Standard Method for

Verification of Contractor Asphalt Acceptance Test Results

SCDOT Designation: SC-T-97 (06/2021)

1. SCOPE

This method covers the statistical analysis of comparing two sets of data; Contractor's acceptance test results and SCDOT verification test results, to determine if the results are from the same population.

There are three types of tests that will be used on most paving projects:

- Quality Acceptance (QA) Tests – performed by the Contractor and, if statistically verified by the Department, used to calculate LOT pay factors.
- Verification Tests – performed by the Department and used to statistically verify whether or not the Contractor's acceptance tests can be used.
- Independent Assurance (IA) Tests – performed by the Department and used to ensure that the testers and equipment remain capable of performing the tests properly. The IA program is handled independently of this standard method of testing and is therefore not discussed herein.

Two other types of tests, Referee and Dispute Resolution, may be necessary if the above testing results in concerns over the validity of any of the test results.

In addition to the required testing, the Contractor is encouraged to perform quality control testing and use control charts to better control their process. The results of these additional tests would be for the benefit of the Contractor and would not be used for acceptance purposes.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards:

- R 9

2.2 SCDOT Supplemental Technical Specifications:

- SC-M-400

2.3 SC Test Methods:

- SC-T-87
- SC-T-98

3. SUMMARY OF TEST METHOD

3.1 Department and Contractor's acceptance test results of asphalt material properties will be compared using the F-test and t-test for verification. Tests to be evaluated will include asphalt binder content and volumetric properties.

4. SIGNIFICANCE AND USE

4.1 The purpose of this procedure is to validate, with a certain level of confidence, the consistency of the asphalt mix produced in the acceptance decision in accordance with the job mix formula and SCDOT specifications.

5. APPARATUS

5.1 None

6. TEST SPECIMEN

6.1 Asphalt test results obtained from Contractors according to SC-M-400 and asphalt test results obtained from SCDOT verification labs using SC-T-98.

7. PROCEDURE

7.1 Obtain Contractor's acceptance test results and SCDOT verification test results for the asphalt mix properties for binder content, gradation and maximum specific gravity (MSG) and forward to the Asphalt Verification Manager (AVM).

7.2 Verification Testing

Verification testing will be performed by OMR field personnel at a Department field verification laboratory. All OMR field personnel involved in the sampling and testing process must be SCDOT Level 1 certified.

A verification sample will not be taken from the same truck as an acceptance sample.

The OMR representative will direct the contractor to obtain and split the verification sample into three portions. One will be for the verification, one will be the contractor verification split, and the third for potential dispute resolution testing.

If either one of the following conditions exists then the OMR representative may obtain and split the sample:

- The Contractor's representative is not SCDOT Asphalt Level 1 certified.
- The Contractor's representative is not available at the time of the desired sample.

The OMR representative will immediately take possession of the verification samples. The dispute resolution sample will be immediately labeled with the file number, mix type, LOT number, date produced and secured with an approved tagging mechanism as described in SC-T-87. Store the dispute resolution sample at the Contractor's laboratory in a safe, dry location.

The OMR representative will test the verification sample as soon as practical and forward the results to the OMR Central Laboratory.

The Contractor will be required to test their portion (verification split) of each day's first verification test. The verification split sample cannot be used as an acceptance sample. The Contractor has the option to test the splits from the other verification tests. The Contractor will email the plant's verification split test worksheet (Form 400.03) to the OMR field verification laboratory within 48 hours from the time the sample was taken.

When the Contractor and Department test results do not compare (see Table 1), the field verification laboratory representative will immediately notify the Contractor of which property does not compare and if any properties are outside of job mix formula tolerance. The Asphalt Level 3 QC Manager from the Contractor has the option of requesting that the dispute resolution sample be tested when the difference between the verification results are outside the tolerance limit as listed in Table 1. Request must be made by email to the AVM within 24 hours from receiving the results.

Table 1. Allowable Tolerances

Characteristic	Surface	Intermediate	Base
	Tolerance	Tolerance	Tolerance
Asphalt Binder Content, %	0.32	0.38	0.44
Gradation (See Critical Sieves In Table 2 and 3)	1/2"	± 6.5	
	3/8"	± 5.5	
	No. 4	± 5.5	
	No. 8	± 5.0	

When the Contractor and Department test results do compare, the results of the Department's verification tests will be available to the Contractor as soon as practical, but not before the Department has received all of the Contractor's test results for that data set.

