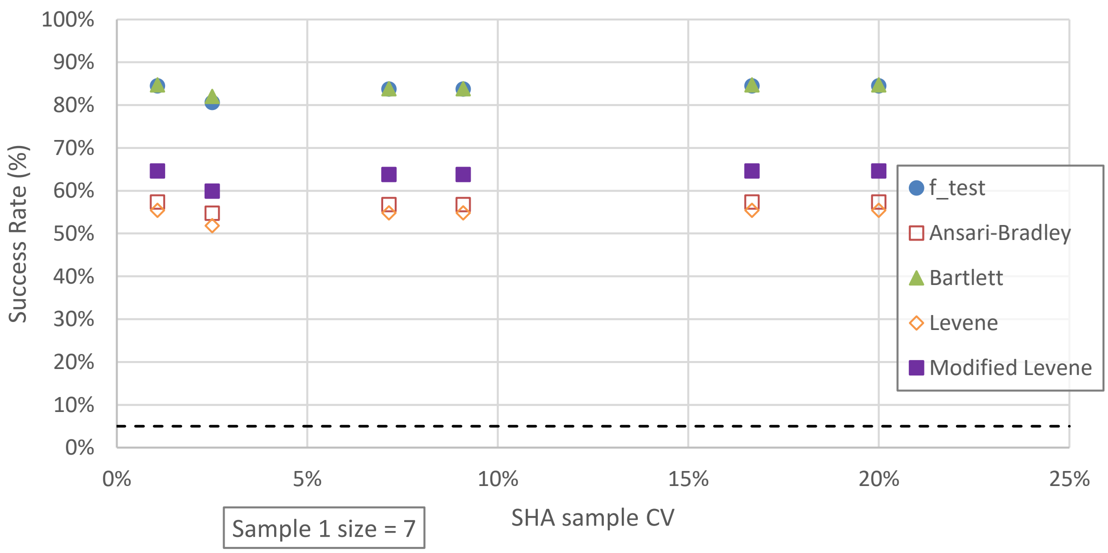

Figure C.30. Numerical Simulations Results – Equal Means and Unequal Standard Deviations.

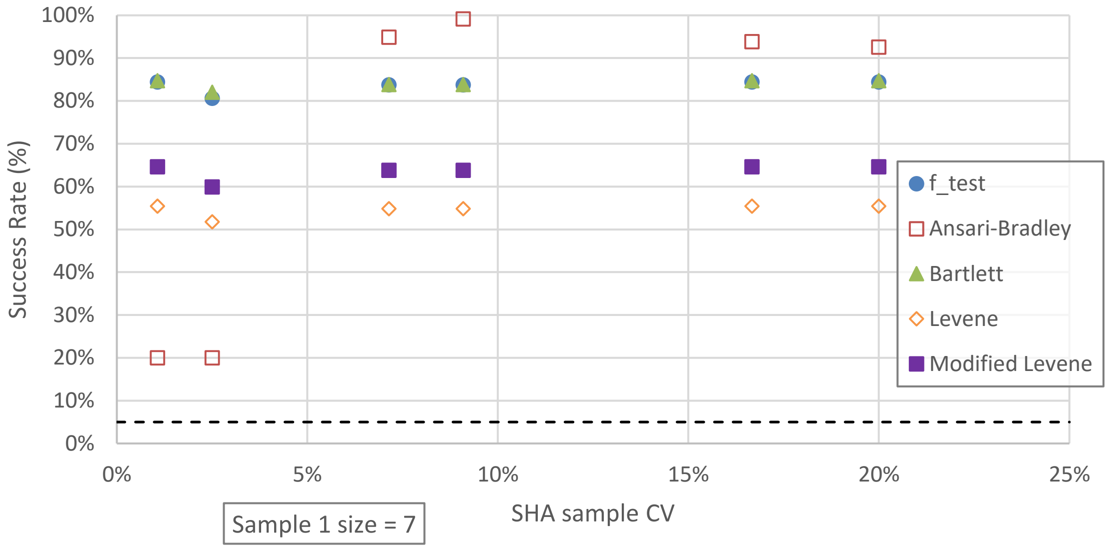

Figure C.31. Numerical Simulations Results – Unequal Means and Unequal Standard Deviations.

APPENDIX D. SHA DATA ANALYSIS

Data from SHA projects were used to test the effectiveness of the validation procedures. Six states were identified to obtain actual project data from, representing a wide regional distribution across the U.S. They represent the East, Southeast, Midwest, Southwest, Rocky Mountain and West regions. The data received included PCC, HMA, and Aggregate Base test results.

Data Processing

The SHA data were processed as discussed in Section **Error! Reference source not found.**. A MATLAB code was developed to scan and sort the data based on the project number and lot number. The test results of a lot represented a sample. All the XLS spreadsheets were processed using MATLAB, and Table D.1 summarizes the SHA data received and processed for further analysis. HMA AQCs included density, Air Voids (AV), AC, and VMA.

Table D.1. SHA data processed for further analysis

SHA ID	Material Type	AQC	No. of Projects	Average Lots per Project	Total Samples (Lots)
SHA 1	HMA	Density	259	15	3,804
		Air Voids	302	7	2,050
	PCC	Strength	16	22	354
		Thickness	16	22	354
SHA 2	PCC	Strength	18	1	25
SHA 3	HMA	Density	690	7	5,084
		Air Voids	708	8	5,620
		AC	720	9	6,488
		No. 8 Sieve	720	9	6,487
		No. 200 Sieve	720	9	6,490
SHA 4	Aggregates Base	2 inch Sieve	3	41	123
		1 inch Sieve	3	41	123
		3/8 inch Sieve	3	41	123
		No. 10 Sieve	3	41	123
		No. 40 Sieve	3	41	123
		No. 200 Sieve	3	41	123
		Liquid Limit (LL)	3	41	123
		Plasticity Index (PI)	3	41	123
		Moisture Content (MC)	3	41	123
SHA 5	HMA	Air Voids	289	6	1,734
		AC	289	6	1,734
		VMA	289	6	1,734

Processing of SHAs data revealed the following observations:

- Most of the SHA data received were obtained using independent sampling techniques. However, some SHAs obtained data using split samples between the SHA and Contractor. Using split rather than independent samples can put SHAs at significant risk of making wrong acceptance and payment decisions if not handled properly. While independent samples contain up to four sources of variability: material, process, sampling, and test method; split samples contain only test method variability. Sampling methods are discussed with an example under Section **Error! Reference source not found.**.

- SHA definitions of lots, sampling, and testing frequencies are variable, resulting in numerous scenarios for the number of SHA and Contractor samples. In general, the different scenarios can be categorized in three categories based on the number of SHA samples per lot: 1) single SHA result per lot, 2) three to twenty SHA results per lot, and 3) more than twenty SHA results per lot. The three SHA sample size categories are discussed with an example under Section **Error! Reference source not found.**.

A Plan for Sampling, Testing, and Validation

The observations made during the SHA data processing revealed that some SHA sampling and testing plans that use Contactor data in acceptance decisions do not meet the requirements of 23 CFR 637B, due to a lack of independent samples. Other SHA sampling and testing plans used a single SHA sample per lot. Based on these observations the research team developed two plans for sampling and testing the SHA data, and for Contractor data validation. These plans, Case 1: Minimum SHA tests per lot and Case 2: Cumulative Validation Lots, were discussed in Section **Error! Reference source not found.**.

SHA Raw data

Data were obtained, from SHA 5 which requires Contactors to perform QC tests on samples split from the same bulk samples the SHA uses for each lot. The data contained recent SHA and Contractor results of percent AV of HMA. Sample raw data sets of percent AV and AC are presented in the following sections. A MATLAB code was developed to scan and sort the data based on SHA sample size per lot. All lots with less than six SHA samples were filtered out as the minimum criteria for the proposed sampling, testing, and validation plan is six sublots per lot.

Air Voids

SHA and Contractor results of percent AV of HMA are presented in Figure D.1 through Figure D.10. The target specification values are showed in the figures with a dashed horizontal line, the USLs and the LSLs are also presented with horizontal dotted lines.

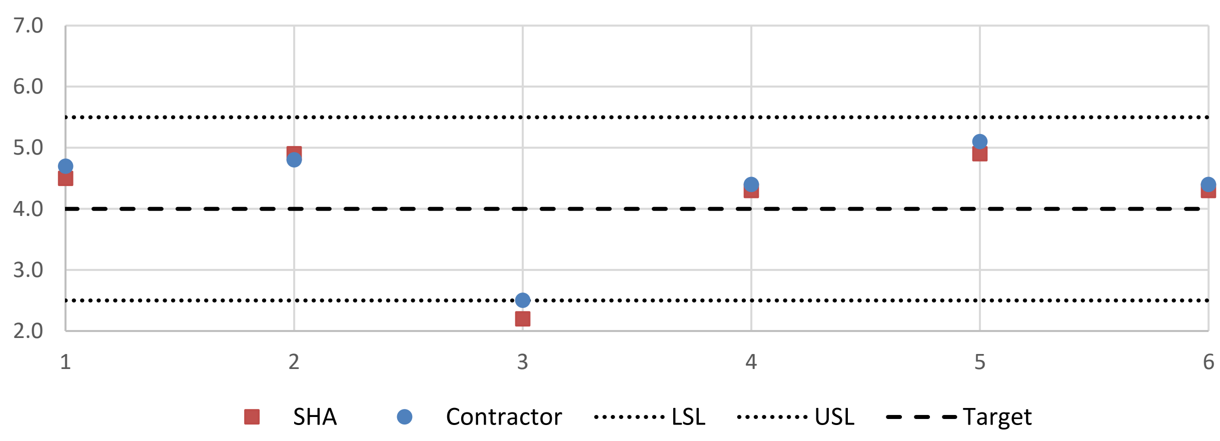

Figure D.1. SHA Raw Data - Air Voids – Sample 1-1.

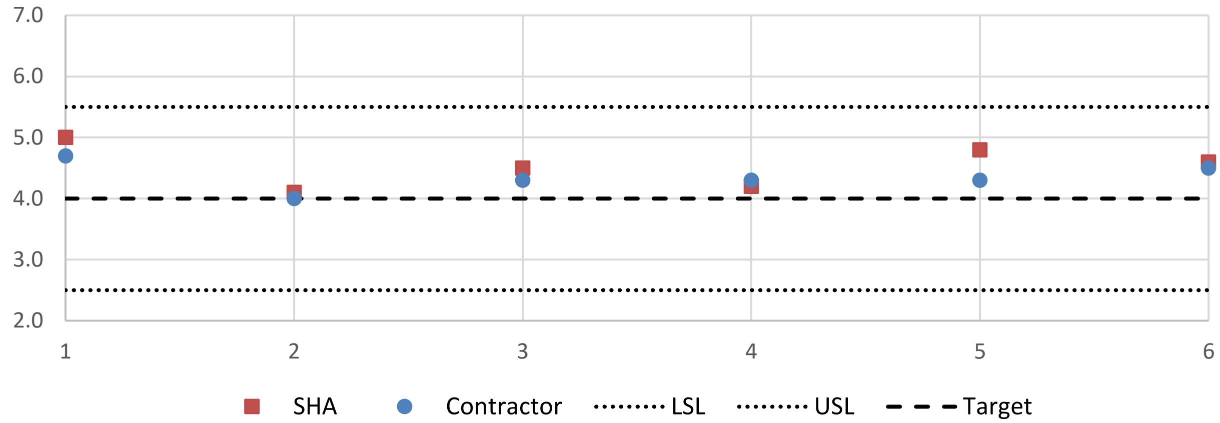

Figure D.2. SHA Raw Data - Air Voids – Sample 1-2.

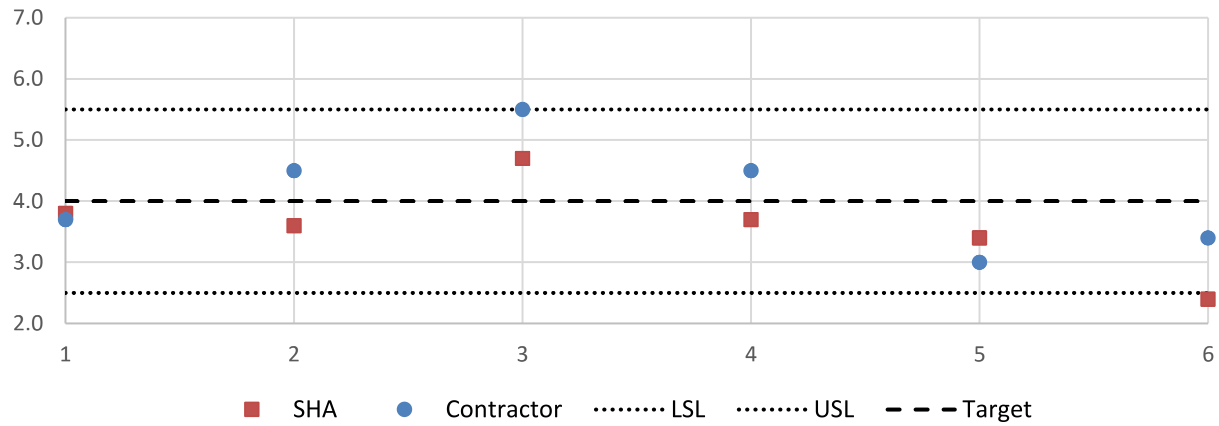

Figure D.3. SHA Raw Data - Air Voids – Sample 2-1.

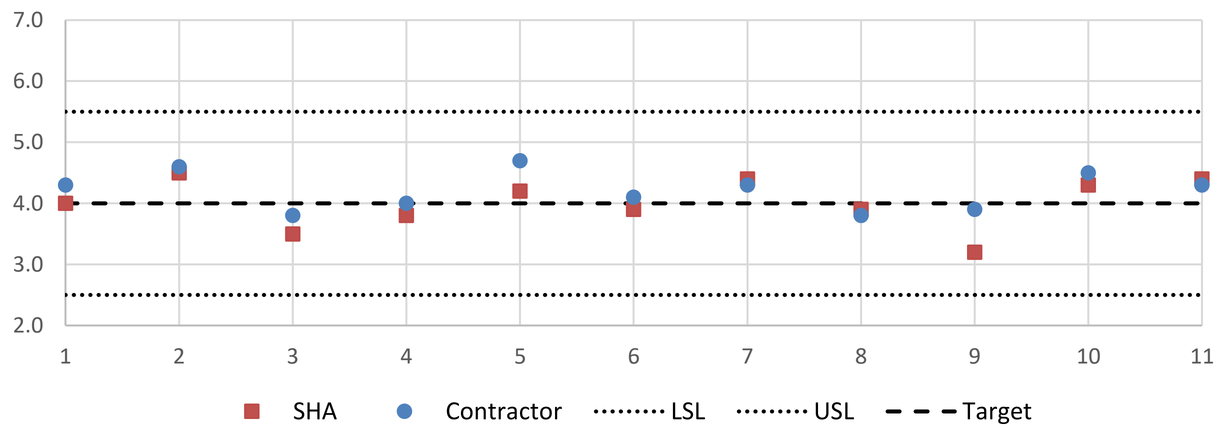

Figure D.4. SHA Raw Data - Air Voids – Sample 16-1.

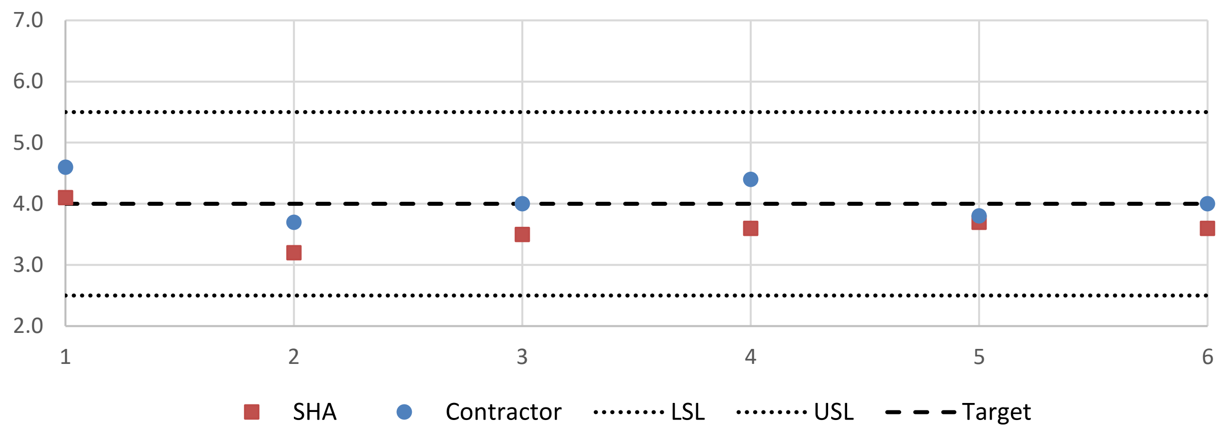

Figure D.5. SHA Raw Data - Air Voids – Sample 16-2.

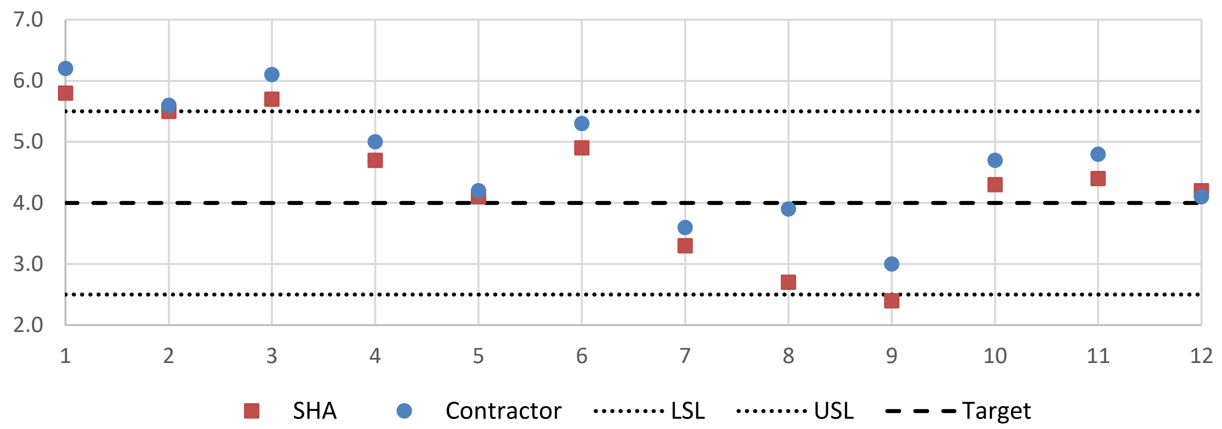

Figure D.6. SHA Raw Data - Air Voids – Sample 28-1.

