Chapter 558

Van der Waerden Normal Quantiles Tests of Means (Simulation)

Introduction

This procedure analyzes the power and significance level of the Van der Waerden Normal Quantiles test which is used to test statistical hypotheses in a one-way experimental design. For each scenario that is set up, two simulation studies are run. One simulation estimates the significance level and the other estimates the power.

Technical Details

Computer simulation allows us to estimate the power and significance level that is actually achieved by a test procedure in situations that are not mathematically tractable. Computer simulation was once limited to mainframe computers. But, in recent years, as computer speeds have increased, simulation studies can be completed on desktop and laptop computers in a reasonable period of time.

The steps to a simulation study are:

1. Specify how the test is carried out. This includes indicating how the test statistic is calculated and how the significance level is specified.

2. Generate random samples from the distributions specified by the alternative hypothesis. Calculate the test statistics from the simulated data and determine if the null hypothesis is accepted or rejected. Tabulate the number of rejections and use this to calculate the test’s power.

3. Generate random samples from the distributions specified by the null hypothesis. Calculate each test statistic from the simulated data and determine if the null hypothesis is accepted or rejected. Tabulate the number of rejections and use this to calculate the test’s significance level.

4. Repeat steps 2 and 3 several thousand times, tabulating the number of times the simulated data leads to a rejection of the null hypothesis. The power is the proportion of simulated samples in step 2 that lead to rejection. The significance level is the proportion of simulated samples in step 3 that lead to rejection.
Generating Random Distributions

Two methods are available in PASS to simulate random samples. The first method generates the random variates directly, one value at a time. The second method generates a large pool (over 10,000) of random values and then draws the random numbers from this pool. This second method can cut the running time of the simulation by 70%.

The second method begins by generating a large pool of random numbers from the specified distributions. Each of these pools is evaluated to determine if its mean is within a small relative tolerance (0.0001) of the target mean. If the actual mean is not within the tolerance of the target mean, individual members of the population are replaced with new random numbers if the new random number moves the mean towards its target. Only a few hundred such swaps are required to bring the actual mean to within tolerance of the target mean. This population is then sampled with replacement using the uniform distribution. We have found that this method works well as long as the size of the pool is at least the maximum of twice the number of simulated samples desired and 10,000.

Van der Waerden Normal Quantiles Test

This section summarizes the van der Waerden Normal Quantiles test. This test is popular because its asymptotic efficiency relative to the standard F-test is one when the underlying data are normal. When the data are not normal, the A.R.E. is often greater than one. See Conover (1999) and Gibbons and Chakraborti (2011) for more details.

Assumptions

1. A simple random sample is available from each group. This implies that the individual subjects with the sample are independent.
2. There is mutual independence between samples.
3. The measurement scale is at least ordinal (the data can be ranked).
4. The $g$ distributions are identical, or, some groups tend to produce larger values than others.

Test Statistic

Suppose that $X_{kj}$ represents the (at least ordinal) data value of the $j^{th}$ subject in the $k^{th}$ group. Let $r_{kj}$ represent the rank of $X_{kj}$ when the $N$ values are ranked without regard to their group. Let $n_1, n_2, ..., n_g$ denote the number of subjects in each group and let $N$ denote the total sample size of all groups.

The formula for the van der Waerden test is

$$T = \frac{1}{S^2} \sum_{k=1}^{g} n_k \bar{A}_k^2$$

where

$$A_{kj} = \Phi^{-1} \left( \frac{r_{kj}}{N+1} \right)$$

$$\bar{A}_k = \frac{1}{n_k} \sum_{j=1}^{n_k} A_{kj}$$

$$S^2 = \frac{1}{N-1} \sum_{k=1}^{g} \left[ \sum_{j=1}^{n_k} (A_{kj} - \bar{A})^2 \right]$$

$\Phi^{-1}(x)$ is the normal quantile of $x$. 

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Distribution of $T$
If these assumptions are met, the distribution of $T$ follows the *Chi-square* distribution with $g-1$ degrees of freedom. These results can be used to form an approximate statistical test of the null hypothesis that the distributions of all groups are equal versus the alternative hypothesis that at least one group tends to produce larger values than the others.