7.3 Input test data into the computerized statistical program. Ensure that the test data is correlated into the spreadsheet by LOT number and date.

7.3.1 The data set will be evaluated once the results of 3 or more verification tests are conducted by the Department. The Contractor's acceptance test results and SCDOT verification test results from LOT 1 thru the closure of the LOT that the 3rd verification test was obtained will be statistically analyzed and a decision to accept the Contractor's acceptance test results will be based on whether the data set is believed equal and therefore, has come from the same population. If the analysis of the data set proves a non-comparison of the test results, then the SCDOT verification test results will be used for acceptance. The next data set will comprise test results of the Contractor's acceptance tests from the LOT following data set 1 thru the completed LOT that the 3rd verification test was obtained, statistically analyzed and a decision will be made whether to accept or reject the Contractor's acceptance test

results. This process continues until production is completed. If the last data set has less than the minimum of the 3 verification tests, close the data set and evaluate the F & t statistics.

7.4 Following AASHTO R9, conduct an F-Test for the sample variances for binder content and gradation.

7.4.1 Use a level of significance of $\alpha = 0.01$ for the test.

7.4.2 Compute the mean for the Contractor's acceptance tests ($\overline{X_c}$) and the SCDOT verification tests ($\overline{X_v}$) and standard deviation for the Contractor's acceptance tests (s_c) and the SCDOT verification tests (s_v).

7.4.3 Compute the variance for the Contractor's acceptance tests (s_c^2) and the SCDOT verification tests (s_v^2). (Variance is the square of the standard deviation).

7.4.4 Compute F-statistic (F), using the largest variance (s^2) value in the numerator.

7.4.5 Determine the critical F value (F_{crit}) from the F-distribution table making sure to use the correct degrees of freedom (n-1) associated with each set of tests results. (See Table 4 in the appendix for Critical Values, F_{crit}, for the F-test for a Level of Significance $\alpha = 0.01$).

7.4.6 Evaluate if $F \geq F_{crit,}$ or $F < F_{crit}$.

7.4.7 If $F \geq F_{crit,}$ then conclude that the two data sets of tests have significantly different variabilities. If $F < F_{crit,}$ then conclude that there is no reason to believe that the variabilities are significantly different.

7.5 Following AASHTO R9, conduct t-test for the sample means for binder content and gradation.

Note: Two approaches for the t-test are necessary. If the sample variances are found to be equal from the F- Test, then the t-test is conducted based on the two samples using a pooled estimate for the variance and the pooled degrees of freedom. If the sample variances are found to be different from the F-Test, then the t-test is conducted using the individual sample variances, the individual sample sizes, and the effective degrees of freedom.

7.5.1 Use a level of significance of $\alpha = 0.01$ for the test.

7.5.2 Compute the mean for the Contractor's quality acceptance tests ($\overline{X_c}$) and the SCDOT verification tests ($\overline{X_v}$).

7.5.3 Compute the t-statistic (t), using either the pooled variance (s_p^2) equation (equal variances) or the equation for unequal variances as appropriate.

7.5.4 Determine the critical t value (t_{crit}) using the level of significance (α) the pooled degrees of freedom ($n_c + n_a - 2$) or the effective degrees of freedom (f') as appropriate. (See Table 5 in the appendix for Critical Values, t_{crit}, for the t-test).

7.5.5 Evaluate if $t \geq t_{crit,}$ or $t < t_{crit}$.

7.5.6 If $t \geq t_{crit,}$ then conclude that the two data sets of tests have significantly different means. If $t < t_{crit,}$ then conclude that there is no reason to believe that the means are significantly different.

7.6 Determine if the two data sets are statistically equal based on statistical hypothesis two-tailed tests.

7.7 If the result of either the F- or t - test is deemed not statistically equal (the null hypothesis is rejected and either the means or variances are significantly different), contact the District Asphalt Manager and Asphalt Materials Manager and investigate to determine if any discrepancies or issues in the production, sampling or testing of the Asphalt can be identified.