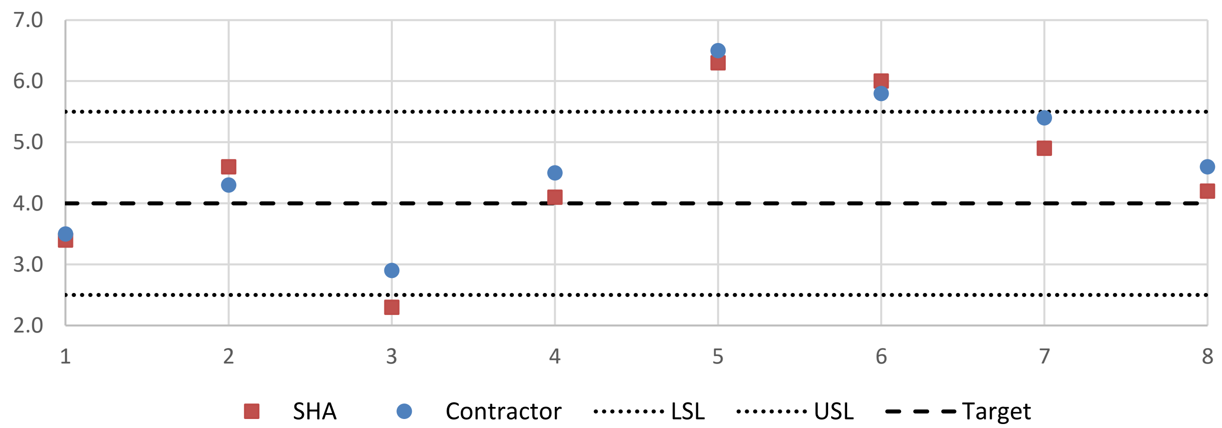

Figure D.7. SHA Raw Data - Air Voids – Sample 30-1.

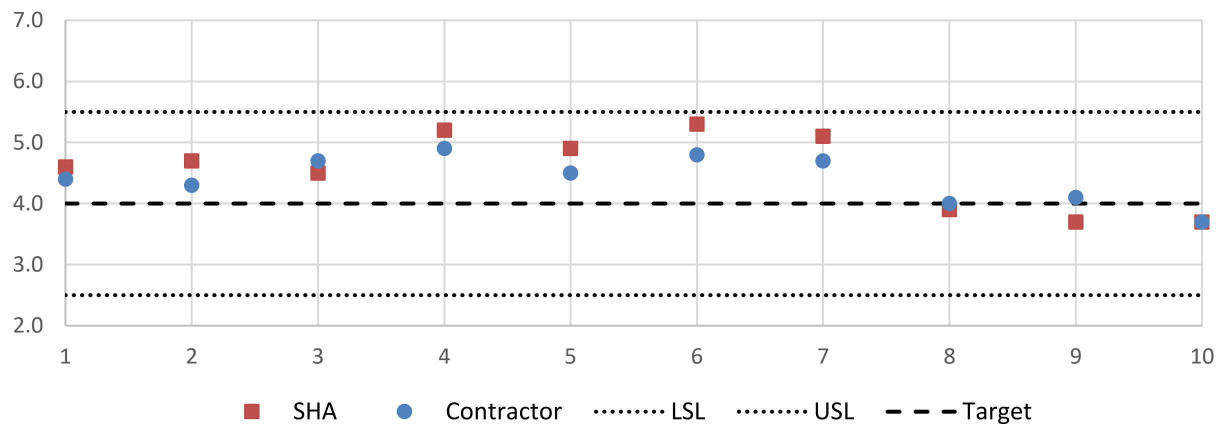

Figure D.8. SHA Raw Data - Air Voids – Sample 145-1.

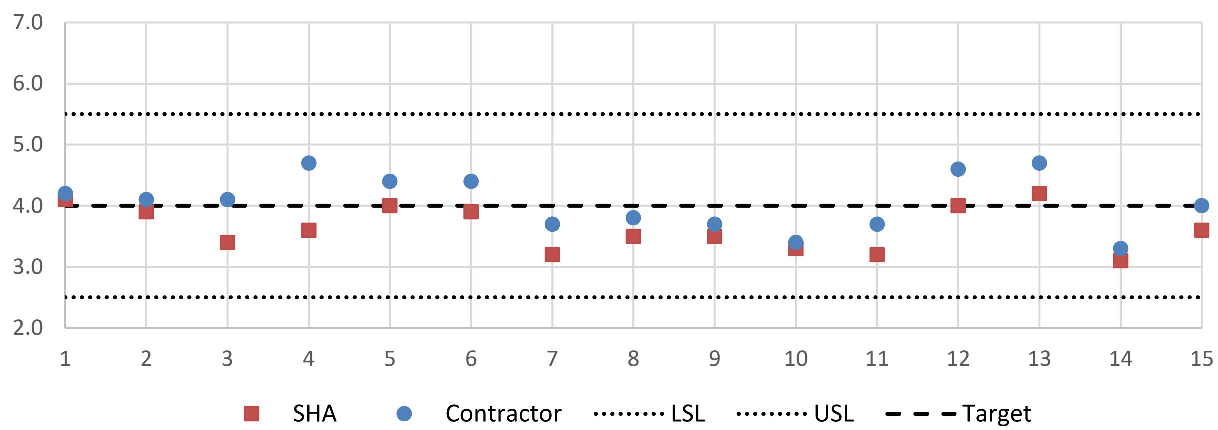

Figure D.9. SHA Raw Data - Air Voids – Sample 151-1.

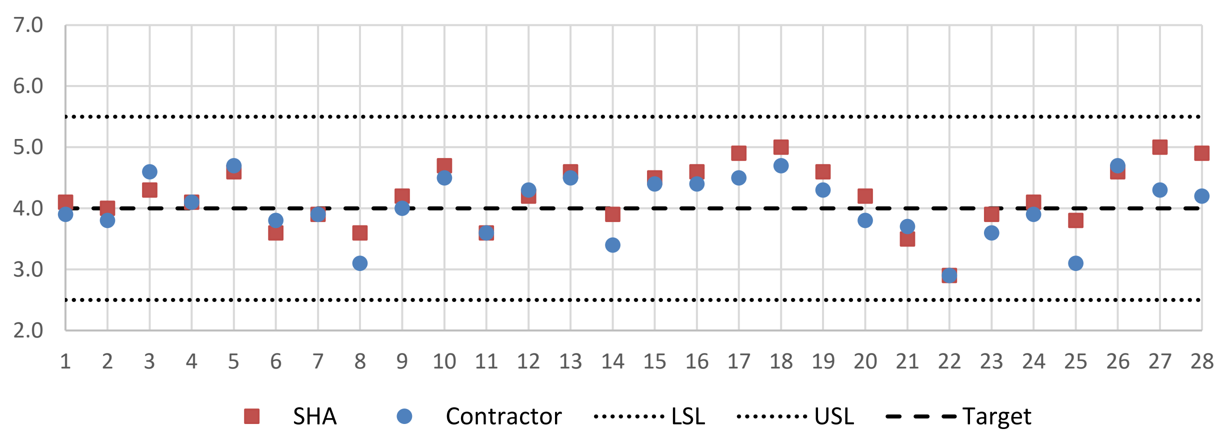

Figure D.10. SHA Raw Data - Air Voids – Sample 152-1.

Asphalt Binder Content (AC)

SHA and Contractor results of percent AC of HMA are presented in Figure D.11 through Figure D.20. The target specification values are showed with a dashed horizontal line, the USLs and the LSLs are marked with horizontal dotted lines in the figures.

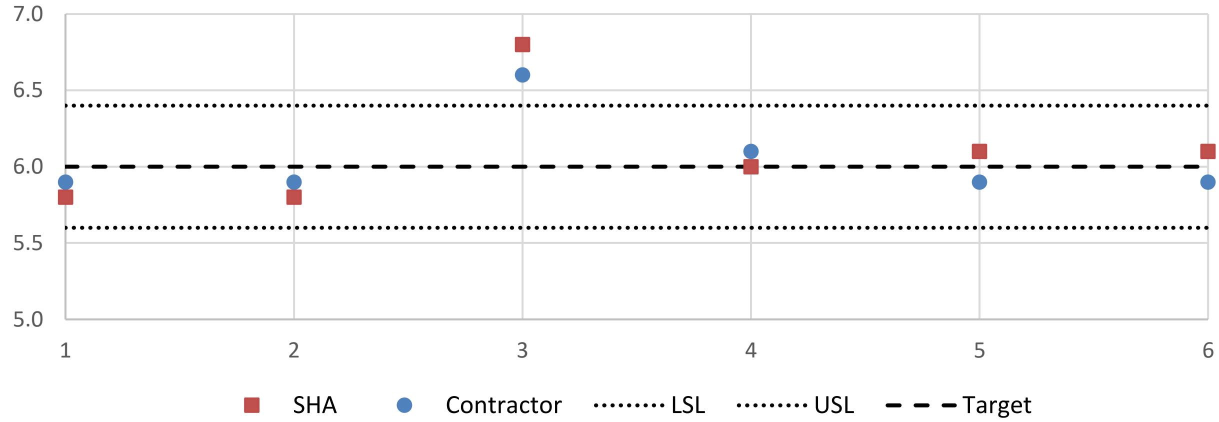

Figure D.11. SHA Raw Data – Asphalt Binder Content – Sample 1-1.

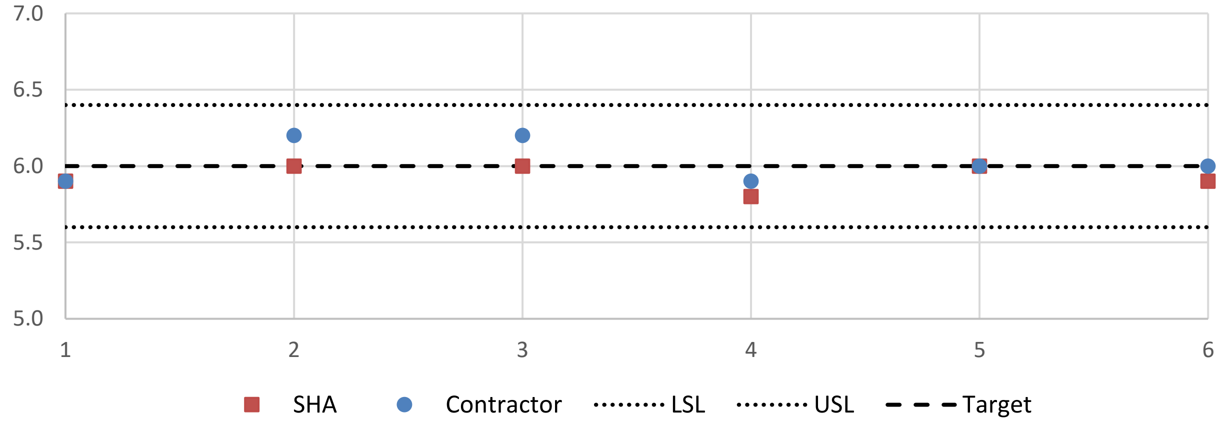

Figure D.12. SHA Raw Data – Asphalt Binder Content – Sample 1-2.

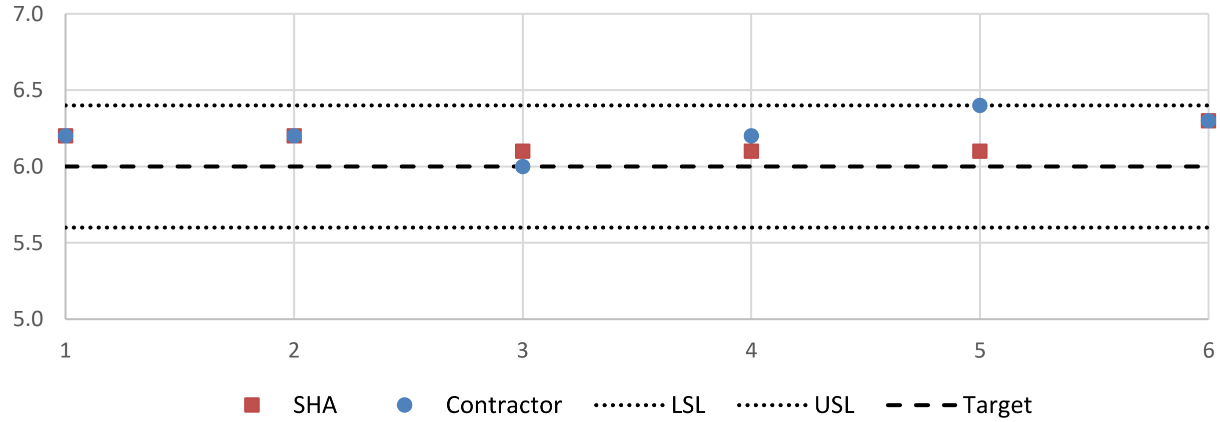

Figure D.13. SHA Raw Data – Asphalt Binder Content – Sample 2-1.

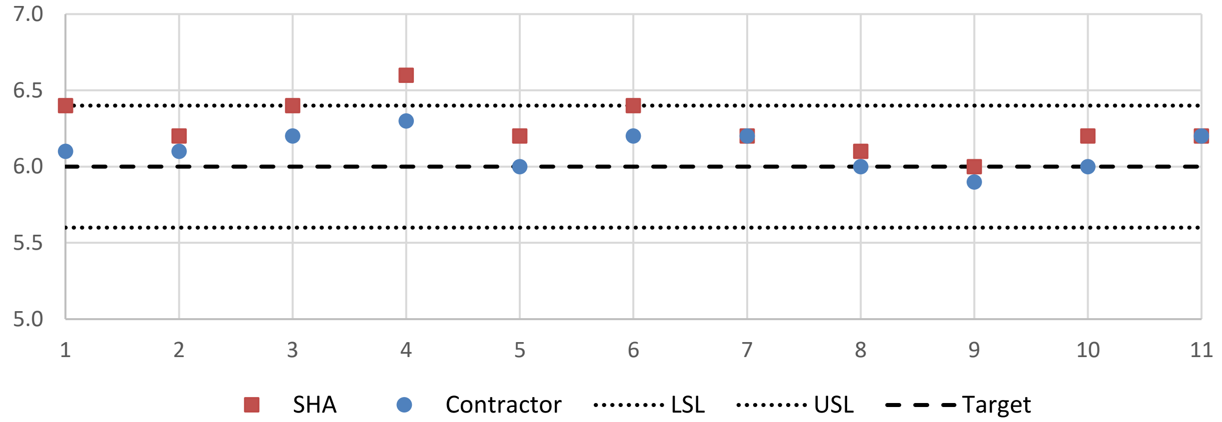

Figure D.14. SHA Raw Data – Asphalt Binder Content – Sample 16-1.

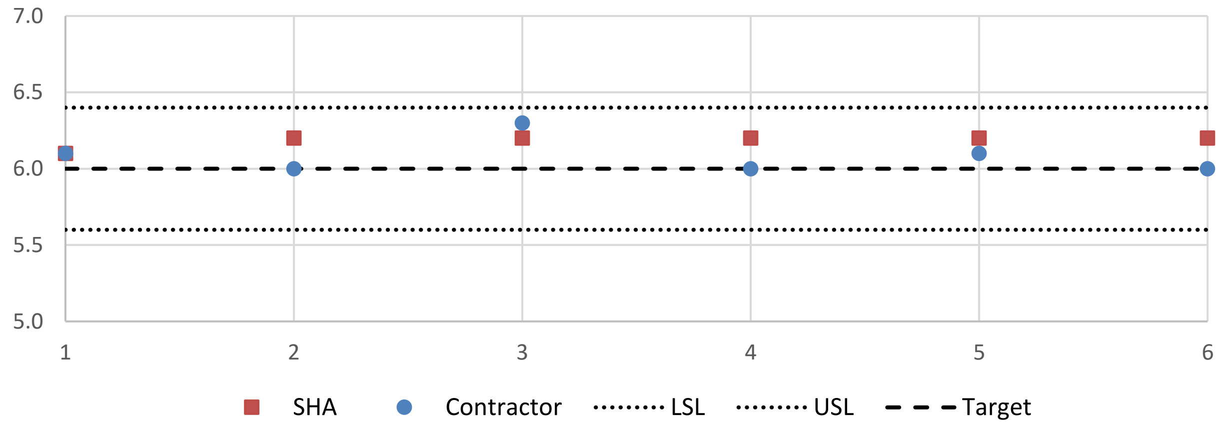

Figure D.15. SHA Raw Data – Asphalt Binder Content – Sample 16-2.

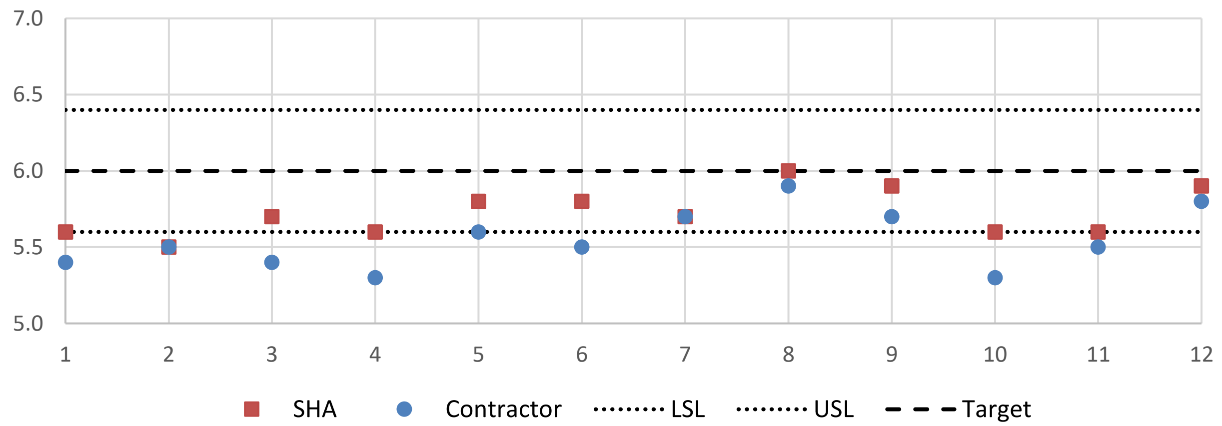

Figure D.16. SHA Raw Data – Asphalt Binder Content – Sample 28-1.