Procedure Options
This section describes the options that are specific to this procedure. These are located on the Design and Simulation tabs. For more information about the options of other tabs, go to the Procedure Window chapter.

Design Tab
The Design tab contains the parameters and options needed to described the experimental design, the data distributions, the error rates, and sample sizes.

Solve For
This option specifies the parameter to be calculated using the values of the other parameters.
Select *Power* when you want to determine the power based on the values of the other parameters.
Select *Sample Size* when you want to determine the sample size needed to achieve a given power and alpha error level. This option is very computationally intensive, so it may take a long time (several hours) to complete.

Power, Alpha, and Simulations

Power (Only shown when Solve For is set to Sample Size)
This option specifies one or more values for power. Power is the probability of rejecting a false null hypothesis, and is equal to one minus beta. Beta is the probability of a type-II error, which occurs when a false null hypothesis is not rejected. In this procedure, a type-II error occurs when you fail to reject the null hypothesis of equal means when in fact the means are different.

Power values must be between zero and one. Historically, 0.80 was used for power. Now, 0.90 is also commonly used.
You may enter a single value or a range of values such as *0.8 to 0.95 by 0.05*.

Alpha
This option specifies one or more values for the probability of a type-I error, alpha. A type-I error occurs when a true null hypothesis is rejected. In this procedure, a type-I error occurs when you reject the null hypothesis of equal means when in fact the means are equal.

Alpha values must be between zero and one. Historically, 0.05 has been used for alpha. This means that about one test in twenty will falsely reject the null hypothesis. You should pick a value for alpha that represents the risk of a type-I error you are willing to take in your experimental situation.
You may enter a single value or a range of values such as *0.01 0.05 0.10 or 0.01 to 0.10 by 0.01*.

Simulations
This option specifies the number of simulations, $M$. The larger the number of simulations, the longer the running time and the more accurate the results.

The precision of the simulated power estimates are calculated from the binomial distribution. Thus, confidence intervals may be constructed for various power values using the binomial distribution. The following table gives
an estimate of the precision that is achieved for various simulation sizes when the power is either 0.50 or 0.95. The table values are interpreted as follows: a 95% confidence interval of the true power is given by the power reported by the simulation plus and minus the ‘Precision’ amount given in the table.

<table>
<thead>
<tr>
<th>Simulation Size</th>
<th>Precision when M Power = 0.50</th>
<th>Precision when M Power = 0.95</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.100</td>
<td>0.044</td>
</tr>
<tr>
<td>500</td>
<td>0.045</td>
<td>0.019</td>
</tr>
<tr>
<td>1000</td>
<td>0.032</td>
<td>0.014</td>
</tr>
<tr>
<td>2000</td>
<td>0.022</td>
<td>0.010</td>
</tr>
<tr>
<td>5000</td>
<td>0.014</td>
<td>0.006</td>
</tr>
<tr>
<td>10000</td>
<td>0.010</td>
<td>0.004</td>
</tr>
<tr>
<td>50000</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>100000</td>
<td>0.003</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Notice that a simulation size of 1000 gives a precision of plus or minus 0.01 when the true power is 0.95. Also note that as the simulation size is increased beyond 5000, there is only a small amount of additional accuracy achieved.

**Random Seed**

Specify a numeric seed for random number generation. This value must be between 0 and 2147483647 and may be a decimal number.

**Obtaining a Computer-Generated Random Seed**

Enter Random, 0, or leave this option blank for a randomly generated seed based on the computer’s internal clock. If a randomly generated seed is used, its value will be displayed in the output.

**Using a Non-Zero Random Seed**

If you enter a non-zero random seed, the same random sequence will be generated with each run and the output will not change. This is often used to replicate previous results.

**Number of Groups and Sample Size Allocation**

**Number of Groups**

Enter the number of groups in the design. The program can handle between 2 and 20 groups.

**Group Allocation (If Solve For is set to Power)**

Select the method used to allocate subjects to groups. The choices are

- **Equal (n = n1 = n2 = ...)**
  All group sample sizes are the same. The value(s) of n are entered in the n (Group Size) box that will appear immediately below this box. See also n (Group Size) below.