7.7.1 The Pay factor will be administered as follows

Determine pay factors for asphalt binder content and gradation using Table 2 and 3 (refer to mix type) based on the average absolute difference from job mix targets.

Surface Mixtures A-E, Intermediate B-BS, OGFC, PMTLSC, and Base C-D - Table 2

Mixture Characteristics	Pay Factor	Mean of the Deviations from the Job Mix Formula	
			3 or More
Asphalt Binder Content (Extraction, Ignition)	1.05		0.00 - 0.28
	1.00		0.29 - 0.48
	0.95		0.49 - 0.53
	0.90		0.54 - 0.58
	0.80		0.59 - 0.63
	See Section 7.9		0.64 - or More
3/8 in. (9.5 mm) Sieve	1.05		0.0 - 2.6
	1.00		2.7 - 5.0
	0.98		5.1 - 5.5
	0.95		5.6 - 6.0
	0.90		6.1 - 6.6
	0.85		6.7 - 7.2
	0.80		7.3 - 7.5
	See Section 7.9		7.6 - or More
No. 4 (4.75 mm) Sieve	1.05		0.0 - 2.7
	1.00		2.8 - 5.1
	0.98		5.2 - 5.5
	0.95		5.6 - 6.0
	0.90		6.1 - 6.4
	0.85		6.5 - 6.8
	0.80		6.9 - 7.0
	See Section 7.9		7.1 - or More
No. 8 (2.36 mm) Sieve	1.05		0.0 - 2.3
	1.00		2.4 - 4.4
	0.98		4.5 - 4.8
	0.95		4.9 - 5.3
	0.90		5.4 - 5.8
	0.85		5.9 - 6.2
	0.80		6.3 - 6.8
	See Section 7.9		6.9 - or More

Base A & B, Intermediate A & C, & SWC – Table 3

Mixture Characteristics	Pay Factor	Mean of the Deviations from the Job Mix Formula	
			3 or More
Asphalt Binder Content (Extraction, Ignition)	1.05		0.00 - 0.33
	1.00		0.34 - 0.56
	0.95		0.57 - 0.61
	0.90		0.62 - 0.66
	0.80		0.67 - 0.71
	See Section 7.9		0.72 - or More
1/2 in. (12.5 mm) Sieve	1.05		0.0 - 3.0
	1.00		3.1 - 5.9
	0.98		6.0 - 6.5
	0.95		6.6 - 7.0
	0.90		7.1 - 7.6
	0.85		7.7 - 7.8
	0.80		7.9 - 8.0
	See Section 7.9		8.1 - or More
No. 4 (4.75 mm) Sieve	1.05		0.0 - 2.7
	1.00		2.8 - 5.1
	0.98		5.2 - 5.5
	0.95		5.6 - 6.0
	0.90		6.1 - 6.4
	0.85		6.5 - 6.8
	0.80		6.9 - 7.0
	See Section 7.9		7.1 - or More
No. 8 (2.36 mm) Sieve	1.05		0.0 - 2.5
	1.00		2.6 - 4.8
	0.98		4.9 - 5.2
	0.95		5.3 - 5.7
	0.90		5.8 - 6.1
	0.85		6.2 - 6.3
	0.75		6.4 - 6.6
	See Section 7.9		6.7 - or More

7.8 Dispute Resolution Testing

Dispute resolution testing will only be used in those instances when the Contractor's and Department's test results for a verification sample do not compare.

Dispute resolution testing will be performed by personnel at the OMR central laboratory. All OMR central laboratory personnel involved in the testing process will be SCDOT Asphalt Level 1 certified and will be responsible for performing yearly AASHTO ReSource proficiency samples.

When dispute resolution testing is performed, the central laboratory's results will be used for verification purposes in lieu of the field verification laboratory's results.

7.9 Investigation of Non-Comparing Data Set

In accordance with Table 2 and 3, when a data set does not compare between the contractor's QA test results and the verification test results and the pay factor of the mean of the deviations from the JMF falls below the 0.80 limit, an investigation of non-comparing data sets will be initiated. This investigation may include but not be limited to the following: evaluation by the SCDOT IA personnel to determine whether further testing is needed, verification of all calibration records and testing equipment, round robin testing, identification of questionable lots, evaluation of in-place density results as well as inspection of the plant site for potential concerns.