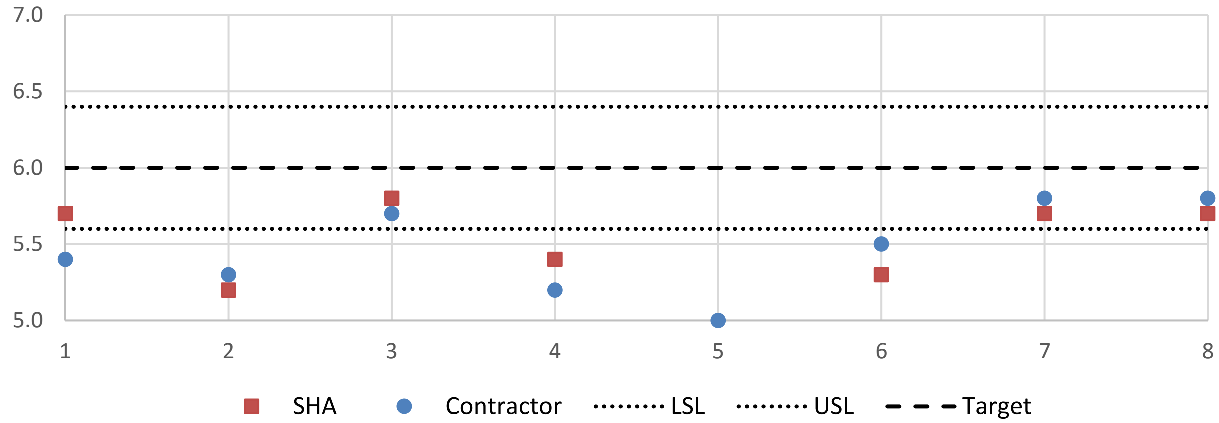

Figure D.17. SHA Raw Data – Asphalt Binder Content – Sample 30-1.

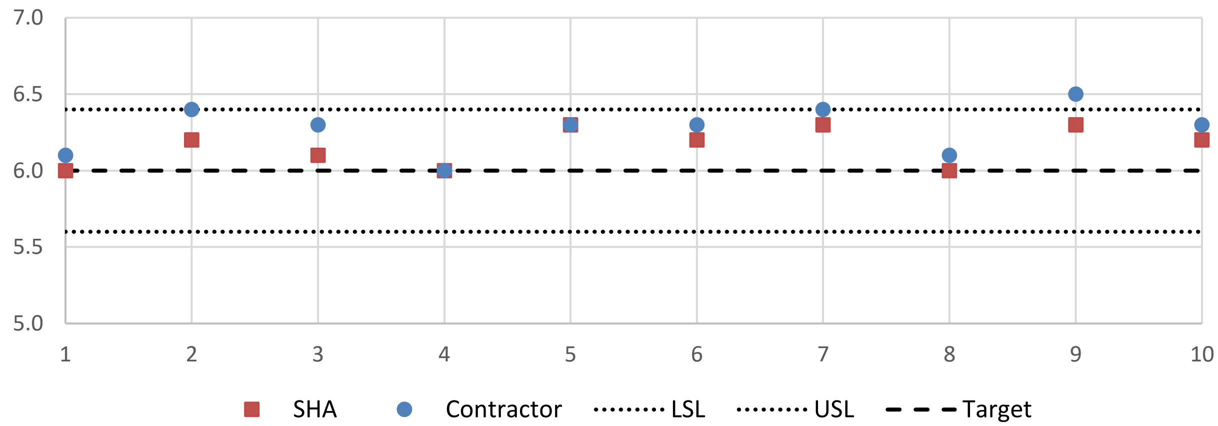

Figure D.18. SHA Raw Data – Asphalt Binder Content – Sample 145-1.

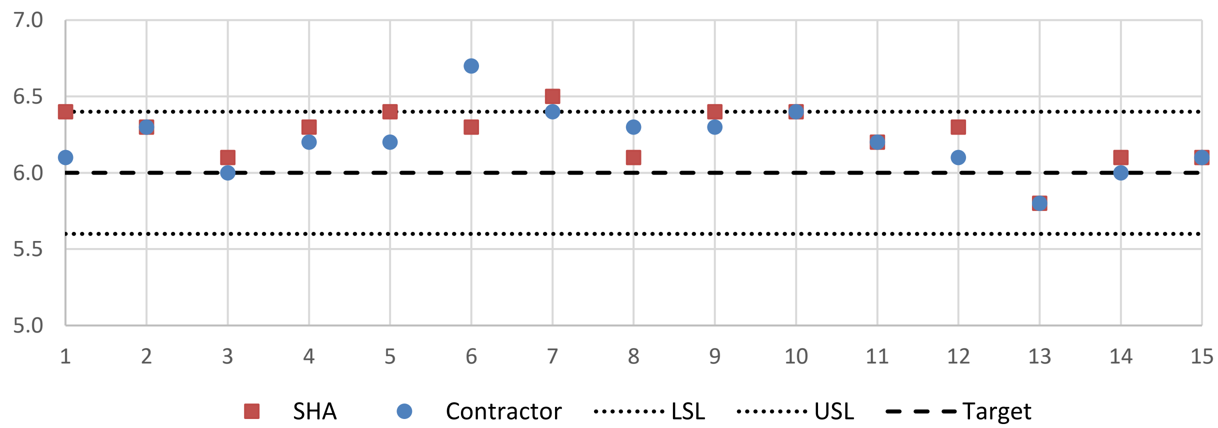

Figure D.19. SHA Raw Data – Asphalt Binder Content – Sample 151-1.

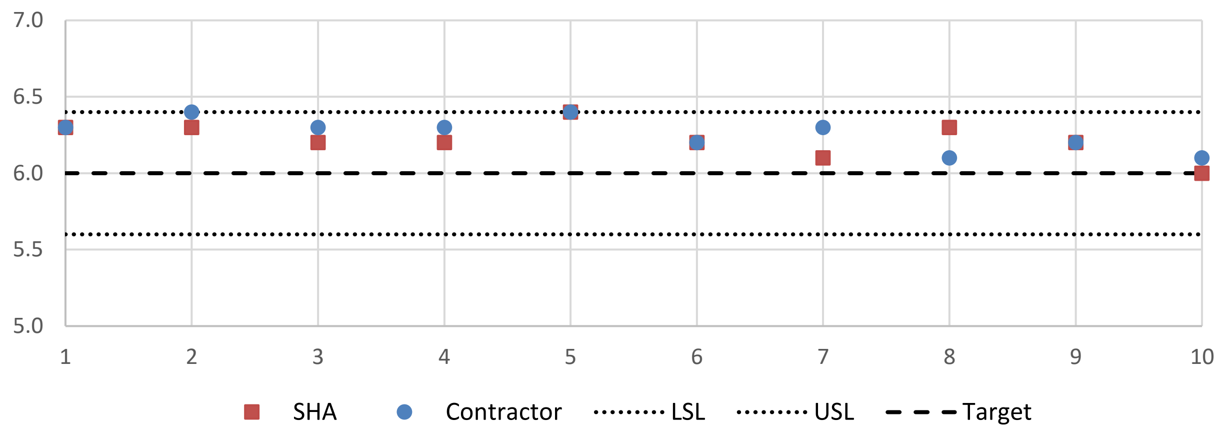

Figure D.20. SHA Raw Data – Asphalt Binder Content – Sample 151-2.

SHA Data Findings

The statistical tests recommended from the numerical simulations, i.e., *F*-test and Welch's *t*-test (unequal variance *t*-test), were used on SHA data according to the sampling, testing, and validation plan presented under the Research Approach Chapter. The results of applying the plan to SHA data are presented in the following sections.

Case 1 SHA results

During the sampling stage, three sublots were randomly selected to represent the SHA sample for validation. The results of the Contractor tests on the sublots corresponding to the SHA samples were excluded from the Contractor sample for the primary validation stage. So, the Contractor sample for primary validation consisted of total number of sublots minus the three SHA sublots. Note that the SHA test results are now independent of the Contractor test results (not from the same sublot). In the primary validation stage, the initial step was testing the SHA and Contractor data sets for outlying observations. The ASTM E178 procedure was applied on both SHA and Contractor samples prior to conducting hypothesis testing ***(Error! Reference source not found.)***. The independent data set of the Contractor was validated against the SHA data set using the *F*-test and Welch's *t*-test at a significant level, *α*, of 0.05. In cases where the Contractor test results were not validated in the primary validation, a secondary validation was conducted comparing the SHA results to the Contractor results from the same sublots using the paired *t*-test.

Air Voids

Eighty six samples qualified from the percent AV data using the six sublots per lot criteria. The results of analysis carried on the 86 samples is presented in Table D.2. The table presents the tally of the hypothesis test results, where the value of 1 was given to the "Pass" results and a value of 0 was given to the "Fail" results. As shown in Table D.2, 8.1 percent (7 of 86) of the sample failed the *F*-test and 3.5 percent (3 of 86) failed Welch's *t*-test. In total, 11.6 percent (10 of 86) samples failed the primary validation; from these 10 samples failing the primary validation, 20 percent (2 of 10) failed the secondary validation. Please note that in Table D.2 there are 88 samples for the paired *t*-test while, because a couple of lots had a variance value close to zero, which disqualified them for the *F*-test and Primary Validation, but, were still qualified for the paired *t*-test.

Table D.2. Case 1 SHA 5 results of percent in-place air voids of HMA

	Independent Samples		Primary Validation	Split Samples		Secondary Validation
	F-test	Welch's *t*-test		Paired *t*-test	D2S	
Pass or Validated	79	83	76	67	84	8
Fail or Non-validated	7	3	10	21	4	2
Total	86	86	86	88	88	10
Percent Fail	8.1%	3.5%	11.6%	23.9%	4.5%	20.0%

The results of the Welch's *t*-test on all 86 samples are presented in Figure D.21. The means ratio is shown on the x-axis, i.e., the ratio of SHA sample mean (μ_1) to the Contractor sample mean (μ_2), and the p-values on the y-axis. However, since the p-values were very small, the values presented on the y-axis are the negative value of the logarithm to base 10 of the p-values [$-\log_{10}$ (p-value)]. As seen in Figure D.21, the p-values take a symmetrical shape around a means ratio of one. The horizontal dotted line in the figure is the threshold value for a 95 percent confidence level ($\alpha = 0.05$). Since [$-\log_{10}(0.05) = 1.3$], all values below the horizontal dotted line represent "Fail" results. Figure D.22 shows similar Welch's *t*-test results as a function of the standard deviations ratio, ratio of SHA sample standard deviation (σ_1) to the Contractor sample standard deviation (σ_2).

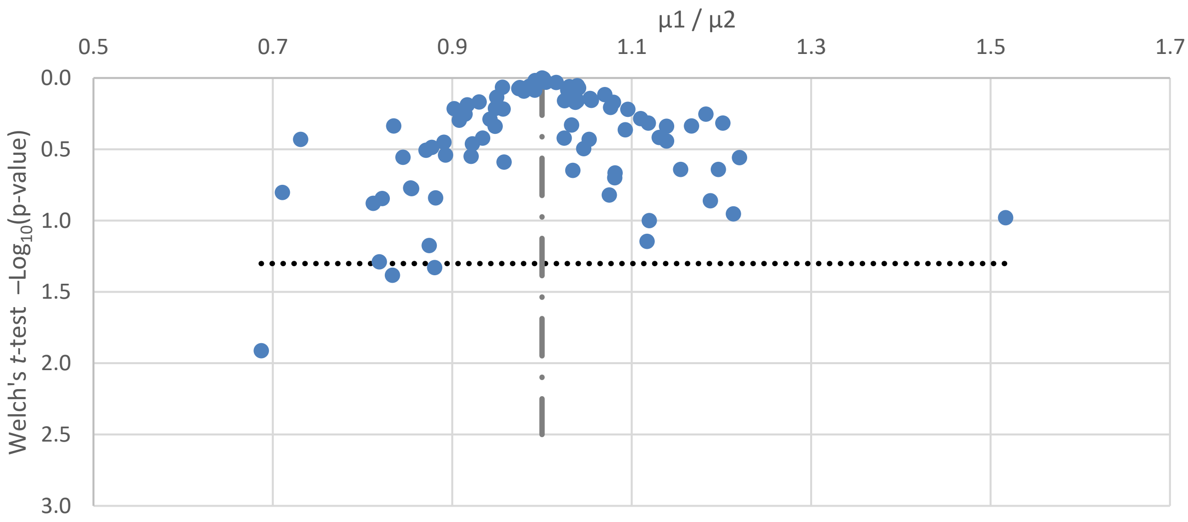

Figure D.21. Case 1, Welch's *t*-test Results as a Function of Means Ratio (μ_1 / μ_2).

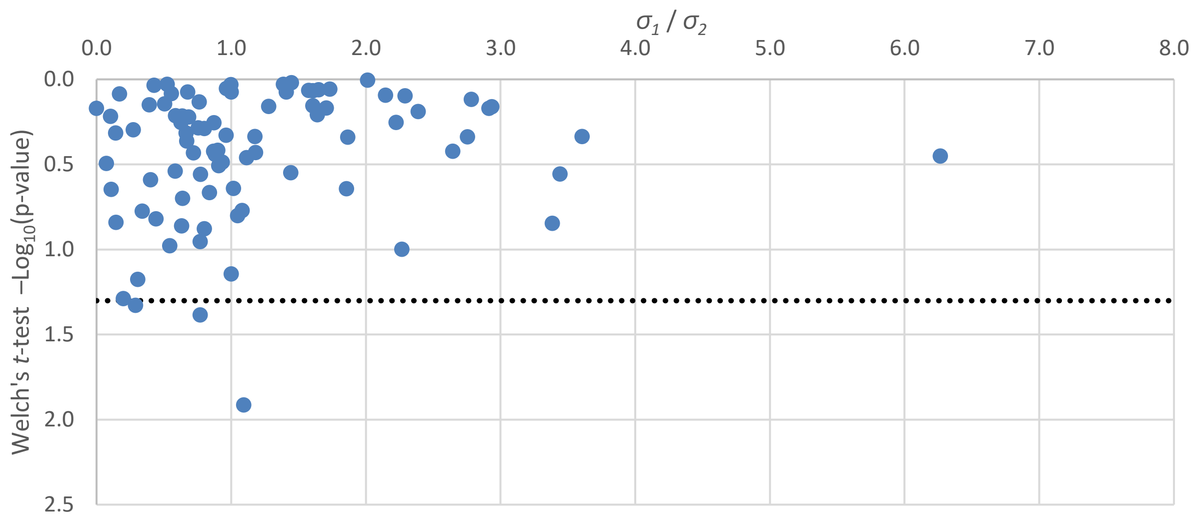

Figure D.22. Case 1, Welch's *t*-test Results as a Function of Standard Deviations Ratio (σ_1 / σ_2).

The results of the *F*-test on all 86 samples are presented in Figure D.23. The standard deviations ratio is shown on the x-axis, i.e., the ratio of SHA sample standard deviation (σ_1) to the Contractor sample standard deviation (σ_2), and the p-values [– $\log_{10}$ (p-value)] on the y-axis. The *F*-test results (Figure D.23) showed a similar trend to what was observed in the Welch's *t*-test results (Figure D.21); the p-values take a symmetrical shape around a standard deviations ratio of one. The horizontal dotted line in the figure is the threshold value for a 95 percent confidence level (α = 0.05). Since [– $\log_{10}$ (0.05) = 1.3], all values below the horizontal dotted line represent "Fail" results. Figure D.24 shows similar *F*-test results as a function of the means ratio, ratio of SHA sample mean (μ_1) to the Contractor sample mean (μ_2).

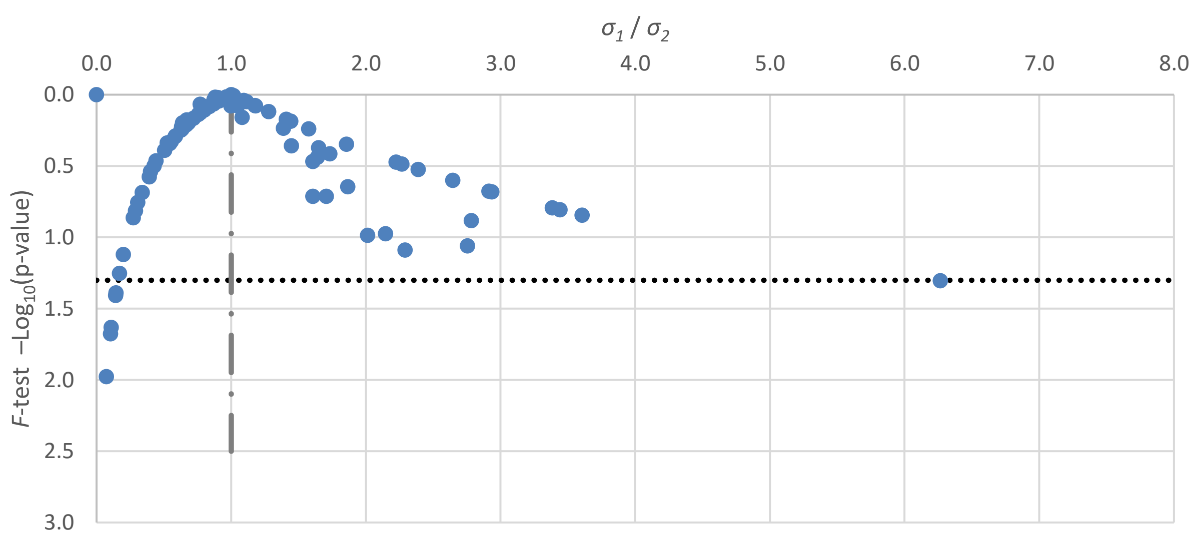

Figure D.23. Case 1, *F*-test Results as a Function of Standard Deviations Ratio (σ_1 / σ_2).

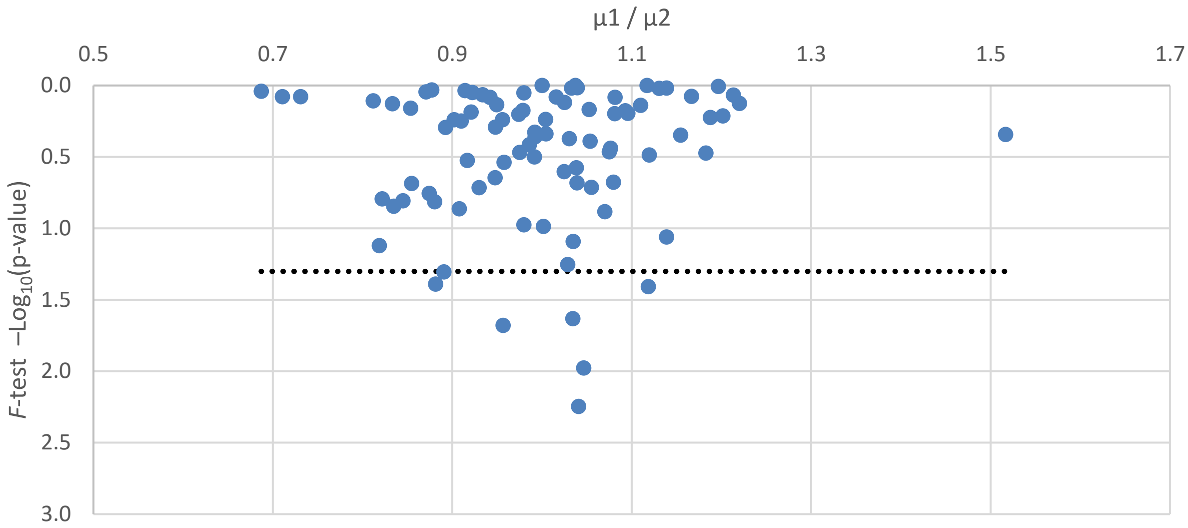

Figure D.24. Case 1, *F*-test Results as a Function of Means Ratio (μ_1 / μ_2).