- **Enter base group size and group multipliers**
  The group sample sizes are found by multiplying the corresponding Multiplier value (found in the Power Simulation section) times the Base Group Size that will appear immediately below this box. See also Base Group Size and Multiplier below.
Enter total sample size and group percentages
The group sample sizes are found by taking the corresponding percentage (found in the Power Simulation section) of the $N$ (Total Size) value that will appear immediately below this box. See also $N$ (Total Size) and Percent of $N$ below.

Note that the Percent of $N$ values are adjusted so they sum to 100%.

Enter individual group sample sizes
Enter each group's sample size directly in the corresponding Sample Size box in the Power Simulation section. See also Sample Size below.

Group Allocation (If Solve For is set to Sample Size)
Select the method used to allocate subjects to groups. The choices are

- Equal ($n_1 = n_2 = ...$)
  All group sample sizes are the same. This sample size itself will be searched for.

- Enter group multipliers
  The group sample sizes are found by multiplying the corresponding Multiplier value (found in the Power Simulation section) times the Base Group Size that is being searched for.

n (Group Size)
This is the group sample size of all groups. One or more values, separated by blanks or commas, may be entered. A separate analysis is performed for each value listed here.

Base Group Size
This is the base sample size per group. One or more values, separated by blanks or commas, may be entered. A separate analysis is performed for each value listed here.

The individual group samples sizes are determined by multiplying this value times the corresponding Multiplier value entered in the Power Simulation section.

If the Multiplier numbers are represented by $m_1, m_2, m_3, ...$
and this value is represented by $n$, the group sample sizes are calculated as follows:

\[
\begin{align*}
  n_1 &= \lceil n(m_1) \rceil \\
  n_2 &= \lceil n(m_2) \rceil \\
  n_3 &= \lceil n(m_3) \rceil 
\end{align*}
\]

where the operator, $\lceil X \rceil$ means the next integer after $X$, e.g. $\lceil 3.1 \rceil = 4$.

For example, suppose there are three groups and the multipliers are set to 1, 2, and 3. If $n$ is 5, the resulting group sample sizes will be 5, 10, and 15.

N (Total Size)
This is the total sample size. One or more values, separated by blanks or commas, may be entered. A separate analysis is performed for each value listed here.

The individual group samples sizes are determined by multiplying this value times the corresponding Percent of $N$ value entered in the Power Simulation section.

If the Percent values are represented by $p_1, p_2, p_3, ...$
and this value is represented by N, the group sample sizes are calculated as follows:

\[ n_1 = \lceil N(p_1) \rceil \]
\[ n_2 = \lceil N(p_2) \rceil \]
\[ n_3 = \lceil N(p_3) \rceil \]

where the operator, \([X]\), means the next integer after X, e.g. \([3.1]=4\).

For example, suppose there are three groups and the percentages are set to 25, 25, and 50. If \(N\) is 36, the resulting group sample sizes will be 9, 9, and 18.

---

**Power Simulation**

These options specify the distributions to be used in the power simulation, one row per group. The first option specifies distribution. The second option, if visible, specifies the sample size of that group.

**Distribution**

Specify the distribution of each group under the alternative hypothesis, \(H_1\). This distribution is used in the simulation that determines the power.

A fundamental quantity in a power analysis is the amount of variation among the group means. In fact, in classical power analysis formulas, this variation is summarized as the standard deviation of the means. You must pay particular attention to the values you give to the means of these distributions because they are fundamental to the interpretation of the simulation.

For convenience in specifying a range of values, the parameters of the distribution can be specified using numbers or letters. If letters are used, their values are specified in the **Parameter Values** boxes below.

Following is a list of the distributions that are available and the syntax used to specify them. Each of the parameters should be replaced with a number or parameter name.

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**Distributions with Common Parameters**

- Beta(Shape1, Shape2, Min, Max)
- Binomial(P, N)
- Cauchy(Mean, Scale)
- Constant(Value)
- Exponential(Mean)
- Gamma(Shape, Scale)
- Gumbel(Location, Scale)
- Laplace(Location, Scale)
- Logistic(Location, Scale)
- Lognormal(Mu, Sigma)
- Multinomial(P1, P2, P3, ..., Pk)
- Normal(Mean, Sigma)
- Poisson(Mean)
- TukeyGH(Mu, S, G, H)
- Uniform(Min, Max)
- Weibull(Shape, Scale)
Details of writing mixture distributions, combined distributions, and compound distributions are found in the chapter on Data Simulation and will not be repeated here.