Halt production of asphalt for the effected project beginning the following production day upon notification to the contractor's Quality Control Manager, District Asphalt Manager and Resident Construction Engineer by the Asphalt Verification Manager. The RCE will ensure all aspects of the project are safe for production to be halted and project delivery is not negatively compromised.

The contractor's QC Manager shall provide the RCE a corrective action report that identifies the potential issue as well as measures taken to minimize the risk on another non-comparison data set.

8. CALCULATION

8.1 All calculations for validation of the asphalt properties will be conducted using the statistical F-test and t-test method for computing two sets of data as indicated in AASHTO R 9. Results from calculations will be sent to the contractor within 48 hours of receipt of all documentation needed to analyze data set.

8.2 Example Calculation 1- Percent Binder Content in Asphalt: Sample Variances Assumed to be Equal

A Contractor has 12 quality acceptance tests and SCDOT has 5 verification tests over the same period of time for the percent binder content (%AC). Is it likely that the test came from the same population or lot?

Contractor QA Test Results (n_c)			SCDOT Verification Test Results (n_v)
3.50	3.77	3.79	5.05
3.56	3.05	2.77	2.65
3.06	3.78		3.78
3.12	4.48		3.18
4.00	3.34		4.51

Step 1. Compute the mean and standard deviation for each set of data:

QA test results	SCDOT Verification test results
$\overline{X}_c = 3.5183$	$\overline{X}_v = 3.834$
$s_c = 0.4809$	$s_v = 0.9706$
$n_c = 12$	$n_v = 5$

Step 2. Compute the variance, s^2, for each set of tests:

$s_c^2 = 0.2313$ $\quad$ $s_v^2 = 0.9421$

Step 3. Compute F, using the largest variance (s^2) in the numerator:

$$F = s_v^2 \div s_c^2 = 0.9421 \div 0.2313 = 4.07$$

Step 4. Determine F_{crit} from the F-distribution table making sure to use the correct degrees of freedom for the numerator ($n_v - 1 = 5\text{-}1 = 4$) and the denominator ($n_c - 1 = 12\text{-}1 = 11$).

Using $\alpha = 1$ % and the degrees of freedom (n-1) $\quad F_{crit} = 6.88$

Conclusion: Since $F < F_{crit}$ (ie. $4.07 < 6.88$), there is no reason to believe that the two data sets of tests have different variabilities. That is, they could have come from the same population. Since we can assume that the variances are equal, we can use *the pooled variance* to calculate the t-test statistic, and *the pooled degrees of freedom* to determine the critical t value, t_{crit}.

Step 5. Compute the pooled variance, s_p^2, using the pooled sample variance and the pooled degrees of freedom from above.

$$s_p^2 = \frac{s_c^2(n_c - 1) + s_v^2(n_v - 1)}{n_c + n_v - 2}$$

$$s_p^2 = \frac{(0.2313)(11) + (0.9421)(4)}{12 + 5 - 2} = 0.4208$$

Step 6. Compute the t-test statistic, t, using the pooled sample variance.

$$t = \frac{\left|\overline{X}_c - \overline{X}_v\right|}{\sqrt{\frac{s_p^2}{n_c} + \frac{s_p^2}{n_v}}} \qquad t = \frac{\left|3.5183 - 3.834\right|}{\sqrt{\frac{0.4208}{12} + \frac{0.4208}{5}}} = \frac{0.3157}{\sqrt{0.1192}} = 0.914$$

Step 7. Determine the critical t value t_{crit}, for the pooled degrees of freedom.

Degrees of freedom = $(n_c + n_v - 2) = (12 + 5 - 2) = 15$

Using $\alpha = 1$ % and the degrees of freedom = 15 (pooled variance will always be an integer for degrees of freedom) $t_{crit} = 2.947$

Conclusion: Since $t < t_{crit}$ (ie. $0.914 < 2.947$), there is no reason to assume that the sample means are not equal. It is, therefore, reasonable to assume that the sets of test results came from the same population (or LOT). Therefore, the contractor's test results can be used for acceptance

8.3 Example Calculation 2- Percent Binder Content in Asphalt: Sample Variances Assumed to be Different

A Contractor has 10 quality acceptance tests and SCDOT has 5 verification tests over the same period of time for the percent binder content (%AC). Is it likely that the test came from the same population or LOT?

