PWL*Pay*
User's Manual

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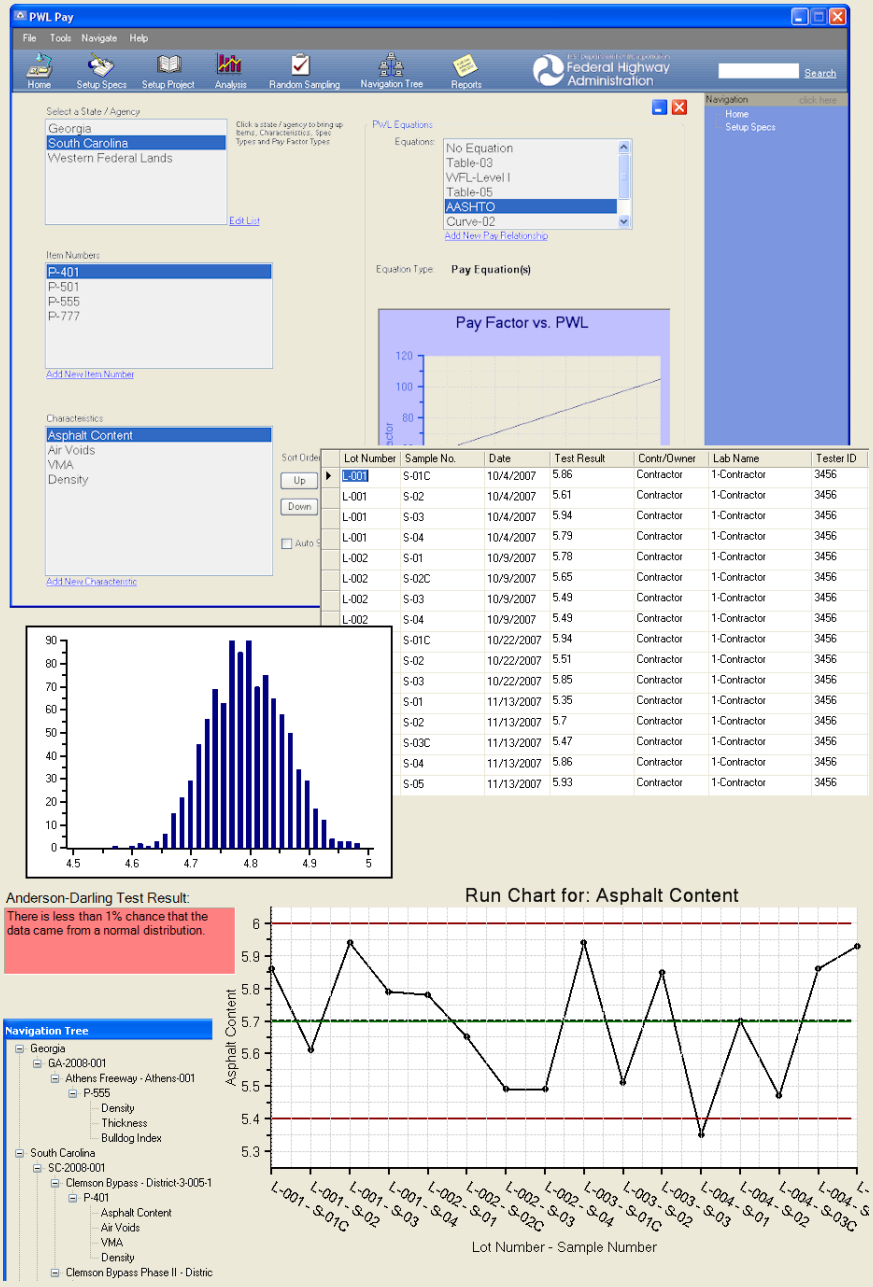

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PWL*Pay* was developed at Clemson University under contract from the Federal Highway Administration Western Federal Lands Highway Division (FHWA-WFLHD). James L. Burati, Jr. was the principal investigator and provided all technical guidance. Thomas P. McAfee, Jr. performed the computer programming for **PWL***Pay.* Bruce E. Wasill was the technical representative for FHWA-WFLHD.

PWL*Pay* allows users to input any Percent Within Limits (PWL) acceptance plan, along with the corresponding quality characteristics and their test results. The software then allows the user to compute payment factors; to consider the potential impacts of various changes in the process mean, standard deviation, or both; and to develop and display control charts.

PWL*Pay* should provide a powerful tool for contractors to use to track their processes, develop control charts, determine payment factors, analyze risks, and make informed decisions necessary to maximize profit while providing agencies with the quality product they desire. The software will provide agencies that do not already have a materials database a simple way of collecting and tracking contractor and agency test data.

Forward

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1 Getting Started

Overview

PWL*Pay* was developed at Clemson University under contract from the Federal Highway Administration Western Federal Lands Highway Division (FHWA-WFLHD). The software allows users to input any Percent Within Limits (PWL) acceptance plan, along with the corresponding quality characteristics and their test results. The software then allows the user to compute payment factors; to consider the potential impacts of various changes in the process mean, standard deviation, or both; and to develop and display control charts.

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PWL*Pay* Capabilities

PWL*Pay* is not intended to allow development of a statistical acceptance plan, but rather to allow the determination of the risks associated with a particular acceptance plan. Other software, such as *SpecRisk*, is available from FHWA to assist in developing PWL acceptance plans. **PWL*Pay*** is intended to be used as a tool to assist both owners and contractors in their quality assurance (QA) tasks, including both acceptance and process control. **PWL*Pay*** allows the user to

- Input PWL acceptance plans, including acceptable quality limits (AQL), rejectable quality limits (RQL), sample sizes (n), payment relationships, specification limits, etc.
- Input test results for the contractor and agency.
- Conduct verification tests, including F-tests and t-tests for both independent and paired data sets.
- Determine descriptive statistics, including mean, standard deviation, skewness, and kurtosis, for the input test results.
- Test the input data for normality using both graphical and statistical hypothesis tests.
- Compute current payment factors.
- Compute projected payment factors.
- Develop and plot Run Charts, as well as Control Charts for individuals and moving ranges, and for sample means and ranges.
- Play “what if games” to determine the potential impacts of changes in the process mean, standard deviation, or both.

Typographical Conventions in this Manual

File ▸ Exit — Denotes a menu command. In this case choose **Exit** from the **File** menu. Here is another example: **File ▸ Open Project ▸ Show All Projects** means open the **File** menu, then open the **Open Project** submenu, and finally choose **Show All Projects**.

Click **OK**. — Bold text clarifies dialog box items and buttons and **PWL*Pay*** commands.

Enter *Test 1*. — Italic text specifies text the user needs to enter.

Installing PWL*Pay*

PWL*Pay* is written to run on all versions of the Microsoft Windows operating system, including Windows 2000, XP, and Vista. Installing **PWL*Pay*** is simple—just run **PWL*Pay***'s **Setup** program and follow its instructions.

If Obtained Online

If you downloaded **PWL*Pay*** from a Website, you have probably already run **PWL*Pay* Setup**. In case you have not, run the file you downloaded (SETUP.EXE) and follow the instructions.

If Obtained on CD

If you are installing **PWL*Pay*** from a CD-ROM, **PWL*Pay* Setup** will usually start automatically when you insert the CD-ROM into the drive. If it does not, run SETUP.EXE and follow the instructions. You can run it using the **Run** command on the **Start** menu, or from the **My Documents** window.

Administrator Rights

You must have administrator rights to install **PWL*Pay***. Users whose organizations have particularly strict security policies may need to have their information technology department revise the user's permission rights for **PWL*Pay***.

Starting PWL*Pay*

The Setup program installs a **PWL*Pay*** shortcut on your **Desktop**. Run this shortcut to start **PWL*Pay***. The program opens to the **Home** screen. All of **PWL*Pay***'s capabilities can be accessed from this screen, including:

Home

Setup Specs

Setup Project

Analysis

Random Sampling

Navigation Tree

Reports

These selections are discussed in the following chapters.

The Process for Using PWL*Pay*

The general steps for beginning to use **PWL*Pay*** are shown below:

1. Use **Setup Specs** to enter the acceptance characteristics and payment equations for the various items (e.g., PCC, hot mix asphalt) in the agency's specifications.

2. Use **Setup Project** to enter the items and their specification limits for a project.

3. Use **Random Sampling** to determine random sample locations or times for a project.

4. Add contractor acceptance and quality control test results, as well as any agency acceptance or verification tests for the project.

5. Use **Analysis** to perform various analyses on the data for one project or multiple projects. These analyses could include, for example, calculation of basic statistics, checks for normality of the entered data, preparation of run charts or process control charts, statistical tests to verify contractor test results, and pay factor calculations.

Detailed explanations of the features of **PWL*Pay***, as well as instructions on how to use each of these features, are presented in the following chapters of this manual.

Format of this Manual

This manual is provided as a PDF file and it is likely that it will most often be used as an electronic file. For users who wish to print a copy, the manual is formatted for two-sided printing with a larger left margin to accommodate binding. If printed on only one side, even and odd pages will be slightly offset from one another.

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2 The Home Screen

The Layout

PWL*Pay* opens to a **Home** screen similar to that shown in **Figure 2.1**. The **Recent Projects** section that forms the majority of the screen shows the most recently created or edited projects. The first time **PWL*Pay*** is opened, this area will be empty.

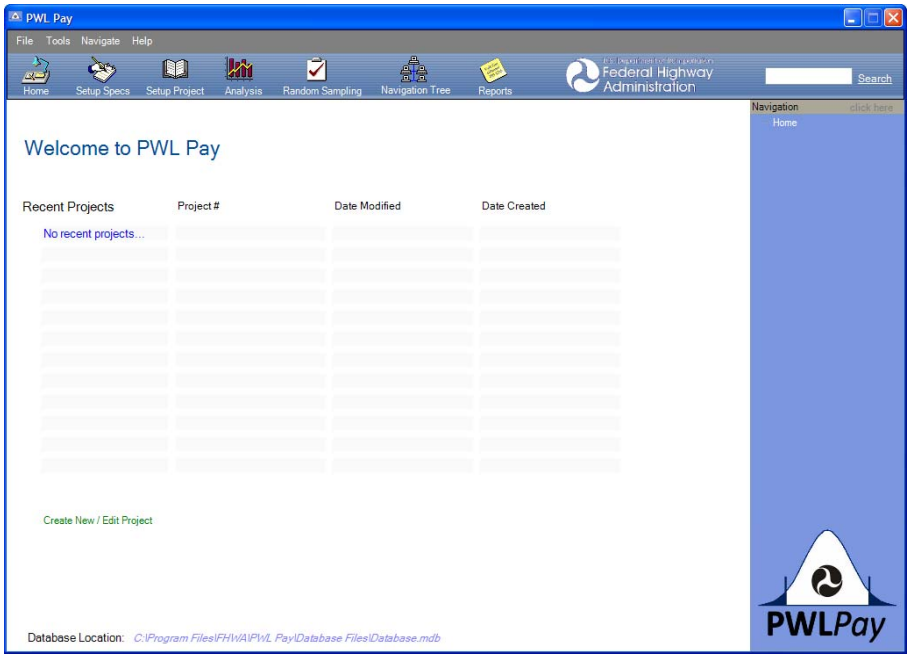


Figure 2.1

Drop down menus for **File**, **Tools**, **Navigate**, and **Help** appear along the top of the **Home** screen. The **Navigation Pane** is the **blue** shaded region on the far right side of the **Home** screen in **Figure 2.1**. *Note*: **PWL*Pay*** is designed for use with the Windows default blue **Appearance** under **Display Properties**. It is recommended that **PWL*Pay*** be used with these default settings.

The File Menu

The options accessible from the **File** menu are shown in **Figure 2.2**.

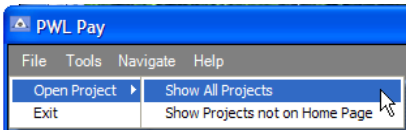


Figure 2.2

From the **File** submenu the user can display projects, e.g., **File ▸ Open Project ▸ Show All Projects**, that can then be selected for editing or data entry. The user can also **Exit** the program from this menu.

The Tools Menu

The options accessible from the **Tools** menu are shown in **Figure 2.3**.

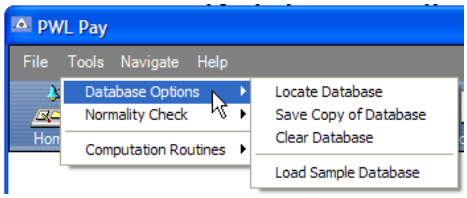


Figure 2.3

On the **Tools** menu, **Database Options** opens a submenu with 4 options. **Locate Database** opens a window (see **Figure 2.4**) that allows the user to browse for and then load an existing database. **Save Copy of Database** allows the user to save a copy of the current database. **Clear Database** empties the contents of the current database, leaving a blank database. **Load Sample Database** loads the sample database that was used to create the figures in this user's manual.

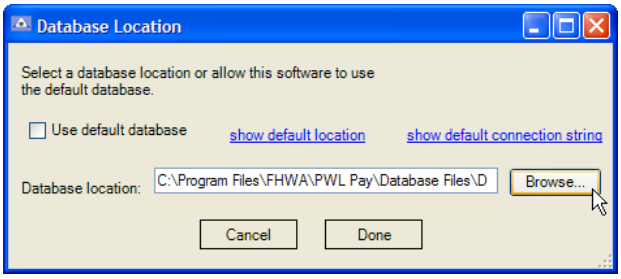


Figure 2.4

Normality Check on the **Tools** menu opens a submenu (see **Figure 2.5**).

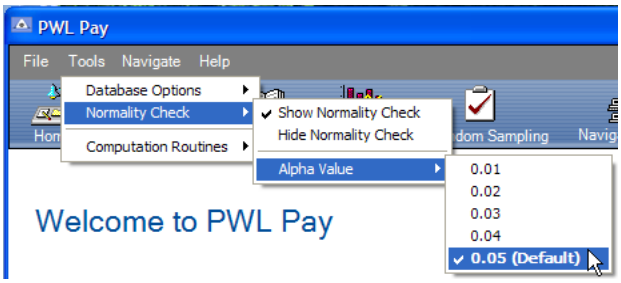


Figure 2.5

The submenu under **Normality Check** provides the option of selecting **Show Normality Check** (selected in **Figure 2.5**) or **Hide Normality Check**. This determines whether or not the program automatically checks data as they are entered and warns the user when the data appear to have not come from a normal distribution. This warning is explained in detail later in this manual.

Highlighting **Alpha Value** opens another submenu that allows the user to select the alpha value (α) that the program uses when performing the automatic test for the normality of the input data. In **Figure 2.5** the default value, $\alpha = 0.05$, is selected.

Tools ▸ Computation Routines is discussed in detail later in this manual.

The Navigate Menu

The options accessible from the **Navigate** menu are shown in **Figure 2.6**.

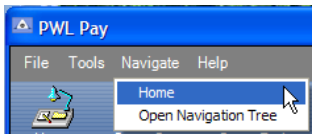


Figure 2.6

The options on the **Navigate** menu include **Home**, which takes the user to the **Home** screen, and **Open Navigation Tree**. The **Navigation Tree** is discussed in detail later in this manual.

Help

Clicking on **Help** (see) opens the submenu shown in **Figure 2.7**. **PWL Pay Manual** opens a copy of this user's manual as a PDF file in another window. About opens the window shown in **Figure 2.8**.

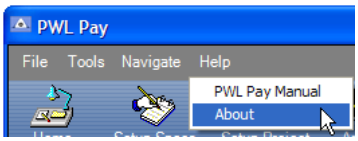


Figure 2.7

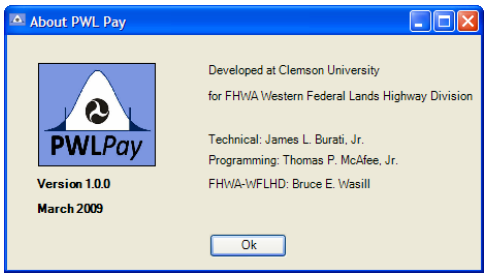


Figure 2.8

Recent Projects

The first time **PWL*Pay*** is opened, the **Recent Projects** section will be empty. As projects are entered into the program, this area shows the most recently created or edited projects, as shown in the example screen in **Figure 2.9**.

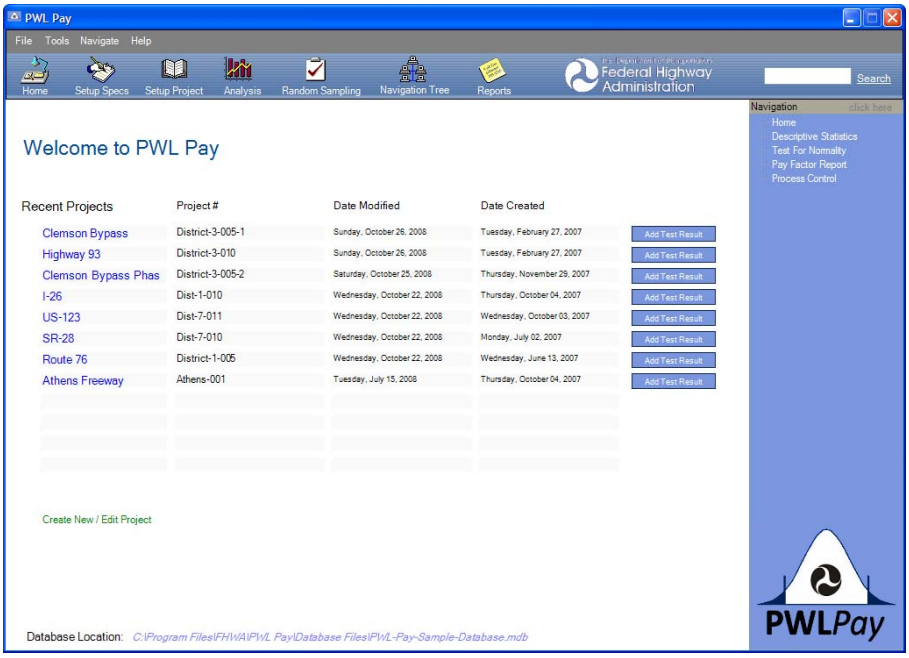


Figure 2.9

The projects are shown in order of the most recent date they were modified. The projects are created by selecting the **Setup Project** option. The program will not allow the **Setup Project** option to be selected until at least one specification has been input to the program using the **Setup Specs** option.

In **Figure 2.9**, eight projects have been created. Either left or right clicking the mouse on a project opens the menu shown in **Figure 2.10**.

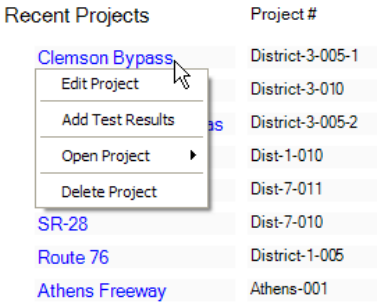
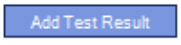


Figure 2.10

Edit Project opens a window that allows changes to be made to the information, such as item numbers and specification limits, associated with the project. **Add Test Results** opens a window that allows test data to be input or edited. These windows are discussed in detail later in this manual. The user can go directly to the test result window by clicking the blue **Add Test Result** button associated with each project. **Open Project** and **Delete Project** are self-explanatory.



The Navigation Pane

The **Navigation** pane is the **blue** shaded region on the far right side of **Figure 2.8**. It shows the most recent locations that have been visited in the program. The **Navigation** pane can be used to go directly to any of these locations by clicking the mouse on that location.

Miscellaneous Items

The user can create a new or edit an existing project directly by clicking on the green **Create New / Edit Project** link (see **Figure 2.8**) on the **Home** page. The storage location of the current database file is shown in the lower left hand corner of the **Home** screen.

If the computer has Internet access, clicking on the FHWA logo in the upper right corner opens the FHWA website in a new browser window, while the **Search** box in the upper right corner allows the user to perform a key word search of the FHWA website.

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3 Setting Up Specs

The Empty Setup Specs Window

The first thing that must be done to use **PWL*Pay*** is to setup one or more specifications. The first time that the **Setup Specs** icon is selected the window in **Figure 3.1** is displayed.

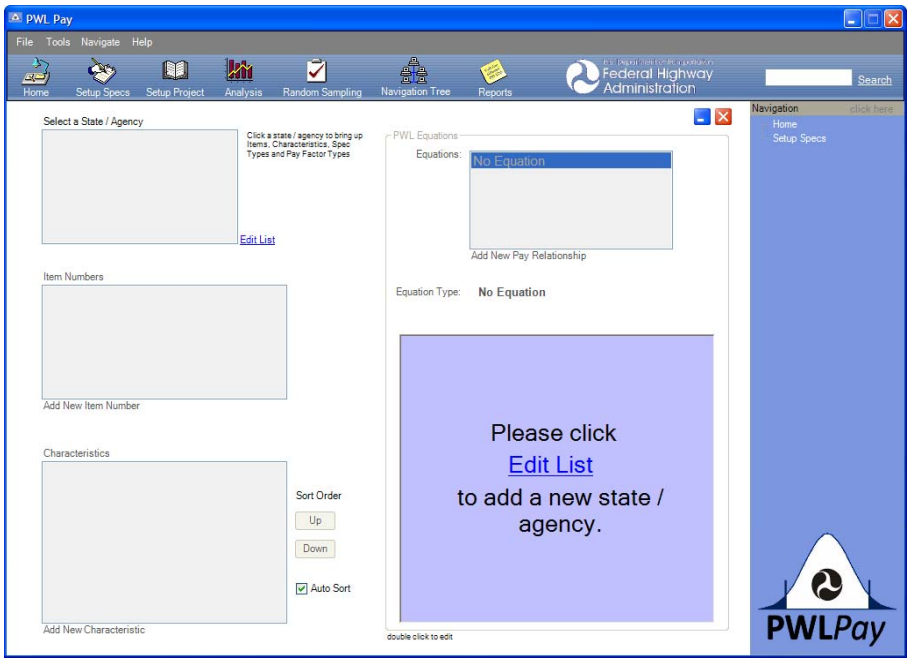
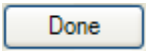


Figure 3.1

Select a State / Agency

The user must first select or input the state and/or agency to which the specification applies. The user selects **Edit List** to open a window with a list of states and agencies from which to choose. The user can also add to the list an agency that is not currently included. Any number of states or agencies can be added at this time. **Figure 3.2** shows an example of the window with the selection list. In **Figure 3.2**, two states and one Federal agency have been selected. The *Western Federal Lands* agency was added by entering the name into the **Add State / Agency** box and selecting **Add**.



When **Done** is selected the program returns to the **Setup Specs** window as shown in **Figure 3.3**.

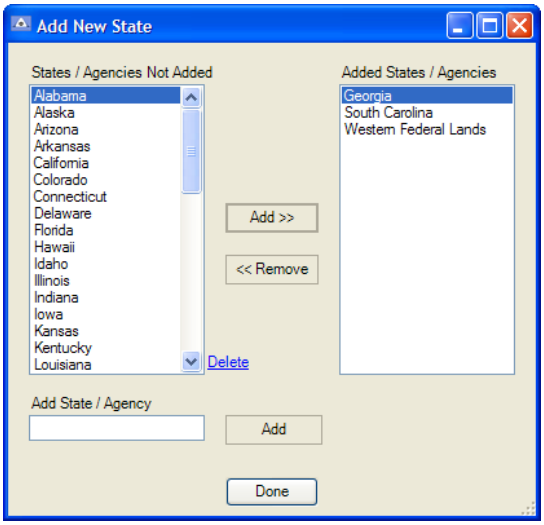


Figure 3.2

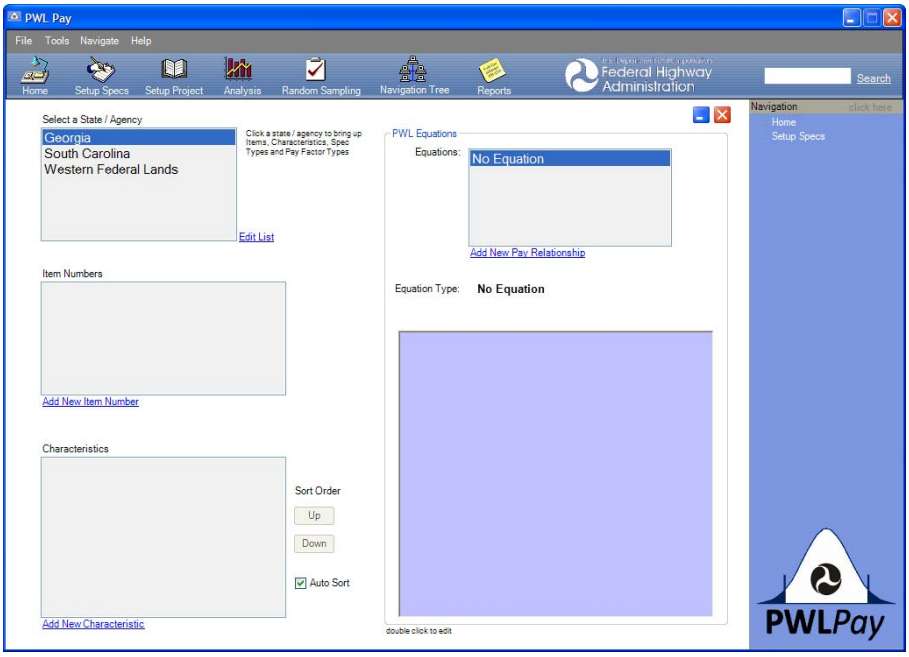


Figure 3.3

Item Numbers

Next, select Add New Item Number to open the **Add Item Number** window shown in **Figure 3.4** to enter the item number to which the specification applies.

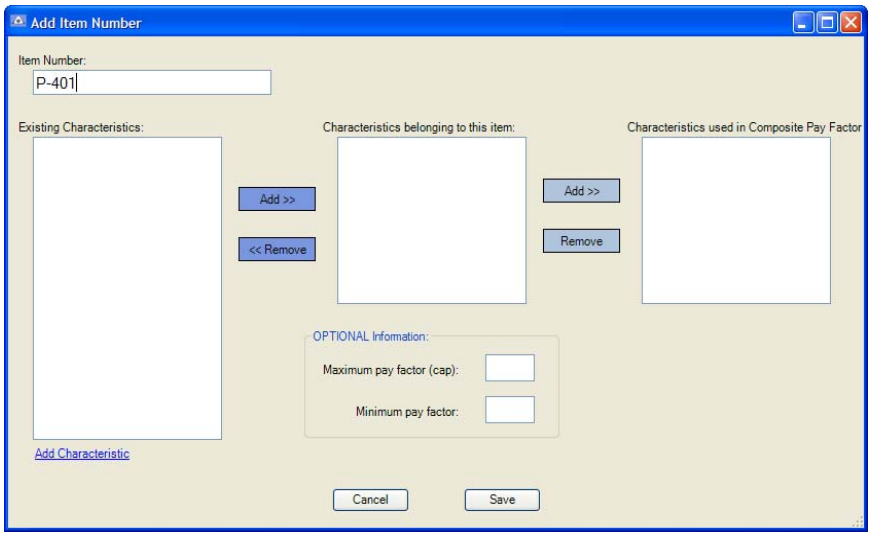


Figure 3.4

Characteristics

The user can select any characteristics from the **Existing Characteristics** box to associate with this item number. If the **Existing Characteristics** box does not contain the necessary characteristics for the item number, then the user can select Add Characteristic to open the window in **Figure 3.5** and enter the required quality characteristic and information to be associated with this item number. Any number of characteristics can be associated with a given item number. Note that the user can also add characteristics from the **Setup Specs** window by clicking Add New Characteristic (see **Figure 3.3**).