Finding the Value of the Mean of a Specified Distribution

The mean of a distribution created as a linear combination of other distributions is found by applying the linear combination to the individual means. However, the mean of a distribution created by multiplying or dividing other distributions is not necessarily equal to applying the same function to the individual means. For example, the mean of 4 Normal(4, 5) + 2 Normal(5, 6) is 4*4 + 2*5 = 26, but the mean of 4 Normal(4, 5) * 2 Normal(5, 6) is not exactly 4*4*2*5 = 160 (although it is close).

Multiplier

The group allocation Multiplier for this group is entered here. Typical values of this parameter are 0.5, 1, and 2.

- Solve For = Power
  The group sample size is found by multiplying this value times the Base Group Size value and rounding up to the next whole number.

- Solve For = Sample Size
  The group sample size is found by multiplying this value times the base group size that is being searched for and rounding up to the next whole number.

Percent of N

This is the percentage of the total sample size that is allocated to this group. The individual group samples sizes are determined by multiplying this value times the N (Total Size) value entered above.

If these values are represented by p1, p2, p3, ... the group sample sizes are calculated as follows:

\[ n1 = \lceil N(p1) \rceil \]
\[ n2 = \lceil N(p2) \rceil \]
\[ n3 = \lceil N(p3) \rceil \]

where the operator, \( \lceil X \rceil \) means the next integer after X, e.g. \( \lceil 3.1 \rceil = 4 \).

For example, suppose there are three groups and these percentages are set to 25, 25, and 50. If N is 36, the resulting group sample sizes will be 9, 9, and 18.

Sample Size

This option allows you to enter the sample size of this group directly.
Power Simulation – Parameter Values for Group Distributions

These options specify the names and values for the parameters used in the distributions.

Name

Up to six sets of named parameter values may be used in the simulation distributions. This option lets you select an appropriate name for each set of values. Possible names are

- M1 to M5
  You might use M1 to M5 for means.

- SD
  You might use SD for standard deviations.

- A to T
  You might use these letters for location, shape, and scale parameters.

Value(s)

These values are substituted for the Parameter Name (M1, M2, SD, A, B, C, etc.) in the simulation distributions. If more than one value is entered, a separate calculation is made for each value.

You can enter a single value such as “2” or a series of values such as “0 2 3” or “0 to 3 by 1”.

Alpha Simulation

These options specify the distributions to be used in the alpha simulation, one row per group. The alpha simulation generates an estimate of the actual alpha value that will be achieved by the test procedure. The magnitude of the differences of the means of these distributions, which is often summarized as the standard deviation of the means, represents the magnitude of the mean differences specified under H0. Usually, the means are assumed to be equal under H0, so their standard deviation should be zero except for rounding.

Specify Alpha Distributions

This option lets you choose how you will specify the alpha distributions. Possible choices are

- All equal to the group 1 distribution of the power simulation
  Often, the first group will represent a neutral group such as the control group. This option indicates that the first group of the power distributions should be used for all of the alpha simulation groups. Typically, this is what you want since the null hypothesis assumes that all distributions are the same.

- All equal to a custom distribution
  Set all group distributions in the alpha simulation equal to the custom alpha distribution specified below.

- Enter each distribution separately
  Each group’s simulation distribution is entered individually below.

Custom Alpha Distribution

Specify the alpha distribution to be used for all groups. The syntax is the same as that for the Power Simulation Distribution (see above) and will not be repeated here.

Individual Alpha Distributions

Specify a separate distribution for each group. The syntax is the same as that for the Power Simulation Distribution (see above) and will not be repeated here.