Although only 10 samples went through to the secondary validation, the paired *t*-test was performed on all available samples. The results of the paired *t*-test on all samples are presented in Figure D.25. The means ratio is shown on the x-axis and the p-values on the y-axis [– $\log_{10}$ (p-value)]. As seen in Figure D.25, the p-values take a less pronounced symmetrical shape around a means ratio of one and seem almost random. The horizontal dotted line in the figure is the threshold value for a 95 percent confidence level (α = 0.05). Since [– $\log_{10}$ (0.05) = 1.3], all values below the horizontal dotted line represent "Fail" results; 23.9 of the samples failed the paired *t*-test. Figure D.26 shows similar paired *t*-test results as a function of the standard deviations ratio, ratio of SHA sample standard deviation (σ_1) to the Contractor sample standard deviation (σ_2).

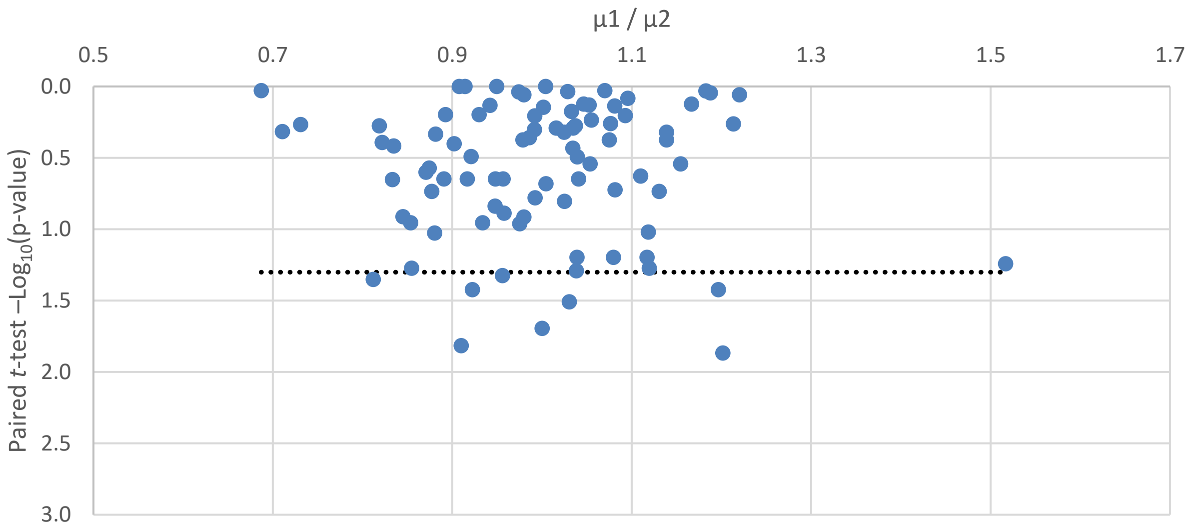

Figure D.25. Case 1, Paired *t*-test Results as a Function of Means Ratio (μ_1 / μ_2).

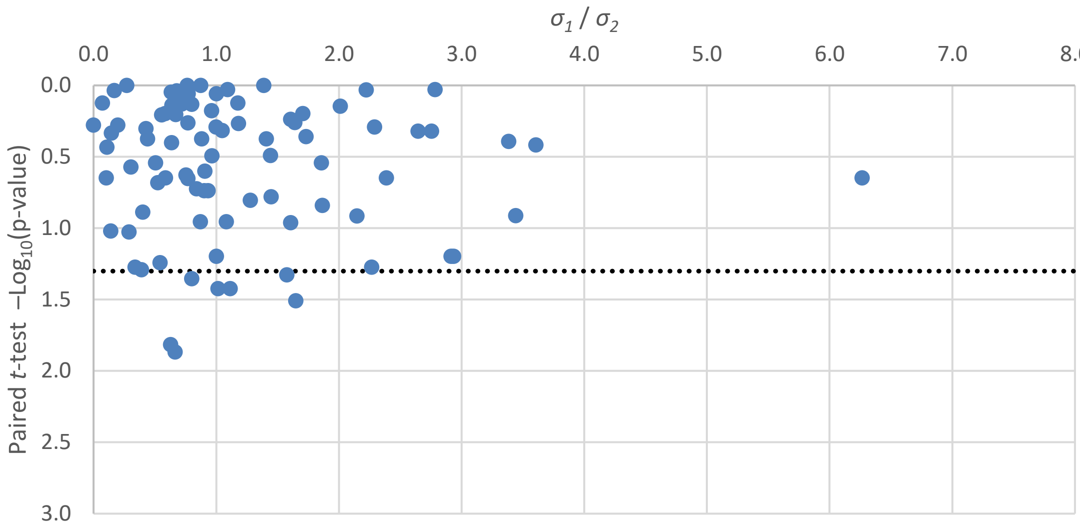

Figure D.26. Case 1, Paired *t*-test Results as a Function of Standard Deviations Ratio (σ_1 / σ_2).

D2S limits

Details of the summary results presented in Table D.2 are presented in Table D.3 through Table D.5. The original SHA and Contractor samples are presented to the left side of the tables under original region. During the sampling stage three sublots were randomly selected to represent the SHA sample for validation. The results of the Contractor tests on the sublots corresponding to the SHA samples were excluded from the Contractor sample for the primary validation stage. So, the Contractor sample for primary validation consisted of the total number of sublots minus the three SHA sublots. Note that the SHA test results are now independent of the Contractor test results (not from the same sublot). This stage is presented in Table D.3 through Table D.5 under independent samples region. The independent data set of the Contractor was validated against the SHA data set using the *F*-test and Welch's *t*-test at a significance level, α, of 0.05, and the results are presented under independent samples region.

In cases where the Contractor test results were not validated in the primary validation, a secondary validation was conducted comparing the SHA results to the Contractor results from the same sublots (split samples) using the paired *t*-test. This stage is presented in Table D.3 through Table D.5 under portions of the table titled Split Samples. The paired *t*-test performed on the split samples was compared to D2S limits performed on the same split samples as shown under the table's split samples region.

The results of SHA data analysis presented in Table D.2, include the results of applying D2S limits on split samples. The paired *t*-test performed on all available split samples indicated that 23.9% of the samples failed the paired *t*-test. However, using the D2S limits on the same split samples only 4.5% failed the D2S limits. In the survey of SHAs presented in Section **Error! Reference source not found.**, a number of SHAs indicated using D2S and $\bar{X} \pm CR$ for validation. These low power tests put SHAs at risk of making wrong acceptance and payment decisions, along with being susceptible to data manipulation and fraud.

Table D.3. SHA Case 1 results of percent in-place air voids of HMA – part 1 of 3

Original				Independent Samples									Split Samples								
#	Project-Lot ID	Agency Sample Size	Contractor Sample Size	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 2 Sample Size	Contractor 2 Sample mean	Contractor 2 Sample sd	*F*-test	UV *t*-test	**Primary Validation**	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 1 Sample Size	Contractor 1 Sample mean	Contractor 1 Sample sd	Paired *t*-test	D2S	**Secondary Validation**
1	1-1	6	6	3	3.9	1.46	3	4.6	0.40	Pass	Pass	**Valid**	5	4.6	0.30	5	4.7	0.29	Pass	Pass	
2	1-2	6	6	3	4.8	0.25	3	4.3	0.25	Pass	Pass	**Valid**	6	4.5	0.34	6	4.4	0.23	Pass	Pass	
3	2-1	6	6	3	4.0	0.59	3	3.6	0.78	Pass	Pass	**Valid**	6	3.6	0.74	6	4.1	0.91	Pass	Pass	
4	2-2	6	6	3	3.8	1.83	3	5.2	1.55	Pass	Pass	**Valid**	6	4.2	1.60	6	4.1	1.68	Pass	Fail	
5	5-4	6	6	3	4.5	0.25	3	4.4	0.64	Pass	Pass	**Valid**	6	4.6	0.37	5	4.0	0.13	Pass	Pass	
6	16-1	11	11	3	4.1	0.51	8	4.2	0.24	Pass	Pass	**Valid**	11	4.0	0.41	11	4.2	0.31	Fail	Pass	
7	16-2	6	6	3	3.8	0.31	3	4.0	0.35	Pass	Pass	**Valid**	6	3.6	0.29	6	4.1	0.35	Fail	Pass	
8	28-1	12	12	3	5.1	0.87	9	4.5	0.97	Pass	Pass	**Valid**	12	4.3	1.10	12	4.7	0.99	Fail	Fail	
9	**30-1**	**8**	**8**	**3**	**3.7**	**1.21**	**5**	**5.2**	**1.15**	**Pass**	**Pass**	**Valid**	**8**	**4.5**	**1.31**	**8**	**4.7**	**1.18**	**Pass**	**Pass**	
10	35-1	6	6	3	5.4	1.10	3	4.5	1.66	Pass	Pass	**Valid**	6	5.0	1.22	6	4.6	1.31	Fail	Pass	
11	40-1	6	6	3	4.8	0.15	3	4.6	0.90	Pass	Pass	**Valid**	5	4.9	0.19	6	4.7	0.63	Pass	Pass	
12	41-1	6	6	3	4.7	1.08	3	4.0	0.92	Pass	Pass	**Valid**	6	4.4	1.18	6	4.4	1.03	Pass	Pass	
13	48-1	7	7	3	3.6	0.67	4	4.0	0.76	Pass	Pass	**Valid**	7	3.8	0.50	7	3.8	0.65	Pass	Pass	
14	48-2	6	6	3	3.2	0.42	3	3.9	0.52	Pass	Pass	**Valid**	6	3.5	0.54	6	3.9	0.54	Pass	Pass	
15	54-1	6	6	3	3.8	0.45	3	3.9	0.67	Pass	Pass	**Valid**	6	3.9	0.47	6	3.8	0.69	Pass	Pass	
16	61-1	7	7	3	4.1	1.31	4	3.8	0.47	Pass	Pass	**Valid**	6	4.4	0.42	7	3.9	0.63	Pass	Pass	
17	66-1	6	6	3	4.1	0.32	3	4.0	0.25	Pass	Pass	**Valid**	5	4.2	0.07	6	3.9	0.38	Pass	Pass	
18	66-2	6	6	3	4.0	0.57	3	4.4	0.91	Pass	Pass	**Valid**	6	4.4	0.70	6	4.1	0.78	Fail	Pass	
19	66-3	6	6	3	2.6	0.35	3	3.8	0.32	Pass	Fail	**N.V.**	6	3.3	0.84	6	3.3	0.76	Pass	Pass	**Valid**
20	66-4	6	6	3	3.8	0.58	3	4.0	0.76	Pass	Pass	**Valid**	6	3.7	0.46	6	3.9	0.65	Pass	Pass	
21	67-1	6	6	3	3.4	1.08	3	3.3	0.06	Fail	Pass	**N.V.**	6	3.4	0.72	6	3.3	0.62	Pass	Pass	**Valid**
22	74-1	11	11	3	3.9	0.76	8	3.7	0.33	Pass	Pass	**Valid**	11	4.0	0.43	11	3.7	0.34	Pass	Pass	
23	80-1	8	8	3	3.8	0.36	4	3.8	0.00				8	3.9	0.32	8	3.7	0.26	Fail	Pass	
24	83-1	9	9	3	3.8	0.12	6	3.9	0.29	Pass	Pass	**Valid**	9	3.7	0.24	9	3.9	0.23	Fail	Pass	
25	86-1	11	11	3	4.2	0.26	7	3.9	0.41	Pass	Pass	**Valid**	11	3.9	0.59	10	4.0	0.39	Pass	Pass	
26	86-2	7	7	3	4.0	0.25	4	4.0	0.59	Pass	Pass	**Valid**	6	3.9	0.28	7	4.1	0.55	Pass	Pass	
27	93-1	8	8	3	3.9	0.00	5	3.8	0.69				8	3.8	0.43	6	3.8	0.16	Pass	Pass	
28	93-2	9	9	3	3.8	0.21	6	3.8	0.40	Pass	Pass	**Valid**	9	3.8	0.26	9	3.9	0.37	Pass	Pass	
29	95-1	15	15	3	4.3	1.15	12	4.6	0.68	Pass	Pass	**Valid**	15	4.4	0.74	15	4.5	0.80	Pass	Pass	
30	95-2	7	7	3	3.9	0.40	4	4.2	0.51	Pass	Pass	**Valid**	7	3.9	0.55	7	4.1	0.48	Pass	Pass	
31	98-1	6	6	3	3.1	0.15	3	3.7	0.45	Pass	Pass	**Valid**	6	3.1	0.36	6	3.6	0.33	Fail	Pass	
32	98-2	6	6	3	3.4	0.06	3	3.9	0.20	Pass	Fail	**N.V.**	6	3.7	0.31	6	3.9	0.26	Pass	Pass	**Valid**
33	98-3	6	6	3	4.0	0.12	3	4.1	0.21	Pass	Pass	**Valid**	5	4.1	0.19	6	4.0	0.20	Pass	Pass	
34	103-1	6	6	3	5.0	1.27	3	4.6	0.44	Pass	Pass	**Valid**	6	4.7	0.93	6	5.0	0.85	Fail	Pass	
35	104-1	6	6	3	4.6	0.67	3	4.7	0.47	Pass	Pass	**Valid**	6	4.5	0.45	6	4.7	0.43	Pass	Pass	
36	104-2	6	6	3	3.1	0.55	3	3.4	0.87	Pass	Pass	**Valid**	6	3.1	0.60	6	3.4	0.60	Fail	Pass	
37	110-1	11	11	3	4.0	0.98	8	3.9	0.99	Pass	Pass	**Valid**	11	4.0	0.83	11	3.9	0.92	Pass	Pass	
38	112-1	7	7	3	4.5	1.15	4	4.4	0.70	Pass	Pass	**Valid**	7	4.1	0.92	7	4.7	0.85	Fail	Pass	

Table D.4. SHA Case 1 results of percent in-place air voids of HMA – part 2 of 3

Original				Independent Samples									Split Samples								
#	Project-Lot ID	Agency Sample Size	Contractor Sample Size	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 2 Sample Size	Contractor 2 Sample mean	Contractor 2 Sample sd	*F*-test	UV *t*-test	Primary Validation	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 1 Sample Size	Contractor 1 Sample mean	Contractor 1 Sample sd	Paired *t*-test	D2S	Secondary Validation
39	114-1	7	7	3	4.1	0.29	4	4.1	0.21	Pass	Pass	Valid	7	4.1	0.19	7	4.1	0.28	Pass	Pass	
40	115-1	6	6	3	4.0	0.87	3	4.7	0.25	Pass	Pass	Valid	6	4.0	0.61	6	4.7	0.54	Fail	Pass	
41	122-1	0	0																Pass	Pass	
42	127-1	21	21	3	4.4	0.06	18	4.2	0.79	Fail	Pass	N.V.	20	4.0	0.48	21	4.2	0.75	Pass	Pass	Valid
43	127-2	15	15	3	3.9	0.12	12	4.0	1.12	Fail	Pass	N.V.	15	3.9	0.92	15	4.0	1.01	Pass	Pass	Valid
44	127-3	14	14	3	4.6	0.58	11	3.8	0.75	Pass	Pass	Valid	14	4.1	0.68	14	4.1	0.91	Pass	Fail	
45	**134-1**	**8**	**8**	**3**	**4.6**	**0.61**	**5**	**4.7**	**0.61**	**Pass**	**Pass**	**Valid**	**8**	**4.7**	**0.54**	**8**	**4.6**	**0.51**	**Pass**	**Pass**	
46	136-1	9	9	3	3.9	0.80	6	4.0	0.50	Pass	Pass	Valid	9	4.2	0.56	9	3.9	0.63	Fail	Pass	
47	138-1	6	6	3	5.0	0.15	3	4.5	1.08	Fail	Pass	N.V.	6	4.8	0.68	3	4.8	0.00			N.V.
48	140-1	6	6	3	4.9	0.42	3	5.1	0.71	Pass	Pass	Valid	6	5.0	0.39	6	5.0	0.55	Pass	Pass	
49	140-2	6	6	3	4.6	0.46	3	4.4	0.91	Pass	Pass	Valid	6	4.6	0.67	6	4.4	0.67	Pass	Pass	
50	141-1	6	6	3	3.4	0.51	3	3.1	0.75	Pass	Pass	Valid	6	3.5	0.46	6	3.3	0.60	Pass	Pass	
51	145-1	10	10	3	4.7	0.20	7	4.4	0.45	Pass	Pass	Valid	10	4.6	0.61	10	4.4	0.39	Pass	Pass	
52	148-1	9	9	3	4.3	0.90	6	4.3	0.62	Pass	Pass	Valid	9	4.3	0.88	7	4.1	0.30	Pass	Pass	
53	149-1	7	7	3	3.5	0.10	4	4.3	0.51	Pass	Pass	Valid	6	3.8	0.34	7	3.9	0.58	Pass	Pass	
54	150-1	6	6	3	3.2	0.32	3	3.4	0.29	Pass	Pass	Valid	5	3.4	0.11	6	3.4	0.27	Pass	Pass	
55	151-1	15	15	3	3.5	0.52	12	4.1	0.48	Pass	Pass	Valid	15	3.6	0.36	15	4.1	0.45	Fail	Pass	
56	151-2	10	10	3	3.9	0.40	6	4.2	0.22	Pass	Pass	Valid	10	3.8	0.29	9	4.2	0.23	Pass	Pass	
57	152-1	28	28	3	4.2	0.06	25	4.0	0.53	Fail	Pass	N.V.	28	4.2	0.52	28	4.0	0.51	Fail	Pass	N.V.
58	159-1	6	6	3	3.3	0.49	3	3.8	0.53	Pass	Pass	Valid	6	3.4	0.38	6	3.8	0.64	Fail	Pass	
59	**160-1**	**28**	**28**	**3**	**4.6**	**0.92**	**25**	**4.4**	**0.58**	**Pass**	**Pass**	**Valid**	**27**	**3.9**	**0.51**	**28**	**4.4**	**0.63**	**Pass**	**Pass**	
60	169-1	6	6	3	3.5	0.59	3	4.3	0.17	Pass	Pass	Valid	6	3.8	0.50	5	4.2	0.18	Pass	Pass	
61	169-2	6	6	3	4.4	0.67	3	3.6	0.86	Pass	Pass	Valid	6	3.7	1.20	5	4.3	0.36	Pass	Pass	
62	170-1	9	9	3	4.6	0.21	6	5.3	0.68	Pass	Pass	Valid	9	4.6	0.61	8	5.1	0.33	Pass	Pass	
63	171-1	17	17	3	5.1	0.90	14	4.5	1.02	Pass	Pass	Valid	17	4.5	1.06	17	4.7	1.08	Pass	Fail	
64	174-1	6	6	3	3.6	1.31	3	3.8	0.83	Pass	Pass	Valid	6	3.5	1.03	6	4.0	0.94	Fail	Pass	
65	174-2	6	6	3	4.7	0.64	3	4.1	0.35	Pass	Pass	Valid	6	4.3	0.60	6	4.6	0.59	Pass	Pass	
66	174-3	6	6	3	4.3	0.64	3	4.9	0.70	Pass	Pass	Valid	6	4.2	0.63	6	4.7	0.60	Fail	Pass	
67	182-1	6	6	3	4.1	1.51	3	3.5	0.68	Pass	Pass	Valid	5	3.5	0.49	6	3.8	1.35	Pass	Pass	
68	182-2	6	6	3	5.0	0.35	3	4.5	0.15	Pass	Pass	Valid	5	5.0	0.25	6	4.6	0.21	Pass	Pass	
69	182-3	6	6	3	4.5	0.56	3	3.0	1.03	Pass	Pass	Valid	6	3.8	1.03	6	3.7	1.07	Fail	Pass	
70	186-1	6	6	3	4.4	0.61	3	4.3	0.21	Pass	Pass	Valid	6	4.4	0.48	6	4.2	0.42	Pass	Pass	
71	187-1	6	6	3	4.4	0.25	3	4.1	0.30	Pass	Pass	Valid	6	4.5	0.29	6	4.1	0.21	Fail	Pass	
72	187-2	6	6	3	4.2	0.20	3	4.1	0.21	Pass	Pass	Valid	6	4.3	0.43	6	4.1	0.36	Pass	Pass	
73	**190-1**	**8**	**8**	**3**	**5.0**	**1.16**	**5**	**4.4**	**0.42**	**Pass**	**Pass**	**Valid**	**8**	**4.6**	**0.80**	**8**	**4.6**	**0.56**	**Pass**	**Pass**	
74	193-1	6	6	3	4.0	0.06	3	4.5	0.40	Fail	Pass	N.V.	6	4.2	0.31	6	4.4	0.43	Pass	Pass	Valid