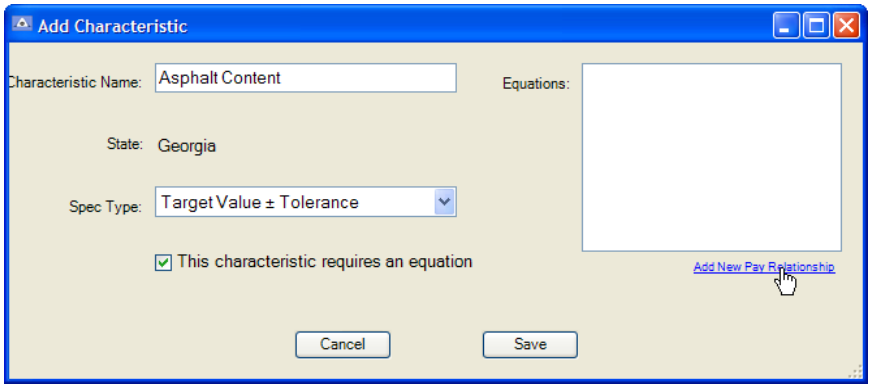


Figure 3.5

Spec Type

Since different characteristics have different specification requirements, selecting **Spec Type:** opens a drop down menu that allows the user to select the type of specification that is appropriate for the selected quality characteristic. As shown in **Figure 3.6**, there are five different specification types from which to choose.

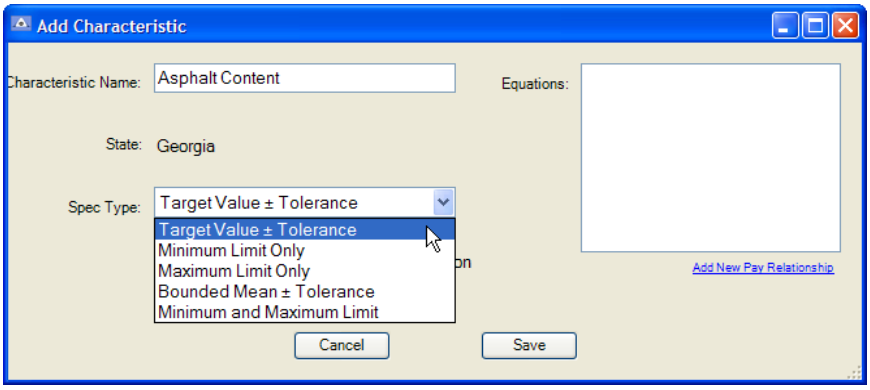


Figure 3.6

Target Value ± Tolerance. This applies to a characteristic such as asphalt content where there is a target value with allowable tolerances both above and below the target value.

Minimum Limit Only. This applies to a characteristic such as concrete compressive strength where there is only a lower specification limit to be met.

Maximum Limit Only. This applies in the case of a characteristic such as percent passing the 0.075 mm (No. 200) sieve for which there is only an upper specification limit to be met.

Bounded Mean ± Tolerance. This might apply in the case of a characteristic such as aggregate gradation where there is a target value and allowable tolerances above and below the target, but there might also be a master band that cannot be exceeded by the allowable tolerances. For example, there might be a characteristic for which the target was 75 with ± tolerances of 10. But, if there is a master band that requires specification limits to be between 60 and 80, then the allowable lower specification limit would be 75 – 10 = 65, while the allowable upper specification limit would not be 75 + 10 = 85, but would be limited by the master band to be 80.

Minimum and Maximum Limit. This might apply to a case where there is not a specific target value, but where there are stipulated lower and upper specification limits. For example, the specification limits for air content of portland cement concrete might be 3% to 5%.

Pay Information

In most cases a pay relationship will be assigned to the quality characteristic, and this relationship can be selected from the list in the **Equations:** box, or it can be entered by selecting **Add New Pay Relationship**. In some cases, such as if the lot payment factor is to be determined by an expected life approach, there is no pay relationship needed and the **This characteristic requires an equation** box can be unchecked (see **Figure 3.5**).

Selecting **Add New Pay Relationship** allows the user to select from two options for the pay relationship: **Tabular Pay Factors** or **Pay Equations(s)** (see **Figure 3.7**).

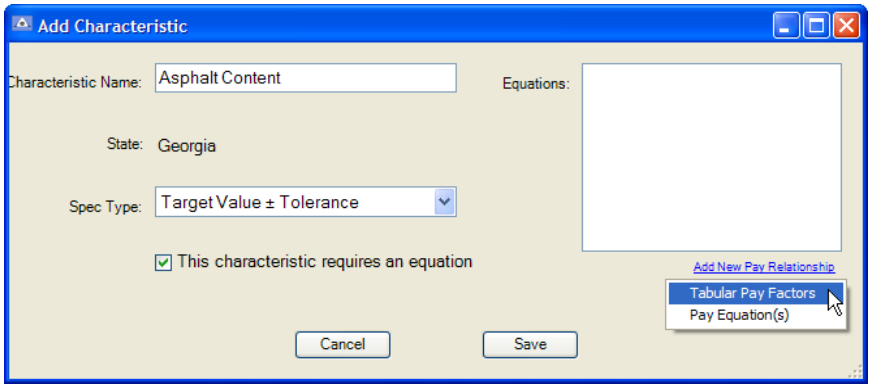


Figure 3.7

Tabular Pay Factors

If **Tabular Pay Factors** is selected, the **Add Tabular Equation** window shown in **Figure 3.8** is opened so that the pay relationship can be entered.

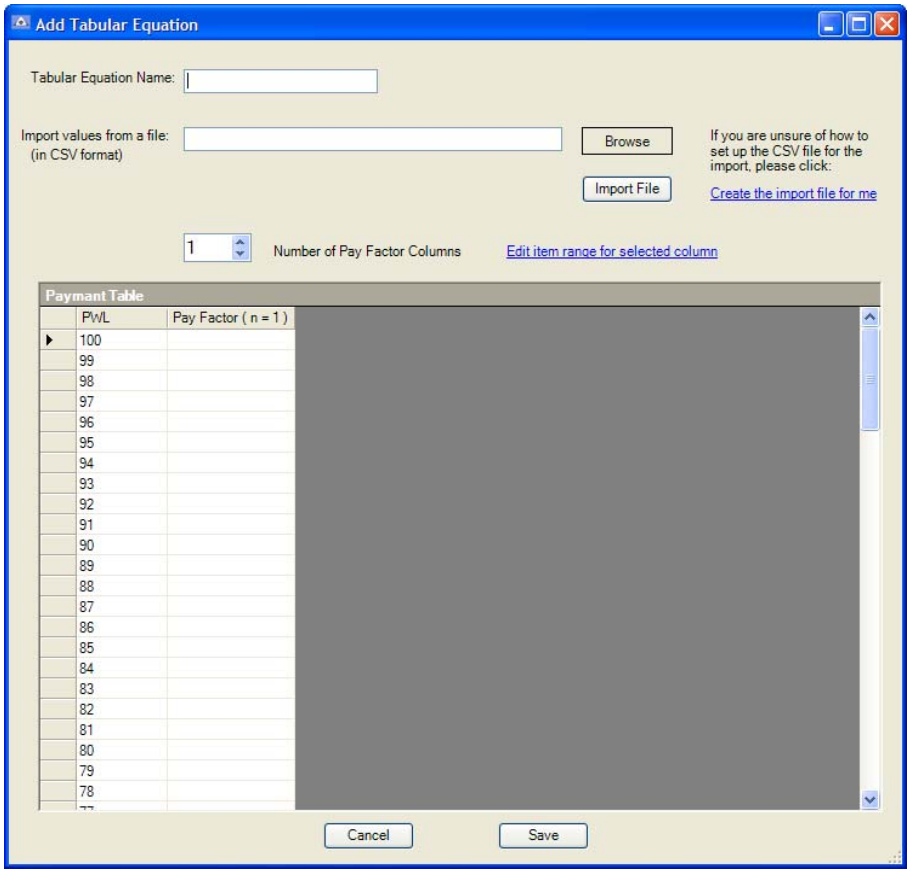


Figure 3.8

The user can enter a name for the pay relationship in the **Tabular Equation Name:** box. The user can then either import a CSV file with the pay relationship information, or create the payment table with the options in this window.

Entering a Pay Relationship

The **Number of Pay Columns** box can be increased to account for the total number of sample sizes for which there are pay factors in the table, and the Edit item range for selected column can be selected to enter the range of sample sizes for which each pay factor applies. Each time the number of columns is increased, the window in **Figure 3.9** pops up to allow the user to enter the sample size range for the new column. The example in **Figure 3.9** shows that the column will include the pay factors for a sample size of $n = 3$.

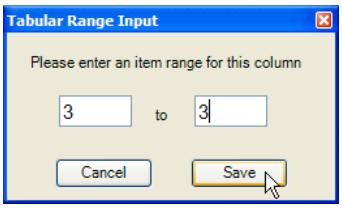


Figure 3.9

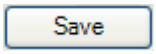


Figure 3.10 shows the input values for an example pay relationship table. Clicking on **Save** saves the pay relationship under the name *Example Pay Table 3-10*.

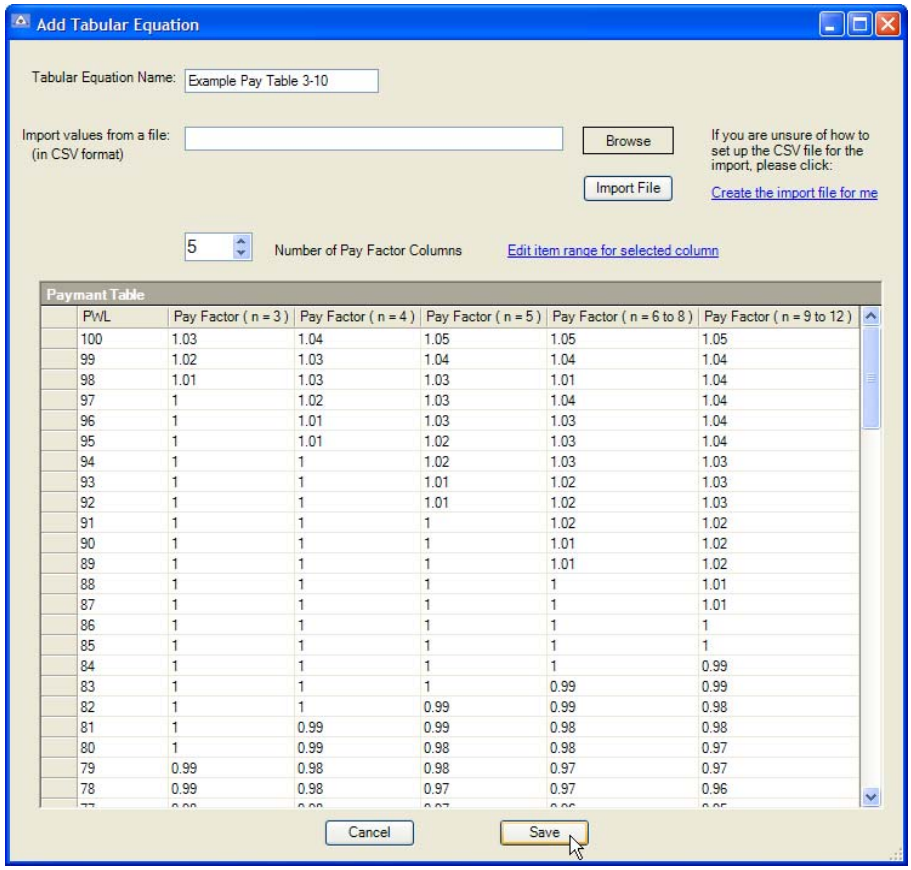


Figure 3.10

Importing a Pay Relationship

Clicking Create the import file for me (see **Figure 3.8**) brings up the window shown in **Figure 3.11**, which can be used to create a blank CSV file that can then be used to import the pay relationship.

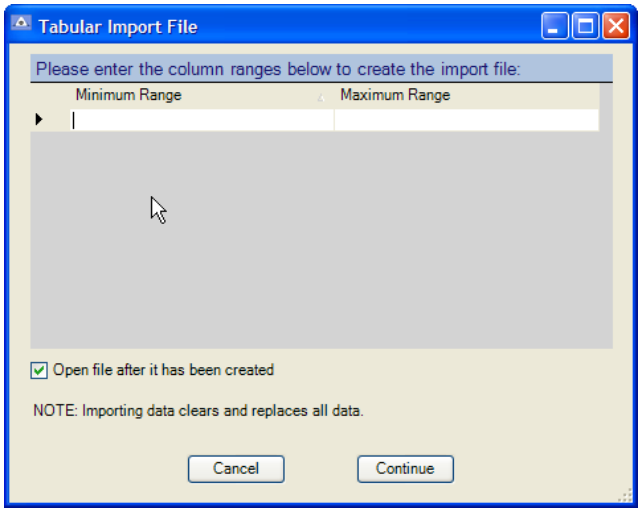


Figure 3.11

The **Minimum Range** and **Maximum Range** columns are used to input the range of sample sizes for which the pay factor in the column will apply. The same sample size ranges used in **Figure 3.10** have been entered in the example window in **Figure 3.12**.

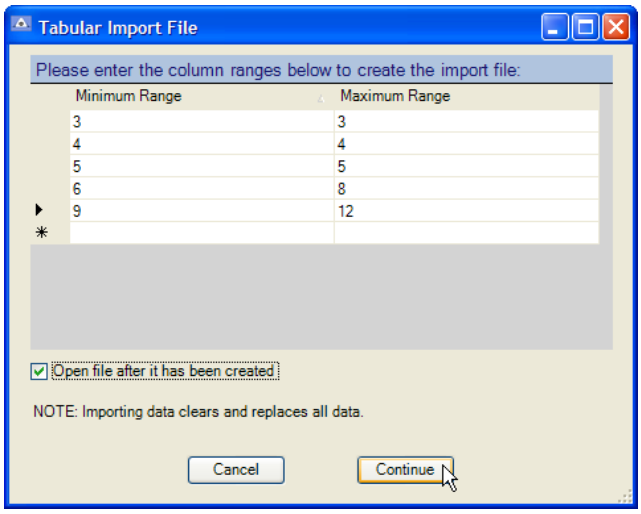
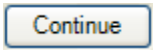


Figure 3.12



Clicking **Continue** will create a CSV file and, if the **Open file after it has been created** box is checked, the file will be opened in Excel. A portion of the CSV file for **Figure 3.12** is shown in **Figure 3.13**. The PWL column runs from 100 down to 0, and a corresponding pay factor must be entered for each row and column in the spreadsheet.

	A	B	C	D	E	F
1	PWL	Pay Factor (n = 3 to 3)	Pay Factor (n = 4 to 4)	Pay Factor (n = 5 to 5)	Pay Factor (n = 6 to 8)	Pay Factor (n = 9 to 12)
2	100					
3	99					
4	98					
5	97					
6	96					
7	95					
8	94					
9	93					
10	92					
11	91					
12	90					

Figure 3.13

Pay Equation(s)

If **Pay Equation(s)** is selected in the **Add Characteristic** window (see **Figure 3.7**), the **Add / Edit Payment Equation(s)** window (see **Figure 3.14**) is opened. This allows the user a wide range of options for entering a continuous pay relationship based on one to four separate equations, and allows the user to input different pay relationships for differing sample sizes.

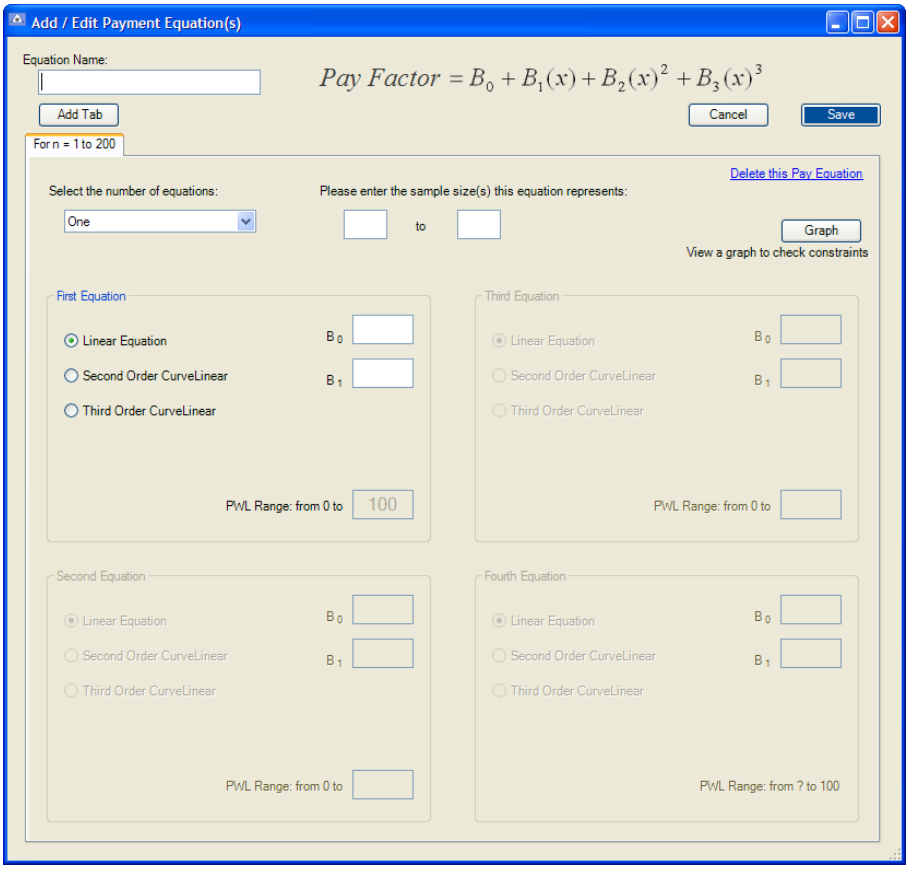


Figure 3.14

The user first enters a name for the equation(s). In **Figure 3.15**, *Example Equation Figure 3-15* has been entered in the **Equation Name:** box. The **Select the number of equations:** drop down menu allows the user to select up to four equations to represent the continuous pay relationship. Each equation can be either linear, a second order curve, or a third order curve. The equation at the top of **Figure 3.15** defines the input coefficients for the equations.

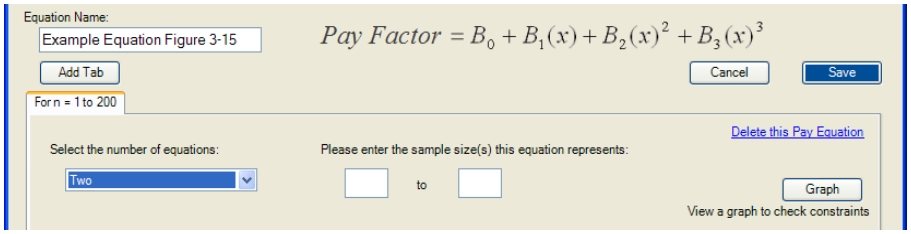
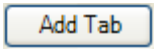


Figure 3.15

Note that by default the input equation(s) apply for sample sizes **For n = 1 to 200**. These values can be changed by entering a new range in the **Please enter the sample size(s) this equation represents:** boxes. If the user wishes to enter different pay equations for different sample sizes, this can be accomplished by clicking the **Add Tab** button, which creates a new equation input screen and allows the user to enter the range of sample sizes for which the equation(s) apply. In **Figure 3.16**, three sample ranges, *3* to *10*, *11* to *30*, and *31* to *200* have been entered. The sample size range from *31* to *200* has one equation for the pay relationship.



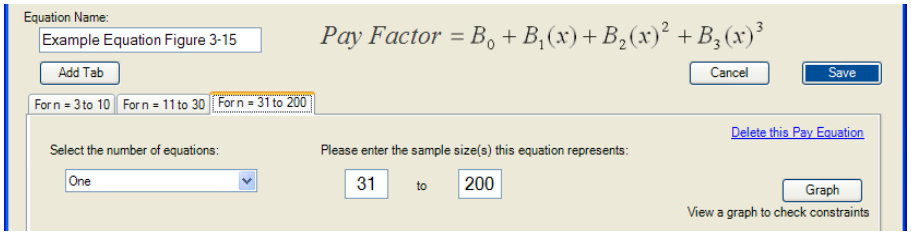


Figure 3.16

Once the number of equations has been selected the coefficients for each equation must be entered. **Figure 3.17** shows a pay relationship based on a single linear equation that applies to sample sizes from *3* to *10*.

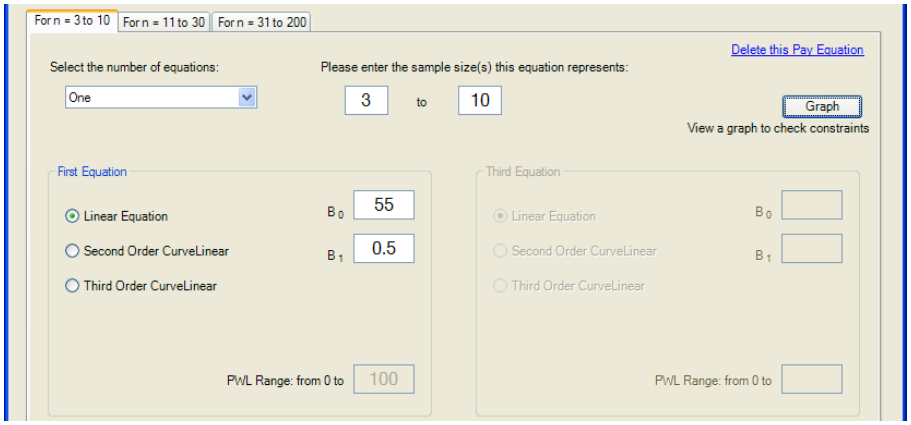
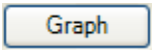


Figure 3.17

Note that coefficients can be input for only the selected number of equations. For example, in **Figure 3.17** only the coefficients for the first equation can be input. The other coefficient boxes are inactive. For the example in **Figure 3.17**, $B_0 = 55$ and $B_1 = 0.5$. Therefore, the pay relationship is represented by the equation $Pay = 0.5PWL + 55$. Also note that with a single equation the **PWL Range: from 0 to** box automatically has a value of 100 and requires no input from the user.



A plot of the pay equation(s) can be shown by clicking the **Graph** button. Clicking on **Graph** in **Figure 3.17** provides the plot shown in **Figure 3.18**.

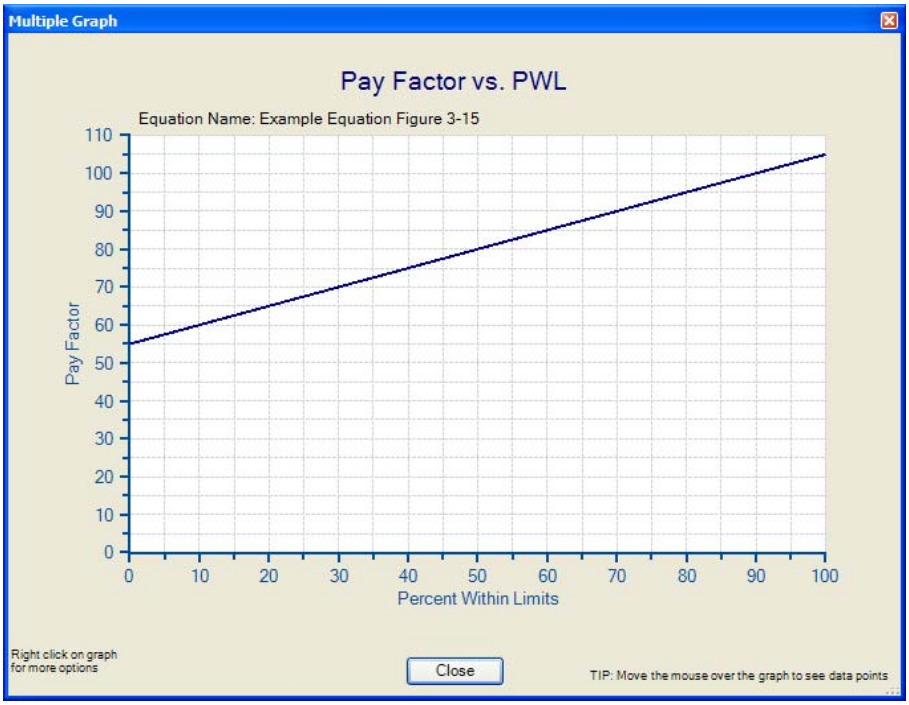


Figure 3.18

Figure 3.19 shows a pay relationship based on two equations–one straight line (which is really a constant in this example) and one second order curve. Since more than one equation is used, it is necessary to input the range of estimated PWL values for which each equation applies. The first equation applies for PWL values from 0 to *50*, while the second equation applies to PWL values from 50 to 100. The program automatically checks to see if the equations give consistent values at their points of intersection. If the pay factors at the intersection for the two equations differ by more than 0.01, a warning message such as the one in **Figure 3.20** is displayed. Note that in **Figure 3.20** the two equations differ in payment by 0.76 at their intersection. At this point the higher pay factor would be used.

The plot for the pay relationship in **Figure 3.19** is shown in **Figure 3.21**.

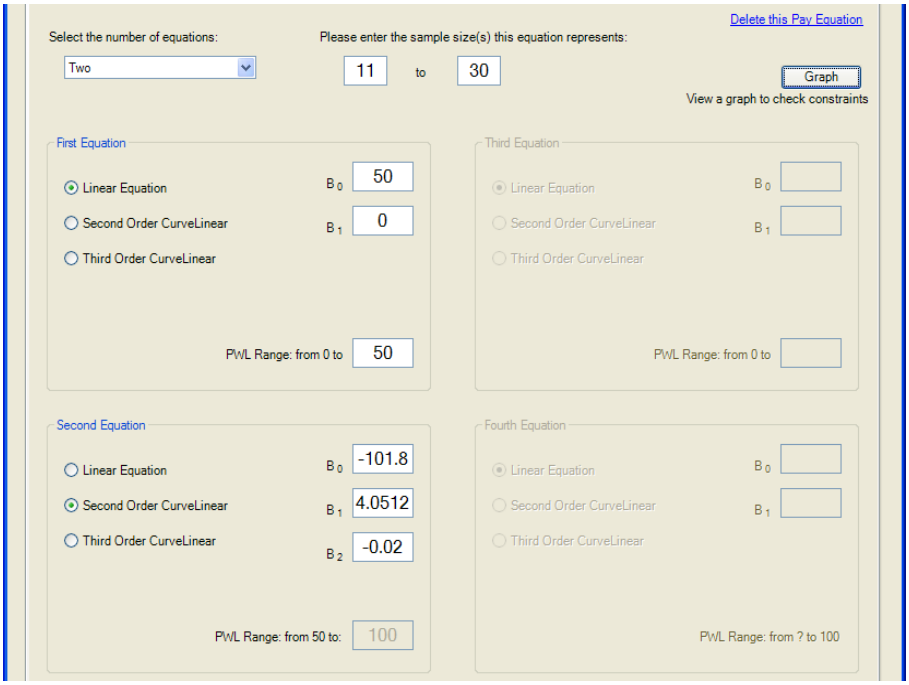


Figure 3.19

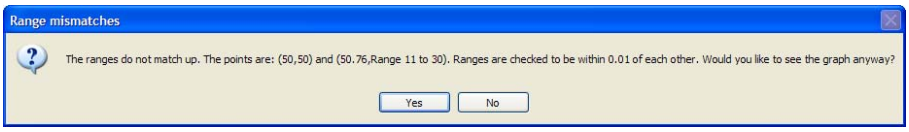


Figure 3.20

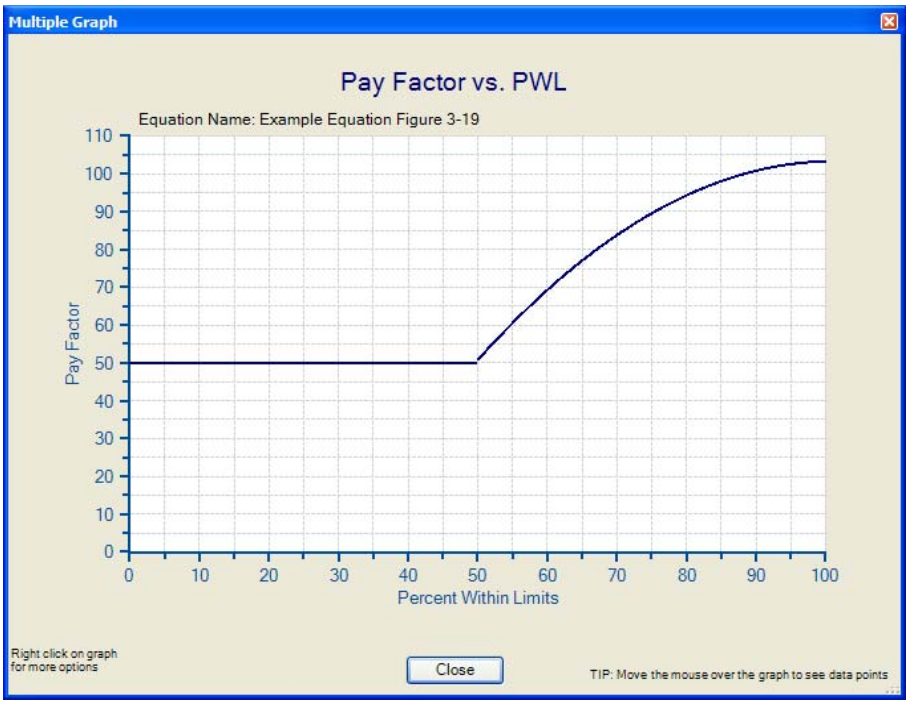


Figure 3.21

Figure 3.22 shows a pay relationship based on four straight line equations. The plot for this pay relationship is shown in **Figure 3.23**.