Keep in mind that the null hypothesis assumes that all distributions are the same.
Simulations Tab

The option on this tab controls the generation of the random numbers. For complicated distributions, a large pool of random numbers from the specified distributions is generated. Each of these pools is evaluated to determine if its mean is within a small relative tolerance (0.0001) of the target mean. If the actual mean is not within the tolerance of the target mean, individual members of the population are replaced with new random numbers if the new random number moves the mean towards its target. Only a few hundred such swaps are required to bring the actual mean to within tolerance of the target mean. This population is then sampled with replacement using the uniform distribution. We have found that this method works well as long as the size of the pool is at least the maximum of twice the number of simulated samples desired and 10,000.

Random Number Pool Size

This is the size of the pool of values from which the random samples will be drawn. Pools should be at least the minimum of 10,000 and twice the number of simulations. You can enter Automatic and an appropriate value will be calculated.

If you do not want to draw numbers from a pool, enter 0 here.
Example 1 – Power at Various Sample Sizes

For this first example we repeat Example 1 of the regular One-Way ANOVA procedure. This will allow you to compare the values obtained by simulation with the actual values obtained from the theoretical results.

An experiment is being designed to compare the means of four groups using an $F$ test with a significance level of 0.05. Previous studies have shown that the standard deviation within a group is 18. Treatment means of 40, 10, 10, and 10 represent clinically important treatment differences. To better understand the relationship between power and sample size, the researcher wants to compute the power for group sample sizes of 4, 8, and 12. The group sample sizes are equal.

Setup

This section presents the values of each of the parameters needed to run this example. First, from the PASS Home window, load the procedure window. You may then make the appropriate entries as listed below, or open Example 1 by going to the File menu and choosing Open Example Template.

<table>
<thead>
<tr>
<th>Option</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Tab</td>
<td></td>
</tr>
<tr>
<td>Solve For</td>
<td>Power</td>
</tr>
<tr>
<td>Alpha</td>
<td>0.05</td>
</tr>
<tr>
<td>Simulations</td>
<td>5000</td>
</tr>
<tr>
<td>Random Seed</td>
<td>Blank or Random</td>
</tr>
<tr>
<td>Number of Groups</td>
<td>4</td>
</tr>
<tr>
<td>Group Allocation</td>
<td>Equal</td>
</tr>
<tr>
<td>n (Group Size)</td>
<td>4 8 12</td>
</tr>
<tr>
<td>Group 1 Distribution</td>
<td>Normal(M1 SD)</td>
</tr>
<tr>
<td>Group 2 Distribution</td>
<td>Normal(M2 SD)</td>
</tr>
<tr>
<td>Group 3 Distribution</td>
<td>Normal(M2 SD)</td>
</tr>
<tr>
<td>Group 4 Distribution</td>
<td>Normal(M2 SD)</td>
</tr>
<tr>
<td>M1</td>
<td>40</td>
</tr>
<tr>
<td>M2</td>
<td>10</td>
</tr>
<tr>
<td>SD</td>
<td>18</td>
</tr>
<tr>
<td>Specify Alpha Distributions</td>
<td>All equal to the group 1 distribution of the power simulation</td>
</tr>
</tbody>
</table>
Annotated Output

Click the Calculate button to perform the calculations and generate the following output.

Numeric Results Report

Simulation Summary

<table>
<thead>
<tr>
<th>Group</th>
<th>Power Distribution</th>
<th>Alpha Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal(M1 SD)</td>
<td>Normal(M1 SD)</td>
</tr>
<tr>
<td>2</td>
<td>Normal(M2 SD)</td>
<td>Normal(M1 SD)</td>
</tr>
<tr>
<td>3</td>
<td>Normal(M2 SD)</td>
<td>Normal(M1 SD)</td>
</tr>
<tr>
<td>4</td>
<td>Normal(M2 SD)</td>
<td>Normal(M1 SD)</td>
</tr>
</tbody>
</table>

Number of Groups 4
Random Number Pool Size 10000
Number of Simulations Per Run 5000