Table D.5. SHA Case 1 results of percent in-place air voids of HMA – part 3 of 3

Original				Independent Samples									Split Samples								
#	Project-Lot ID	Agency Sample Size	Contractor Sample Size	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 2 Sample Size	Contractor 2 Sample mean	Contractor 2 Sample sd	*F*-test	UV *t*-test	**Primary Validation**	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 1 Sample Size	Contractor 1 Sample mean	Contractor 1 Sample sd	Paired *t*-test	D2S	**Secondary Validation**
75	194-1	7	7	3	4.1	0.72	3	4.6	0.12	Fail	Pass	**N.V.**	7	4.2	0.72	7	4.0	0.82	Pass	Pass	**Valid**
76	197-1	6	6	3	3.1	0.30	3	3.4	0.21	Pass	Pass	**Valid**	6	3.1	0.20	5	3.3	0.19	Pass	Pass	
77	205-1	14	14	3	4.2	0.74	11	4.2	0.37	Pass	Pass	**Valid**	14	4.1	0.46	14	4.3	0.34	Fail	Pass	
78	218-1	8	8	3	4.1	0.83	5	3.8	0.51	Pass	Pass	**Valid**	8	4.0	0.65	8	3.9	0.57	Pass	Pass	
79	218-2	7	7	3	3.5	0.46	4	3.6	0.26	Pass	Pass	**Valid**	7	3.6	0.33	7	3.4	0.26	Pass	Pass	
80	218-3	6	6	3	3.7	1.04	3	4.0	0.44	Pass	Pass	**Valid**	5	4.2	0.38	5	4.1	0.36	Pass	Pass	
81	222-1	6	6	3	3.9	0.32	3	4.3	0.55	Pass	Pass	**Valid**	6	3.9	0.69	6	4.1	0.48	Pass	Pass	
82	230-1	6	6	3	3.3	0.23	3	4.0	0.30	Pass	Fail	**N.V.**	6	3.6	0.36	6	3.8	0.34	Pass	Pass	**Valid**
83	235-1	7	7	3	3.8	0.35	4	3.2	0.55	Pass	Pass	**Valid**	7	3.6	0.51	7	3.5	0.56	Pass	Pass	
84	238-1	6	6	3	3.5	1.02	3	3.4	1.06	Pass	Pass	**Valid**	6	3.5	0.74	6	3.3	0.77	Pass	Pass	
85	240-1	6	6	3	3.9	0.23	3	4.3	0.85	Pass	Pass	**Valid**	6	4.0	0.48	6	4.1	0.68	Pass	Pass	
86	240-2	6	6	3	4.7	0.23	3	4.4	0.32	Pass	Pass	**Valid**	6	4.7	0.15	6	4.5	0.28	Pass	Pass	
87	242-1	6	6	3	4.7	0.67	3	3.9	0.66	Pass	Pass	**Valid**	6	4.3	0.68	6	4.2	0.65	Pass	Pass	
88	**243-1**	**8**	**8**	**3**	**4.0**	**0.46**	**5**	**3.7**	**0.68**	**Pass**	**Pass**	**Valid**	**8**	**3.6**	**0.70**	**8**	**3.9**	**0.70**	**Pass**	**Pass**	
89	316-1	6	6	3	4.2	0.15	3	4.1	0.06	Pass	Pass	**Valid**	6	4.0	0.34	6	4.1	0.23	Pass	Pass	
Pass or Valid										79	83	76							67	84	8
Fail or N.V.										7	3	10							21	4	2
Total										86	86	86							88	88	10
Pass or Valid										91.9%	96.5%	88.4%							76.1%	95.5%	80.0%
Fail or N.V.										8.1%	3.5%	11.6%							23.9%	4.5%	20.0%

Asphalt Binder Content (AC)

Ninety-nine samples qualified from the percent AC data using the six sublots per lot criteria. The results of analysis carried on the 99 samples is presented in Table D.6, the table presents the tally of the hypothesis test results, where the value of 1 was given to the "Pass" results and a value of 0 was given to the "Fail" results. As shown in Table D.6, only 1.0 percent (1 of 99) of the samples failed the *F*-test and 10.1 percent (10 of 99) failed Welch's *t*-test. In total, 11.1 percent (11 of 99) samples failed the primary validation; from these 11 samples failing the primary validation, 9.1 percent (1 of 11) failed the secondary validation. Please note that there are only 98 samples for the paired *t*-test. The paired *t*-test requires an equal sample size for both samples, and in case(s) where the sample sizes where not equal, the paired *t*-test results were excluded.

Table D.6. Case 1 SHA 5 results of percent Asphalt binder content of HMA

–	Independent Samples		**Primary Validation**	Split Samples		**Secondary Validation**
	F-test	Welch's *t*-test		Paired *t*-test	D2S	
Pass or Validated	98	89	88	90	80	10
Fail or Non-validated	1	10	11	8	18	1
Total	99	99	99	98	98	11
Percent Fail	1.0%	10.1%	11.1%	8.2%	18.4%	9.1%

–No data

The results of the Welch's *t*-test on all 99 samples are presented in Figure D.27. The means ratio is shown on the x-axis, i.e., the ratio of SHA sample mean (μ_1) to the Contractor sample mean (μ_2), and the p-values on the y-axis. However, since the p-values were very small, the values presented on the y-axis are the negative value of the logarithm to base 10 of the p-values [$-\log_{10}$ (p-value)]. As seen in Figure D.27, the p-values take a symmetrical shape around a means ratio of one. The horizontal dotted line in the figure is the threshold value for a 95 percent confidence level ($\alpha = 0.05$). Since [$-\log_{10}(0.05) = 1.3$]; all values below the horizontal dotted line represent "Fail" results. Figure D.28 shows similar Welch's *t*-test results as a function of the standard deviations ratio, ratio of SHA sample standard deviation (σ_1) to the Contractor sample standard deviation (σ_2).

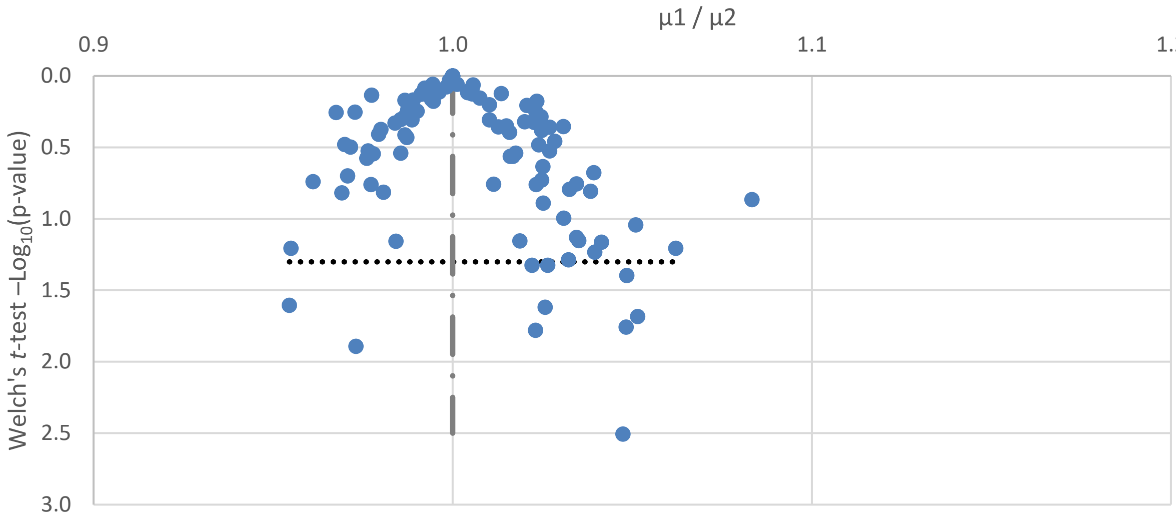

Figure D.27. Case 1, Welch's *t*-test Results as a Function of Means Ratio (μ_1 / μ_2).

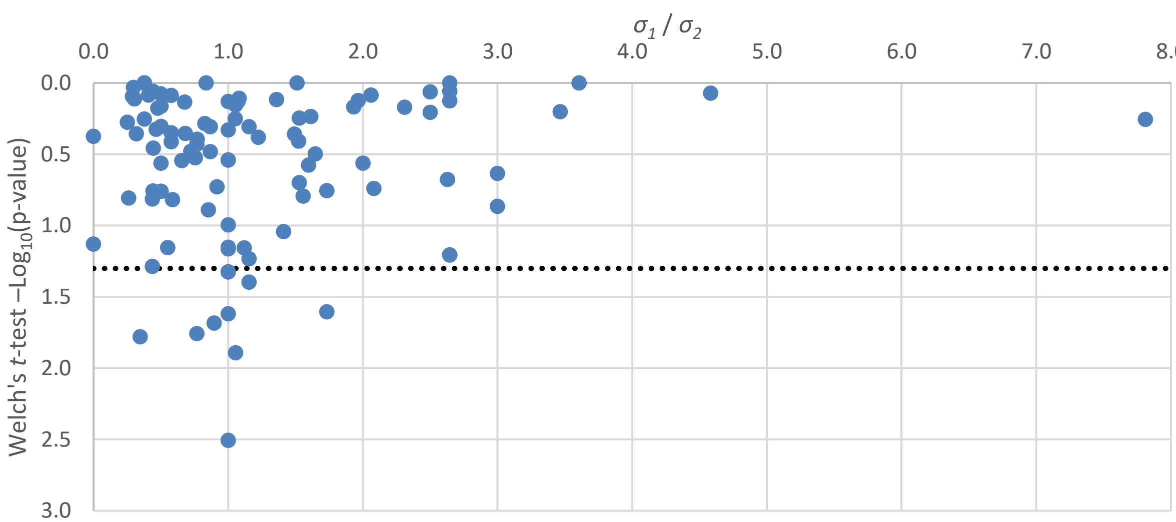

Figure D.28. Case 1, Welch's *t*-test Results as a Function of Standard Deviations Ratio (σ_1 / σ_2).

The results of the *F*-test on all 99 samples are presented in Figure D.29. The standard deviations ratio is shown on the x-axis, i.e., the ratio of SHA sample standard deviation (σ_1) to the Contractor sample standard deviation (σ_2), and the p-values [$-\log_{10}$ (p-value)] on the y-axis. The *F*-test results (Figure D.29) showed a similar trend to what was observed in the Welch's *t*-test results (Figure D.27); the p-values take a symmetrical shape around a standard deviations ratio of one. The horizontal dotted line in the figure is the threshold value for a 95 percent confidence level (α = 0.05). Since [$-\log_{10}$ (0.05) = 1.3], all values below the horizontal dotted line represent "Fail" results. Figure D.30 show similar *F*-test results as a function of the means ratio, ratio of SHA sample mean (μ_1) to the Contractor sample mean (μ_2).

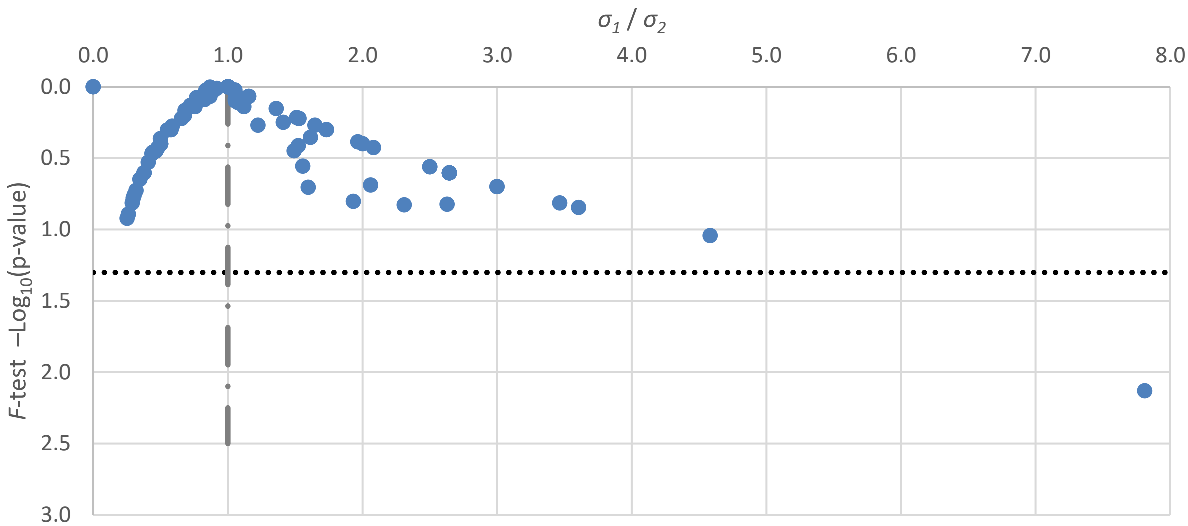

Figure D.29. Case 1, *F*-test Results as a Function of Standard Deviations Ratio (σ_1 / σ_2).

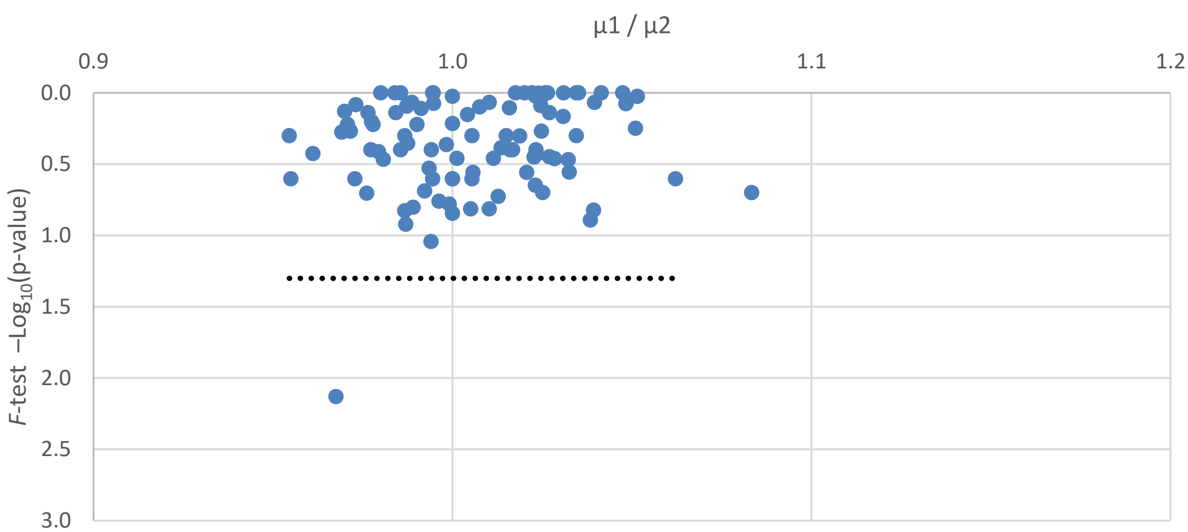

Figure D.30. Case 1, *F*-test Results as a Function of Means Ratio (μ_1 / μ_2).

Only 11 samples went through to the secondary validation. The paired *t*-test was performed on all available samples. However, the sample size was limited this time to three to investigate the influence of a small sample size. The results of the paired *t*-test on all samples are presented in Figure D.31. The means ratio is shown on the x-axis and the p-values on the y-axis [– $\log_{10}$ (p-value)]. As seen in Figure D.31, the p-values take a less pronounced symmetrical shape around a means ratio of one and seem almost random. The horizontal dotted line in the figure is the threshold value for a 95 percent confidence level (α = 0.05). Since [– $\log_{10}$ (0.05) = 1.3], all values below the horizontal dotted line represent "Fail" results, 8.2 percent of the samples failed the paired *t*-

test. Figure D.32 shows similar paired *t*-test results as a function of the standard deviations ratio, ratio of SHA sample standard deviation (σ_1) to the Contractor sample standard deviation (σ_2).

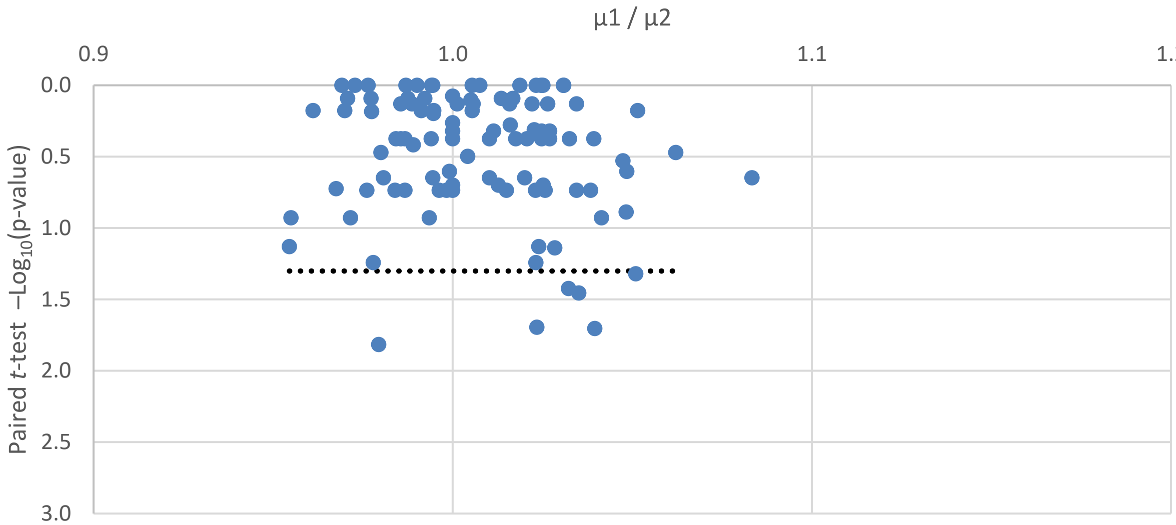

Figure D.31. Case 1, Paired *t*-test Results as a Function of Means Ratio (μ_1 / μ_2).