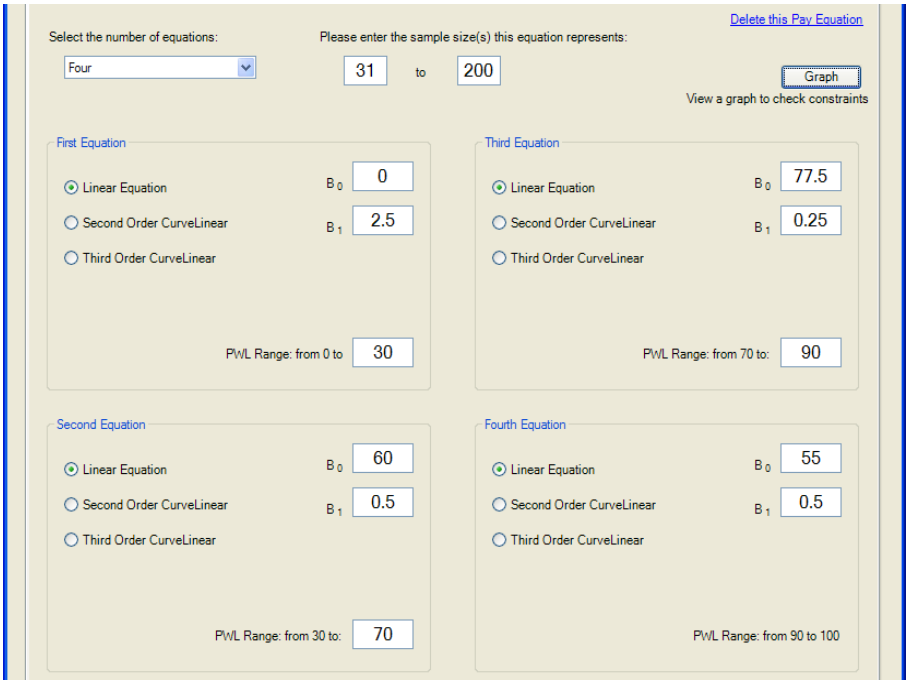


Figure 3.22

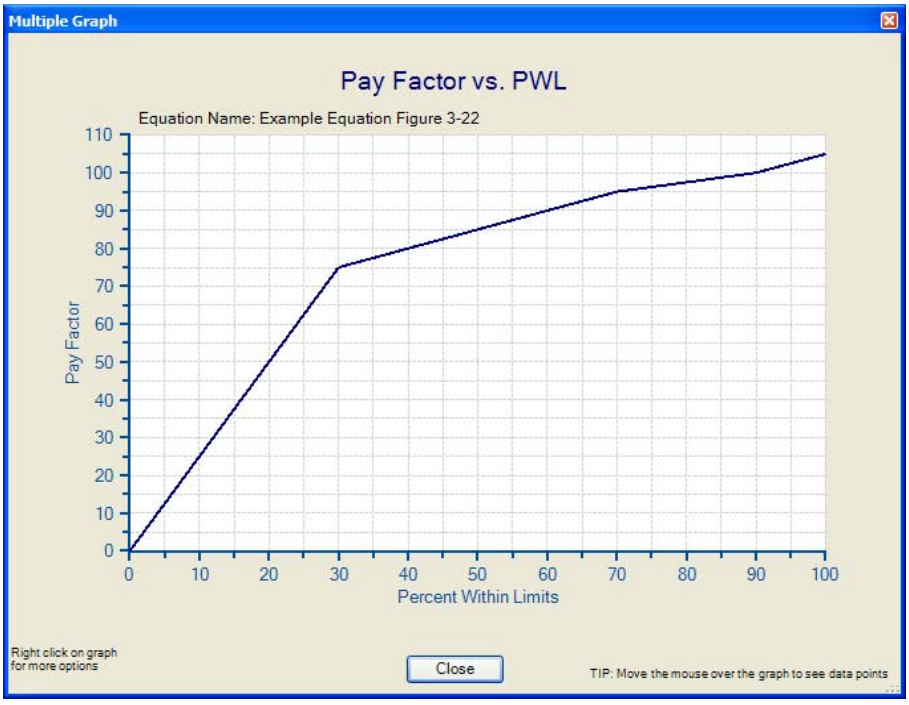
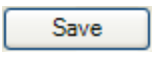


Figure 3.23



Clicking on **Save** in either the **Add / Edit Payment Equation(s)** window or the **Add Tabular Equation** window returns the user to the **Add Item Number** window in **Figure 3.24**.

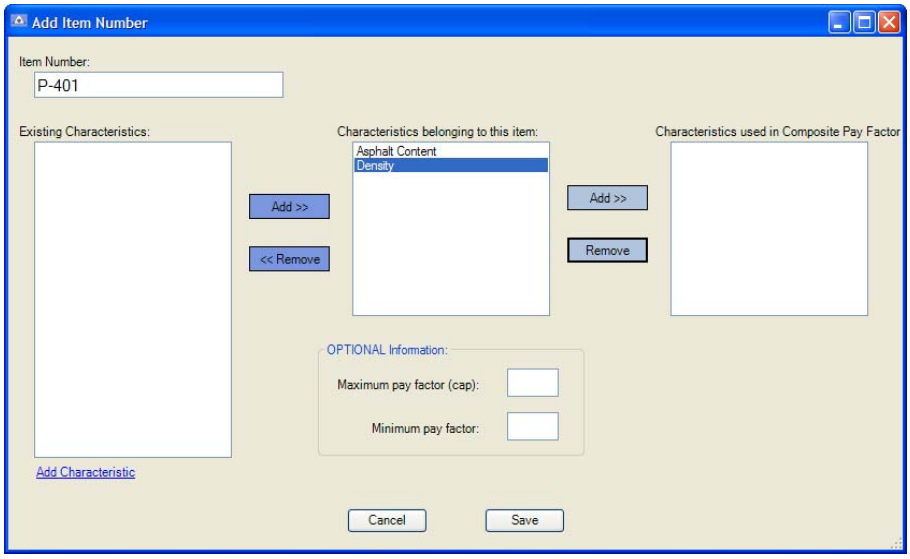


Figure 3.24

Composite Pay Factor

Any additional characteristics to be associated with the item number can be entered. All of the input characteristics will appear in the **Characteristics belonging to this item:** window. For those characteristics to be used in the determination of the lot pay factor, highlighting them and clicking on **Add>>** will add them to the **Characteristics used in the Composite Pay Factor** window (see **Figure 3.25**).

Once the characteristics for the composite pay factor have been entered, the user must select one of the options from the **Select a Composite Pay Equation:** drop down menu.

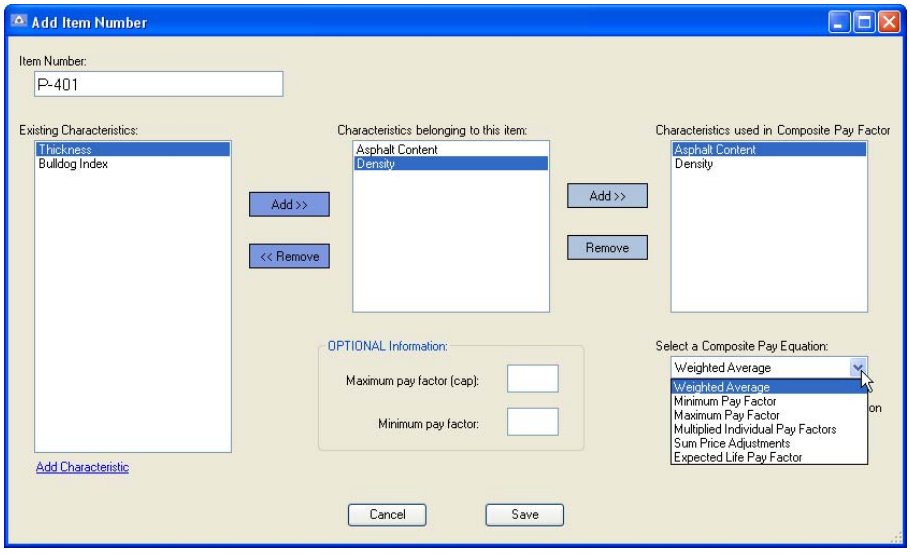


Figure 3.25

The possible methods for combining the individual characteristics' pay factors into a single composite pay factor for the lot (see **Figure 3.25**) include the following:

Weighted Average. This method assigns a weighting factor to each characteristic and then sums the products of the individual weighting factors times the pay factors for the individual characteristics.

Minimum Pay Factor. This method assigns the lot pay factor as the minimum of the pay factors for the individual characteristics.

Maximum Pay Factor. This method assigns the lot pay factor as the maximum of the pay factors for the individual characteristics.

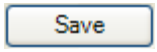
Multiplied Individual Pay Factors. This method multiplies the pay factors (expressed as decimals rather than percents) for the individual characteristics.

Sum of Price Adjustments. This method uses the arithmetic sum of the differences from 100 for each of the individual pay factors.

Expected Life Pay Factor. This method is based on estimating the expected life of the as-built product and using the difference between the design life and the expected as-built life to determine the appropriate pay factor for the lot. Due to its uniqueness compared with the other methods, the expected life approach is covered in a separate section at the end of this chapter.

Composite Weights

If the Minimum, Maximum, Multiplied, or Sum composite pay factor is selected, then no additional input is required. However, if the Weighted Average method is selected to determine the composite pay factor, then the weights must be entered for each of the characteristics in the composite pay equation.



In **Figure 3.26**, the **Weighted Average** approach has been selected. Also note that the **Allow me to fill in the equation information when I click Save** box is checked by default. When this box is checked, clicking **Save** will save the **Add Item Number** information and also call up the window in **Figure 3.27** to allow input of the weighting factors for each characteristic.

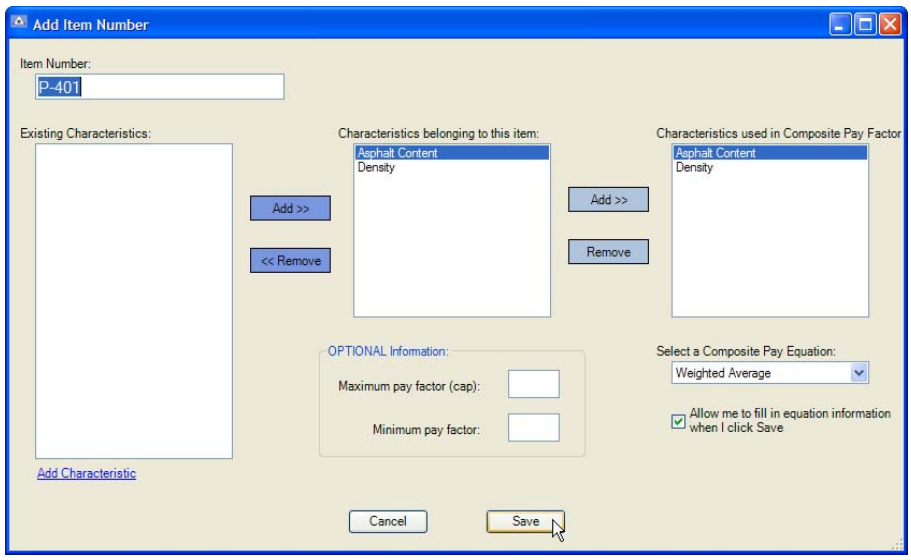


Figure 3.26

In **Figure 3.27**, weights have been entered for the two characteristics associated with this item number. The sum of the weights must be 1.0, and the program will give a warning message if the user tries to save a combination of weights that does not sum to 1.

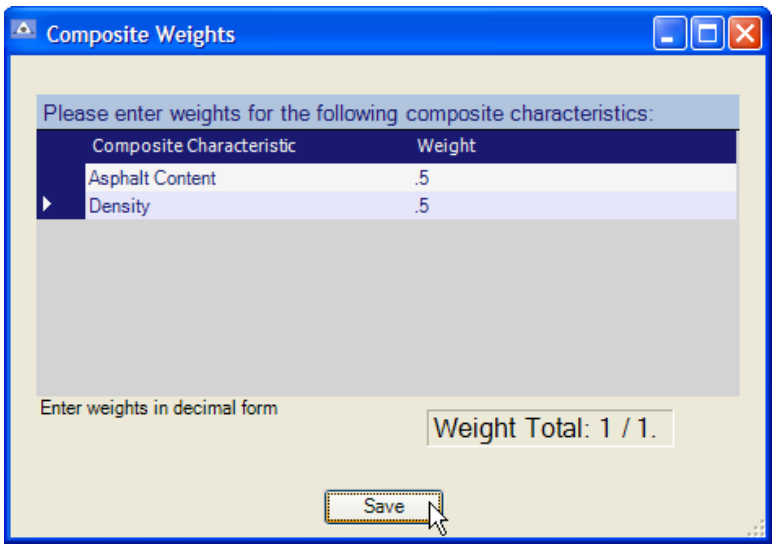


Figure 3.27

Max / Min Pay Factors

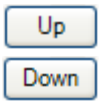
The user also has the option of entering maximum and minimum pay factors in the **OPTIONAL Information:** region of the **Add Item Number** window (see **Figure 3.26**). If entered, these values would override the composite pay factor in the event that the pay relationship produced a pay factor that either exceeded the value entered for **Maximum pay factor (cap):**, or was less than the value entered for the **Minimum pay factor:**.

The Completed Setup Specs Window

When the item number information is saved the user is returned to the **Setup Specs** window in **Figure 3.28**. Note that when a state or agency is highlighted in the **Select a State / Agency** window, all of the items associated with that state or agency are visible in the **Item Numbers** window. Similarly, when one of the items is highlighted, all of the characteristics associated with that item are visible in the **Characteristics** window. Similarly, when one of the characteristics is highlighted, the pay relationship associated with that characteristic is highlighted in the **PWL Equations** window and a plot of the pay relationship is shown in the window below the **PWL Equations** window.

For example, in **Figure 3.28**, **South Carolina** has four items associated with it; item number **P-401** has four characteristics associated with it; the pay equation **AASHTO** is associated with **Asphalt Content**, and the pay relationship is shown as a straight line in the plot. If a different characteristic were highlighted a different pay relationship and plot might be highlighted and displayed.

The order in which the characteristics are displayed in the **Characteristics** window, which is also the order in which any output regarding the



characteristics will be displayed, can be changed by clicking on the **Up** or **Down** buttons under **Sort Order**. Checking the **Auto Sort** box sorts the characteristics in alphabetical order.

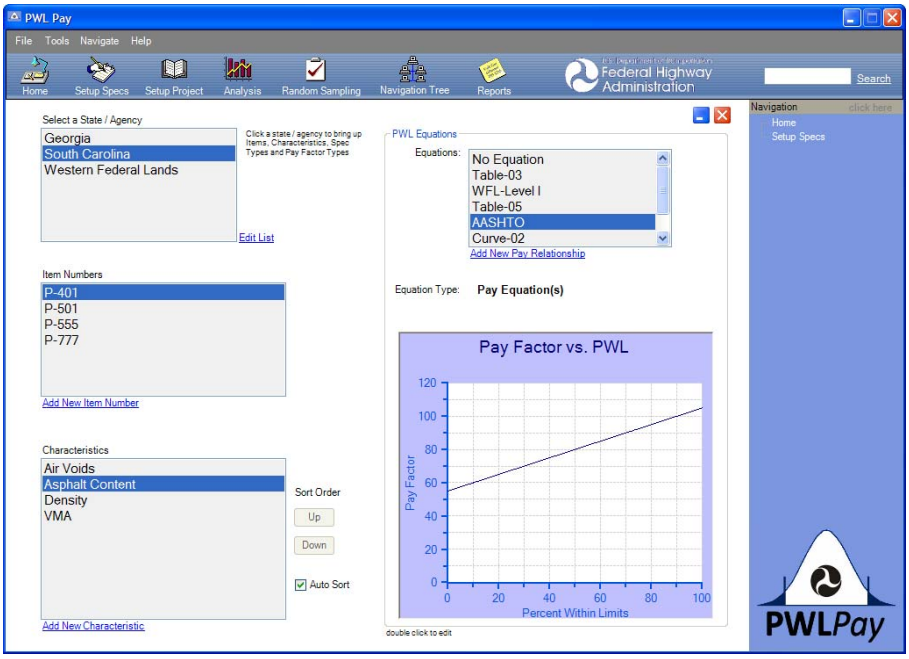


Figure 3.28

If, for a characteristic, different pay relationships apply for different sample sizes (see, for example, **Figure 3.16**), then there will be multiple lines in the **Pay Factor vs. PWL** plot. For example, in **Figure 3.29** there are three pay relationships associated with different sample sizes for the characteristic **Performance Index**.

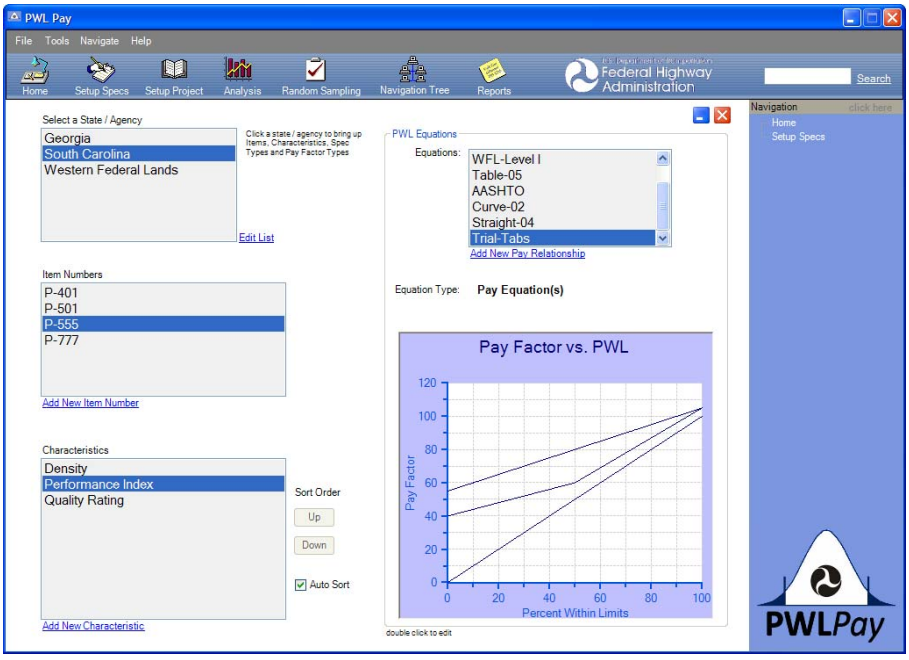


Figure 3.29

To determine which line applies to which sample size or range of sample sizes, the user can hover the mouse pointer over any portion of a line to display a popup with information concerning the sample sizes to which the line applies as well as the specific values for **PWL** and **Pay Factor** where the pointer rests on the line. This is seen in **Figure 3.30** where it shows that the selected line applies to sample sizes in the **Range 4 to 6** and that when **PWL = 80** the **Pay Factor = 87**.

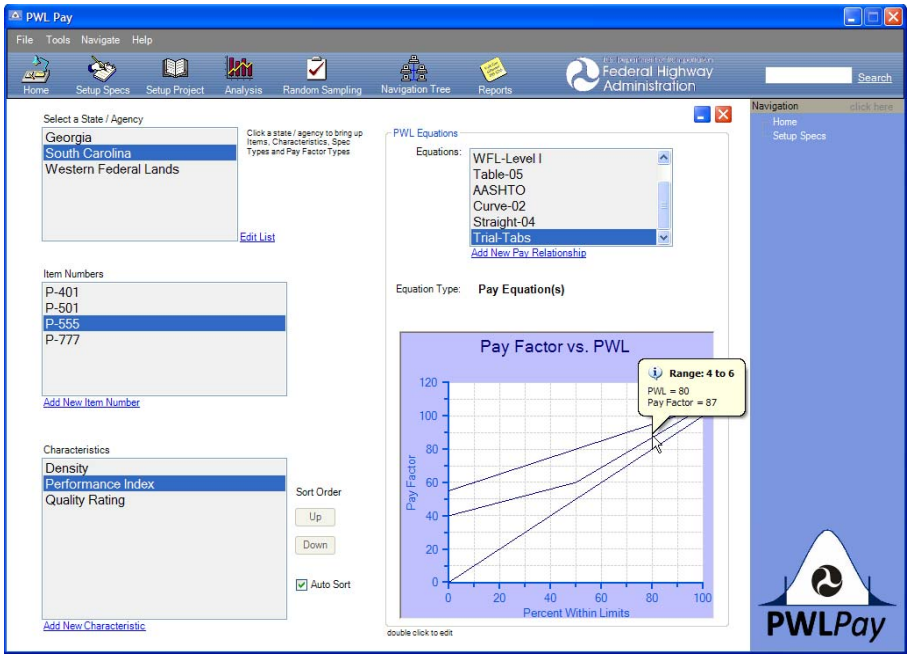


Figure 3.30

The Expected Life Approach

In the **Select a Composite Pay Equation:** drop down menu shown in **Figure 3.25** the user can select from six methods for determining the composite pay factor for a lot. The first five are discussed previously in this chapter. The sixth method, the **Expected Life Pay Factor**, is quite different in concept from the first five. It is discussed in depth below.

A thorough discussion of the expected life approach for determining payment for a lot is well beyond the scope of this manual. It is, therefore, assumed that the user of **PWL***Pay* has a thorough understanding of this approach. As such, this manual covers only the implementation of the expected life approach using **PWL***Pay*.

Reference

A thorough description and detailed discussion of the expected life approach are presented in *Optimal Procedures for Quality Assurance Specificatons, Publication No. FHWA-RD-02-095, April 2003*.

Figure 3.31 shows the **Setup Specs** screen with **Item P-501** highlighted in the **Item Numbers** window. **Compressive Strength** is highlighted in the **Characteristics** window. Note that in the **PWL Equations** section, for **Compressive Strength** the **Equations:** box has **No Equation** highlighted. An item for which the pay factor is determined by the expected life approach will have no pay equation associated with its characteristics.

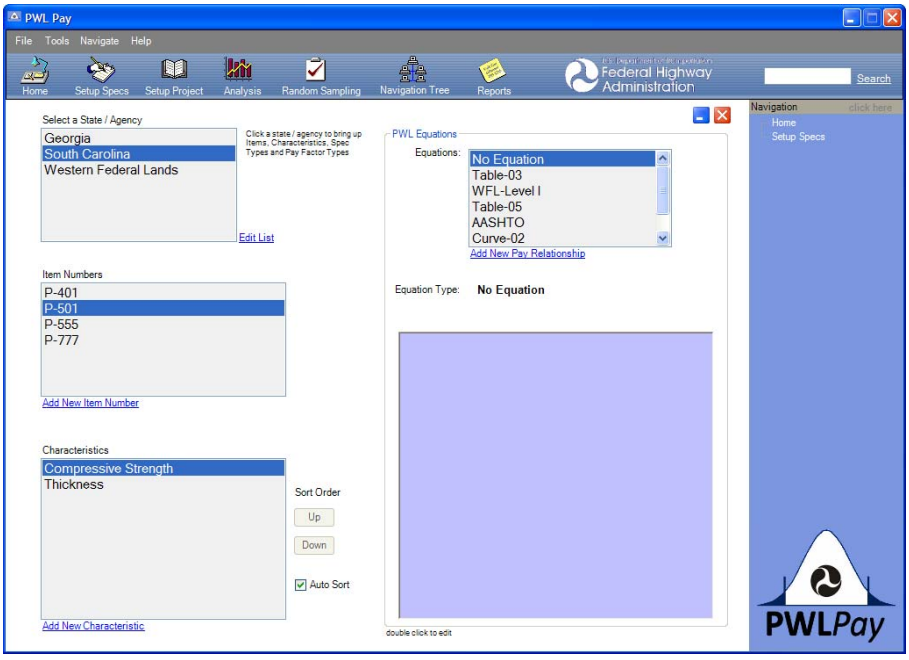


Figure 3.31

Expected Life Input Procedures

Figure 3.32 shows the completed **Add Item Number** input screen for **Item P-501**. **Compressive Strength** and **Thickness** have been selected as the **Characteristics used in Composite Pay Factor**. Note that **Expected Life Pay Factor** has been selected as the composite pay equation.

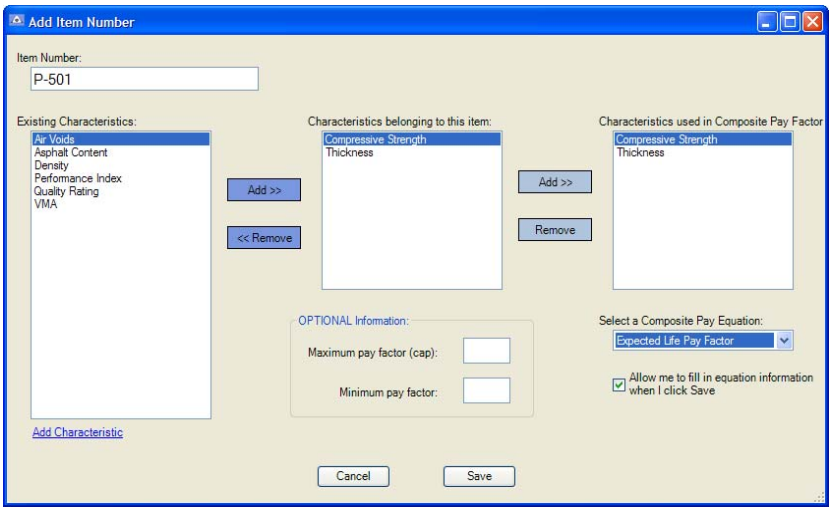


Figure 3.32

Figure 3.33 shows the completed **Add Characteristic** input screen for **Compressive Strength** as it was entered for use with an expected life approach for pay factor determination. Note that the **This characteristic requires an equation** box is not checked. As a result, the Equations: window is grayed out and no equation can be assigned to this characteristic. This is the case for any characteristic that is used in determining an expected life pay factor.

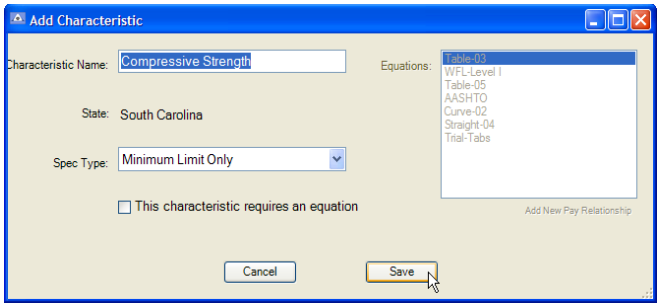
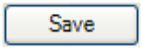


Figure 3.33



When **Save** is selected in the window in **Figure 3.32** the **Select An Expected Life Equation** window shown in **Figure 3.34** is displayed. This window allows the user to enter the equation that estimates the expected life for the pavement based on the PWL values for the various characteristics.