Numeric Results

<table>
<thead>
<tr>
<th>Row</th>
<th>Power</th>
<th>Mean Group Sample Size</th>
<th>Total Sample Size</th>
<th>Target Alpha</th>
<th>Actual Alpha</th>
<th>Std Dev of H1 μ's</th>
<th>Mean of H1 σ's</th>
<th>M1</th>
<th>M2</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.380</td>
<td>4.0</td>
<td>16</td>
<td>0.050</td>
<td>0.031</td>
<td>13.0</td>
<td>17.9</td>
<td>40.0</td>
<td>10.0</td>
<td>18.0</td>
</tr>
<tr>
<td>2</td>
<td>0.874</td>
<td>8.0</td>
<td>32</td>
<td>0.050</td>
<td>0.039</td>
<td>13.0</td>
<td>17.9</td>
<td>40.0</td>
<td>10.0</td>
<td>18.0</td>
</tr>
<tr>
<td>3</td>
<td>0.981</td>
<td>12.0</td>
<td>48</td>
<td>0.050</td>
<td>0.043</td>
<td>13.0</td>
<td>18.0</td>
<td>40.0</td>
<td>10.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Run Time: 3.45 seconds.

Definitions of the Numeric Results Report

- **Row** identifies this line of the report. It will be used cross-reference this line in other reports.
- μ represents the mean of a group.
- σ represents the within-group standard deviation.
- H0 is the null hypothesis that all μ's are equal.
- H1 is the alternative hypothesis that at least one μ is different from the others.
- Power is the probability of rejecting H0 when it is false. This is the actual value calculated by the power simulation.
- Mean Group Sample Size n is the average of the individual group sample sizes.
- Total Sample Size N is the total sample size found by summing all group sample sizes.
- Target Alpha is the planned probability of rejecting a true H0. This is the planned Type-1 error rate.
- Actual Alpha is the alpha achieved by the test as calculated by the alpha simulation. Note that the alpha simulation is separate from the power simulation.
- Std Dev of H1 μ's is the standard deviation of the group μ's used in the power simulation. This measures the magnitude of the difference among the μ's.
- Mean of H1 σ's is the mean of the group σ's used in the power simulation. This measures the magnitude of the σ's.

Summary Statements

A one-way design with 4 groups has sample sizes of 4, 4, 4, and 4. The null hypothesis is that the standard deviation of the group means is 0.0 and the alternative standard deviation of the group means is 13.0. The total sample of 16 subjects achieves a power of 0.380 using the Van der Waerden Test with a target significance level of 0.050 and an actual significance level of 0.031. The average within group standard deviation assuming the alternative distribution is 13.0. These results are based on 5000 Monte Carlo samples from the null distributions: Normal(M1 SD); Normal(M1 SD); Normal(M1 SD); and Normal(M1 SD) and the alternative distributions: Normal(M1 SD); Normal(M2 SD); Normal(M2 SD); and Normal(M2 SD). Other parameters used in the simulation were: M1 = 40.0, M2 = 10.0, and SD = 18.0.

These reports show the output for this run. We will annotate the Numeric Results report.

Power

This is the probability of rejecting a false null hypothesis. This value is estimated by the power simulation. The Power and Alpha Confidence Interval report displayed next will provide estimates of the precision of these power values.

Mean Group Size n

This is the average of the group sample sizes.
Total Sample Size N
This is the total sample size of the study.

Target Alpha
The target value of alpha: the probability of rejecting a true null hypothesis. This is often called the significance level.

Actual Alpha
This is the value of alpha estimated by the alpha simulation. It should be compared with the Target Alpha. The Power and Alpha Confidence Interval report displayed next will provide estimates of the precision of these Actual Alpha values.

Std Dev of H1 μ’s
This is the standard deviation of the hypothesized means of the power (H1) simulation distributions, σ_m|H1. Under H0, this value is zero. So this value represents the magnitude of the difference among the means that is being tested.

Note that a popular definition of effect size is the ratio of σ_m|H1 and σ|H1.

Mean of H1 σ’s
This is the mean of the group standard deviations calculated from the power simulation distributions, σ|H1.

M1
These are the values entered for M1, the group 1 mean in the power simulation.

M2
These are the values entered for M2, the groups 2, 3, and 4 means in the power simulation.

SD
These are the values entered for SD, the standard deviation.