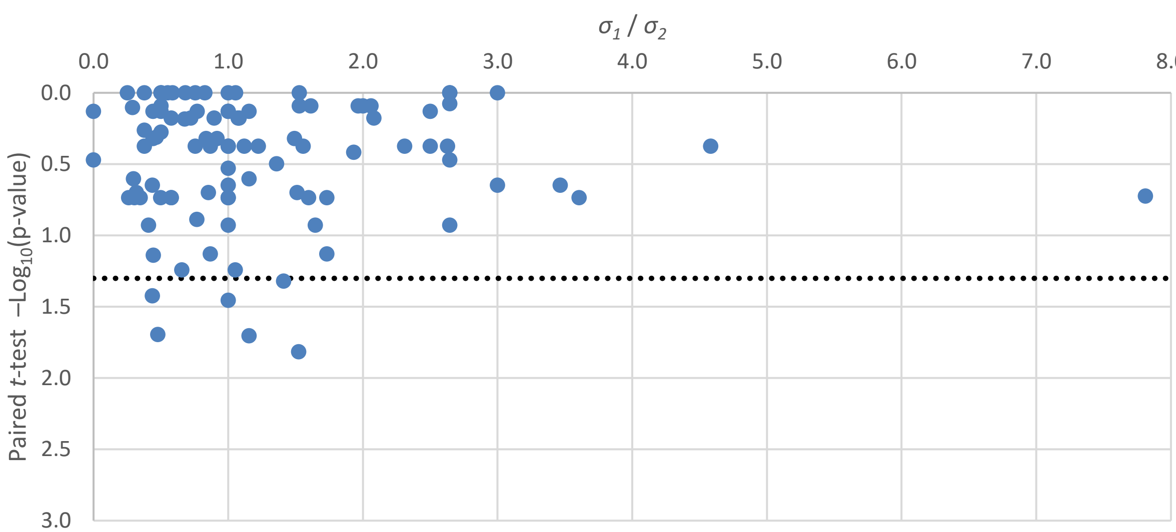

Figure D.32. Case 1, Paired *t*-test Results as a Function of Standard Deviations Ratio (σ_1 / σ_2).

D2S limits

Details of the summary results presented in Table D.6 are presented in Table D.7 through Table D.9. The original SHA and Contractor samples are presented to the left side of the tables under original region. During the sampling stage three sublots were randomly selected to represent the SHA sample for validation. The results of the Contractor tests on the sublots corresponding to the SHA samples were excluded from the Contractor sample for the primary validation stage. So, the Contractor sample for primary validation consisted of the total number of sublots minus the three

SHA sublots. Note that the SHA test results are now independent of the Contractor test results (not from the same sublot). This stage is presented in Table D.7 through Table D.9 under independent samples region. The independent data set of the Contractor was validated against the SHA data set using the *F*-test and Welch's *t*-test at a significance level, α, of 0.05, and the results are presented under independent samples region.

In cases where the Contractor test results were not validated in the primary validation, a secondary validation was conducted comparing the SHA results to the Contractor results from the same sublots (split samples) using the paired *t*-test. This stage is presented in Table D.7 through Table D.9 under split samples region. The paired *t*-test performed on the split samples was compared to D2S limits performed on the same split samples as shown under the table's split samples region.

The results of the SHA data analysis presented in Table D.6 include the results of applying D2S limits on split samples. The paired *t*-test performed on 3 vs 3 split samples indicated that 8.2% of the samples failed the paired *t*-test. However, using the D2S limits on the same split samples 18.4% failed the D2S limits.

Table D.7. SHA Case 1 results of percent Asphalt binder content of HMA – part 1 of 3

Original				Independent Samples									Split Samples								
#	Project-Lot ID	Agency Sample Size	Contractor Sample Size	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 2 Sample Size	Contractor 2 Sample mean	Contractor 2 Sample sd	*F*-test	UV *t*-test	Primary Validation	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 1 Sample Size	Contractor 1 Sample mean	Contractor 1 Sample sd	Paired *t*-test	D2S	Secondary Validation
1	1-1	6	6	3	6.0	0.15	3	6.1	0.40	Pass	Pass	Valid	3	6.0	0.15	3	6.0	0.12	Pass	Pass	
2	1-2	6	6	3	5.9	0.10	3	6.0	0.15	Pass	Pass	Valid	3	5.9	0.10	3	6.0	0.15	Pass	Pass	
3	2-1	6	6	3	6.2	0.12	3	6.2	0.00				3	6.2	0.12	3	6.2	0.21	Pass	Pass	
4	2-2	6	6	3	6.1	0.15	3	6.2	0.15	Pass	Pass	Valid	3	6.1	0.15	3	6.2	0.17	Pass	Pass	
5	5-4	6	6	3	6.1	0.12	3	6.0	0.06	Pass	Pass	Valid	3	6.1	0.12	3	6.0	0.15	Pass	Pass	
6	16-1	11	11	3	6.3	0.12	8	6.1	0.14	Pass	Pass	Valid	3	6.3	0.12	3	6.1	0.10	Pass	Pass	
7	16-2	6	6	3	6.2	0.06	3	6.0	0.06	Pass	Fail	N.V.	3	6.2	0.06	3	6.1	0.15	Pass	Pass	Valid
8	28-1	12	12	3	5.7	0.17	9	5.6	0.20	Pass	Pass	Valid	3	5.7	0.17	3	5.5	0.20	Pass	Pass	
9	**30-1**	**8**	**8**	**3**	**5.6**	**0.23**	**5**	**5.4**	**0.34**	**Pass**	**Pass**	Valid	**3**	**5.6**	**0.23**	**3**	**5.6**	**0.21**	**Pass**	**Pass**	
10	35-2	6	6	3	5.9	0.12	3	6.0	0.12	Pass	Pass	Valid	3	5.9	0.12	3	5.8	0.21	Pass	Pass	
11	40-2	6	6	3	5.9	0.26	3	5.8	0.25	Pass	Pass	Valid	3	5.9	0.26	3	5.8	0.29	Pass	Pass	
12	41-2	6	6	3	5.9	0.31	3	6.0	0.12	Pass	Pass	Valid	3	5.9	0.31	3	5.9	0.12	Pass	Pass	
13	48-1	7	7	3	5.5	0.10	4	5.7	0.17	Pass	Pass	Valid	3	5.5	0.10	3	5.5	0.10	Pass	Pass	
14	48-2	6	6	3	5.7	0.10	3	5.7	0.26	Pass	Pass	Valid	3	5.7	0.10	3	5.6	0.06	Pass	Pass	
15	54-1	6	6	3	5.6	0.21	3	5.4	0.25	Pass	Pass	Valid	3	5.6	0.21	3	5.6	0.06	Pass	Pass	
16	61-1	7	7	3	5.5	0.45	4	5.7	0.06	Fail	Pass	N.V.	3	5.5	0.45	3	5.8	0.21	Pass	Fail	Valid
17	66-2	6	6	3	5.8	0.06	3	5.8	0.15	Pass	Pass	Valid	3	5.8	0.06	3	5.9	0.26	Pass	Fail	
18	66-3	6	6	3	6.0	0.17	3	5.8	0.10	Pass	Pass	Valid	3	6.0	0.17	3	5.9	0.15	Pass	Pass	
19	66-4	6	6	3	6.0	0.00	3	5.8	0.10				3	6.0	0.00	3	6.0	0.15			
20	66-5	6	6	3	5.9	0.06	3	5.7	0.12	Pass	Pass	Valid	3	5.9	0.06	3	5.9	0.32	Pass	Fail	
21	67-1	6	6	3	5.8	0.21	3	6.0	0.10	Pass	Pass	Valid	3	5.8	0.21	3	5.8	0.06	Pass	Pass	
22	74-1	11	11	3	5.7	0.26	8	5.6	0.18	Pass	Pass	Valid	3	5.7	0.26	3	5.8	0.10	Pass	Pass	
23	**80-1**	**8**	**8**	**3**	**5.6**	**0.06**	**5**	**5.6**	**0.23**	**Pass**	**Pass**	Valid	**3**	**5.6**	**0.06**	**3**	**5.6**	**0.15**	**Pass**	**Pass**	
24	83-1	9	9	3	5.6	0.21	6	5.7	0.19	Pass	Pass	Valid	3	5.6	0.21	3	5.6	0.30	Pass	Pass	
25	86-1	11	11	3	5.7	0.10	8	5.4	0.13	Pass	Fail	N.V.	3	5.7	0.10	3	5.5	0.15	Pass	Pass	Valid
26	86-3	7	7	3	5.6	0.06	4	5.4	0.22	Pass	Pass	Valid	3	5.6	0.06	3	5.6	0.12	Pass	Pass	
27	**93-1**	**8**	**8**	**3**	**6.3**	**0.06**	**5**	**6.4**	**0.05**	**Pass**	**Fail**	N.V.	**3**	**6.3**	**0.06**	**3**	**6.4**	**0.06**	**Fail**	**Pass**	N.V.
28	93-2	9	9	3	6.4	0.06	6	6.3	0.10	Pass	Pass	Valid	3	6.4	0.06	3	6.4	0.12	Pass	Pass	
29	95-1	15	15	3	6.7	0.06	12	6.6	0.13	Pass	Pass	Valid	3	6.7	0.06	3	6.6	0.25	Pass	Pass	
30	95-2	7	7	3	6.8	0.25	4	6.6	0.10	Pass	Pass	Valid	3	6.8	0.25	3	6.7	0.12	Pass	Pass	
31	98-1	6	6	3	6.2	0.21	3	6.2	0.06	Pass	Pass	Valid	3	6.2	0.21	3	6.0	0.15	Pass	Pass	
32	98-2	6	6	3	6.2	0.15	3	6.1	0.06	Pass	Pass	Valid	3	6.2	0.15	3	6.2	0.21	Pass	Pass	
33	98-3	6	6	3	6.1	0.12	3	5.9	0.10	Pass	Pass	Valid	3	6.1	0.12	3	5.9	0.17	Fail	Pass	
34	103-1	6	6	3	6.7	0.12	3	6.5	0.12	Pass	Pass	Valid	3	6.7	0.12	3	6.7	0.12	Pass	Pass	
35	104-1	6	6	3	6.6	0.06	3	6.5	0.06	Pass	Fail	N.V.	3	6.6	0.06	3	6.5	0.10	Pass	Pass	Valid
36	104-2	6	6	3	6.6	0.06	3	6.6	0.20	Pass	Pass	Valid	3	6.6	0.06	3	6.7	0.44	Pass	Fail	
37	110-1	11	11	3	6.4	0.25	8	6.4	0.13	Pass	Pass	Valid	3	6.4	0.25	3	6.5	0.35	Pass	Pass	
38	112-1	7	7	3	6.5	0.20	4	6.2	0.14	Pass	Pass	Valid	3	6.5	0.20	3	6.3	0.17	Fail	Pass	

Table D.8. SHA Case 1 results of percent Asphalt binder content of HMA – part 2 of 3

Original				Independent Samples									Split Samples								
#	Project-Lot ID	Agency Sample Size	Contractor Sample Size	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 2 Sample Size	Contractor 2 Sample mean	Contractor 2 Sample sd	*F*-test	UV *t*-test	Primary Validation	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 1 Sample Size	Contractor 1 Sample mean	Contractor 1 Sample sd	Paired *t*-test	D2S	Secondary Validation
39	114-2	7	7	3	6.3	0.15	4	6.3	0.14	Pass	Pass	Valid	3	6.3	0.15	3	6.2	0.06	Pass	Pass	
40	115-3	6	6	3	6.3	0.06	3	6.2	0.12	Pass	Pass	Valid	3	6.3	0.06	3	6.3	0.21	Pass	Pass	
41	122-1	6	6	3	6.6	0.10	3	6.5	0.12	Pass	Pass	Valid	3	6.6	0.10	3	6.6	0.15	Pass	Pass	
42	127-1	21	21	3	6.5	0.10	18	6.6	0.23	Pass	Pass	Valid	3	6.5	0.10	3	6.6	0.20	Pass	Pass	
43	127-2	15	15	3	6.6	0.06	12	6.6	0.13	Pass	Pass	Valid	3	6.6	0.06	3	6.5	0.12	Pass	Pass	
44	127-3	14	14	3	6.5	0.06	11	6.5	0.20	Pass	Pass	Valid	3	6.5	0.06	3	6.7	0.30	Pass	Fail	
45	**134-1**	**8**	**8**	**3**	**5.9**	**0.31**	**5**	**6.0**	**0.15**	**Pass**	**Pass**	Valid	**3**	**5.9**	**0.31**	**3**	**5.9**	**0.10**	**Pass**	**Pass**	
46	136-1	9	9	3	6.3	0.21	6	6.5	0.14	Pass	Pass	Valid	3	6.3	0.21	3	6.6	0.20	Fail	Pass	
47	138-1	6	6	3	6.8	0.25	3	7.0	0.15	Pass	Pass	Valid	3	6.8	0.25	3	7.1	0.12	Pass	Fail	
48	140-1	6	6	3	6.6	0.15	3	6.7	0.10	Pass	Pass	Valid	3	6.6	0.15	3	6.6	0.06	Pass	Pass	
49	140-2	6	6	3	6.8	0.17	3	6.6	0.06	Pass	Pass	Valid	3	6.8	0.17	3	6.8	0.26	Pass	Pass	
50	141-1	6	6	3	6.8	0.10	3	6.7	0.17	Pass	Pass	Valid	3	6.8	0.10	3	6.7	0.15	Pass	Pass	
51	145-1	10	10	3	6.2	0.06	7	6.3	0.19	Pass	Pass	Valid	3	6.2	0.06	3	6.3	0.00			
52	148-1	9	9	3	6.7	0.17	6	6.7	0.16	Pass	Pass	Valid	3	6.7	0.17	3	6.7	0.00			
53	149-1	7	7	3	6.5	0.12	4	6.2	0.13	Pass	Fail	N.V.	3	6.5	0.12	3	6.4	0.23	Pass	Pass	Valid
54	150-3	6	6	3	6.2	0.12	3	6.2	0.20	Pass	Pass	Valid	3	6.2	0.12	3	6.2	0.00			
55	151-1	15	15	3	6.4	0.10	12	6.2	0.23	Pass	Pass	Valid	3	6.4	0.10	3	6.2	0.15	Fail	Pass	
56	151-2	10	10	3	6.2	0.06	6	6.3	0.05	Pass	Pass	Valid	3	6.2	0.06	3	6.2	0.06	Pass	Pass	
57	152-1	28	28	3	6.2	0.17	25	6.4	0.11	Pass	Pass	Valid	3	6.2	0.17	3	6.3	0.15	Pass	Pass	
58	159-1	6	6	3	6.4	0.12	3	6.4	0.09	Pass	Pass	Valid	3	6.4	0.12	3	6.3	0.08	Pass	Pass	
59	**160-1**	**28**	**28**	**3**	**6.4**	**0.06**	**25**	**6.3**	**0.17**	**Pass**	Fail	N.V.	**3**	**6.4**	**0.06**	**3**	**6.2**	**0.15**	**Pass**	**Pass**	Valid
60	169-3	6	6	3	5.8	0.26	3	5.8	0.10	Pass	Pass	Valid	3	5.8	0.26	3	5.8	0.12	Pass	Pass	
61	169-4	6	6	3	5.8	0.35	3	5.9	0.52	Pass	Pass	Valid	3	5.8	0.35	3	5.3	1.16	Pass	Fail	
62	170-2	9	9	3	6.0	0.15	6	5.9	0.34	Pass	Pass	Valid	3	6.0	0.15	3	5.8	0.10	Pass	Pass	
63	171-1	17	17	3	5.6	0.06	14	5.6	0.12	Pass	Pass	Valid	3	5.6	0.06	3	5.4	0.21	Pass	Fail	
64	174-4	6	6	3	5.8	0.21	3	5.7	0.44	Pass	Pass	Valid	3	5.8	0.21	3	5.4	0.12	Fail	Fail	
65	174-5	6	6	3	5.5	0.15	3	5.7	0.10	Pass	Pass	Valid	3	5.5	0.15	3	5.5	0.26	Pass	Pass	
66	174-6	6	6	3	5.5	0.12	3	5.7	0.15	Pass	Pass	Valid	3	5.5	0.12	3	5.5	0.12	Pass	Pass	
67	182-1	6	6	3	5.9	0.23	3	5.9	0.15	Pass	Pass	Valid	3	5.9	0.23	3	5.4	0.25	Pass	Fail	
68	182-3	6	6	3	5.9	0.29	3	5.8	0.12	Pass	Pass	Valid	3	5.9	0.29	3	5.9	0.30	Pass	Pass	
69	182-5	6	6	3	5.8	0.12	3	5.9	0.10	Pass	Pass	Valid	3	5.8	0.12	3	5.9	0.21	Pass	Pass	
70	186-1	6	6	3	5.9	0.12	3	5.6	0.12	Pass	Pass	Valid	3	5.9	0.12	3	5.6	0.06	Pass	Fail	
71	187-2	6	6	3	5.7	0.06	3	5.9	0.12	Pass	Pass	Valid	3	5.7	0.06	3	5.8	0.15	Pass	Pass	
72	187-3	6	6	3	5.8	0.10	3	5.7	0.10	Pass	Pass	Valid	3	5.8	0.10	3	5.8	0.12	Pass	Pass	
73	**190-1**	**8**	**8**	**3**	**5.8**	**0.20**	**5**	**6.0**	**0.28**	**Pass**	**Pass**	Valid	**3**	**5.8**	**0.20**	**3**	**5.8**	**0.23**	**Pass**	**Pass**	
74	193-2	6	6	3	5.6	0.10	3	5.9	0.06	Pass	Fail	N.V.	3	5.6	0.10	3	5.8	0.10	Pass	Pass	Valid
75	194-1	7	7	3	5.9	0.12	4	5.8	0.15	Pass	Pass	Valid	3	5.9	0.12	3	5.9	0.10	Pass	Pass	
76	197-1	6	6	3	5.5	0.26	3	5.5	0.06	Pass	Pass	Valid	3	5.5	0.26	3	5.6	0.20	Pass	Pass	