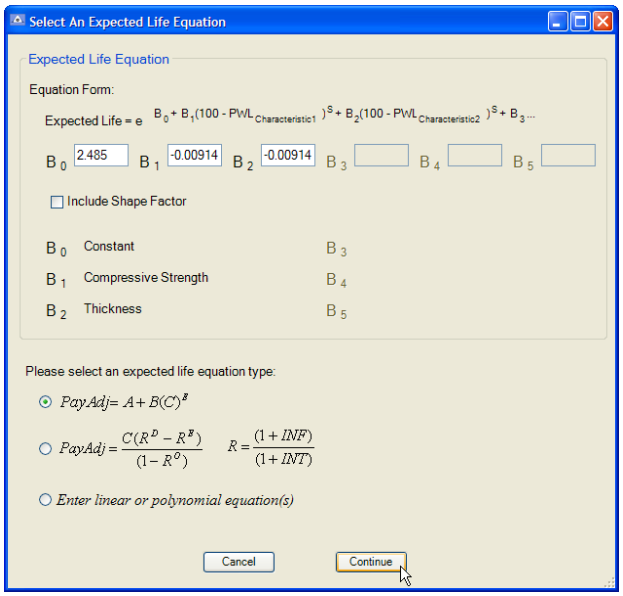


Figure 3.34

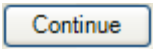
The general form for the expected life equation, as shown at the top of **Figure 3.34**, is

$$Expected\ Life = e^{B_0+B_1(100-PWL_1)^S+B_2(100-PWL_2)^S+\cdots+B_5(100-PWL_5)^S}$$

In the above equation, *S* is a shape factor that defaults to 1 unless the **Include Shape Factor** box is checked.

Pay Adjustment Input Procedures

Once the expected life equation has been entered the user can select from one of three forms for the pay adjustment equation (see the bottom of **Figure 3.34**). If the first button is selected as in **Figure 3.34**, selecting **Continue** opens the **Pay Adjustment Equation** window shown in **Figure 3.35** and allows the user to input the coefficients for the pay adjustment equation.



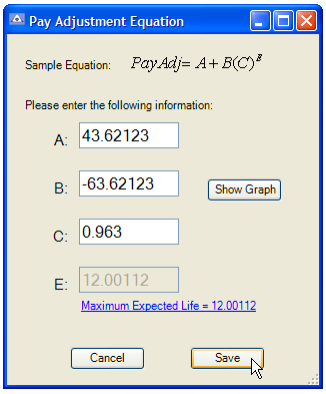
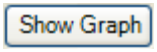


Figure 3.35

In **Figure 3.35**, the values for **A:**, **B:**, and **C:**, the coefficients of the pay adjustment equation, are entered by the user. **PWL***Pay* automatically displays the value for **E:,** which is obtained from the expected life equation when the PWL is 100 for all characteristics in the equation.



Selecting **Show Graph** displays the plot of the pay adjustment equation shown in **Figure 3.36**. As with all other charts in **PWL***Pay*, the user can hover the cursor over any point on the line to display the expected life and pay adjustment values. The pay adjustment is in dollars per unit, and can be either positive or negative.

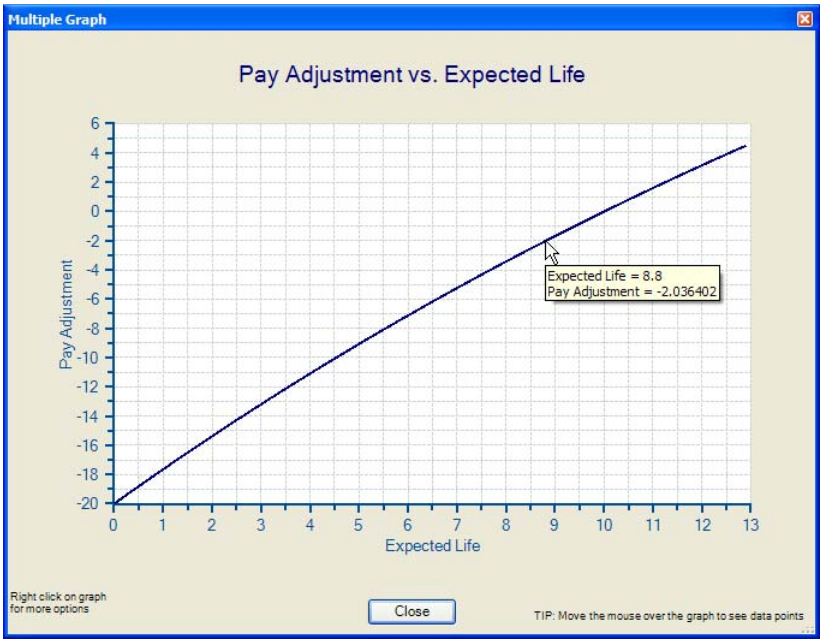
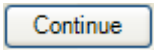


Figure 3.36



If the second button is selected in **Figure 3.34**, selecting **Continue** opens the **Pay Equation** window shown in **Figure 3.37** and allows the user to input the necessary information for the pay adjustment equation.

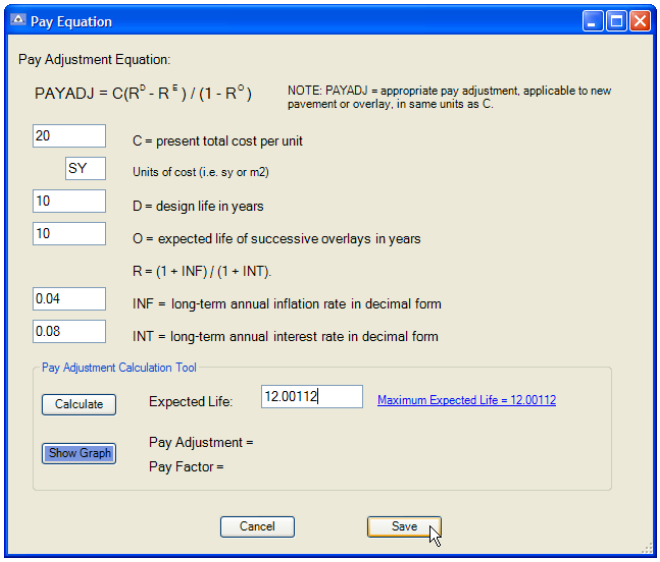
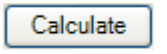


Figure 3.37

The input values for the pay adjustment equation are relatively self-explanatory. A thorough description and detailed discussion of these values are presented in *Optimal Procedures for Quality Assurance Specificatons, Publication No. FHWA-RD-02-095, April 2003*.

The **Pay Adjustment Calculation Tool** section at the bottom of **Figure 3.37** can be used to determine the pay adjustment, in terms of dollars per unit or as a percent pay factor, for any value entered into the **Expected Life:** box. In **Figure 3.38**, an expected life of *9.5* years has been entered and once **Calculate** is selected the corresponding pay adjustment and pay factor values are shown.



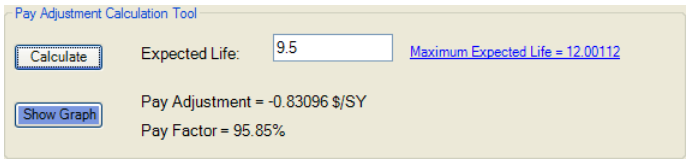
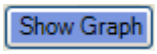


Figure 3.38



Selecting **Show Graph** displays the menu shown in **Figure 3.39**, which allows the user to select to **Graph Expected Life vs. Pay Factor** or **Graph Expected Life vs. Pay Adjustment**. **Figure 3.40** shows the plot of expected life vs. pay factor for the example shown in **Figure 3.37**.

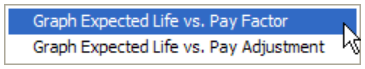


Figure 3.39

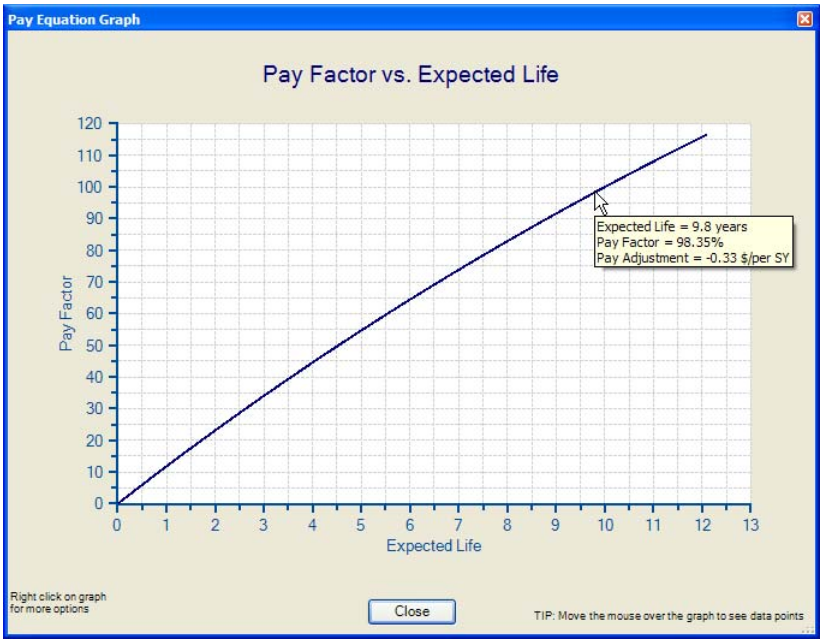
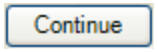


Figure 3.40



If the third button is selected in **Figure 3.34**, selecting **Continue** opens the **Add / Edit Pay Adjustment Equation(s)** window shown in **Figure 3.41** and allows the user to input the necessary information for the pay adjustment equation. The input procedures for this window are similar to those presented with the discussion of **Figure 3.14**, except that **(*x*)** is now expected life.

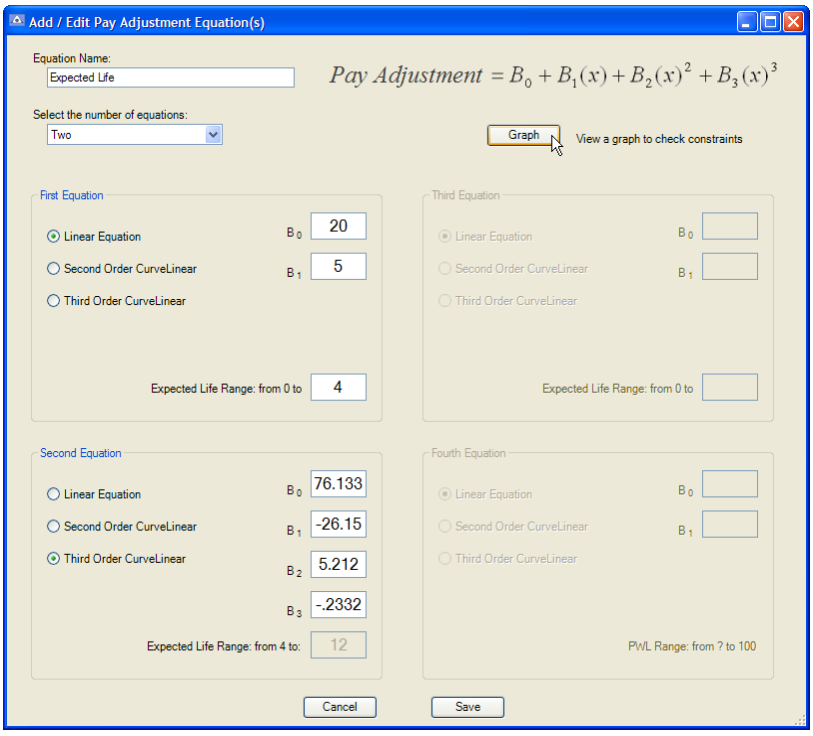
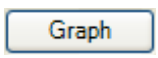


Figure 3.41



Selecting **Graph** in **Figure 3.41** displays the pay adjustment equation plot shown in **Figure 3.42**.

Multiple Graph
Pay Adjustment vs. Expected Life
Equation Name: Expected Life
Pay Adjustment
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Expected Life
Right click on graph for more options
Close
TIP: Move the mouse over the graph to see data points

Figure 3.42

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4 Setting Up Projects

The Setup Project Window

Once one or more specifications have been setup, clicking the **Setup Project** icon opens the screen shown in **Figure 4.1**. Any states or agencies that have been input using the **Setup Specs** option are displayed in the **Select a State / Agency to continue** window. If any projects have been setup previously and associated with a state or agency they are displayed in the **Select the contract number** window when that state or agency is highlighted.

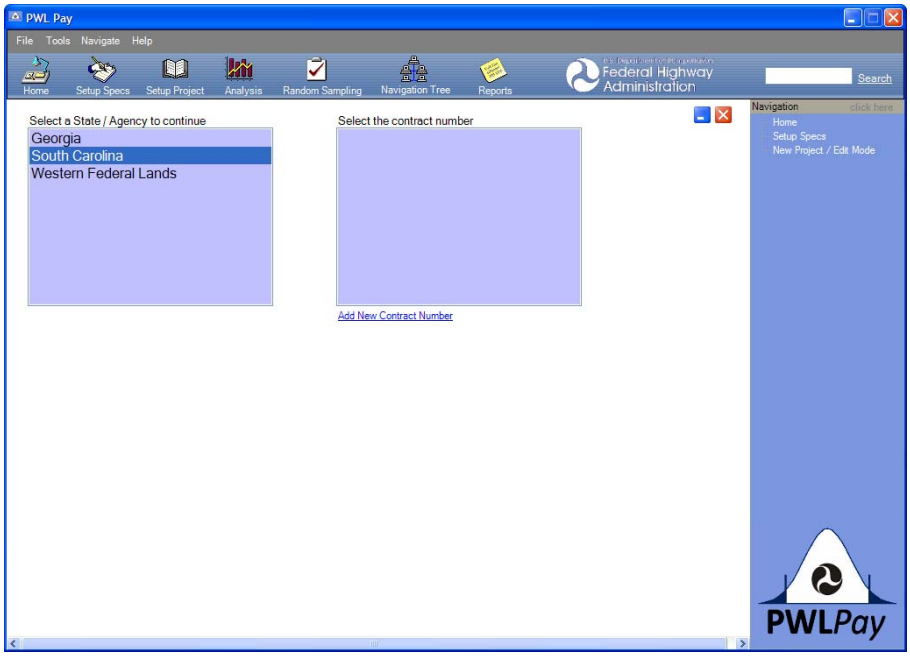


Figure 4.1

Adding a Project

The user must first select the state or agency for which the new project applies. For example, in **Figure 4.1 South Carolina** is selected as the agency and, since the **Select the contract number** window is empty, no projects have yet been entered for this agency.

Contract Number

Clicking on Add New Contract Number opens the window shown in **Figure 4.2** that allows the user to enter a contract number for the project to be added.

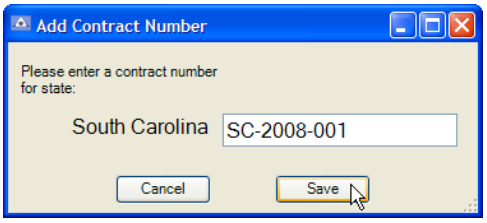
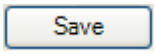


Figure 4.2

Project Name and Number



When **Save** is selected the program returns to the **Setup Project** window as shown in **Figure 4.3**. The new contract number is highlighted and new windows are displayed from which project names and numbers can be assigned to the highlighted contract number.

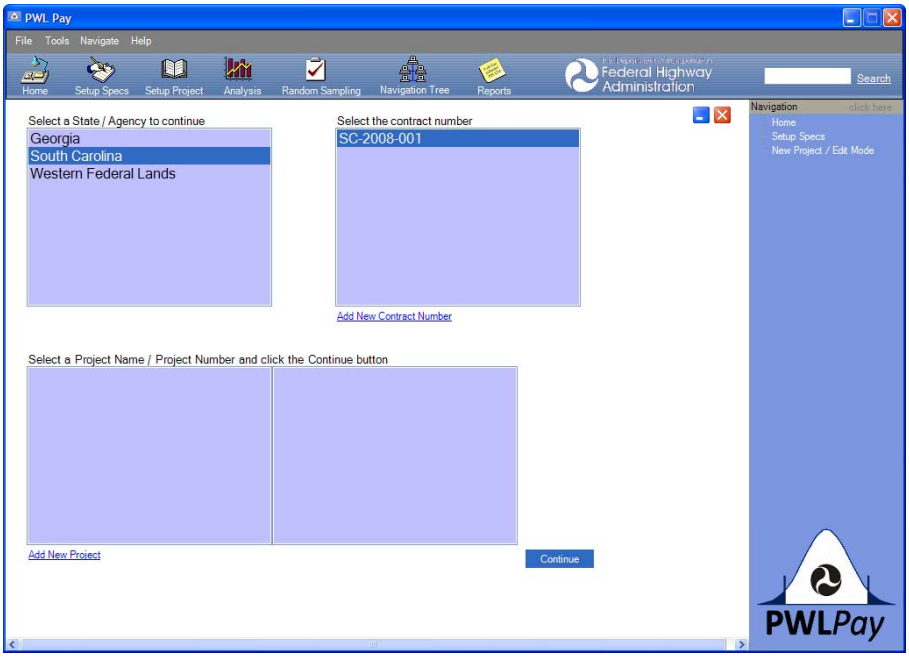


Figure 4.3

The **Select the contract number** window displays all contract numbers that have previously been assigned to the state or agency highlighted in the **Select a State / Agency to continue** window. Similarly, the **Select a Project Name / Project Number and click the Continue button** window displays the project name(s) and number(s) that are part of the highlighted contract number in the **Select the contract number** window. **Figure 4.4** shows the contract numbers associated with the state **South Carolina** and the project names, **Clemson Bypass** and **Clemson Bypass Phase II**, and numbers, **District-3-005-1** and **District-3-005-2**, associated with contract number **SC-2008-001**.

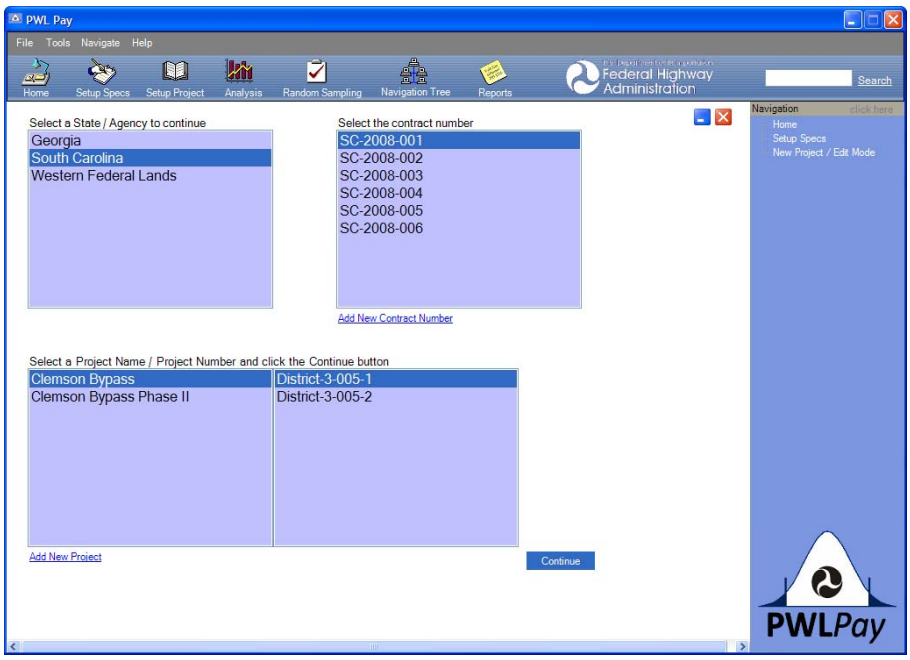


Figure 4.4

Clicking Add New Project opens the **Project Setup** window shown in **Figure 4.5**. In this figure, the user has entered *Clemson Bypass Phase II* as the **Project Name** and *District-3-005-2* as the **Project Number** for the new project. Also note that all of the item numbers that have been associated with South Carolina are displayed in the **Items in South Carolina Not Added to this Project** window.

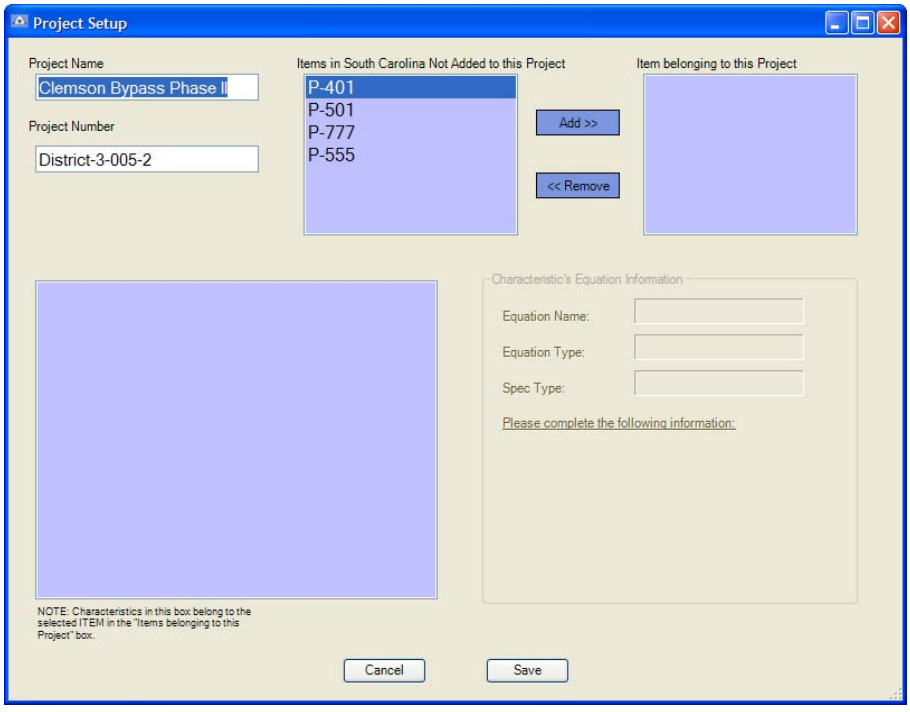
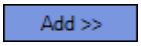


Figure 4.5

Adding Project Details

Items



The **Project Setup** window, shown in **Figure 4.5**, allows the user to input project-specific information regarding the type of project, as represented by the associated item numbers, and the specification limits for the project. The user highlights an item number and then uses the **Add >>** button to select it for the project. Any number of item numbers can be assigned to a given project.

In **Figure 4.6**, items **P-401** and **P-501** have been added to the project as shown in the **Items belonging to this Project** window. The characteristics associated with the highlighted item are shown in the box in the lower left corner of the **Project Setup** window. **Figure 4.6** shows that the characteristics **Asphalt Content**, **Air Voids**, **VMA**, and **Density** are associated with item **P-401**.

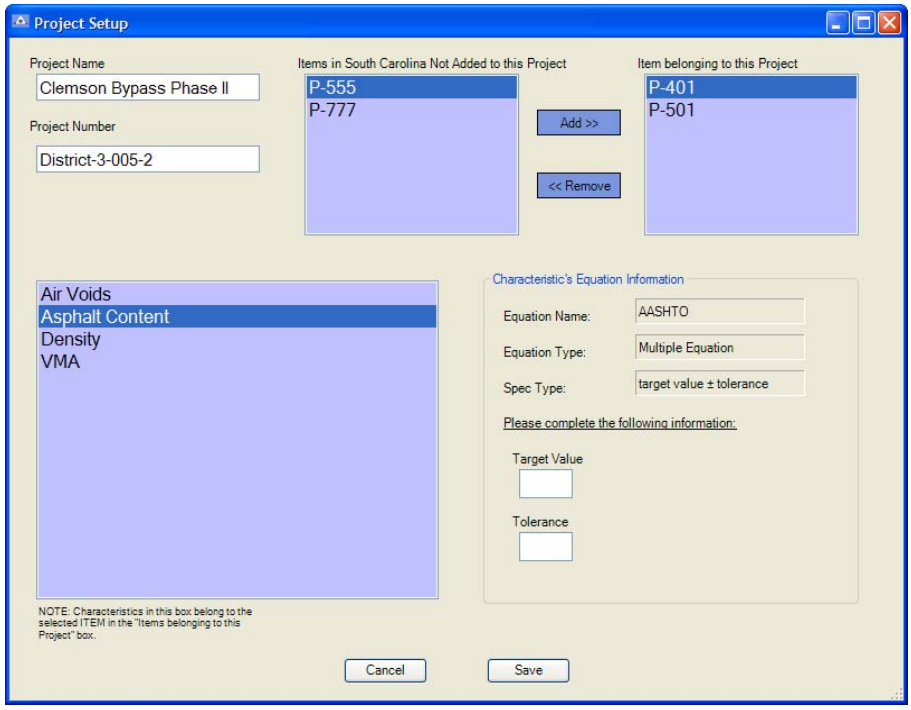


Figure 4.6

Spec Limits

The **Project Setup** window is also used to enter the specification limits for the various characteristics associated with each of the item numbers associated with the selected project. In **Figure 4.6**, the **Characteristic's Equation Information** box displays detailed information regarding the specification requirements for the characteristic that is highlighted in the box in the lower left corner of the window. This is also where the specification limits for the characteristic are entered for the selected project.

Figure 4.6 shows that the characteristic **Asphalt Content** uses the pay equation named **AASHTO**, that the pay equation type is **Multiple Equation** (as opposed to using Expected Life), and that the specification has a **target value with ± tolerance** limits. The user must enter the specification limits for all

characteristics before the project setup information can be saved. If the **Save** button is clicked before all limits have been entered a message such as that shown in **Figure 4.7** is displayed.

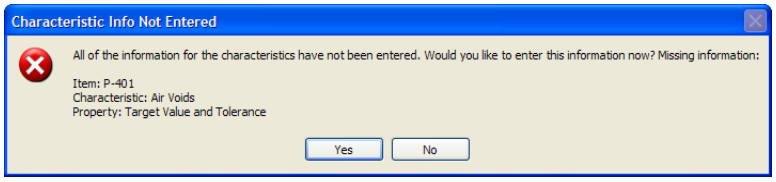


Figure 4.7

Figure 4.8, which is the bottom portion of the **Project Setup** window, shows that for the characteristic **Density**, the pay equation is **Curve-02** and the specification has both a **minimum and maximum limit**, with a **Minimum Limit** of *92.0* and a **Maximum Limit** of *96.5*.

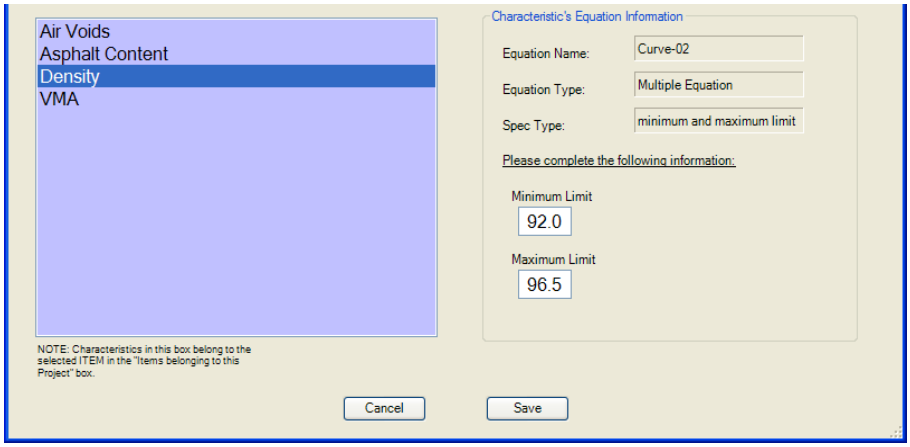
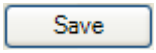
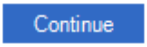


Figure 4.8



Once all of the specification limits have been entered, clicking on the **Save** button saves the information in the database and returns the user to the **Setup Project** window. Note in **Figure 4.9** that the newly added project name, **Clemson Bypass Phase II,** and project number, **District-3-005-2**, are shown in the **Select a Project Name / Project Number and click the Continue button** window. Clicking on **Continue** takes the user to the data input screen for the selected project so that test results can be entered.