Contractor QA Test Results (n_c)		SCDOT Verification Test Results (n_v)
6.42	7.98	7.52
7.18	6.32	11.38
5.04	6.08	9.20
4.56	5.92	5.32

7.12 5.78 3.18

Step 1. Compute the mean and standard deviation for each set of data:

QA test results	SCDOT Verification test results
$\overline{X}_c = 6.24$	$\overline{X}_v = 7.32$
$s_c = 1.036$	$s_v = 10.299$
$n_c = 10$	$n_v = 5$

Step 2. Compute the variance, s^2, for each set of tests:

$s_c^2 = 1.036$ $s_v^2 = 10.299$

Step 3. Compute F, using the largest variance (s^2) in the numerator:

$$F = s_v^2 \div s_c^2 = 10.299 \div 1.036 = 9.94$$

Step 4. Determine F_{crit} from the F-distribution table making sure to use the correct degrees of freedom for the numerator ($n_v - 1 = 5\text{-}1 = 4$) and the denominator ($n_c - 1 = 10\text{-}1 = 9$).

Using $\alpha = 1$ % and the degrees of freedom (n-1) $F_{crit} = 7.96$

Conclusion: Since $F > F_{crit}$ (ie. $9.94 > 7.96$), it is unlikely that the two data sets came from the same population. Therefore, conclude that the Contractor and SCDOT results came from different populations.

Step 5. Compute the t-test statistic, t, using the equation for unequal variances.

$$t = \frac{\left|\overline{X}_c - \overline{X}_v\right|}{\sqrt{\frac{s_c^2}{n_c} + \frac{s_v^2}{n_v}}} \qquad t = \frac{\left|6.24 - 7.32\right|}{\sqrt{\frac{1.036}{10} + \frac{10.299}{5}}} = \frac{1.08}{\sqrt{2.1634}} = 0.734$$

Step 6. Determine the critical t value t_{crit}, for the effective degrees of freedom, *f'*.

$$f' = \frac{\left(\frac{s_c^2}{n_c} + \frac{s_v^2}{n_v}\right)^2}{\left[\frac{\left(\frac{s_c^2}{n_c}\right)^2}{n_c + 1} + \frac{\left(\frac{s_v^2}{n_v}\right)^2}{n_v + 1}\right]} - 2 = \frac{\left(\frac{1.036}{10} + \frac{10.299}{5}\right)^2}{\left[\frac{\left(\frac{1.036}{10}\right)^2}{10 + 1} + \frac{\left(\frac{10.299}{5}\right)^2}{5 + 1}\right]} - 2 = 4.61 = 4$$

Using α = 1 % and the effective degrees of freedom = 4 (the calculated value for effective degrees of freedom is truncated to the lower integer: $t_{crit} = 4.604$

Conclusion: Since $t < t_{crit}$ (ie. $0.734 < 4.604$), there is no reason to assume that the sample means are not equal. However, since the results of the F-test were different, use SCDOT values obtained from Table 2 according to type of mix for Lot Pay Factor according to SC-M-400.

9. REPORT

9.1 Report – F-test and t-test results and a statement as to whether or not the Contractor's acceptance test results compare to the SCDOT verification results and can be used for acceptance will be forwarded to the District Asphalt Manager for completing the project payment functions for the LOTS included in the data set that was affected by the non-comparison.