Table D.9. SHA Case 1 results of percent Asphalt binder content of HMA – part 3 of 3

Original				Independent Samples									Split Samples								
#	Project-Lot ID	Agency Sample Size	Contractor Sample Size	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 2 Sample Size	Contractor 2 Sample mean	Contractor 2 Sample sd	*F*-test	UV *t*-test	Primary Validation	Agency 1 Sample Size	Agency 1 Sample mean	Agency 1 Sample sd	Contractor 1 Sample Size	Contractor 1 Sample mean	Contractor 1 Sample sd	Paired *t*-test	D2S	Secondary Validation
77	205-1	14	14	3	5.9	0.15	11	5.7	0.10	Pass	Pass	Valid	3	5.9	0.15	3	5.8	0.12	Pass	Pass	
78	218-1	8	8	3	5.8	0.06	5	5.8	0.18	Pass	Pass	Valid	3	5.8	0.06	3	5.7	0.15	Pass	Pass	
79	218-2	7	7	3	5.9	0.12	4	5.7	0.13	Pass	Pass	Valid	3	5.9	0.12	3	5.8	0.12	Pass	Pass	
80	218-3	6	6	3	5.9	0.10	3	5.7	0.10	Pass	Pass	Valid	3	5.9	0.10	3	5.6	0.20	Fail	Fail	
81	222-1	6	6	3	5.6	0.06	3	5.7	0.12	Pass	Pass	Valid	3	5.6	0.06	3	5.6	0.06	Pass	Pass	
82	230-1	6	6	3	5.8	0.12	3	5.5	0.10	Pass	Fail	N.V.	3	5.8	0.12	3	5.5	0.15	Pass	Fail	Valid
83	235-1	7	7	3	6.6	0.21	4	6.7	0.13	Pass	Pass	Valid	3	6.6	0.21	3	6.6	0.10	Pass	Pass	
84	238-1	6	6	3	6.4	0.15	3	6.7	0.06	Pass	Pass	Valid	3	6.4	0.15	3	6.6	0.20	Pass	Fail	
85	240-1	6	6	3	6.8	0.10	3	6.9	0.20	Pass	Pass	Valid	3	6.8	0.10	3	6.8	0.21	Pass	Pass	
86	240-2	6	6	3	6.8	0.10	3	6.9	0.10	Pass	Pass	Valid	3	6.8	0.10	3	6.7	0.06	Pass	Pass	
87	242-1	6	6	3	6.6	0.20	3	6.5	0.06	Pass	Pass	Valid	3	6.6	0.20	3	6.5	0.17	Pass	Pass	
88	243-1	8	8	3	6.2	0.10	5	6.3	0.13	Pass	Pass	Valid	3	6.2	0.10	3	6.3	0.10	Fail	Pass	
89	252-2	6	6	3	5.1	0.15	3	4.8	0.06	Pass	Pass	Valid	3	5.1	0.15	3	5.0	0.15	Pass	Pass	
90	254-1	8	8	3	5.1	0.12	5	5.1	0.28	Pass	Pass	Valid	3	5.1	0.12	3	5.3	0.26	Pass	Fail	
91	257-1	6	6	3	5.0	0.30	3	4.9	0.15	Pass	Pass	Valid	3	5.0	0.30	3	5.0	0.21	Pass	Pass	
92	257-2	6	6	3	5.2	0.30	3	4.8	0.10	Pass	Pass	Valid	3	5.2	0.30	3	5.0	0.10	Pass	Fail	
93	257-3	6	6	3	4.9	0.29	3	4.8	0.12	Pass	Pass	Valid	3	4.9	0.29	3	4.9	0.26	Pass	Pass	
94	259-1	8	8	3	4.9	0.23	5	5.0	0.10	Pass	Pass	Valid	3	4.9	0.23	3	4.9	0.12	Pass	Pass	
95	259-2	6	6	3	5.1	0.12	3	4.9	0.15	Pass	Pass	Valid	3	5.1	0.12	3	5.0	0.06	Pass	Pass	
96	261-1	6	6	3	5.1	0.10	3	5.0	0.22	Pass	Pass	Valid	3	5.1	0.10	3	5.5	0.79	Pass	Fail	
97	262-2	6	6	3	4.9	0.06	3	5.0	0.10	Pass	Pass	Valid	3	4.9	0.06	3	4.9	0.06	Pass	Pass	
98	264-1	6	6	3	5.1	0.20	3	5.0	0.00				3	5.1	0.20	3	5.2	0.17	Pass	Pass	
99	264-2	6	6	3	5.2	0.06	3	5.0	0.06	Pass	Fail	N.V.	3	5.2	0.06	3	5.1	0.15	Pass	Pass	Valid
100	265-1	14	14	3	5.1	0.21	11	5.0	0.17	Pass	Pass	Valid	3	5.1	0.21	3	5.2	0.06	Pass	Pass	
101	265-2	6	6	3	4.9	0.00	3	5.0	0.17				3	4.9	0.00	3	5.1	0.23			
102	268-1	11	11	3	4.8	0.10	8	4.8	0.12	Pass	Pass	Valid	3	4.8	0.10	3	4.7	0.17	Pass	Pass	
103	316-1	6	6	3	6.6	0.06	3	6.3	0.06	Pass	Fail	N.V.	3	6.6	0.06	3	6.4	0.35	Pass	Fail	Valid
Pass or Valid										98	89	88							90	80	10
Fail or N.V.										1	10	11							8	18	1
Total										99	99	99							98	98	11
Pass or Valid										99.0%	89.9%	88.9%							91.8%	81.6%	90.9%
Fail or N.V.										1.0%	10.1%	11.1%							8.2%	18.4%	9.1%

APPENDIX E. STATISTICAL TABLES

Table E.1. Critical Values, t_{crit}, for the *t*-test for multiple levels of significance (Two-Tail) *

Two tail *α*, / ***degrees of freedom***	***α* = 0.01**	***α* = 0.025**	***α* = 0.05**	***α* = 0.10**
1	63.657	25.452	12.706	6.314
2	9.925	6.205	4.303	2.920
3	5.841	4.177	3.182	2.353
4	4.604	3.495	2.776	2.132
5	4.032	3.163	2.571	2.015
6	3.707	2.969	2.447	1.943
7	3.499	2.841	2.365	1.895
8	3.355	2.752	2.306	1.860
9	3.250	2.685	2.262	1.833
10	3.169	2.634	2.228	1.812
11	3.106	2.593	2.201	1.796
12	3.055	2.560	2.179	1.782
13	3.012	2.533	2.160	1.771
14	2.977	2.510	2.145	1.761
15	2.947	2.490	2.131	1.753
16	2.921	2.473	2.120	1.746
17	2.898	2.458	2.110	1.740
18	2.878	2.445	2.101	1.734
19	2.861	2.433	2.093	1.729
20	2.845	2.423	2.086	1.725
21	2.831	2.414	2.080	1.721
22	2.819	2.405	2.074	1.717
23	2.807	2.398	2.069	1.714
24	2.797	2.391	2.064	1.711
25	2.787	2.385	2.060	1.708
26	2.779	2.379	2.056	1.706
27	2.771	2.373	2.052	1.703
28	2.763	2.368	2.048	1.701
29	2.756	2.364	2.045	1.699
30	2.750	2.360	2.042	1.697
40	2.704	2.329	2.021	1.684
50	2.678	2.311	2.009	1.676
60	2.660	2.299	2.000	1.671
70	2.648	2.291	1.994	1.667
80	2.639	2.284	1.990	1.664
90	2.632	2.280	1.987	1.662
100	2.626	2.276	1.984	1.660
110	2.621	2.272	1.982	1.659
120	2.617	2.270	1.980	1.658
∞	2.576	2.242	1.960	1.645

*Table generated using MS Excel (T.INV.2T) function.

Table E.2. Critical Values, F_{crit}, for the F-test for a significance level, α of 0.01 (Two-Tail) *

	Degrees of Freedom for numerator														
Degrees of Freedom for denominator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	16211	20000	21615	22500	23056	23437	23715	23925	24091	24224	24334	24426	24505	24572	24630
2	198.5	199.0	199.2	199.2	199.3	199.3	199.4	199.4	199.4	199.4	199.4	199.4	199.4	199.4	199.4
3	55.55	49.80	47.47	46.19	45.39	44.84	44.43	44.13	43.88	43.69	43.52	43.39	43.27	43.17	43.08
4	31.33	26.28	24.26	23.15	22.46	21.97	21.62	21.35	21.14	20.97	20.82	20.70	20.60	20.51	20.44
5	22.78	18.31	16.53	15.56	14.94	14.51	14.20	13.96	13.77	13.62	13.49	13.38	13.29	13.21	13.15
6	18.63	14.54	12.92	12.03	11.46	11.07	10.79	10.57	10.39	10.25	10.13	10.03	9.95	9.88	9.81
7	16.24	12.40	10.88	10.05	9.52	9.16	8.89	8.68	8.51	8.38	8.27	8.18	8.10	8.03	7.97
8	14.69	11.04	9.60	8.81	8.30	7.95	7.69	7.50	7.34	7.21	7.10	7.01	6.94	6.87	6.81
9	13.61	10.11	8.72	7.96	7.47	7.13	6.88	6.69	6.54	6.42	6.31	6.23	6.15	6.09	6.03
10	12.83	9.43	8.08	7.34	6.87	6.54	6.30	6.12	5.97	5.85	5.75	5.66	5.59	5.53	5.47
11	12.23	8.91	7.60	6.88	6.42	6.10	5.86	5.68	5.54	5.42	5.32	5.24	5.16	5.10	5.05
12	11.75	8.51	7.23	6.52	6.07	5.76	5.52	5.35	5.20	5.09	4.99	4.91	4.84	4.77	4.72
13	11.37	8.19	6.93	6.23	5.79	5.48	5.25	5.08	4.94	4.82	4.72	4.64	4.57	4.51	4.46
14	11.06	7.92	6.68	6.00	5.56	5.26	5.03	4.86	4.72	4.60	4.51	4.43	4.36	4.30	4.25
15	10.80	7.70	6.48	5.80	5.37	5.07	4.85	4.67	4.54	4.42	4.33	4.25	4.18	4.12	4.07
16	10.58	7.51	6.30	5.64	5.21	4.91	4.69	4.52	4.38	4.27	4.18	4.10	4.03	3.97	3.92
17	10.38	7.35	6.16	5.50	5.07	4.78	4.56	4.39	4.25	4.14	4.05	3.97	3.90	3.84	3.79
18	10.22	7.21	6.03	5.37	4.96	4.66	4.44	4.28	4.14	4.03	3.94	3.86	3.79	3.73	3.68
19	10.07	7.09	5.92	5.27	4.85	4.56	4.34	4.18	4.04	3.93	3.84	3.76	3.70	3.64	3.59
20	9.94	6.99	5.82	5.17	4.76	4.47	4.26	4.09	3.96	3.85	3.76	3.68	3.61	3.55	3.50
21	9.83	6.89	5.73	5.09	4.68	4.39	4.18	4.01	3.88	3.77	3.68	3.60	3.54	3.48	3.43
22	9.73	6.81	5.65	5.02	4.61	4.32	4.11	3.94	3.81	3.70	3.61	3.54	3.47	3.41	3.36
23	9.63	6.73	5.58	4.95	4.54	4.26	4.05	3.88	3.75	3.64	3.55	3.47	3.41	3.35	3.30
24	9.55	6.66	5.52	4.89	4.49	4.20	3.99	3.83	3.69	3.59	3.50	3.42	3.35	3.30	3.25
25	9.48	6.60	5.46	4.84	4.43	4.15	3.94	3.78	3.64	3.54	3.45	3.37	3.30	3.25	3.20
26	9.41	6.54	5.41	4.79	4.38	4.10	3.89	3.73	3.60	3.49	3.40	3.33	3.26	3.20	3.15
27	9.34	6.49	5.36	4.74	4.34	4.06	3.85	3.69	3.56	3.45	3.36	3.28	3.22	3.16	3.11
28	9.28	6.44	5.32	4.70	4.30	4.02	3.81	3.65	3.52	3.41	3.32	3.25	3.18	3.12	3.07
29	9.23	6.40	5.28	4.66	4.26	3.98	3.77	3.61	3.48	3.38	3.29	3.21	3.15	3.09	3.04
30	9.18	6.35	5.24	4.62	4.23	3.95	3.74	3.58	3.45	3.34	3.25	3.18	3.11	3.06	3.01
40	8.83	6.07	4.98	4.37	3.99	3.71	3.51	3.35	3.22	3.12	3.03	2.95	2.89	2.83	2.78
50	8.63	5.90	4.83	4.23	3.85	3.58	3.38	3.22	3.09	2.99	2.90	2.82	2.76	2.70	2.65
60	8.49	5.79	4.73	4.14	3.76	3.49	3.29	3.13	3.01	2.90	2.82	2.74	2.68	2.62	2.57
70	8.40	5.72	4.66	4.08	3.70	3.43	3.23	3.08	2.95	2.85	2.76	2.68	2.62	2.56	2.51
80	8.33	5.67	4.61	4.03	3.65	3.39	3.19	3.03	2.91	2.80	2.72	2.64	2.58	2.52	2.47
90	8.28	5.62	4.57	3.99	3.62	3.35	3.15	3.00	2.87	2.77	2.68	2.61	2.54	2.49	2.44
100	8.24	5.59	4.54	3.96	3.59	3.33	3.13	2.97	2.85	2.74	2.66	2.58	2.52	2.46	2.41
110	8.21	5.56	4.52	3.94	3.57	3.30	3.11	2.95	2.83	2.72	2.64	2.56	2.50	2.44	2.39
120	8.18	5.54	4.50	3.92	3.55	3.28	3.09	2.93	2.81	2.71	2.62	2.54	2.48	2.42	2.37
∞	7.88	5.30	4.28	3.72	3.35	3.09	2.90	2.75	2.62	2.52	2.43	2.36	2.30	2.24	2.19

*Table generated using MS Excel (F.INV) function.

Table E.3. Critical Values, F_{crit}, for the F-test for a significance level, α of 0.025 (Two-Tail) *

		Degrees of Freedom for numerator														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Degrees of Freedom for denominator	**1**	2593	3200	3458	3600	3689	3750	3794	3828	3854	3876	3893	3908	3920	3931	3941
	2	78.5	79.0	79.2	79.2	79.3	79.3	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4
	3	29.07	26.35	25.22	24.60	24.20	23.93	23.73	23.57	23.45	23.36	23.28	23.21	23.15	23.10	23.06
	4	18.62	15.89	14.77	14.15	13.75	13.48	13.28	13.13	13.01	12.91	12.83	12.76	12.70	12.65	12.61
	5	14.52	11.93	10.86	10.28	9.90	9.64	9.45	9.31	9.19	9.10	9.02	8.95	8.90	8.85	8.81
	6	12.40	9.93	8.91	8.35	8.00	7.75	7.56	7.42	7.31	7.22	7.14	7.08	7.02	6.98	6.94
	7	11.12	8.74	7.77	7.22	6.88	6.64	6.46	6.32	6.21	6.12	6.05	5.99	5.93	5.89	5.85
	8	10.28	7.96	7.02	6.49	6.15	5.92	5.74	5.61	5.50	5.41	5.34	5.28	5.23	5.18	5.14
	9	9.68	7.42	6.49	5.98	5.65	5.41	5.24	5.11	5.00	4.92	4.85	4.79	4.73	4.69	4.65
	10	9.23	7.01	6.10	5.60	5.27	5.04	4.88	4.74	4.64	4.56	4.48	4.42	4.37	4.33	4.29
	11	8.89	6.70	5.81	5.31	4.99	4.76	4.60	4.47	4.36	4.28	4.21	4.15	4.10	4.05	4.01
	12	8.61	6.45	5.57	5.08	4.76	4.54	4.37	4.25	4.14	4.06	3.99	3.93	3.88	3.83	3.80
	13	8.39	6.26	5.38	4.90	4.58	4.36	4.20	4.07	3.97	3.88	3.81	3.75	3.70	3.66	3.62
	14	8.20	6.09	5.23	4.74	4.43	4.21	4.05	3.92	3.82	3.74	3.67	3.61	3.56	3.51	3.48
	15	8.05	5.95	5.10	4.62	4.31	4.09	3.93	3.80	3.70	3.62	3.55	3.49	3.44	3.39	3.36
	16	7.91	5.83	4.98	4.51	4.20	3.98	3.82	3.70	3.60	3.51	3.44	3.39	3.33	3.29	3.25
	17	7.80	5.73	4.89	4.42	4.11	3.89	3.73	3.61	3.51	3.42	3.36	3.30	3.25	3.20	3.16
	18	7.70	5.65	4.80	4.33	4.03	3.82	3.65	3.53	3.43	3.35	3.28	3.22	3.17	3.13	3.09
	19	7.61	5.57	4.73	4.26	3.96	3.75	3.59	3.46	3.36	3.28	3.21	3.15	3.10	3.06	3.02
	20	7.53	5.50	4.67	4.20	3.90	3.69	3.53	3.40	3.30	3.22	3.15	3.09	3.04	3.00	2.96
	21	7.46	5.44	4.61	4.15	3.84	3.63	3.47	3.35	3.25	3.17	3.10	3.04	2.99	2.94	2.91
	22	7.40	5.38	4.56	4.10	3.79	3.58	3.42	3.30	3.20	3.12	3.05	2.99	2.94	2.90	2.86
	23	7.34	5.33	4.51	4.05	3.75	3.54	3.38	3.26	3.16	3.08	3.01	2.95	2.90	2.85	2.82
	24	7.29	5.29	4.47	4.01	3.71	3.50	3.34	3.22	3.12	3.04	2.97	2.91	2.86	2.82	2.78
	25	7.24	5.25	4.43	3.97	3.67	3.46	3.31	3.18	3.08	3.00	2.93	2.87	2.82	2.78	2.74
	26	7.20	5.21	4.40	3.94	3.64	3.43	3.27	3.15	3.05	2.97	2.90	2.84	2.79	2.75	2.71
	27	7.16	5.18	4.36	3.91	3.61	3.40	3.24	3.12	3.02	2.94	2.87	2.81	2.76	2.72	2.68
	28	7.13	5.15	4.33	3.88	3.58	3.37	3.22	3.09	2.99	2.91	2.84	2.79	2.74	2.69	2.65
	29	7.09	5.12	4.31	3.85	3.56	3.35	3.19	3.07	2.97	2.89	2.82	2.76	2.71	2.67	2.63
	30	7.06	5.09	4.28	3.83	3.53	3.32	3.17	3.04	2.95	2.86	2.80	2.74	2.69	2.64	2.60
	40	6.84	4.90	4.10	3.66	3.36	3.16	3.00	2.88	2.78	2.70	2.63	2.57	2.52	2.48	2.44
	50	6.71	4.79	4.00	3.56	3.27	3.06	2.91	2.78	2.69	2.61	2.54	2.48	2.43	2.38	2.34
	60	6.63	4.72	3.93	3.49	3.20	3.00	2.84	2.72	2.63	2.54	2.48	2.42	2.37	2.32	2.28
	70	6.57	4.67	3.89	3.45	3.16	2.96	2.80	2.68	2.58	2.50	2.43	2.37	2.32	2.28	2.24
	80	6.53	4.63	3.85	3.41	3.13	2.92	2.77	2.65	2.55	2.47	2.40	2.34	2.29	2.25	2.21
	90	6.50	4.60	3.83	3.39	3.10	2.90	2.74	2.62	2.53	2.44	2.38	2.32	2.27	2.22	2.18
	100	6.47	4.58	3.80	3.37	3.08	2.88	2.72	2.60	2.51	2.43	2.36	2.30	2.25	2.20	2.16
	110	6.45	4.56	3.79	3.35	3.07	2.86	2.71	2.59	2.49	2.41	2.34	2.28	2.23	2.19	2.15
	120	6.43	4.55	3.77	3.34	3.05	2.85	2.70	2.58	2.48	2.40	2.33	2.27	2.22	2.17	2.13
	∞	6.24	4.38	3.62	3.19	2.91	2.71	2.56	2.44	2.34	2.26	2.19	2.13	2.08	2.03	1.99

*Table generated using MS Excel (F.INV) function.