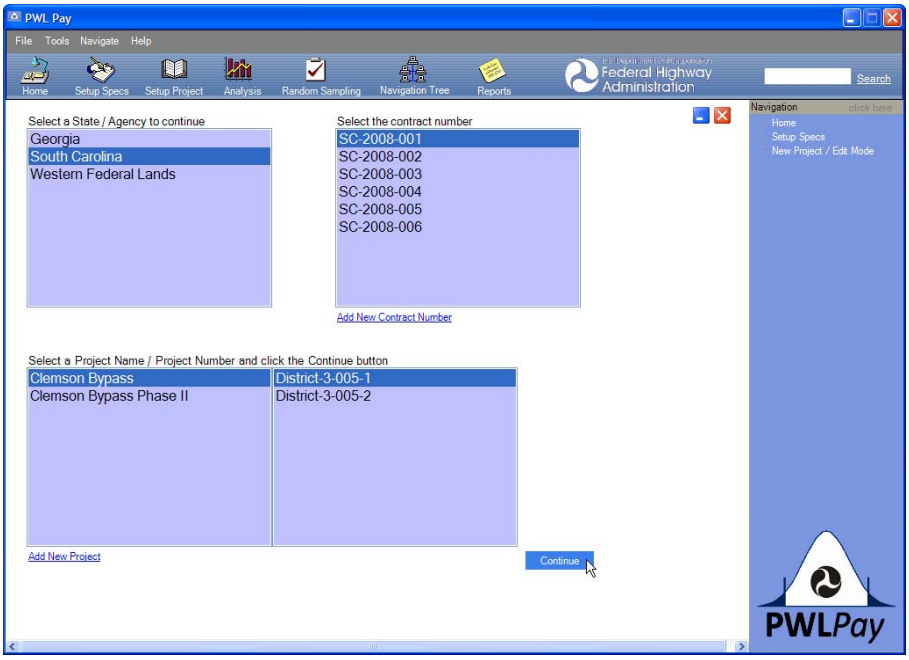

PWL Pay
File Tools Navigate Help
Home
Setup Specs
Setup Project
Analysis
Random Sampling
Navigation Tree
Reports
Federal Highway Administration
Search
Select a State / Agency to continue
Georgia
South Carolina
Western Federal Lands
Select the contract number
SC-2008-001
SC-2008-002
SC-2008-003
SC-2008-004
SC-2008-005
SC-2008-006
Add New Contract Number
Select a Project Name / Project Number and click the Continue button
Clemson Bypass
Clemson Bypass Phase II
District-3-005-1
District-3-005-2
Add New Project
Continue
Navigation
click here
Home
Setup Specs
New Project / Edit Mode
PWLPay

Figure 4.9

5 Entering Test Results

The Add Samples Window

The **Add Samples** window is used to input all test result data for a selected project. **Figure 5.1** shows the **Add Samples** window for a project before any test result data have been entered. Project idenification information, including project name, project number, specification type, and specification limits, is provided at the top of the screen. There are also two drop down menus in this region of the window: one for **Item Number:** and one for **Characteristic:**.

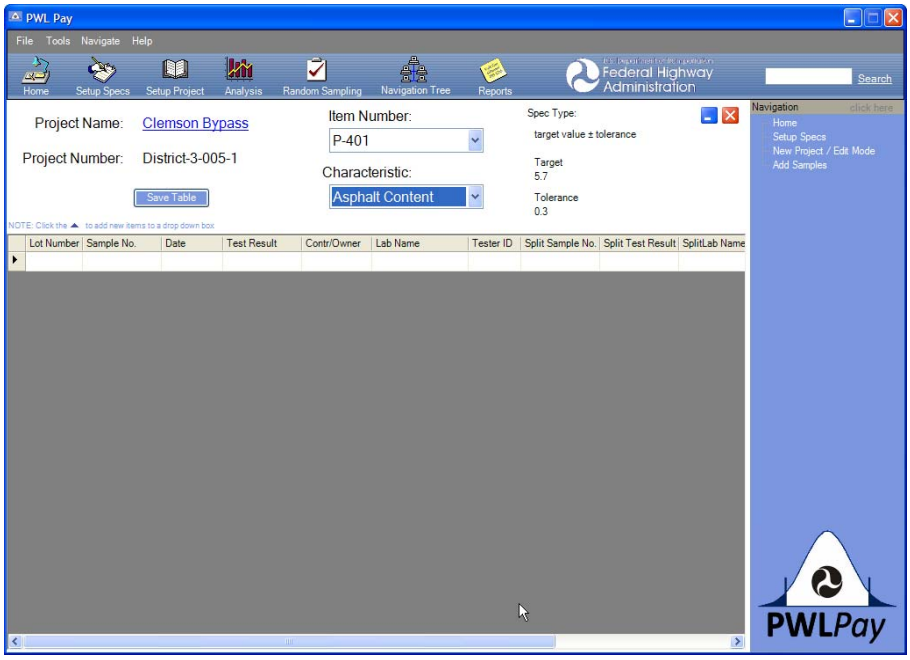


Figure 5.1

Clicking on the project name, Clemson Bypass in **Figure 5.1**, opens the **Project Setup** window for that project. Clicking on the **Item Number:** drop down menu displays a selection list of all item numbers associated with this project (see **Figure 5.2a**). Similarly, clicking on the **Characteristic:** drop down menu displays a selection of all characteristics associated with the selected item number (see **Figure 5.2b**).

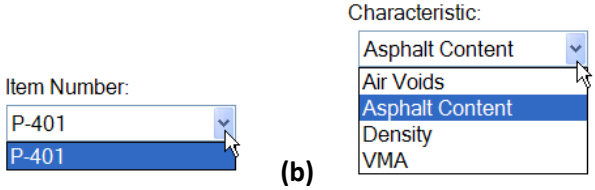
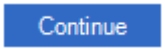


Figure 5.2 **(a)** **(b)**

Opening the Add Samples Window



There are a number of different ways that the user can open the **Add Samples** window to allow input of test result data for a selected project. As shown and noted in Chapter 4, clicking on **Continue** in the **Setup Project** window leads to the **Add Samples** window for the highlighted project (see **Figure 4.9**).

The **Add Samples** window can also be opened two different ways from the **Home** screen. Either left or right clicking on the name (**Clemson Bypass** in **Figure 5.3**) of one of the **Recent Projects** opens the dropdown menu shown in **Figure 5.3**. **Edit Project** opens the **Project Setup** window. **Add Test Results** opens the **Add Samples** window. **Open Project ▸ Show All Projects** or **Open Project ▸ Show Projects Not on Home Page** allows the user to show additional projects not shown in the **Recent Projects** section.

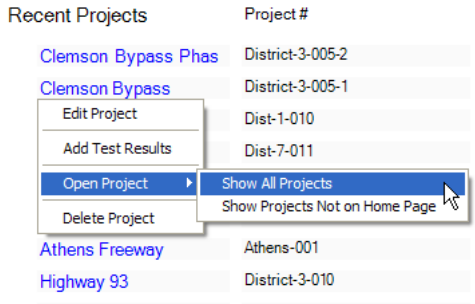


Figure 5.3

The **Add Samples** window can also be opened directly for a project in the **Recent Projects** list by clicking on the **Add Test Result** button at the end of the row in which the project appears (see **Figure 5.4**).

Figure 5.4

Entering Test Results

Test result data can be entered directly into the section of the **Add Samples** screen that has the appearance of a spreadsheet (see **Figure 5.1**). Test result data can also be imported from a CSV (comma separated variables) file that was most likely created using a spreadsheet program.

Data Columns

Test result data can be entered in the **Add Samples** screen as they would be entered into a typical spreadsheet. **Figure 5.1** shows some of the column headings for which data can be entered for a project.

The columns for which data can be entered include:

Lot Number: alpha-numeric lot number to which the test result is associated.

Sample No.: alpha-numeric sample number within the lot.

Date: can be entered in any typically accepted format, e.g., 2-4-07, or 02/04/07, or 2/4/2007, etc. The program automatically converts the date to a standard format.

Test Result: test result for the lot/sample number combination.

Contr/Owner: indicates whether the test was performed by contractor or owner personnel.

Lab Name: name of the laboratory where the test was performed.

Tester ID: alpha-numeric identification number for the technician who performed the test.

Split Sample No.: alpha-numeric identification number for the owner's portion if split samples are used.

Split Test Result: test result for the owner's split sample for the lot/sample combination.

SplitLab Name: name of the laboratory where the split sample was tested.

Split Tester ID: alpha-numeric identification number for the technician who performed the split sample test.

Remarks: whatever comments or additional information the user wishes to add.

Important Note on Lot Numbers & Sample Numbers

Due to the way in which **PWL*Pay*** and spreadsheet programs sort data, it is important that care be taken when assigning and entering lot and sample numbers. Since lot and sample numbers may have letters as well as numbers, to be sorted properly, they must be recognized as "text" by either **PWL*Pay*** or a spreadsheet program. To ensure that this happens without having to remember to declare the cells as text, it is recommended that the user always include a letter as well as numbers when assigning lot and sample numbers. For example, it is preferable to enter L001, L-001, or Lot-001 rather than 001 for the lot number.

It is also important that lot and sample numbers are entered with a consistent number of places. For example, if lot numbers were entered as L-1, L-2, L-3, L-4, L-5, L-6, L-7, L-8, L-9, L-10, L-11, when sorted by lot number the order of display would be L-1, L-10, L-11, L-2, L-3, L-4, L-5, L-6, L-7, L-8, L-9. This problem can be avoided simply by entering leading zeros so that all lots or samples have the same number of values. In the previous example, the lots would be displayed in the proper order if the numbers were entered as L-01, L-02, L-03, L-04, L-05, L-06, L-07, L-08, L-09, L-10, L-11.

Entering Data

Test information and results are entered as in a typical spreadsheet program. **Figure 5.5** shows the spreadsheet format data entry section of the **Add Samples** window before any test result information has been added for the characteristic **Asphalt Content**.

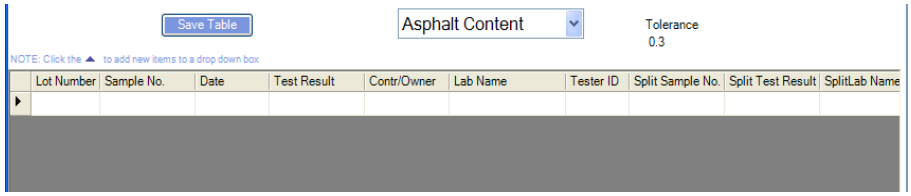
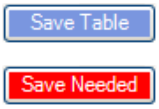


Figure 5.5

Figure 5.6 shows the same section of the **Add Samples** screen while data entry is underway for the first sample for the project. Once any values are input, the **Save Table** button (see **Figure 5.5**) changes to the **Save Needed** button to remind the user to save the input data after entry (see **Figure 5.6**). Note that the input data will be lost if not saved before exiting from the current characteristic. If the user tries to change characteristics before saving the input data, a warning window pops up (see **Figure 5.7**).



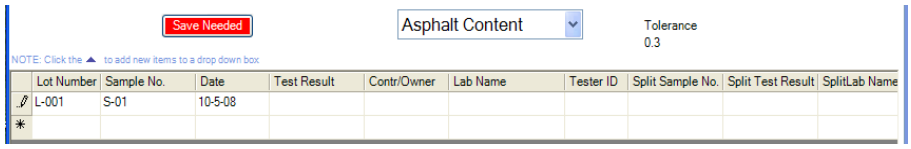


Figure 5.6

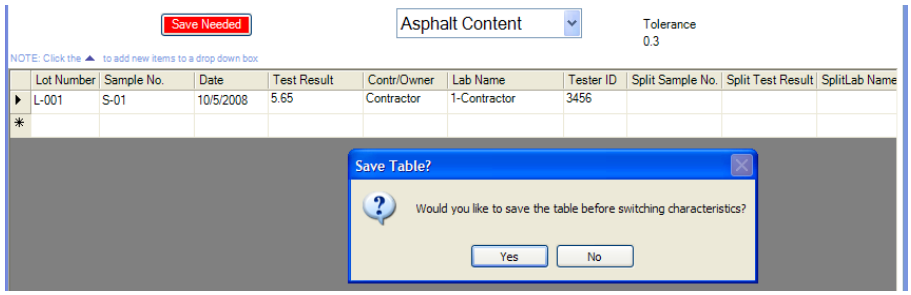


Figure 5.7

The **Date** format in **Figure 5.7** has been automatically changed from the value *10-5-08* (see **Figure 5.6**) that was input to the standard format used by **PWL***Pay*.

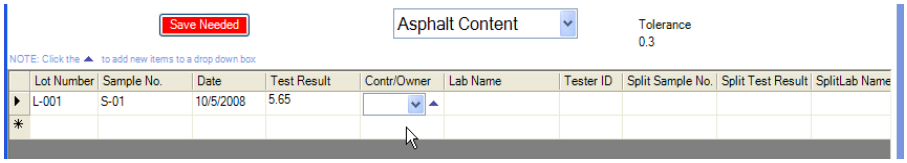


Figure 5.8

The **Contr/Owner** column (see **Figure 5.8**) indicates which party conducted the test and has a limited number of input values. As shown in the NOTE above the spreadsheet section, these allowable values are entered initially by clicking on the ▲ symbol. This displays the drop down window shown in **Figure 5.9a**. Two possible input values have been entered, *Contractor* and *Owner*. Clicking Ok sets these as the only two possible values. The cell will

now auto-complete. That is, for example, entering *c* will cause *Contractor* to be the input value.

Once the allowable values have been entered, clicking on the drop down arrow, , displays the input options for this column, i.e., **Contractor** or **Owner** in **Figure 5.9b**.

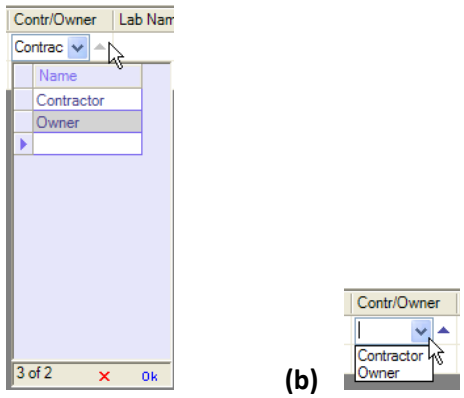


Figure 5.9

Similarly, the **Lab Name** and **Tester ID** columns are limited to values that have been input in the same manner. See, for example, **Lab Name** in **Figure 5.10**. Names for all labs in the state could be entered all at one time and in such a way that allows the auto-complete function to save time. For example, if the state had seven district labs, rather than entering them as *District-1*, *District-2*, etc., it would be better to enter them as *1-District*, *2-District*, etc. In the first case, entering *D* would not allow auto-completion since seven labs begin with D. However, in the second case, entering *1* would auto-complete **1-District** (provided there were no other lab names beginning with 1).

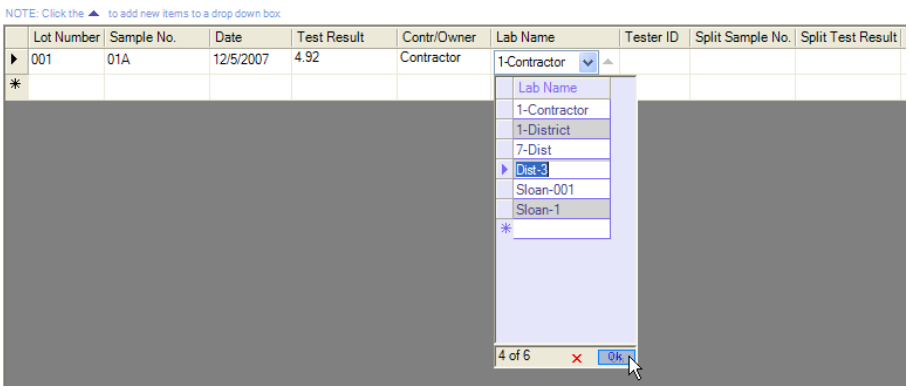


Figure 5.10

The **SplitLab Name** and **Split Tester ID** columns work in similar fashion to the **Lab Name** and **Tester ID** columns.

Importing Data

Test information can also be imported in the form of a CSV file. In this way a spreadsheet could be used to maintain the data and then the file could be saved as a CSV file and imported into **PWL*Pay***. This would also allow existing data, with some adjustments in columns and column titles, to be quickly and easily entered into **PWL*Pay***.

Right clicking the mouse anywhere in the **Add Samples** window opens the drop down menu shown in **Figure 5.11**. Only the **Import Data** option is considered here. The other choices on this menu are covered later in this chapter.

Selecting **Import Data** opens the **Import Test Results** window shown in **Figure 5.12**, which allows several options for importing data from an existing CSV file. The user can **browse** to locate the file to be imported. The default for **Import Data Format:** is **All Data**. The dropdown menu in **Figure 5.12** shows all of the import options.

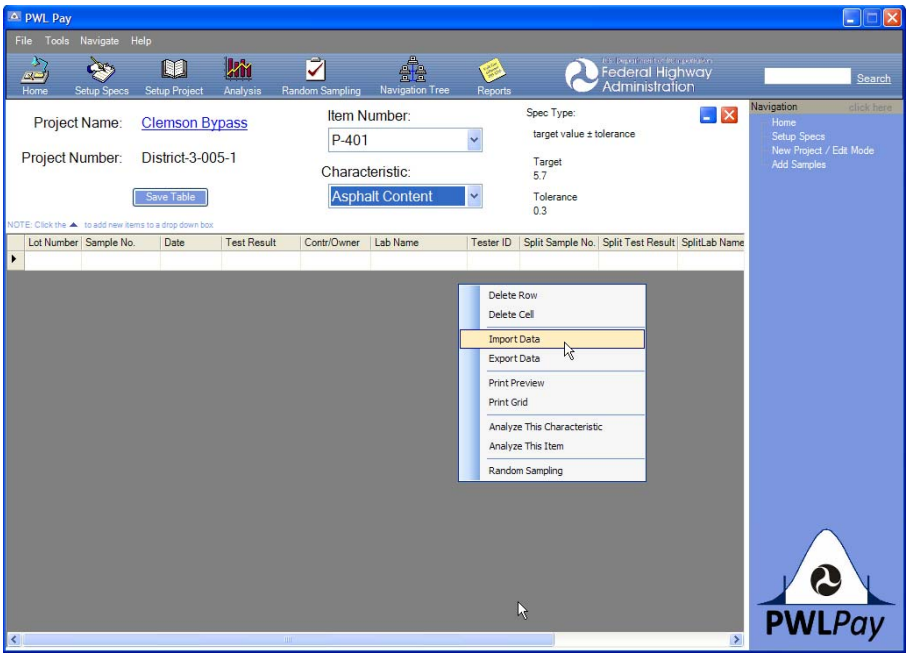


Figure 5.11

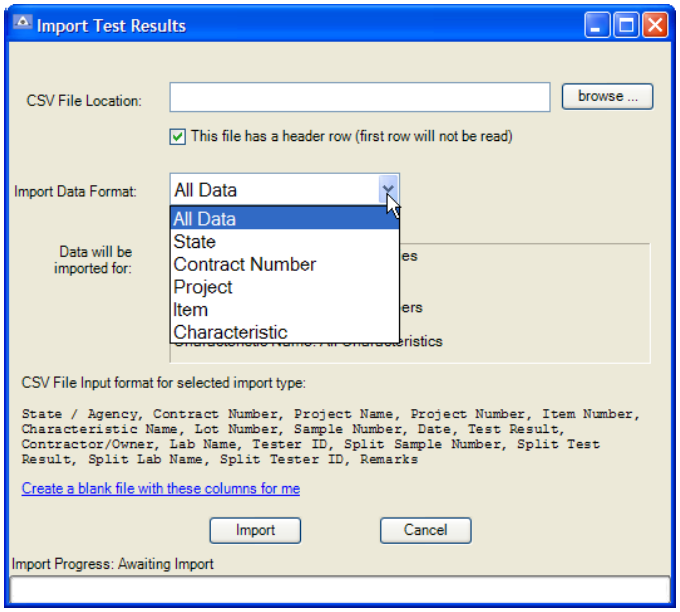


Figure 5.12

The **Data will be imported for:** window, shown in **Figure 5.13**, indicates that **All Data** allows for input of data from multiple states as well as multiple contracts, multiple projects, multiple items, and multiple characteristics for each project. This import format probably would not be used often. A different import format can be selected by clicking to open the drop down menu shown in **Figure 5.12**.

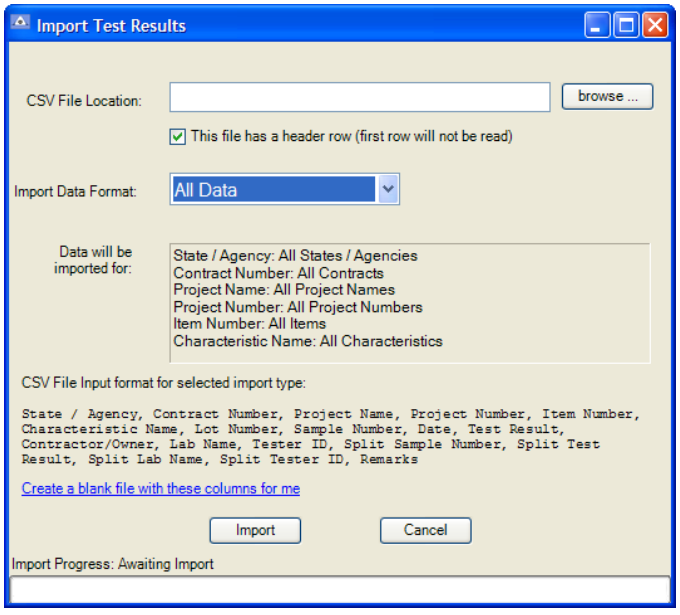
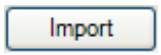


Figure 5.13

Note that the **CSV File Input format for selected import type:** section lists the columns for which import data are needed based on whichever **Import Data Format:** is selected. For example, the column input titles for **All Data** are shown in **Figure 5.13**.

Figure 5.14 shows the column input titles when **Project** is selected for the **Import Data Format:** option. Comparing **Figures 5.13** and **5.14** shows the smaller number of input columns required for the **Project** import format. The **Data will be imported for:** window shows that no input is necessary for **State**, **Contract Number**, **Project Name**, or **Project Number** since these are automatically input as shown based on the **Project** format that is selected.

At this point the user can create a CSV file using the column headings shown in **Figure 5.14**, although this can be accomplished more easily by clicking on Create a blank file with these columns for me. Doing this opens Excel, if it is on the user's computer, with a CSV file open with the required column headings. A sample with the column headings for the CSV file created by clicking Create a blank file with these columns for me from **Figure 5.14** is shown in Figure **5.15**.



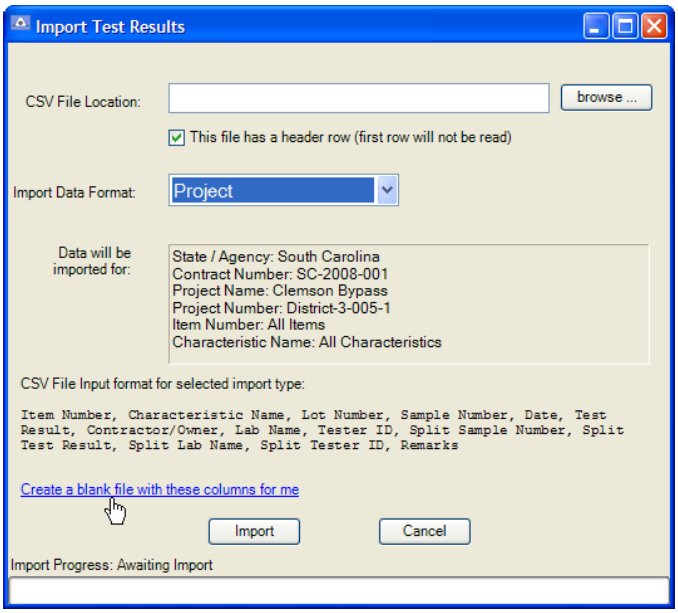


Figure 5.14

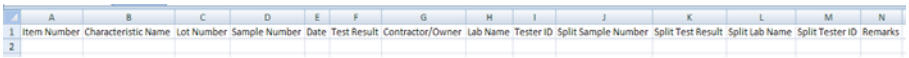


Figure 5.15

The user can then either directly input data into the CSV file in **Figure 5.15**, or else import data from an existing spreadsheet into the appropriate columns in the CSV file. **Figure 5.16** shows a portion of the CSV file from **Figure 5.15** after project data have been entered.

Figure 5.16

Important Note on Cell Formats

In **Figure 5.16** note that the lot and sample numbers all contain at least one letter. This avoids any potential problems with Excel recognizing the input as numeric rather than alpha-numeric (i.e., Excel treats the cell as "Text"). As noted previously, entering these values as text allows for proper sorting when displayed by **PWL*Pay***.

Figure 5.17 shows the **Add Samples** screen after the CSV file shown in **Figure 5.16** has been imported.

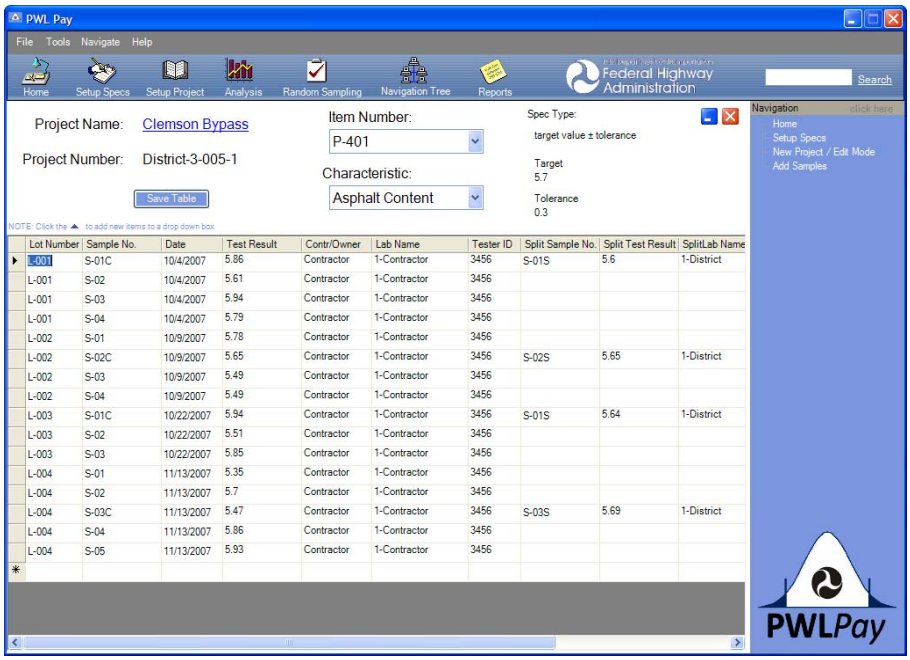


Figure 5.17

Lot Number	Sample No.	Date	Test Result	Contr/Owner	Lab Name	Tester ID	Split Sample No.	Split Test Result	SplitLab Name
L-001	S-01C	10/4/2007	5.86	Contractor	1-Contractor	3456	S-01S	5.6	1-District
L-001	S-02	10/4/2007	5.61	Contractor	1-Contractor	3456			
L-001	S-03	10/4/2007	5.94	Contractor	1-Contractor	3456			
L-001	S-04	10/4/2007	5.79	Contractor	1-Contractor	3456			
L-002	S-01	10/9/2007	5.78	Contractor	1-Contractor	3456			
L-002	S-02C	10/9/2007	5.65	Contractor	1-Contractor	3456	S-02S	5.65	1-District
L-002	S-03	10/9/2007	5.49	Contractor	1-Contractor	3456			
L-002	S-04	10/9/2007	5.49	Contractor	1-Contractor	3456			
L-003	S-01C	10/22/2007	5.94	Contractor	1-Contractor	3456	S-01S	5.64	1-District
L-003	S-02	10/22/2007	5.51	Contractor	1-Contractor	3456			
L-003	S-03	10/22/2007	5.85	Contractor	1-Contractor	3456			
L-004	S-01	11/13/2007	5.35	Contractor	1-Contractor	3456			
L-004	S-02	11/13/2007	5.7	Contractor	1-Contractor	3456			
L-004	S-03C	11/13/2007	5.47	Contractor	1-Contractor	3456	S-03S	5.69	1-District
L-004	S-04	11/13/2007	5.86	Contractor	1-Contractor	3456			
L-004	S-05	11/13/2007	5.93	Contractor	1-Contractor	3456			

Working with Test Results

Once the project data have been entered using the **Add Samples** window they can be edited and sorted in a number of ways.