Table 4 **Critical Values, F_{crit} for the F-test for a Level of Significance, $\alpha = 1\%$**

DEGREES OF FREEDOM FOR NUMERATOR

DEGREES OF FREEDOM FOR DENOMINATOR	1	2	3	4	5	6	7	8	9	10	11	12
1	16210.72	19999.50	21614.74	22499.58	23055.80	23437.11	23714.57	23925.41	24091.00	24224.49	24334.36	24426.37
2	198.50	199.00	199.17	199.25	199.30	199.33	199.36	199.37	199.39	199.40	199.41	199.42
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
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
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
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
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	14.69	11.04	9.60	8.81	8.30	7.95	7.69	7.50	7.34	7.21	7.10	7.01
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
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
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
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
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
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
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
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
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
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
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
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
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

NOTE : This is for a ***two-tailed test*** with the null and alternate hypotheses shown below:

$H_o: \; s_c^2 = s_v^2$

$H_a: \; s_c^2 \neq s_v^2$

Table 4 **Critical Values, F_{crit} for the F-test for a Level of Significance, $\alpha = 1\%$ (contd.)**

DEGREES OF FREEDOM FOR NUMERATOR

DEGREES OF FREEDOM FOR DENOMINATOR	13	14	15	20	24	30	40	50	60	100	120
1	24504.54	24571.77	24630.21	24835.97	24939.57	25043.63	25148.15	25211.09	25253.14	25337.45	25358.57
2	199.42	199.43	199.43	199.45	199.46	199.47	199.47	199.48	199.48	199.49	199.49
3	43.27	43.17	43.08	42.78	42.62	42.47	42.31	42.21	42.15	42.02	41.99
4	20.60	20.51	20.44	20.17	20.03	19.89	19.75	19.67	19.61	19.50	19.47
5	13.29	13.21	13.15	12.90	12.78	12.66	12.53	12.45	12.40	12.30	12.27
6	9.95	9.88	9.81	9.59	9.47	9.36	9.24	9.17	9.12	9.03	9.00
7	8.10	8.03	7.97	7.75	7.64	7.53	7.42	7.35	7.31	7.22	7.19
8	6.94	6.87	6.81	6.61	6.50	6.40	6.29	6.22	6.18	6.09	6.06
9	6.15	6.09	6.03	5.83	5.73	5.62	5.52	5.45	5.41	5.32	5.30
10	5.59	5.53	5.47	5.27	5.17	5.07	4.97	4.90	4.86	4.77	4.75
11	5.16	5.10	5.05	4.86	4.76	4.65	4.55	4.49	4.45	4.36	4.34
12	4.84	4.77	4.72	4.53	4.43	4.33	4.23	4.17	4.12	4.04	4.01
13	4.57	4.51	4.46	4.27	4.17	4.07	3.97	3.91	3.87	3.78	3.76
14	4.36	4.30	4.25	4.06	3.96	3.86	3.76	3.70	3.66	3.57	3.55
15	4.18	4.12	4.07	3.88	3.79	3.69	3.58	3.52	3.48	3.39	3.37
20	3.61	3.55	3.50	3.32	3.22	3.12	3.02	2.96	2.92	2.83	2.81
24	3.35	3.30	3.25	3.06	2.97	2.87	2.77	2.70	2.66	2.57	2.55
30	3.11	3.06	3.01	2.82	2.73	2.63	2.52	2.46	2.42	2.32	2.30
40	2.89	2.83	2.78	2.60	2.50	2.40	2.30	2.23	2.18	2.09	2.06
60	2.68	2.62	2.57	2.39	2.29	2.19	2.08	2.01	1.96	1.86	1.83
120	2.48	2.42	2.37	2.19	2.09	1.98	1.87	1.80	1.75	1.64	1.61

NOTE : This is for a ***two-tailed test*** with the null and alternate hypotheses shown below:

$H_o: \; s_c^2 = s_v^2$

$H_a: \; s_c^2 \neq s_v^2$

Table 5 **Critical Values, t_{crit} for the t-test**

degrees of freedom	$\alpha = 0.01$
1	63.657
2	9.925
3	5.841
4	4.604
5	4.032
6	3.707
7	3.499
8	3.355
9	3.250
10	3.169
11	3.106
12	3.055
13	3.012
14	2.977
15	2.947
16	2.921
17	2.898
18	2.878
19	2.861
20	2.845
21	2.831
22	2.819
23	2.807
24	2.797
25	2.787
26	2.779
27	2.771
28	2.763
29	2.756
30	2.750
40	2.704
60	2.660
120	2.617
∞	2.576

NOTE : This is for a two-tailed test with the null and alternate hypotheses shown below :

H_o : $\overline{X}_c = \overline{X}_v$

H_a : $\overline{X}_c \neq \overline{X}_v$