Table E.4. Critical Values, F_{crit}, for the F-test for a significance level, α of 0.05 (Two-Tail) *

		Degrees of Freedom for numerator														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Degrees of Freedom for denominator	**1**	648	799	864	900	922	937	948	957	963	969	973	977	980	983	985
	2	38.5	39.0	39.2	39.2	39.3	39.3	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
	3	17.44	16.04	15.44	15.10	14.88	14.73	14.62	14.54	14.47	14.42	14.37	14.34	14.30	14.28	14.25
	4	12.22	10.65	9.98	9.60	9.36	9.20	9.07	8.98	8.90	8.84	8.79	8.75	8.71	8.68	8.66
	5	10.01	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68	6.62	6.57	6.52	6.49	6.46	6.43
	6	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52	5.46	5.41	5.37	5.33	5.30	5.27
	7	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82	4.76	4.71	4.67	4.63	4.60	4.57
	8	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36	4.30	4.24	4.20	4.16	4.13	4.10
	9	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03	3.96	3.91	3.87	3.83	3.80	3.77
	10	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78	3.72	3.66	3.62	3.58	3.55	3.52
	11	6.72	5.26	4.63	4.28	4.04	3.88	3.76	3.66	3.59	3.53	3.47	3.43	3.39	3.36	3.33
	12	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44	3.37	3.32	3.28	3.24	3.21	3.18
	13	6.41	4.97	4.35	4.00	3.77	3.60	3.48	3.39	3.31	3.25	3.20	3.15	3.12	3.08	3.05
	14	6.30	4.86	4.24	3.89	3.66	3.50	3.38	3.29	3.21	3.15	3.09	3.05	3.01	2.98	2.95
	15	6.20	4.77	4.15	3.80	3.58	3.41	3.29	3.20	3.12	3.06	3.01	2.96	2.92	2.89	2.86
	16	6.12	4.69	4.08	3.73	3.50	3.34	3.22	3.12	3.05	2.99	2.93	2.89	2.85	2.82	2.79
	17	6.04	4.62	4.01	3.66	3.44	3.28	3.16	3.06	2.98	2.92	2.87	2.82	2.79	2.75	2.72
	18	5.98	4.56	3.95	3.61	3.38	3.22	3.10	3.01	2.93	2.87	2.81	2.77	2.73	2.70	2.67
	19	5.92	4.51	3.90	3.56	3.33	3.17	3.05	2.96	2.88	2.82	2.76	2.72	2.68	2.65	2.62
	20	5.87	4.46	3.86	3.51	3.29	3.13	3.01	2.91	2.84	2.77	2.72	2.68	2.64	2.60	2.57
	21	5.83	4.42	3.82	3.48	3.25	3.09	2.97	2.87	2.80	2.73	2.68	2.64	2.60	2.56	2.53
	22	5.79	4.38	3.78	3.44	3.22	3.05	2.93	2.84	2.76	2.70	2.65	2.60	2.56	2.53	2.50
	23	5.75	4.35	3.75	3.41	3.18	3.02	2.90	2.81	2.73	2.67	2.62	2.57	2.53	2.50	2.47
	24	5.72	4.32	3.72	3.38	3.15	2.99	2.87	2.78	2.70	2.64	2.59	2.54	2.50	2.47	2.44
	25	5.69	4.29	3.69	3.35	3.13	2.97	2.85	2.75	2.68	2.61	2.56	2.51	2.48	2.44	2.41
	26	5.66	4.27	3.67	3.33	3.10	2.94	2.82	2.73	2.65	2.59	2.54	2.49	2.45	2.42	2.39
	27	5.63	4.24	3.65	3.31	3.08	2.92	2.80	2.71	2.63	2.57	2.51	2.47	2.43	2.39	2.36
	28	5.61	4.22	3.63	3.29	3.06	2.90	2.78	2.69	2.61	2.55	2.49	2.45	2.41	2.37	2.34
	29	5.59	4.20	3.61	3.27	3.04	2.88	2.76	2.67	2.59	2.53	2.48	2.43	2.39	2.36	2.32
	30	5.57	4.18	3.59	3.25	3.03	2.87	2.75	2.65	2.57	2.51	2.46	2.41	2.37	2.34	2.31
	40	5.42	4.05	3.46	3.13	2.90	2.74	2.62	2.53	2.45	2.39	2.33	2.29	2.25	2.21	2.18
	50	5.34	3.97	3.39	3.05	2.83	2.67	2.55	2.46	2.38	2.32	2.26	2.22	2.18	2.14	2.11
	60	5.29	3.93	3.34	3.01	2.79	2.63	2.51	2.41	2.33	2.27	2.22	2.17	2.13	2.09	2.06
	70	5.25	3.89	3.31	2.97	2.75	2.59	2.47	2.38	2.30	2.24	2.18	2.14	2.10	2.06	2.03
	80	5.22	3.86	3.28	2.95	2.73	2.57	2.45	2.35	2.28	2.21	2.16	2.11	2.07	2.03	2.00
	90	5.20	3.84	3.26	2.93	2.71	2.55	2.43	2.34	2.26	2.19	2.14	2.09	2.05	2.02	1.98
	100	5.18	3.83	3.25	2.92	2.70	2.54	2.42	2.32	2.24	2.18	2.12	2.08	2.04	2.00	1.97
	110	5.16	3.82	3.24	2.90	2.68	2.53	2.40	2.31	2.23	2.17	2.11	2.07	2.02	1.99	1.96
	120	5.15	3.80	3.23	2.89	2.67	2.52	2.39	2.30	2.22	2.16	2.10	2.05	2.01	1.98	1.94
	∞	5.03	3.69	3.12	2.79	2.57	2.41	2.29	2.19	2.11	2.05	1.99	1.95	1.90	1.87	1.83

*Table generated using MS Excel (F.INV) function.

Table E.5. Critical Values, F_{crit}, for the F-test for a significance level, α of 0.1 (Two-Tail) *

Degrees of Freedom for denominator	Degrees of Freedom for numerator														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	161	200	216	225	230	234	237	239	241	242	243	244	245	245	246
2	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.76	8.74	8.73	8.71	8.70
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.94	5.91	5.89	5.87	5.86
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.70	4.68	4.66	4.64	4.62
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.03	4.00	3.98	3.96	3.94
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.60	3.57	3.55	3.53	3.51
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.31	3.28	3.26	3.24	3.22
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.10	3.07	3.05	3.03	3.01
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.94	2.91	2.89	2.86	2.85
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.82	2.79	2.76	2.74	2.72
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.72	2.69	2.66	2.64	2.62
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.63	2.60	2.58	2.55	2.53
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.57	2.53	2.51	2.48	2.46
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.51	2.48	2.45	2.42	2.40
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.46	2.42	2.40	2.37	2.35
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.41	2.38	2.35	2.33	2.31
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.37	2.34	2.31	2.29	2.27
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.34	2.31	2.28	2.26	2.23
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.31	2.28	2.25	2.22	2.20
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.28	2.25	2.22	2.20	2.18
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.26	2.23	2.20	2.17	2.15
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.24	2.20	2.18	2.15	2.13
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.22	2.18	2.15	2.13	2.11
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.20	2.16	2.14	2.11	2.09
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.18	2.15	2.12	2.09	2.07
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.17	2.13	2.10	2.08	2.06
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.15	2.12	2.09	2.06	2.04
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.14	2.10	2.08	2.05	2.03
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.13	2.09	2.06	2.04	2.01
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.04	2.00	1.97	1.95	1.92
50	4.03	3.18	2.79	2.56	2.40	2.29	2.20	2.13	2.07	2.03	1.99	1.95	1.92	1.89	1.87
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.95	1.92	1.89	1.86	1.84
70	3.98	3.13	2.74	2.50	2.35	2.23	2.14	2.07	2.02	1.97	1.93	1.89	1.86	1.84	1.81
80	3.96	3.11	2.72	2.49	2.33	2.21	2.13	2.06	2.00	1.95	1.91	1.88	1.84	1.82	1.79
90	3.95	3.10	2.71	2.47	2.32	2.20	2.11	2.04	1.99	1.94	1.90	1.86	1.83	1.80	1.78
100	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.97	1.93	1.89	1.85	1.82	1.79	1.77
110	3.93	3.08	2.69	2.45	2.30	2.18	2.09	2.02	1.97	1.92	1.88	1.84	1.81	1.78	1.76
120	3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.02	1.96	1.91	1.87	1.83	1.80	1.78	1.75
∞	3.84	3.00	2.61	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.79	1.75	1.72	1.69	1.67

*Table generated using MS Excel (F.INV) function.

Table E.6. Estimation of Lot PWL - standard deviation method

Q	N=3	N=4	N=5	N=6	N=7	N=8	N=9	N=10	N=15	N=20	N=30	N=50	N=100
0.91	78.89	80.33	80.93	81.22	81.39	81.49	81.56	81.61	81.73	81.77	81.81	81.83	81.85
0.92	79.34	80.67	81.23	81.51	81.67	81.77	81.84	81.89	82.00	82.04	82.08	82.10	82.11
0.93	79.81	81.00	81.54	81.81	81.96	82.05	82.12	82.16	82.27	82.31	82.34	82.36	82.37
0.94	80.27	81.33	81.84	82.10	82.24	82.33	82.39	82.44	82.54	82.57	82.60	82.62	82.63
0.95	80.75	81.67	82.14	82.39	82.52	82.61	82.67	82.71	82.80	82.84	82.86	82.88	82.89
0.96	81.25	82.00	82.45	82.67	82.80	82.88	82.94	82.97	83.06	83.10	83.12	83.13	83.14
0.97	81.75	82.33	82.75	82.96	83.08	83.15	83.21	83.24	83.32	83.35	83.37	83.39	83.39
0.98	82.26	82.67	83.04	83.24	83.35	83.43	83.47	83.51	83.58	83.61	83.63	83.64	83.64
0.99	82.79	83.00	83.34	83.52	83.63	83.69	83.74	83.77	83.84	83.86	83.88	83.88	83.89
1.00	83.33	83.33	83.64	83.80	83.90	83.96	84.00	84.03	84.09	84.11	84.12	84.13	84.13
1.01	83.89	83.67	83.93	84.08	84.17	84.22	84.26	84.28	84.34	84.36	84.37	84.37	84.38
1.02	84.47	84.00	84.22	84.36	84.44	84.49	84.52	84.54	84.59	84.60	84.61	84.62	84.62
1.03	85.07	84.33	84.52	84.63	84.70	84.75	84.77	84.79	84.83	84.85	84.85	84.85	84.85
1.04	85.69	84.67	84.81	84.91	84.97	85.00	85.03	85.04	85.08	85.09	85.09	85.09	85.09
1.05	86.34	85.00	85.09	85.18	85.23	85.26	85.28	85.29	85.32	85.33	85.33	85.32	85.32
1.06	87.02	85.33	85.38	85.45	85.49	85.51	85.53	85.54	85.56	85.56	85.56	85.55	85.55
1.07	87.73	85.67	85.67	85.71	85.74	85.76	85.78	85.78	85.80	85.80	85.79	85.78	85.78
1.08	88.49	86.00	85.95	85.98	86.00	86.01	86.02	86.03	86.03	86.03	86.02	86.01	86.00
1.09	89.29	86.33	86.24	86.24	86.25	86.26	86.27	86.27	86.26	86.26	86.25	86.23	86.23
1.10	90.16	86.67	86.52	86.50	86.51	86.51	86.51	86.50	86.49	86.48	86.47	86.46	86.45
1.11	91.11	87.00	86.80	86.76	86.75	86.75	86.74	86.74	86.72	86.71	86.69	86.68	86.66
1.12	92.18	87.33	87.07	87.02	87.00	86.99	86.98	86.97	86.95	86.93	86.91	86.89	86.88
1.13	93.40	87.67	87.35	87.28	87.25	87.23	87.21	87.20	87.17	87.15	87.13	87.11	87.09
1.14	94.92	88.00	87.63	87.53	87.49	87.46	87.45	87.43	87.39	87.37	87.34	87.32	87.30
1.15	97.13	88.33	87.90	87.78	87.73	87.70	87.68	87.66	87.61	87.58	87.55	87.53	87.51
1.16	100.00	88.67	88.17	88.03	87.97	87.93	87.90	87.88	87.82	87.79	87.76	87.74	87.72
1.17	100.00	89.00	88.44	88.28	88.21	88.16	88.13	88.10	88.04	88.00	87.97	87.94	87.92
1.18	100.00	89.33	88.71	88.53	88.44	88.39	88.35	88.32	88.25	88.21	88.18	88.15	88.12
1.19	100.00	89.67	88.98	88.77	88.67	88.61	88.57	88.54	88.46	88.42	88.38	88.35	88.32
1.20	100.00	90.00	89.24	89.01	88.90	88.83	88.79	88.76	88.66	88.62	88.58	88.54	88.52
1.21	100.00	90.33	89.50	89.25	89.13	89.06	89.00	88.97	88.87	88.82	88.78	88.74	88.71
1.22	100.00	90.67	89.77	89.49	89.35	89.27	89.22	89.18	89.07	89.02	88.97	88.93	88.91
1.23	100.00	91.00	90.03	89.72	89.58	89.49	89.43	89.39	89.27	89.22	89.16	89.12	89.09
1.24	100.00	91.33	90.28	89.96	89.80	89.70	89.64	89.59	89.47	89.41	89.36	89.31	89.28
1.25	100.00	91.67	90.54	90.19	90.02	89.91	89.85	89.79	89.66	89.60	89.54	89.50	89.47
1.26	100.00	92.00	90.79	90.42	90.23	90.12	90.05	90.00	89.85	89.79	89.73	89.68	89.65
1.27	100.00	92.33	91.04	90.64	90.45	90.33	90.25	90.19	90.04	89.98	89.91	89.87	89.83
1.28	100.00	92.67	91.29	90.87	90.66	90.53	90.45	90.39	90.23	90.16	90.10	90.05	90.01
1.29	100.00	93.00	91.54	91.09	90.87	90.74	90.65	90.58	90.42	90.34	90.28	90.22	90.18
1.30	100.00	93.33	91.79	91.31	91.07	90.94	90.84	90.78	90.60	90.52	90.45	90.40	90.36
1.31	100.00	93.67	92.03	91.52	91.28	91.13	91.04	90.97	90.78	90.70	90.63	90.57	90.53
1.32	100.00	94.00	92.27	91.74	91.48	91.33	91.23	91.15	90.96	90.88	90.80	90.74	90.70
1.33	100.00	94.33	92.51	91.95	91.68	91.52	91.41	91.34	91.14	91.05	90.97	90.91	90.87
1.34	100.00	94.67	92.75	92.16	91.88	91.71	91.60	91.52	91.31	91.22	91.14	91.08	91.03
1.35	100.00	95.00	92.98	92.37	92.08	91.90	91.78	91.70	91.48	91.39	91.31	91.24	91.19
1.36	100.00	95.33	93.21	92.58	92.27	92.09	91.96	91.88	91.65	91.56	91.47	91.40	91.35
1.37	100.00	95.67	93.44	92.78	92.46	92.27	92.14	92.05	91.82	91.72	91.63	91.56	91.51
1.38	100.00	96.00	93.67	92.98	92.65	92.45	92.32	92.23	91.99	91.88	91.79	91.72	91.67
1.39	100.00	96.33	93.90	93.18	92.83	92.63	92.49	92.40	92.15	92.04	91.95	91.88	91.82
1.40	100.00	96.67	94.12	93.37	93.02	92.81	92.67	92.56	92.31	92.20	92.10	92.03	91.98
1.41	100.00	97.00	94.34	93.57	93.20	92.98	92.83	92.73	92.47	92.36	92.26	92.18	92.13
1.42	100.00	97.33	94.56	93.76	93.38	93.15	93.00	92.90	92.63	92.51	92.41	92.33	92.27
1.43	100.00	97.67	94.77	93.95	93.55	93.32	93.17	93.06	92.78	92.66	92.56	92.48	92.42
1.44	100.00	98.00	94.98	94.13	93.73	93.49	93.33	93.22	92.93	92.81	92.70	92.62	92.56
1.45	100.00	98.33	95.19	94.32	93.90	93.65	93.49	93.37	93.08	92.96	92.85	92.76	92.70
1.46	100.00	98.67	95.40	94.50	94.07	93.81	93.65	93.53	93.23	93.10	92.99	92.90	92.84

Table E.7. Estimation of Lot PWL - standard deviation method

Q	N=3	N=4	N=5	N=6	N=7	N=8	N=9	N=10	N=15	N=20	N=30	N=50	N=100
3.15	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.97	99.95	99.94
3.16	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.96	99.94
3.17	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.96	99.94
3.18	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.96	99.94
3.19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.96	99.95
3.20	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.96	99.95
3.21	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.96	99.95
3.22	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97	99.95
3.23	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97	99.95
3.24	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.98	99.97	99.96
3.25	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.98	99.97	99.96
3.26	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.97	99.96
3.27	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.97	99.96
3.28	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.97	99.96
3.29	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.96
3.30	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.96
3.31	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97
3.32	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97
3.33	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97
3.34	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97
3.35	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97
3.36	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97
3.37	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97
3.38	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.97
3.39	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98	99.98
3.40	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99	99.98
3.41	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99	99.98
3.42	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99	99.98
3.43	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99	99.98
3.44	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99	99.98
3.45	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98
3.46	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98
3.47	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98
3.48	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98
3.49	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98
3.50	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.98
3.51	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.52	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.53	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.54	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.55	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.56	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.57	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.58	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.59	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.60	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.61	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99
3.62	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99
3.63	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99
3.64	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99
3.65	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99
3.66	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99
3.67	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99
3.68	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99
3.69	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99
3.70	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99