Sorting the Data

Clicking the mouse on any column title causes the data to be sorted based on that column. For example, in **Figure 5.17**, the test data for asphalt content are sorted in increasing order by **Lot Number**. Clicking on the **Lot Number** column title will cause the data to be sorted in decreasing order by **Lot Number**.

Similarly, clicking on any other column title causes the data to be sorted by increasing (or decreasing for a second click) order based on that column. For example, clicking on **Split Sample No**. would bring all split sample results to the top of the spreadsheet so they all could be viewed at once. Similarly, the user might click on the **Test Result** column title to easily identify the lowest and highest test values.

Editing the Data

Figure 5.18 shows the drop down window that opens by right clicking anywhere in the **Add Samples** window (see **Figure 5.11**). This window provides the user a number of options for working with the test data. The **Delete Row** and **Delete Cell** options are obvious. Clicking on these deletes either the highlighted row or cell.

Printing the Data

Print Preview and **Print Grid** allow the user to preview a printout and to print the spreadsheet for the characteristic that is currently displayed in the **Add Samples** window.

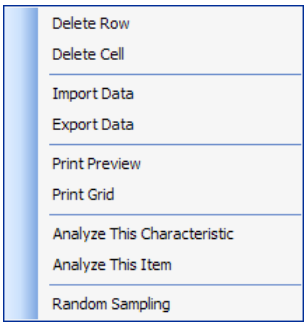


Figure 5.18

Analyzing the Data

The menu in **Figure 5.18** allows the user to directly enter the **Analysis** window with the analysis input already set to either **Analyze This Characteristic**, e.g., **Asphalt Content** in **Figure 5.17**, or **Analyze This Item**, e.g., **P-401** in **Figure 5.17**. The **Analysis** window is covered in detail in Chapter 6. The user can consult Chapter 6 for detailed instructions on the various analyses that can be performed on the item or characteristic.

Random Sampling

The menu in **Figure 5.18** allows the user to directly enter the **Random Sampling** window where sampling locations or times can be randomly generated. The **Random Sampling** window is covered in detail in Chapter 7. The user can consult Chapter 7 for detailed instructions on how to develop random sampling locations or times.

6 Analyzing the Data

The Analysis Window

The **Analysis** window can be reached by clicking on the **Analysis** icon at the top of any screen and selecting **New Analysis**, or from the right click menu on the **Add Samples** window (see **Figures 5.11** and **5.18**). The **Analysis** window is shown in **Figure 6.1**. From this window the user can select a wide range of projects and initiate any of the analyses of which **PWL***Pay* is capable.

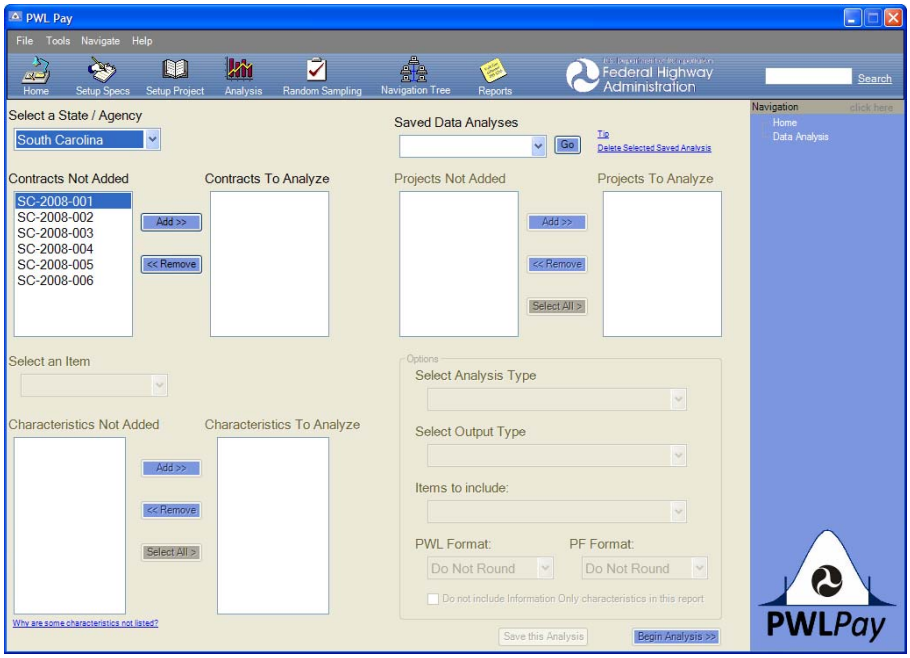
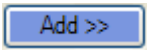


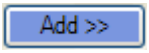
Figure 6.1

Selecting Data for Analysis

The user has a wide array of options for selecting the data for analysis. The user first makes a selection from the **Select a State / Agency** drop down menu. In **Figure 6.1**, **South Carolina** has been selected. The **Contracts Not Added** window automatically displays all contract numbers associated with the selected state / agency. The user can then select **Contracts To Analyze** by highlighting a contract number and clicking **Add>>**.



All projects associated with the contract numbers in the **Contracts To Analyze** window are automatically displayed in the **Projects Not Added** window. Once again, the **Add>>** button is used to select the **Projects To Analyze**. All characteristics associated with the **Projects To Analyze** and the selected item number are automatically displayed in the **Characteristics Not Added** window. As before, clicking on **Add>>** selects the **Characteristics To Analyze**. The user can select all characteristics for analysis with one click by clicking on the **Select All>** button.



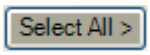


Figure 6.2 shows that the data selected for analysis are from the state of **South Carolina**, contract number **SC-2008-001**, project **Clemson Bypass**, item **P-401**, and for the characteristics **Asphalt Content**, **Air Voids**, **VMA**, and **Density**. Note that the **Clemson Bypass Phase II** has not been selected and therefore appears in the **Projects Not Added** window.

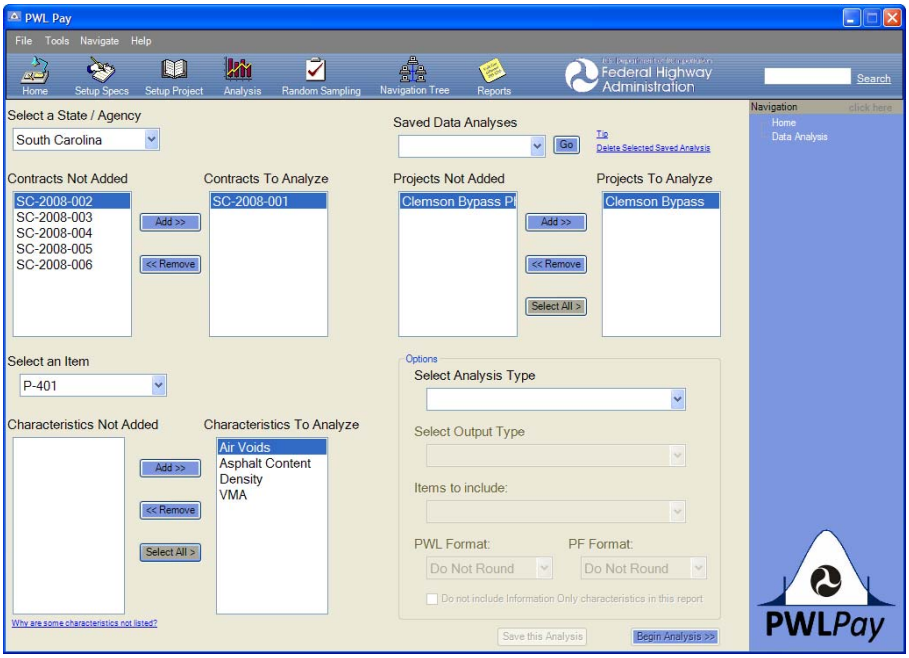


Figure 6.2

Types of Analysis

The analyses of which **PWL*Pay*** is capable are identified in the **Select Analysis Type** drop down menu in the **Options** section. **Figure 6.3** shows the possible analyses that **PWL*Pay*** can perform. Each of these analyses is described in detail in the following sections.

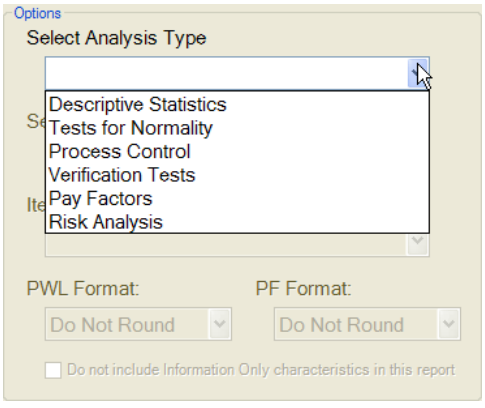
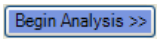


Figure 6.3

Descriptive Statistics



After selecting **Descriptive Statistics** from the choices in **Figure 6.3** the user then clicks the **Begin Analysis >>** button to perform the analysis and display the results.

The **Descriptive Statistics** window is shown in **Figure 6.4**. General informaton regarding the **State / Agency** and the **Item Number:** are displayed at the top of the window. Click on the **Please select a test category:** drop down menu to display the options for which tests to analyze. The choices are shown in **Figure 6.5**.

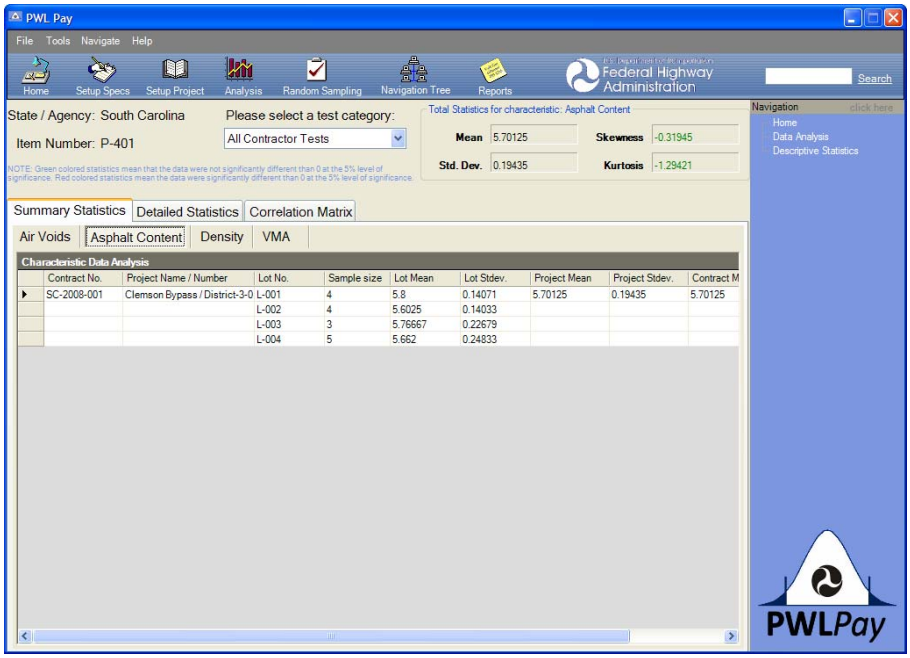


Figure 6.4

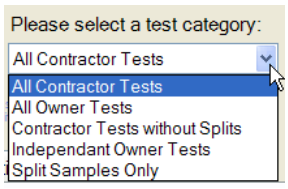


Figure 6.5

Summary Statistics

As shown in **Figure 6.4**, the **Summary Statistics** displayed are for contract number **SC-2008-001** and the **Clemson Bypass** project. The mean and standard deviation for **Asphalt Content** are shown for each lot on the project. In addition, the total mean and standard deviation for all tests are shown in the **Project Mean** and **Project Stdev.** columns. The **Contract Mean** and **Contract Stdev.** columns display the results for all data on the contract. The user must tab or scroll to the right to see the columns that are to the right of the display area.

Note that summary statistics for **Asphalt Content** for all project data are also shown in the upper right corner of the window in the section labeled **Total**

Statistics for characteristic: Asphalt Content. The statistics shown are the mean, standard deviation, skewness, and kurtosis. These are common measures of probability distributions. These values are calculated using the following formulas:

Mean: $$\bar{x} = \frac{\sum x_i}{n}$$

Standard Deviation: $$s = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1}}$$

Skewness: $$g_1 = \frac{n}{(n-1)(n-2)} \sum_{i=1}^{n} \frac{(x_i - \bar{x})^3}{s^3}$$

Kurtosis: $$g_2 = \left\{ \frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum_{i=1}^{n} \frac{(x_i - \bar{x})^4}{s^4} \right\} - \frac{3(n-1)^2}{(n-2)(n-3)}$$

where: $\bar{x}$ = the sample mean,
x_i = the individual values in the sample,
n = the number of values in the sample,
s = the sample standard deviation,
g_1 = the sample skewness coefficient,
g_2 = the sample kurtosis coefficient.

The mean is a measure of the location of the data. The standard deviation is a measure of the variability of the data. The skewness coefficient is a measure of the degree of asymmetry of the data around the mean. A symmetric data set has a skewness coefficient of 0. The kurtosis, which is a measure of the "peakedness" or relative amount of data in the upper and lower tails of the distribution of the data, is not often used.

PWL*Pay* automatically checks the skewness and kurtosis values to see if they could likely have come from a normal population. This check is conducted at the significance level, alpha (α), selected by the user. If the test on either the skewness or kurtosis coefficient indicates that a normal population is unlikely, the coefficient is shown in **bold red print**. Otherwise it is shown in normal green print. A more detailed discussion of normality tests is presented in Chapter 11.

Detailed Statistics

The **Detailed Statistics** for the same project are shown in **Figure 6.6**. In this case each individual test result is displayed on its own row along with its corresponding lot and sample number. The **Lot**, **Project**, and **Contract** means and standard deviations are shown as well. Some of these values are in columns that are to the right of the display area and therefore the user must tab or scroll to the right to see them.

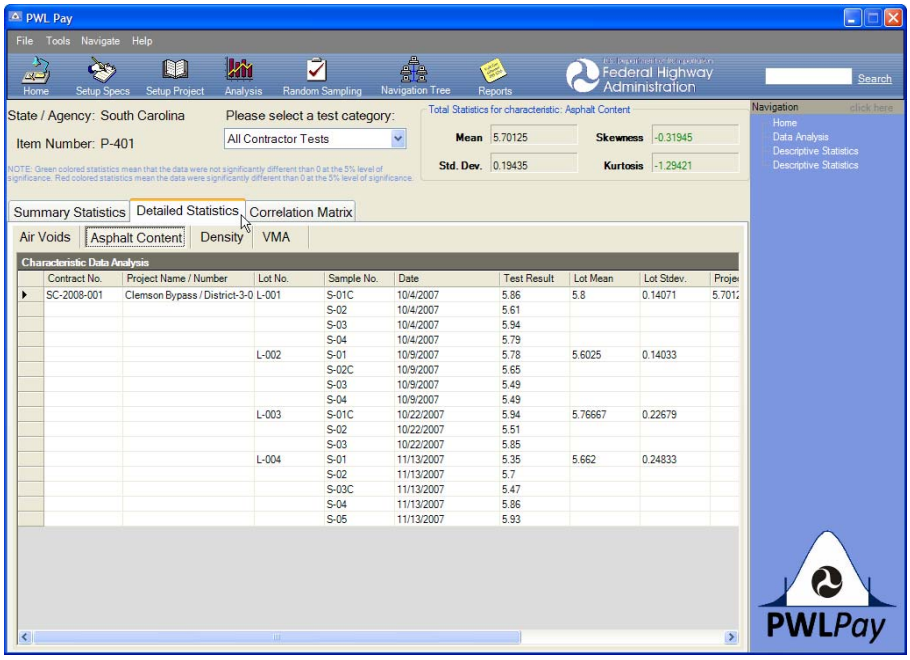


Figure 6.6

Correlation Matrix

The correlation coefficient of two variables x and y, which is always between –1 and 1, measures the linear relationship between x and y.

- If $r = 1$ (or $r = -1$), then x and y are strictly positively (or negatively) linearly related, i.e., y is precisely some positive (negative) multiple of x.
- If $r = 0$, then x and y are not linearly related. It does not mean that they are not related. They could be related in some non-linear way.
- If $r > 0$ (or $r < 0$), then, when x increases, y tends to increase (or decrease). The closer that r is to 1 (or –1), the stronger is the correlation, as indicated by less spread in the data.

Important Note on Correlation between Characteristics

To be able to calculate a correlation coefficient between two variables there must be a paired correspondence between the sample values. That is, for the case of comparing the results of two different characteristics, the test results must be obtained from the same sample.

For example, if asphalt content and VMA are both determined from the same sample obtained at the plant, then there is a direct relationship between the asphalt content and VMA test results for each sample number. Therefore, it is appropriate to calculate a correlation coefficient between asphalt content and VMA.

On the other hand, if density is determined by testing cores obtained from the finished pavement, it is not possible to calculate a correlation coefficient between laboratory-compacted air voids and density since there is no paired correspondence between their test results.

More Info

A detailed discussion of correlation coefficients is presented in Chapter11.

Figure 6.7 shows the **Correlation Matrix** screen for the **Descriptive Statistics** analysis window. The second row of tabs now shows all of the possible pair-wise comparisons among the characteristics for which test results are available. In this case, there are six possible pair-wise comparisons for the four characteristics.

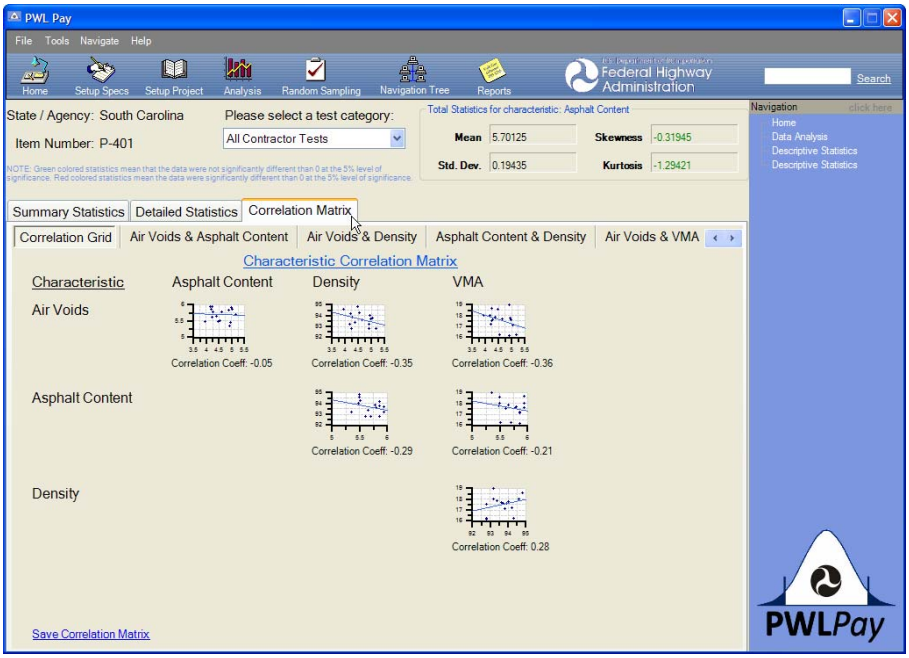


Figure 6.7

Below this row of tabs is a matrix that shows all of the correlation coefficients along with small versions of scatter plots of the two characteristics showing the best straight line fit between the test results for the two characteristics.

The user can save the correlation matrix to a CSV file by clicking Save Correlation Matrix shown in the lower left corner of the screen in **Figure 6.7**.

The user can click on one of the tabs or on one of the plots to open a screen with a large version of the scatter plot that shows the relationship between the two characteristics. **Figure 6.8** shows one of these screens for the **Asphalt Content & VMA** comparison.

The user can click on ◂ ▸ to scroll left or right to access all of the scatter plots.

The best-fit straight line is also shown on the scatter plot. The correlation coefficient and the equation for the fitted line are also shown. In **Figure 6.8** these values are shown by **Correlation Coeff (r): -0.21** and **Trendline Equation: y = -0.925054 x + 22.864589**.

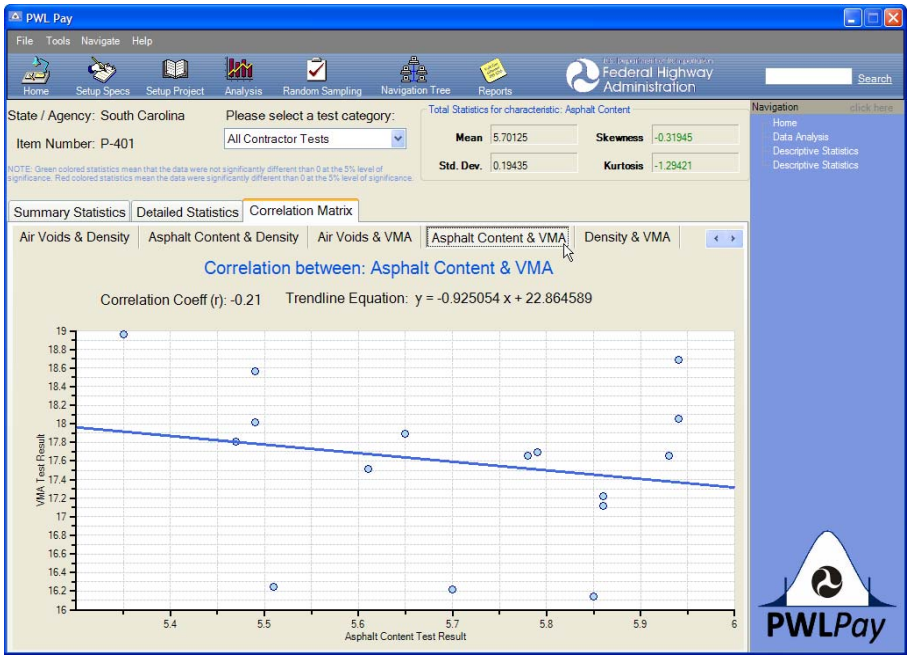


Figure 6.8

Tests for Normality

Significance Level

Before beginning any normality testing the user should select the desired level of significance, α, at which the test will be conducted. This can be done from any screen by clicking on **Tools** in the upper left corner of the screen. As shown in **Figure 6.9**, selecting **Tools ▸ Normality Check ▸ Alpha Value** allows the user to select **0.01**, **0.02**, **0.03**, **0.04**, or **0.05** for the level of significance. If the user does not select an alpha value, the default value of **0.05** is used.

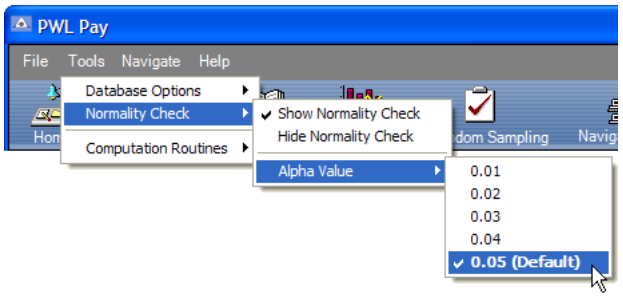


Figure 6.9

Checking Normality in the Background

PWL*Pay* can be configured to automatically run a quick check for normality whenever new data are entered. This check is done in the "background" and the user is notified only if the check indicates that there is a reason to believe that the data are not from a normal population. The user can decide whether or not to have **PWL*Pay*** perform this background check by selecting **Tools ▸ Normality Check**. If **Show Normality Check** is checked, the automatic test is performed. If **Hide Normality Check** is checked, the automatic test is not performed. The user can at any time choose to test data for normality by using the **Analysis** window.

The quick background normality check tests at the selected alpha value whether or not the skewness and kurtosis coefficients calculated for the test data are unlikely to have been obtained from a normal population. When this happens the warning window in **Figure 6.10** is displayed and asks whether or not the user wants more formal normality tests to be performed.

Run Test

Don't Run

As shown in **Figure 6.10**, the warning message informs the user whether the skewness and/or kurtosis values are questionable, and indicates at what alpha value these coefficients were compared. The user selects whether or not to run the normality test by selecting the **Run Test** or **Don't Run** button.

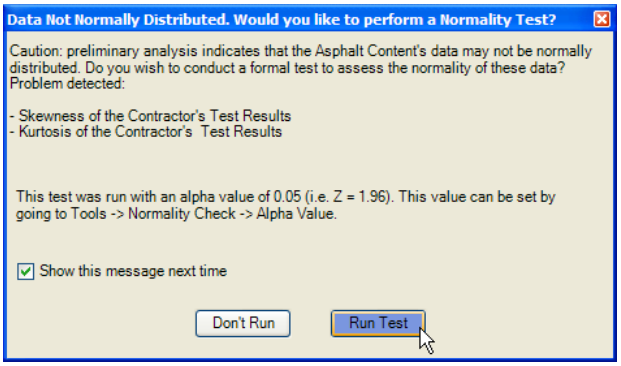


Figure 6.10

If **Run Test** is selected **PWL*Pay*** performs two different checks for normality. The fist is the Anderson-Darling (A-D) goodness of fit test specifically modified to test for normality. This is a formal hypothesis test. Since this test is quite sensitive to departures from normality, in **PWL*Pay*** it is always conducted at the 0.01 level of significance regardless of what value has been selected with the **Tools ▸ Normality Check ▸ Alpha Value** option.

The second check for normality is to plot the data on a quantile-quantile plot (qq-plot). Data that are normally distributed should approximate a straight line on the qq-plot. This is, essentially, the same process as plotting the cumulative distribution of the data on normal probability paper.

More Info

Detailed discussions of the Anderson-Darling test and qq-plots are included in Chapter 10.

Run Test

Figure 6.11 shows the normality test results obtained if **Run Test** is selected from the warning message in **Figure 6.10**. Note that the A-D indicates that **There is less than 1% chance that the data came from a normal distribution**. From the qq-plot it is easy to see why the A-D test for normality decalred the data to be non-normal. One of the test results has been intentionally entered as 20 rather than the correct value of 5.86.

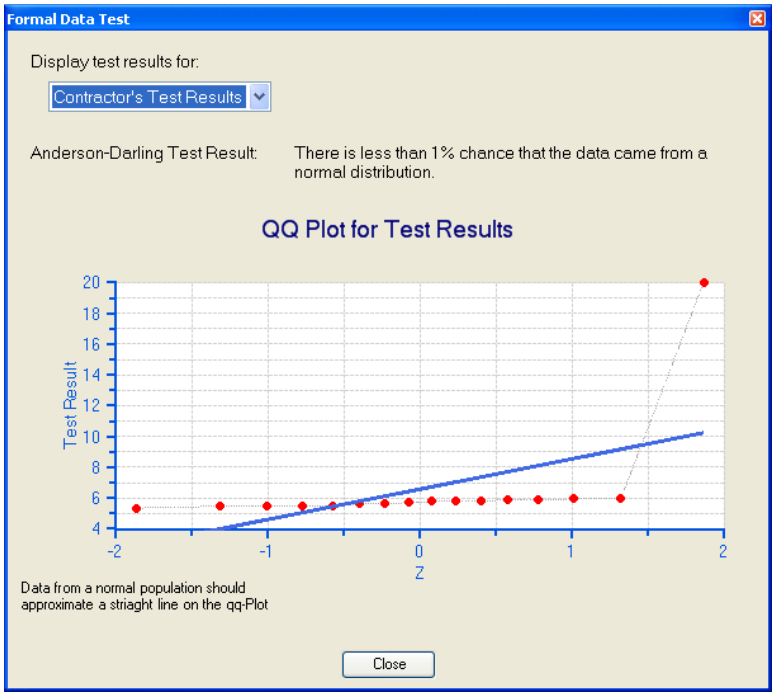


Figure 6.11

Tests for Normality

Begin Analysis >>

After selecting **Tests for Normality** from the choices shown in **Figure 6.3**, the user then selects the **Begin Analysis >>** button to perform tests for the normality of the data and display the results. The **Tests for Normality** window is shown in **Figure 6.12**. General informaton regarding the **State / Agency** and the **Item Number:** are displayed at the top of the window. Click on the **Please select a test category:** drop down to display the options for which tests to analyze.