Power and Alpha Confidence Intervals Report

<table>
<thead>
<tr>
<th>Row</th>
<th>Total Sample Size N</th>
<th>Total Power</th>
<th>Lower Limit of 95% C.I. of Power</th>
<th>Upper Limit of 95% C.I. of Power</th>
<th>Actual Lower Limit of 95% C.I. of Alpha</th>
<th>Actual Upper Limit of 95% C.I. of Alpha</th>
<th>M1 Limit</th>
<th>M2 Limit</th>
<th>SD Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>0.380</td>
<td>0.367</td>
<td>0.394</td>
<td>0.031</td>
<td>0.027</td>
<td>0.036</td>
<td>0.033</td>
<td>0.044</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>0.874</td>
<td>0.865</td>
<td>0.883</td>
<td>0.039</td>
<td>0.033</td>
<td>0.044</td>
<td>0.040</td>
<td>0.049</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>0.981</td>
<td>0.977</td>
<td>0.985</td>
<td>0.043</td>
<td>0.038</td>
<td>0.049</td>
<td>0.040</td>
<td>0.049</td>
</tr>
</tbody>
</table>

Definitions of the Power and Alpha Confidence Intervals Report
Total Sample Size, N, is the total sample size found by summing all group sample sizes.
Power is the probability of rejecting H0 when it is false. This is the actual value calculated by the power simulation.
Lower and Upper Limits of a 95% C.I. for Power are the limits of an exact, 95% confidence interval for power based on the binomial distribution. They are calculated from the power simulation.
Target Alpha is the desired probability of rejecting a true null hypothesis at which the tests were run.
Actual Alpha is the alpha achieved by the test as calculated by the alpha simulation.
Lower and Upper Limits of a 95% C.I. for Alpha are the limits of an exact, 95% confidence interval for alpha based on the binomial distribution. They are calculated from the alpha simulation.

Total Sample Size N
This is the total sample size of the study.
**Lower/Upper Limit of 95% C.I. for Power**

These are the limits of an exact, 95% confidence interval for power using the power simulation. The confidence interval is based on the binomial distribution. The width of this confidence interval is directly related to the number of simulations that were used.

**Lower/Upper Limit of 95% C.I. for Alpha**

These are the limits of an exact, 95% confidence interval for alpha using the alpha simulation. The confidence interval is based on the binomial distribution. The width of this confidence interval is directly related to the number of simulations that were used. Since the target alpha is 0.05, 0.05 should be within these limits.

### Detailed Results Reports

#### Details for Row 1 of the Numeric Results Report

<table>
<thead>
<tr>
<th>Group</th>
<th>ni</th>
<th>Pct of N</th>
<th>H0 μ</th>
<th>H1 μ</th>
<th>H0 σ</th>
<th>H1 σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>25.0</td>
<td>40.0</td>
<td>40.0</td>
<td>17.7</td>
<td>17.8</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>18.0</td>
<td>17.9</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>17.9</td>
<td>18.0</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>18.1</td>
<td>17.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Std Dev of H0 μ's</th>
<th>Std Dev of H1 μ's</th>
<th>Mean of H0 σ's</th>
<th>Mean of H1 σ's</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>16</td>
<td>0.0</td>
<td>13.0</td>
<td>17.9</td>
<td>17.9</td>
</tr>
</tbody>
</table>

#### Details for Row 2 of the Numeric Results Report

<table>
<thead>
<tr>
<th>Group</th>
<th>ni</th>
<th>Pct of N</th>
<th>H0 μ</th>
<th>H1 μ</th>
<th>H0 σ</th>
<th>H1 σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>25.0</td>
<td>40.0</td>
<td>40.0</td>
<td>18.0</td>
<td>17.8</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>18.1</td>
<td>17.7</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>18.1</td>
<td>18.2</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>17.9</td>
<td>18.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Std Dev of H0 μ's</th>
<th>Std Dev of H1 μ's</th>
<th>Mean of H0 σ's</th>
<th>Mean of H1 σ's</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>32</td>
<td>0.0</td>
<td>13.0</td>
<td>18.0</td>
<td>17.9</td>
</tr>
</tbody>
</table>