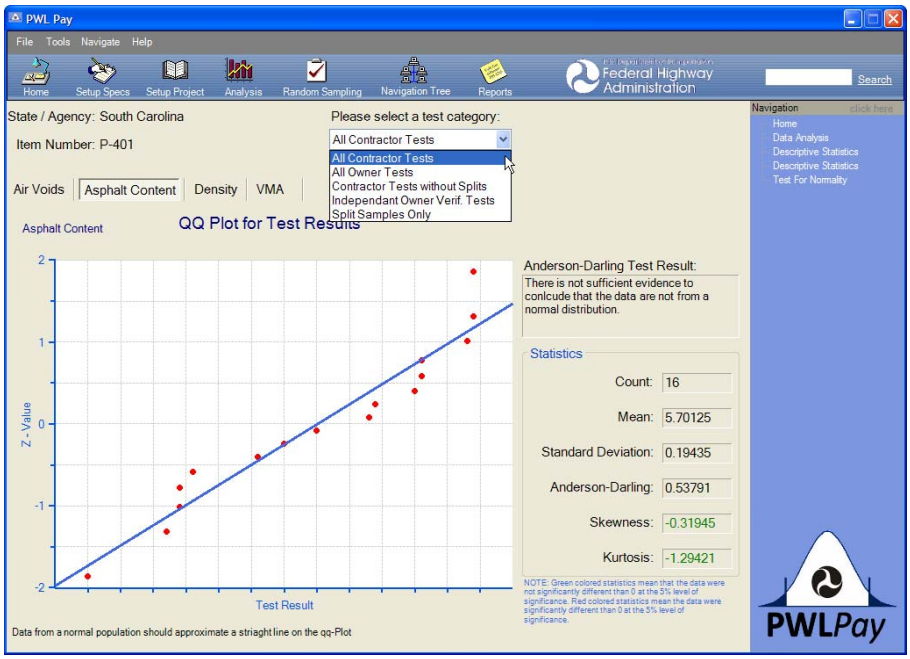


Figure 6.12

qq-Plot

Below the general information there is a row of tabs, one for each characteristic. The **Asphalt Content** test results are displayed in the qq-plot in **Figure 6.12**. The user must subjectively decide whether or not the data approximate the straight line shown. If the answer is no, then the assumption of normality is rejected.

Anderson-Darling Test

The descriptive statistics and the results of the A-D test are shown to the right of the qq-plot. The **Count:**, **Mean:**, and **Standard Deviation:** values are obvious. The test statistic from the A-D test is shown in the **Anderson-Darling:** box. This is for information only, and is unlikely to be of direct use to the user. The conclusion to be drawn from the A-D test is shown in the **Anderson-Darling Test Result:** box. No significant difference from a normal distribution is reported as shown in **Figure 6.13a**, while a significant difference from a normal distribution is reported as shown in **Figure 6.13b**.

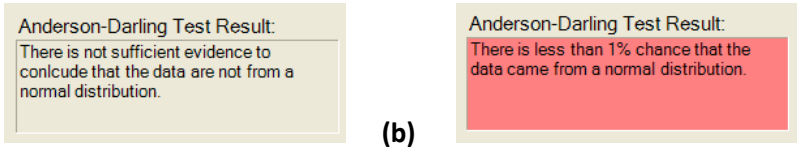


Figure 6.13 **(a)** **(b)**

Skewness & Kurtosis

The **Skewness:** and **Kurtosis:** boxes are obvious. As in the **Descriptive Statistics** window in **Figure 6.8**, the skewness and kurtosis coefficients are checked at the selected significance level to see if they are different than those expected for a normal distribution. No difference is depicted by normal green print, while a difference is depicted by **bold red print**.

Process Control

After selecting **Process Control** from the choices in shown **Figure 6.3**, the user must then select the types of process control charts to be developed as well as how the control limits are to be established. **Figure 6.14a** shows the types of charts that can be prepared and displayed as **Output** by **PWL***Pay*. If one of the four control chart output options is selected, then the user must also select the method to be used to establish the **Control Limits** for the control charts. The two options are shown in **Figure 6.14b**.

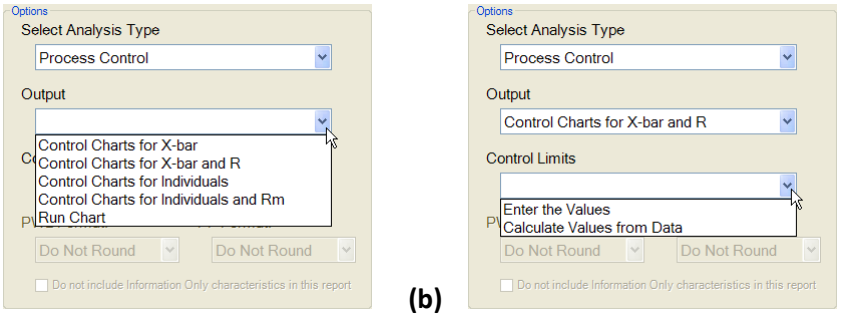
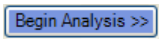


Figure 6.14 **(a)** **(b)**

Run Charts



If **Run Chart** is selected as the **Output**, the user then selects the **Begin Analysis >>** button to display the run charts for the selected characteristic(s). The **Run Chart** screen is shown in **Figure 6.15**. A run chart is a chronological plot of the individual test results along with the specification limits for the characteristic being plotted.

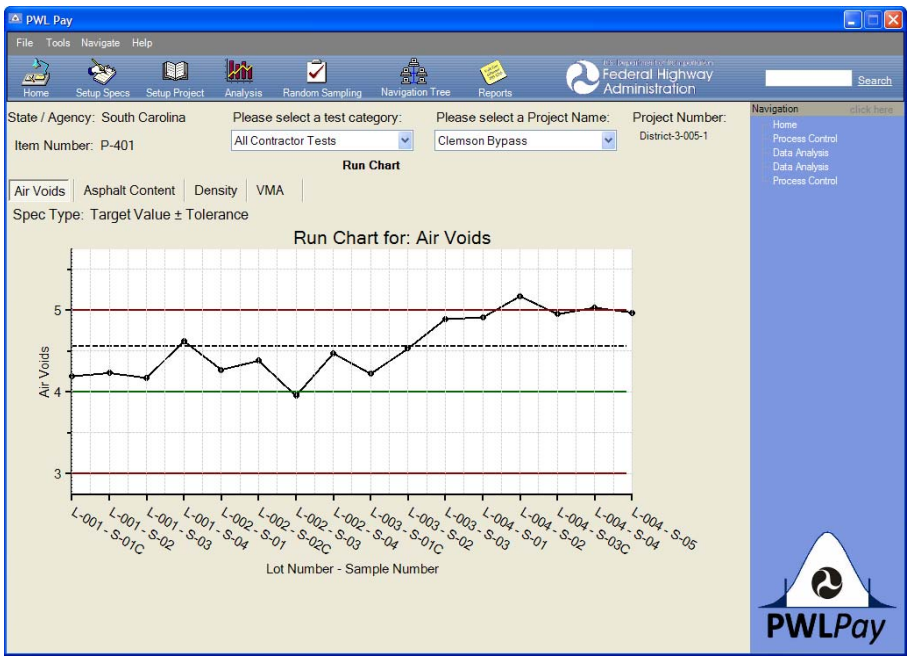


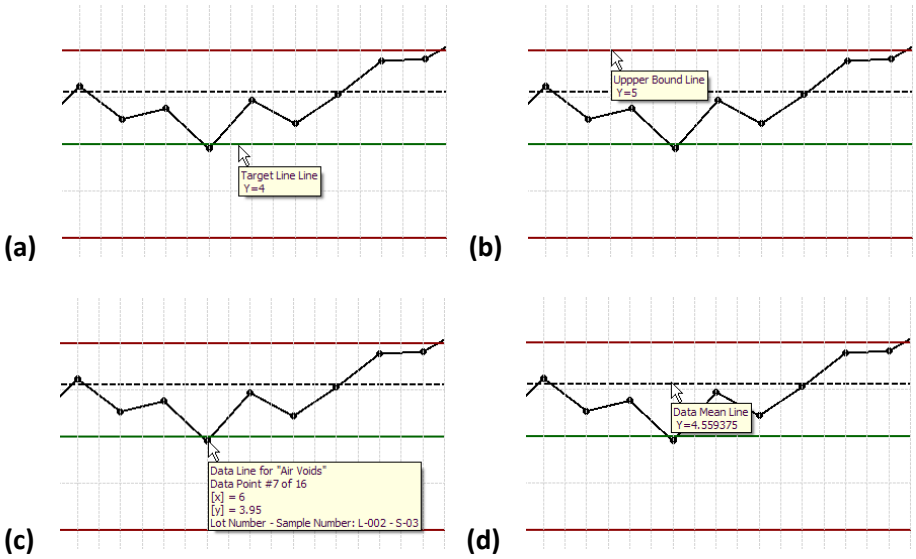
Figure 6.15

At the top of the window is general information on the **State / Agency:**, the **Item Number:**, and the **Project Number:**. There is also a drop down menu to select which tests to analyze. Another drop down menu allows the projcect to be selected. This choice will need to be made only if there is more than one project selected in the Analysis window.

Below the general information there is a row of tabs, one for each characteristic. The **Air Voids** test results are plotted in the run chart in **Figure 6.15**. Below the tabs is a description of the type of specification that applies for the selected characteristic. **PWL***Pay* determines the target value, upper specification limit, and lower specification limit based on the item number and project that are selected.

The run chart plots the individual test results, which are identified on the horizontal axis by their lot number-sample number combination. The dashed line represents the mean of the test results.

The user can hover the mouse pointer over any of the lines or any of the data points to open a bubble with appropriate detailed information. Examples of these information bubbles are shown in **Figures 6.16a – 6.16d**, which represent portions of the run chart in **Figure 6.15**.

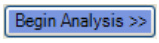


(a) (b) (c) (d)

Figure 6.16

Figures 6.16a and **6.16b** show that the target value is **4** and the upper limit is **5**, respectively. **Figure 6.16c** shows that the data point is for **Air Voids** and that it is **#7 of 16** points that are plotted. The **x** and **y** coordinates for the point are **x = 6** (the plotting routine begins with 0, so the **x** value is one less than the data point number) and **y = 3.95** (which is the air voids test result). The test result is for **Sample Number S-03** within **Lot Number L-002**. Finally, **Figure 16.6d** shows that the mean for all of the plotted test results is **4.56**.

Control Charts



If one of the **Control Chart** outputs is selected (see **Figure 6.14a**) and **Calculate Values from Data** is selected for establishing control limits, then the user selects the **Begin Analysis >>** button to display the selected control chart(s). **PWL***Pay* then calculates the target and standard deviation values for all of the the selected test results (**All Contractor Tests** in **Figure 6.15**) and uses these, along with the type of control chart selected, to determine the control limits.

Control Limits Based on the Data

The **Control Chart** window, based on selecting **Control Charts for X-Bar and R** and selecting **Calculate Values from Data** to determine the control limits, is shown in **Figure 6.17**. The general information at the top of the window is the same as for the **Run Chart** window. However, now there are two tabs for each characteristic—one for the **X-bar** chart and one for the **R** chart. The user can click on to scroll left or right to access all of the tabs.

There are not as many points on the control chart since only one point is plotted for each lot, as opposed to one point for each test for a run chart or for a control chart for individuals. Similar to the **Run Chart** examples in **Figures 6.16a – 6.16d**, more detailed information can be obtained by hovering the mouse pointer over one of the lines or data points.

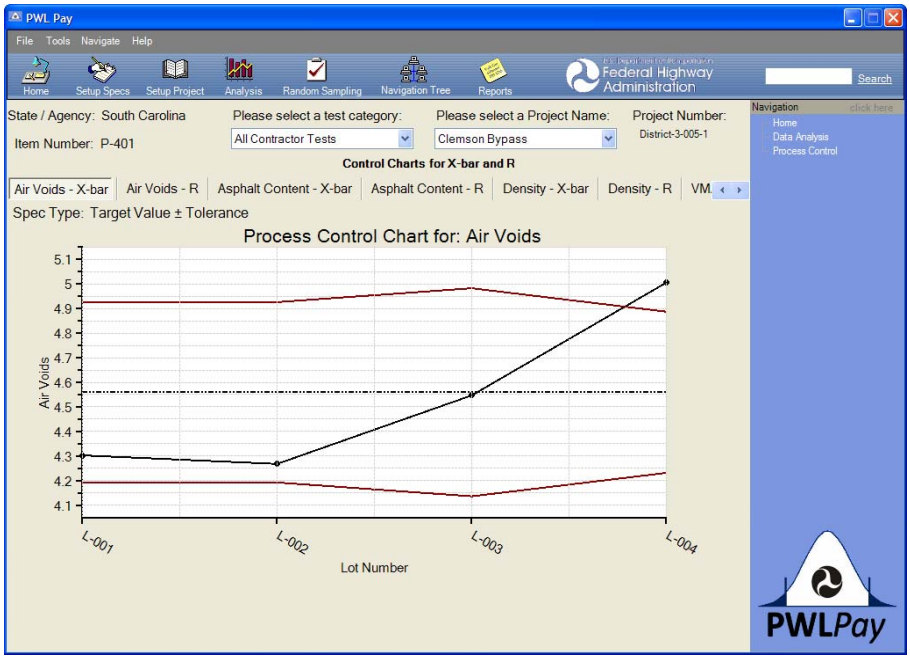


Figure 6.17

One difference between a run chart and a control chart is that the run chart compares the data points to the specification limits, whereas for a control chart the limits are established based on the mean and variability of the process, i.e., the population of avaiable test results. Note in **Figure 6.17** that the control limits are not necessarily horizontal lines. Control limits depend upon the sample size for which the mean is determined. If the sample size is constant, the control limits will be constant horizontal lines. However, if the sample size varies between lots, the control limits will expand for smaller sample sizes and shrink for larger sample sizes.

If individual tests, rather than lot means and ranges, are plotted, then the moving range, **Rm**, is used to control variability. In this case, the first point on the moving range chart will lag by one the first point on the control chart for individuals. **Figure 6.18** shows a sample control chart for individuals. While this chart may appear similar to the run chart in **Figure 6.15**, the control limits in **Figure 6.18** are determined from the process capability and differ considerably from the specification limits plotted in **Figure 6.15**.

Control Limits Entered by User

The user can choose to enter the target values and control limits rather than to have **PWL*Pay*** calculate the limits from the input data. This might be done if the user had a continuous and stable process for which the limits had been established from a large amount of historical data. Since these entered control limits will be constant, this implies that the sample sizes will be the same for all or nearly all lots.

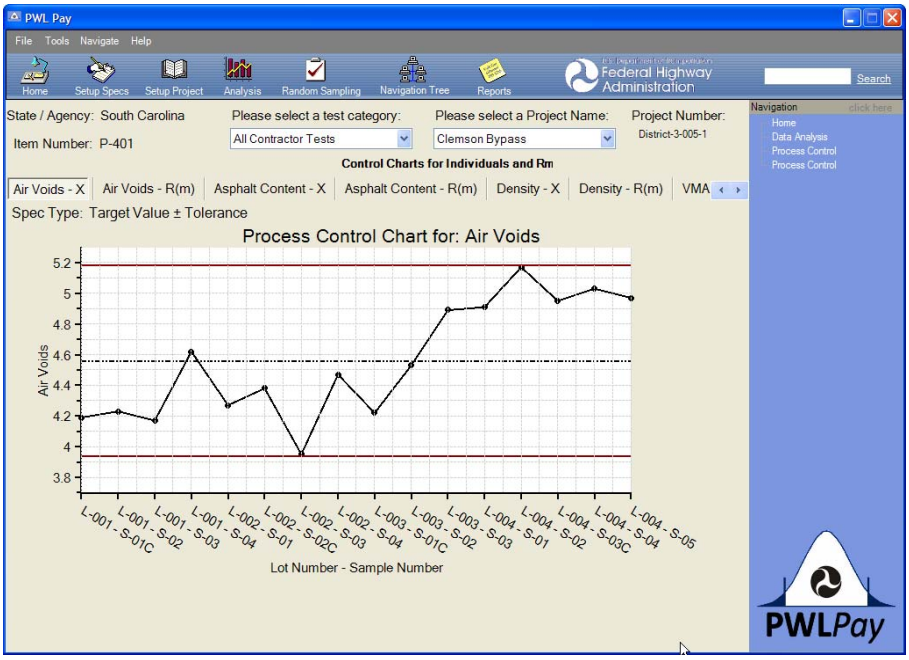
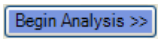


Figure 6.18

Figure 6.19 shows the selections that would be made to plot control charts for individuals and for moving ranges when the target values and control limits will be input by the user. At this point the user selects **Begin Analysis >>** to open the window shown in **Figure 6.20**, which then results in the moving range chart shown in **Figure 6.21**.



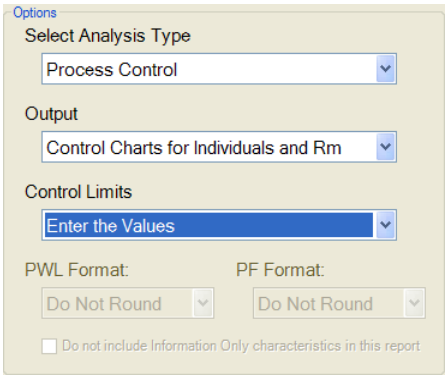


Figure 6.19

Reference

A thorough description of control chart analysis is provided in the ASTM publication *Presentation of Data and Control Chart Analysis, Seventh Edition, February 2002*, which is available at www.ASTM.org.

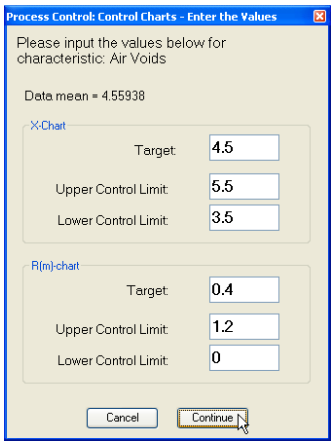


Figure 6.20

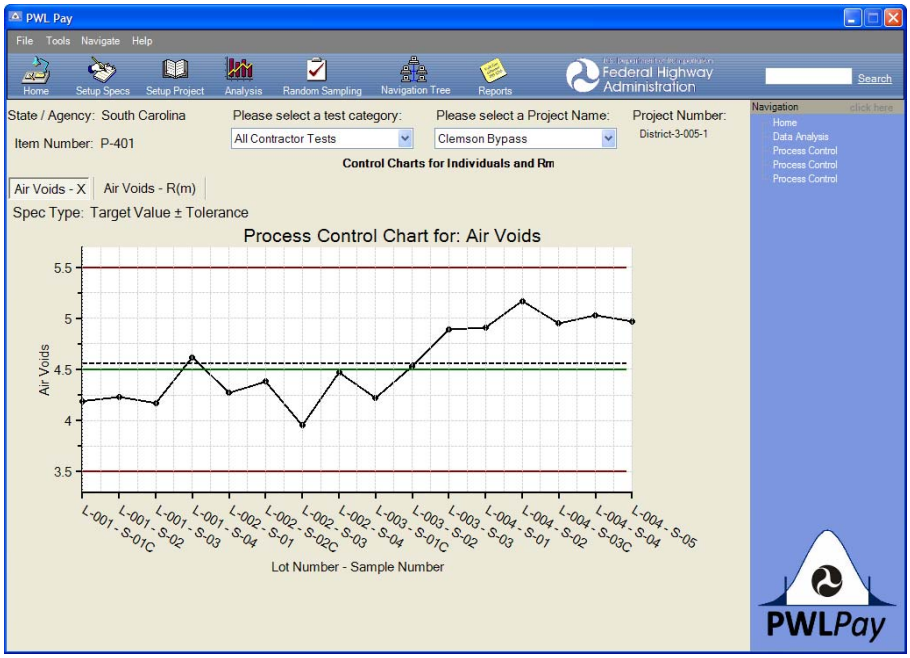


Figure 6.21

Verification Tests

Verification tests are performed to compare two sets of test results to determine whether or not it is reasonable to assume that they came from similar populations. To make this comparison it is necessary to run statistical tests to see whether or not it is reasonable to assume that both their means and variances (variance is the square of the standard deviation) are equal.

The *t*-test is used to compare the sample means of the two sets of test results, while the *F*-test is used to compare their variances. Which form of the *t*-test to use depends upon whether the data to be compared are from split samples or independent samples. If the data are from split samples, then the paired *t*-test is used. If the data are from independent samples, then the two-sample *t*-test is used. The same *F*-test is used for both split or independent samples.

Reference

Thorough descriptions and discussion of *t*-tests and *F*-tests are available from numerous statistical texts and websites. The use of these tests for highway materials and construction is presented in *Optimal Procedures for Quality Assurance Specificatons, Publication No. FHWA-RD-02-095, April 2003*.

After selecting **Verification Tests** from the choices shown in **Figure 6.3**, the user must then select the tests that are to be compared. The **Compare** drop down menu in **Figure 6.22** shows the types of comparisons that can be performed by **PWL***Pay*. The choice of which tests to use for the comparisons dictates the options from which the user selects in the **Which tests do you wish to run?** drop down menu since different tests are performed depending upon whether the data to be compared are from split samples or independent samples.

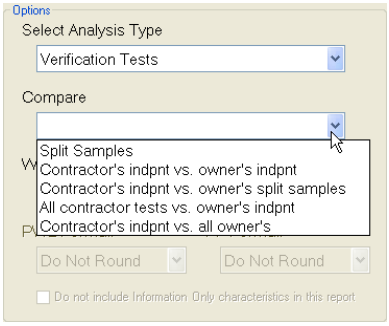


Figure 6.22

Comparing Split Samples

If **Split Samples** is selected as the **Compare** option, then the user must select from the comparison test options shown in **Figure 6.23**. With split samples where the split results make up sample pairs, the paired *t*-test is preferable to the two-sample *t*-test, and thus only the paired *t*-test is available for selection.

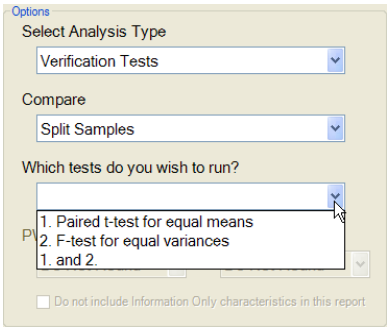
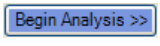


Figure 6.23



The user can choose to run only the paired *t*-test to compare sample means, only the *F*-test to compare sample variances, or both tests. The choice will obviously affect the calculations performed and the resulting output. After making this choice the user selects **Begin Analysis >>** to perform the verification tests.

Figure 6.24 shows an example of the output if the user has selected to run both the paired *t*-test and the *F*-test. The *t*-test output shows the sample means, sample standard deviations, and sample sizes along with the *P*-Value for the test statistic. The *P*-Value is the probability of getting a test statistic

greater than or equal to the one obtained if the two samples came from the same population, i.e., if the two population means were actually equal. Therefore, the smaller the *P*-Value the less likely the sample means are equal. **PWL***Pay* displays a warning message when the means are statistically significantly different at the 0.10, 0.05, or 0.01 levels. This corresponds to *P*-Values less than 0.10, 0.05, or 0.01, respectively.

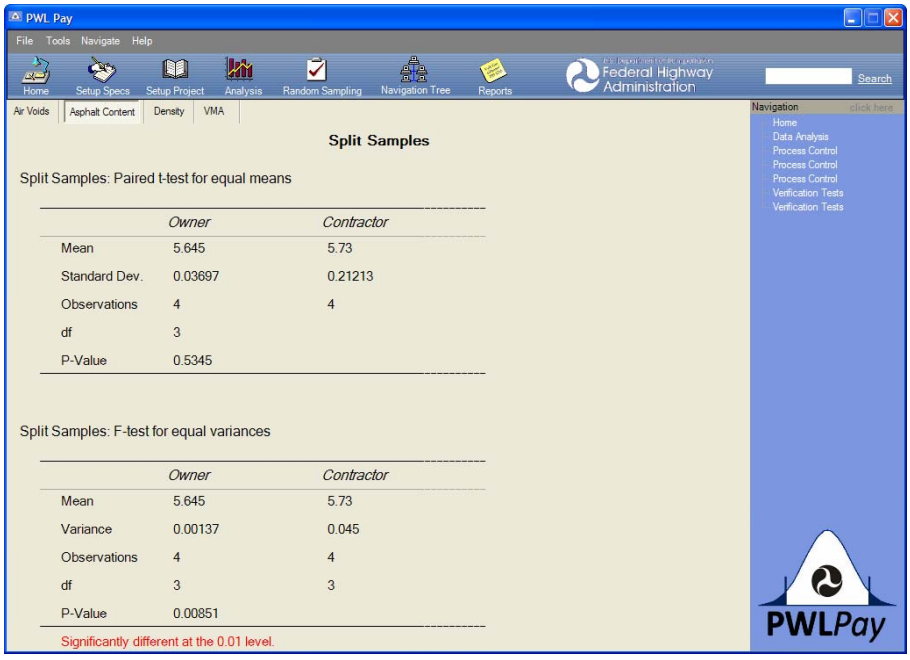


Figure 6.24

The *F*-test output (see **Figure 6.24**) shows the sample means, sample variances, and sample sizes along with the *P*-Value for the test statistic. As with the *t*-test, **PWL***Pay* shows a warning message when the *P*-Value is less than 0.10, 0.05, or 0.01. In **Figure 6.24**, the variances are shown to be Significantly different at the 0.01 level.

Comparing Independent Samples

The user has four different independent sample comparisons in the **Compare** drop down menu shown in **Figure 6.22**. These comparisons are:

Contractor's indpnt vs. owner's indpnt. This would apply in a situation where the contractor was performing acceptance testing for the project, and the owner was also obtaining and testing its own samples from different random sampling locations than those used by the contractor.

Contractor's indpnt vs. owner's split samples. This would apply in a situation where the contractor was performing acceptance testing for the project, but a portion of the samples were split and tested by both the contractor and the owner. In this case the contractor samples that were not split would be independent samples that could be compared with the owner tests on the split samples. The contractor's test results on its portion of the split samples would not be included in this comparison.

All Contractor tests vs. owner's indpnt. This would apply in the event that the contractor was performing the acceptance testing and some of the contractor's samples were split and tested by the owner. However, the owner was also obtaining and testing samples from sample locations that were independent of those used by the contractor. In this case the owner's independent samples could be compared with all of the contractor's samples, including the contractor's portion of any split samples.

Contractor's indpnt vs. all owner's. This would apply in the event that the contractor was performing the acceptance testing and some of the contractor's samples were split and tested by the owner. However, the owner was obtaining and testing samples from sample locations that were independent from those used by the contractor. In this case the contractor's independent samples could be compared with all of the owner's samples, including the owner's portion of any split samples.

If any of these independent comparison options is selected, then the user must select from the comparison test options shown in **Figure 6.25**. Since the samples to be compared are independent, the two-sample *t*-test is performed and the paired *t*-test is not an option.