#### Details for Row 3 of the Numeric Results Report

<table>
<thead>
<tr>
<th>Group</th>
<th>ni</th>
<th>Pct of N</th>
<th>H0 μ</th>
<th>H1 μ</th>
<th>H0 σ</th>
<th>H1 σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>25.0</td>
<td>40.0</td>
<td>40.0</td>
<td>18.0</td>
<td>18.1</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>18.1</td>
<td>18.0</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>18.0</td>
<td>18.0</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>25.0</td>
<td>40.0</td>
<td>10.0</td>
<td>18.1</td>
<td>17.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Std Dev of H0 μ's</th>
<th>Std Dev of H1 μ's</th>
<th>Mean of H0 σ's</th>
<th>Mean of H1 σ's</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>48</td>
<td>0.0</td>
<td>13.0</td>
<td>18.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

These reports show the details of each scenario.

### Row (in Title)

This is the row number of the Numeric Results report about which this report gives the details.

### Group

This is the number of the group shown on this line.

### ni

This is the sample size of each group. This column is especially useful when the sample sizes are unequal.

### Percent of N

This is the percentage of the total sample that is allocated to each group.
**H0 \( \mu \) and H1 \( \mu \)**
These are the means that were used in the alpha and power simulations, respectively.

**H0 \( \sigma \) and H1 \( \sigma \)**
These are the standard deviations that were obtained by the alpha and power simulations, respectively. Note that they often are not exactly equal to what was specified because of the error introduced by simulation.

**Std Dev of H0 (and H1) \( \mu \)'s**
These are the standard deviations of the means that were obtained by the alpha and power simulations, respectively. Under H0, this value should be near zero. The H0 value lets you determine if your alpha simulation was correctly specified. The H1 value represents the magnitude of the effect size (when divided by an appropriate measure of the standard deviation).

**Mean of H0 (and H1) \( \sigma \)'s**
These are the average of the individual group standard deviations that were obtained by the alpha and power simulations, respectively.

**Plots Section**

This plot gives a visual presentation to the results in the Numeric Report. We can quickly see the impact on the power of increasing the sample size.
Example 2 – Validation using Fleiss (1986)

Fleiss (1986) page 374 presents an example of determining an appropriate sample size when using an F-test in an experiment with 4 groups; means of 9.775, 12, 12, and 14.225; standard deviation of 3; alpha of 0.05, and beta of 0.20. He finds a sample size of 11 per group. We anticipate that a slightly larger value will be needed for the van der Waerden Test.

For reproducibility, we’ll use a random seed of 5637299.

Setup

This section presents the values of each of the parameters needed to run this example. First, from the PASS Home window, load the procedure window. You may then make the appropriate entries as listed below, or open Example 2 by going to the File menu and choosing Open Example Template.

Option | Value
--- | ---
**Design Tab**
Solve For | Sample Size
Power | 0.80
Alpha | 0.05
Simulations | 5000
Random Seed | 5637299
Number of Groups | 4
Group Allocation | Equal
Group 1 Distribution | Normal(M1 SD)
Group 2 Distribution | Normal(M2 SD)
Group 3 Distribution | Normal(M3 SD)
Group 4 Distribution | Normal(M4 SD)
M1 | 9.775
M2 | 12
M3 | 12
M4 | 14.225
SD | 3
Specify Alpha Distributions | All equal to the group 1 distribution of the power simulation

**Reports Tab**
Show Numeric Reports | Checked
Show Detail Reports | Checked
All other reports | Unchecked

**Plots Tab**
All plots | Unchecked
Output

Click the Calculate button to perform the calculations and generate the following output.

### Numeric Results

<table>
<thead>
<tr>
<th>Row</th>
<th>Target Power</th>
<th>Actual Power</th>
<th>Mean Group Sample Size</th>
<th>Total Sample Size</th>
<th>Target Alpha</th>
<th>Actual Alpha</th>
<th>Std Dev of H1 μ’s</th>
<th>Mean of H1 α’s</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.800</td>
<td>0.818</td>
<td>12.0</td>
<td>48</td>
<td>0.050</td>
<td>0.048</td>
<td>1.6</td>
<td>3.0</td>
<td>9.8</td>
<td>12.0</td>
<td>12.0</td>
<td>14.2</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Note that **PASS** has found the group sample size to be 12, which is only slightly larger than 11, as expected.