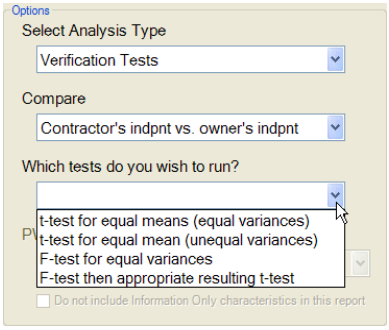
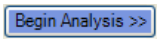


Figure 6.25

As shown in **Figure 6.25**, the user can select to run only the *t*-test. The *t*-test is conducted differently whether or not it is assumed that the sample variances are equal, which is why in **Figure 6.25** there are two choices for running the *t*-test. The user can also select to run only the *F*-test. It is most likely that the user would select the last option to run the **F-test then appropriate resulting t-test**. In this case the user enters the level of significance, alpha, at which to run the *F*-test (see **Figure 6.26**). **PWL***Pay* runs the *F*-test then, depending upon the result, runs either the *t*-test for equal variances or the *t*-test for unequal variances. After selecting one of the options shown in **Figure 25**, the user selects **Begin Analysis >>** to perform the verification tests.



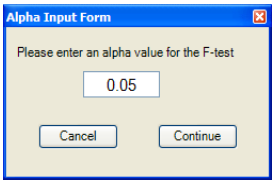


Figure 6.26

Figure 6.27 shows an example of the output if the user had selected the **F-test then appropriate resulting t-test** option for comparing the **Contractor's indpnt vs. owner's split samples** for the characteristic **Asphalt Content**. The *F*-test output shows the sample means, sample variances, and sample sizes along with the *P*-Value for the test statistic. It also shows the entered alpha value (**alpha = 0.05** in **Figure 6.26**). **PWL***Pay* shows a warning message if the variances are significantly different at the entered alpha value. In **Figure 6.27**, the variances are shown to be Significantly different at the 0.05 level.

The results of the *t*-test are shown to the right of the *F*-test results. **PWL***Pay* automatically performs the correct *t*-test based on the results of the *F*-test, and reports the *P*-value. In **Figure 6.27** the *F*-test found the variances to be unequal at the specified alpha value. So, the results are reported for the ***t-Test Assuming Unequal Variances***.

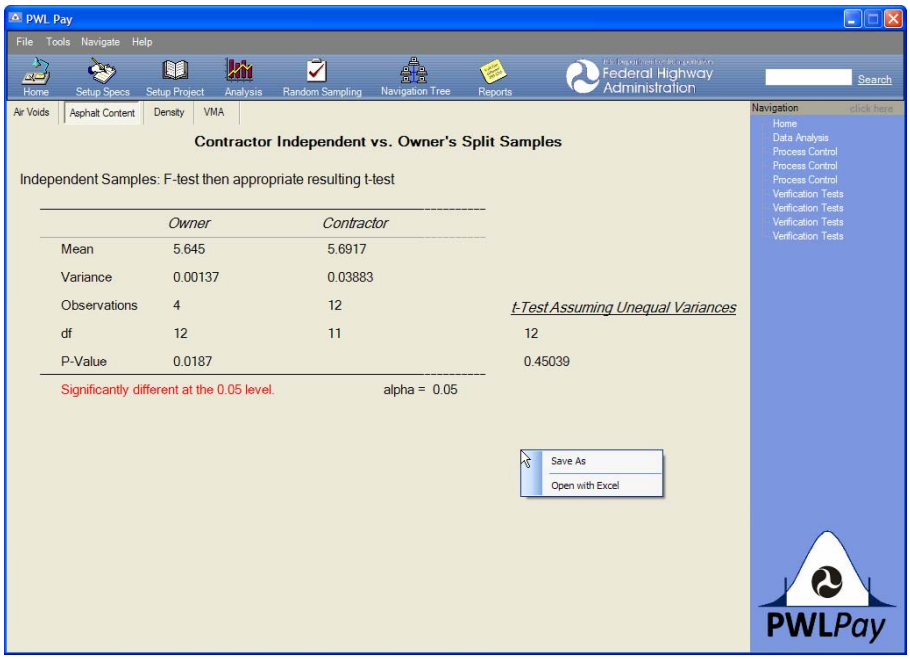


Figure 6.27

Saving Verification Test Results

Right clicking anywhere in the results area of the verification test report opens the popup menu shown in **Figure 6.27**. Selecting **Save As** saves the verification test results as a CSV file in the same format as shown on the screen. The user can also select **Open with Excel** to open the CSV file in Excel if it is available on the user's computer.

Pay Factors

The **Pay Factors** option is used to calculate and report the payment factors for both the individual characteristics and the composite lot payment factor. **PWL***Pay* uses the payment relationships that were entered in the **Setup Specs** window and the specification limits that were entered in the **Setup Project** window to determine the payment factors.

After selecting **Pay Factors** from the choices in **Figure 6.3** the **Output** drop down menu is used to select whether a detailed payment report or just a summary report should be prepared. The **Use** drop down menu then allows the selection of which tests to use to determine the payment factors. The options for which tests to use to determine payment are shown in **Figure 6.28**.

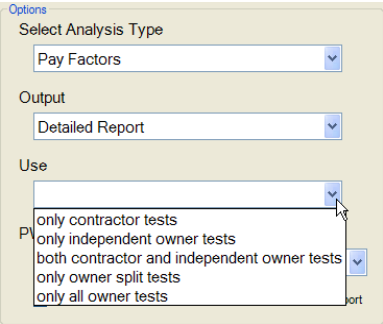


Figure 6.28

Which Tests to Use

The options for which tests to use include:

only contractor tests. This might be chosen if the contractor is performing the acceptance tests and the tests have been verified by owner tests.

only independent owner tests. This might be chosen if the owner is performing the acceptance tests.

Important Note on Combining Owner and Contractor Test Results

both contractor and independent owner tests. This might be chosen if the contractor is performing the acceptance tests and the tests have been verified by independent owner tests. It is not recommended that contractor and owner tests be combined even if both their means and variances have not been declared different in the verification testing. This is because the verification tests do not prove that the two samples are exactly equal, and it is likely that combining the two samples will lead to increased variability.

only owner split tests. This might be chosen if the contractor is performing the acceptance tests and the owner is using split samples for verification testing. If the tests do not verify, then the owner may decide to use its tests, rather than the contractor's, to calculate the payment factors.

only all owner tests. This might be selected if the contractor is performing the acceptance tests and the owner is using both split samples and independent samples for verification tests. If the tests do not verify, then the owner may decide to use all of its tests to calculate the payment factors.

Rounding Format

Since owners use different rounding rules when calculating payment factors, **PWL***Pay* requires the user to specify the rounding procedures to use before payment factor calculations can begin. Rounding can apply to either the calculated PWL values that are used in the payment factor calculations, to the payment factors that have been calculated, or to both. So, the user must

choose from the rounding methods shown in **Figure 6.29** for both the **PWL Format** and the **PF Format**.

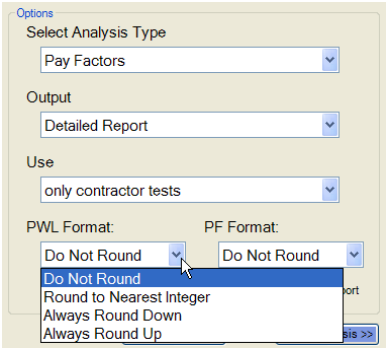


Figure 6.29

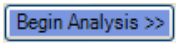
The PWL rounding format is applied to the PWL values that are input into the payment relationship to calculate the payment factors. The PF rounding format is then applied to the calculated payment factors. The rounding format options include:

Do Not Round. This is the default option. No rounding is used for the calculated values.

Round to Nearest Integer. If chosen, the PWL value is rounded to the nearest integer before it is input to the payment relationship. If chosen, the calculated payment factor is rounded to the nearest integer.

Always Round Up. If chosen, the PWL value is always rounded up to the next higher integer before it is input to the payment relationship. For example, a value of 94.02 would be rounded to 95. If chosen, the calculated payment factor is always rounded up to the next integer.

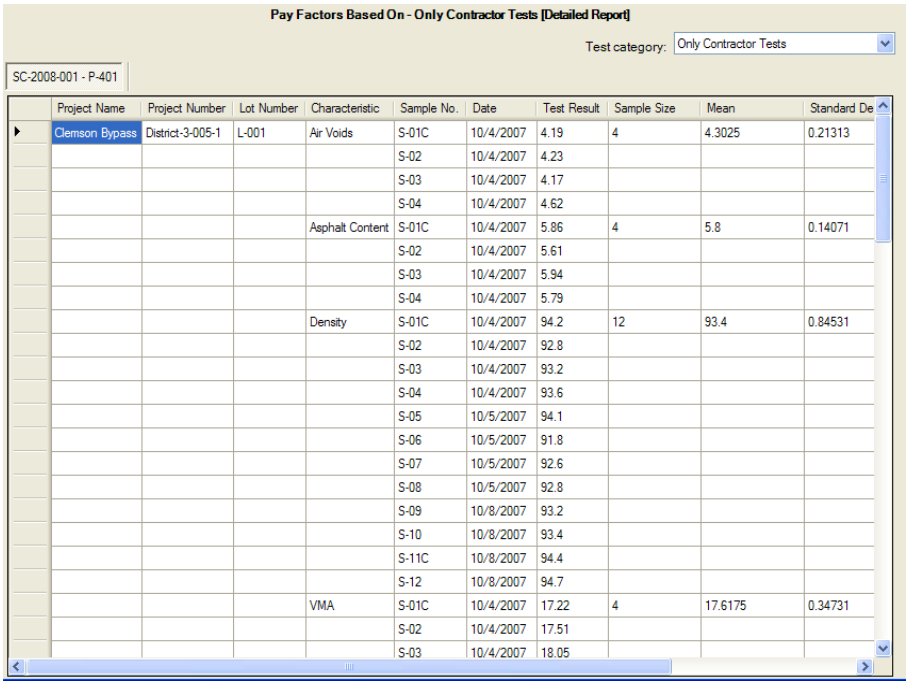
Always Round Down. If chosen, the PWL value is always rounded down to the previous lower integer before it is input to the payment relationship. For example, a value of 94.82 would be rounded to 94. If chosen, the calculated payment factor is always rounded down to the next integer.



After making this choice the user selects **Begin Analysis >>** to calculate and report the payment factors.

Detailed Report

Figure 6.30 shows an example detailed payment report. The title shows that the user had selected a **Detailed Report** and that payment factors be calculated using **Only Contractor Tests**. The report includes the **Project Name**, **Project Number**, **Lot Number**, **Characteristic**, **Sample No.**, **Date**, and the **Test Result**. The full report does not fit in the viewing window; the user must scroll the screen to the right to see the payment information.



Pay Factors Based On - Only Contractor Tests [Detailed Report]

Test category: Only Contractor Tests

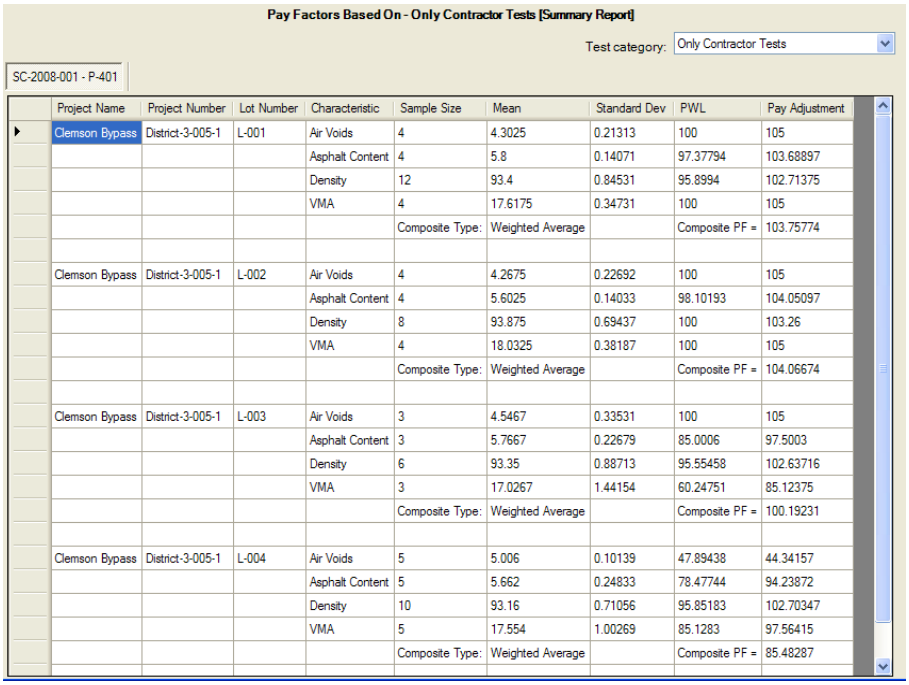
SC-2008-001 - P-401

Project Name	Project Number	Lot Number	Characteristic	Sample No.	Date	Test Result	Sample Size	Mean	Standard De
Clemson Bypass	District-3-005-1	L-001	Air Voids	S-01C	10/4/2007	4.19	4	4.3025	0.21313
				S-02	10/4/2007	4.23			
				S-03	10/4/2007	4.17			
				S-04	10/4/2007	4.62			
			Asphalt Content	S-01C	10/4/2007	5.86	4	5.8	0.14071
				S-02	10/4/2007	5.61			
				S-03	10/4/2007	5.94			
				S-04	10/4/2007	5.79			
			Density	S-01C	10/4/2007	94.2	12	93.4	0.84531
				S-02	10/4/2007	92.8			
				S-03	10/4/2007	93.2			
				S-04	10/4/2007	93.6			
				S-05	10/5/2007	94.1			
				S-06	10/5/2007	91.8			
				S-07	10/5/2007	92.6			
				S-08	10/5/2007	92.8			
				S-09	10/8/2007	93.2			
				S-10	10/8/2007	93.4			
				S-11C	10/8/2007	94.4			
				S-12	10/8/2007	94.7			
			VMA	S-01C	10/4/2007	17.22	4	17.6175	0.34731
				S-02	10/4/2007	17.51			
				S-03	10/4/2007	18.05			

Figure 6.30

Summary Report

Figure 6.31 shows an example summary payment report that would accompany the detailed report shown in **Figure 6.30**. The same columns that appear in the **Detailed Report** appear in the **Summary Report**. However, in the **Summary Report**, only sample sizes, lot means, and lot standard deviations are displayed. The individual test results do not appear in the report.



Pay Factors Based On - Only Contractor Tests [Summary Report]

Test category: Only Contractor Tests

SC-2008-001 - P-401

Project Name	Project Number	Lot Number	Characteristic	Sample Size	Mean	Standard Dev	PWL	Pay Adjustment
Clemson Bypass	District-3-005-1	L-001	Air Voids	4	4.3025	0.21313	100	105
			Asphalt Content	4	5.8	0.14071	97.37794	103.68897
			Density	12	93.4	0.84531	95.8994	102.71375
			VMA	4	17.6175	0.34731	100	105
				Composite Type:	Weighted Average		Composite PF =	103.75774
Clemson Bypass	District-3-005-1	L-002	Air Voids	4	4.2675	0.22692	100	105
			Asphalt Content	4	5.6025	0.14033	98.10193	104.05097
			Density	8	93.875	0.69437	100	103.26
			VMA	4	18.0325	0.38187	100	105
				Composite Type:	Weighted Average		Composite PF =	104.06674
Clemson Bypass	District-3-005-1	L-003	Air Voids	3	4.5467	0.33531	100	105
			Asphalt Content	3	5.7667	0.22679	85.0006	97.5003
			Density	6	93.35	0.88713	95.55458	102.63716
			VMA	3	17.0267	1.44154	60.24751	85.12375
				Composite Type:	Weighted Average		Composite PF =	100.19231
Clemson Bypass	District-3-005-1	L-004	Air Voids	5	5.006	0.10139	47.89438	44.34157
			Asphalt Content	5	5.662	0.24833	78.47744	94.23872
			Density	10	93.16	0.71056	95.85183	102.70347
			VMA	5	17.554	1.00269	85.1283	97.56415
				Composite Type:	Weighted Average		Composite PF =	85.48287

Figure 6.31

Saving the Pay Factors Report

Right clicking anywhere in the spreadsheet area of either payment report opens the popup menu shown in **Figure 6.32**. The user can choose to open the report with Excel, if it is available on the user's computer, or to save the payment report as a CSV file. The user has three options regarding saving the CSV file. Two of the options relate to the format in which the data are stored in the CSV file. The third option brings up the message in **Figure 6.33**, which explains the two different formats.

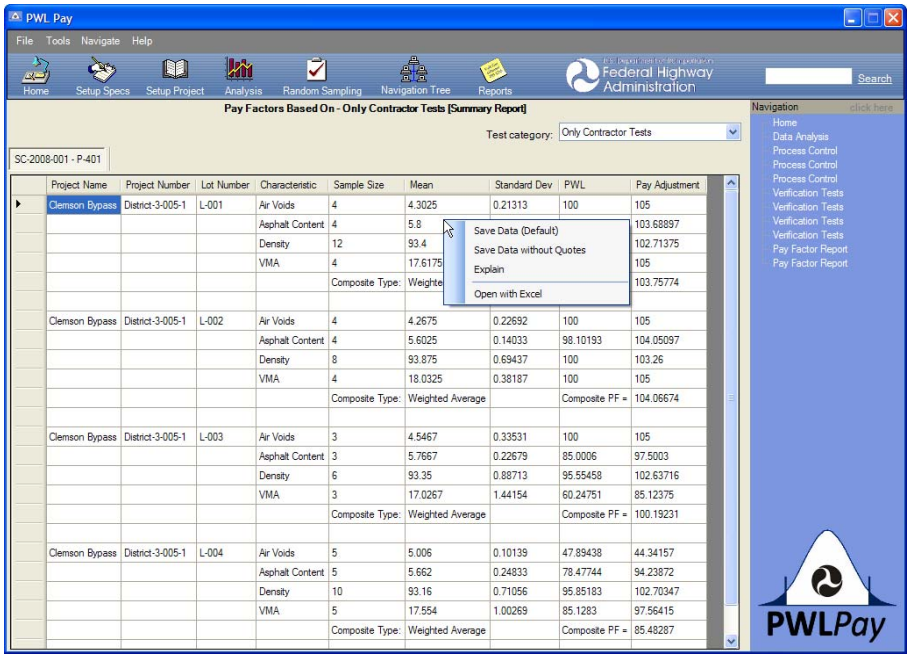


Figure 6.32

Figure 6.33

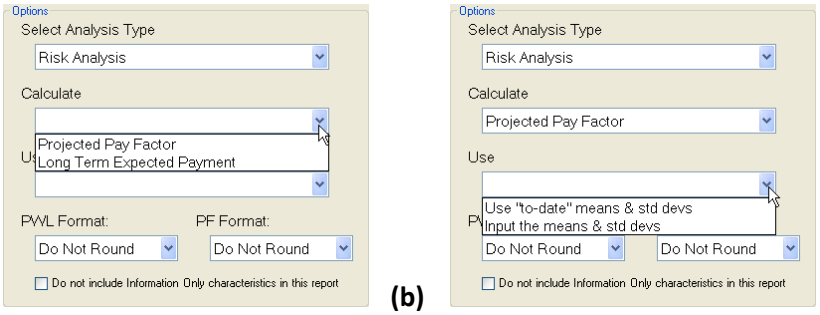
As discussed in Chapter 5, always including a letter in lot and sample numbers will avoid the potential formatting problems that are explained in **Figure 6.33**.

Risk Analysis

Risk Analysis allows the user to ask and answer "what-if" questions about the potential effects of either making or not making changes in their production processes. After selecting **Risk Analysis** from the choices in **Figure 6.3**, the user must then select one of the two options from the **Calculate** drop down menu shown in **Figure 6.34a**. Next, the user selects whether to **Use** "to-date"

means and standard deviations from existing test results, or to enter directly the means and standard deviations to use in the analysis (see **Figure 6.34b**). The "to-date" values would be used if the user wishes to know what will happen if the process remains in its current state. The user would choose to enter new values if a process change is being considered.

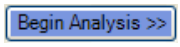
Figure 6.34



Projected Pay Factor

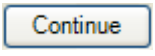
The **Projected Pay Factor** in **Figure 6.34** is the payment that the contractor would be expected to receive for the project if it achieved the means and standard deviations used in the analysis. This value is particularly important in cases where the entire project is the payment lot, and the contractor wishes to project what its likely payment will be for the total project.

While likely less important in cases where the payment lot is a day's production, **Projected Pay Factor** can still be used to determine likely individual lot pay factors for selected process means and standard deviations. For example, if a contractor has received reduced payments for lots early in a project, this analysis could be used to investigate what changes in means and/or standard deviations would be necessary to receive full payment or an incentive payment for future lots.



After selecting the option from the **Use** drop down menu shown in **Figure 6.34b**, the user selects **Begin Analysis >>** to calculate and report the projected payment factors. What happens next depends upon which selection was made in the **Use** menu.

Use "to-date" means & std devs. If the user selected to use means and standard deviations calculated from the current test data, the window in **Figure 6.35** is displayed. The user then enters the projected sample size for each characteristic shown. This will usually be the sample size that is anticipated at the end of the project. After entering the desired sample sizes, the user selects **Continue** to generate the **Projected Pay Factors** report shown in **Figure 6.36**.



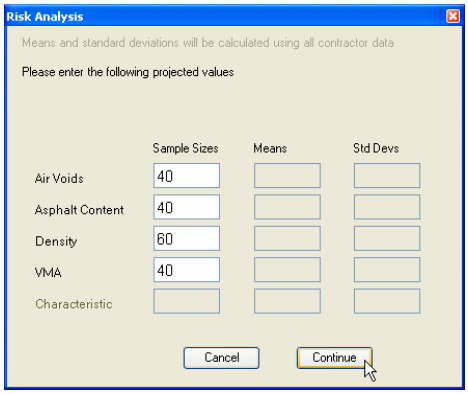


Figure 6.35

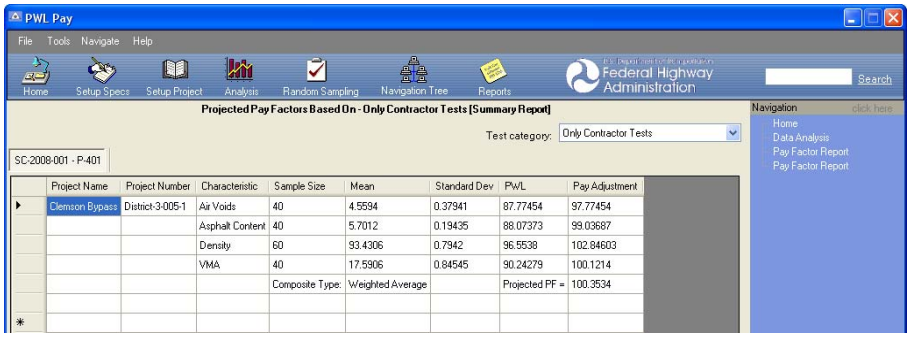


Figure 6.36

As shown in **Figure 6.36**, the **Projected Pay Factors** report shows the contract number, **SC-2008-001**, and item number, **P-401**, at the top left just above the spreadsheet section. Additional project information as well as the projected PWL and payment values is presented in the spreadsheet section. For example, in **Figure 6.36**, for **Air Voids** the mean and standard deviation calculated from the "to-date" data are 4.5594 and 0.37941, respectively.

This information, along with the projected sample size of 40, results in a projected **Air Voids** PWL of 87.77454 with a resulting projected pay factor of **97.77454**. The composite pay factor, based on the Weighted Average approach, for the lot is projected to be 100.3534. As with other screens in **PWL***Pay*, right clicking in the spreadsheet window shown in **Figure 6.36** allows the user to save the report in CSV file format or open it with Excel.

The **Test category** drop down menu shown in the upper right corner of **Figure 6.36** allows the user to select which tests should be used to determine the "to-date" values for mean and standard deviation. In **Figure 6.36**, **Only Contractor Tests** is selected. **Figure 6.37** shows the test categories from which the user may choose.

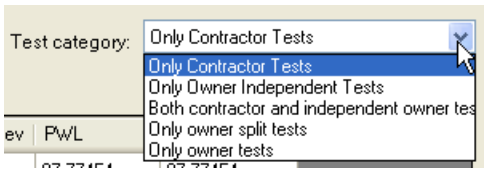
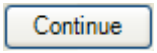


Figure 6.37



Input the means & std devs. If the user selects to input hypothetical means and standard deviations, the window in **Figure 6.38** is displayed. The user then enters the projected sample size, mean, and standard deviation for each characteristic shown. After entering the values, the user selects **Continue** to generate the **Projected Pay Factors** report shown in **Figure 6.39**.

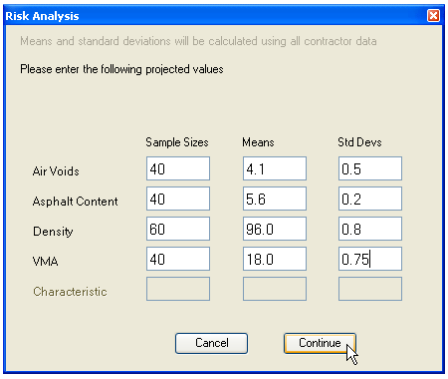


Figure 6.38

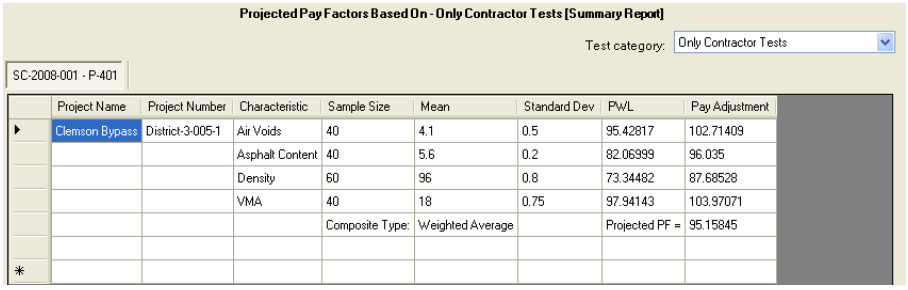
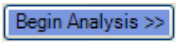


Figure 6.39

Long Term Expected Payment

The **Long Term Expected Payment** shown in **Figure 6.34a** is the payment that the contractor would be expected to receive on the average for a very large number of lots with the stated means and standard deviations for each characteristic. In other words, it is the "average payment in the long run." This gives the contractor an idea of the payment it can expect to receive if it maintains production at the current, or at a hypothetical, process capability. This can help the contractor decide how best to set the target values and how much process control is needed for each characteristic that will be measured for payment.



After selecting the **Long Term Expected Payment** option shown in **Figure 6.34a**, the user selects **Begin Analysis >>** to open the window shown in **Figure 6.40**. The user enters the sample size, mean, and standard deviation for each characteristic shown.

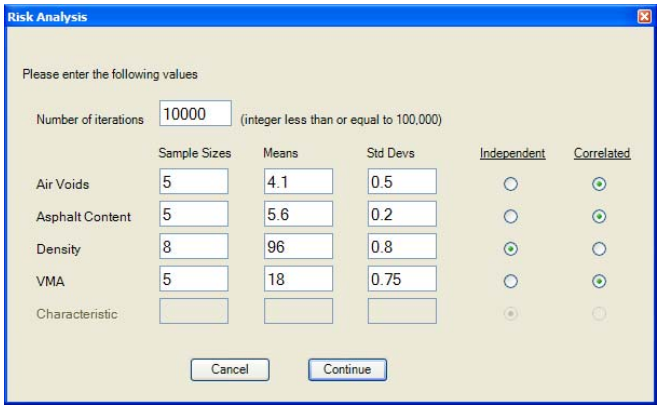


Figure 6.40

Note in **Figure 6.40** that the characteristics can be checked as either **Independent** or **Correlated**. As discussed above in this chapter, to be able to calculate a correlation coefficient between two variables there must be a paired correspondence between the sample values. That is, for the case of comparing the results of different characteristics, the test results must be obtained from the same sample.

Since this is the case, all correlated characteristics checked in **Figure 6.40** must have the same sample size. **PWL***Pay* checks to see if this is true, and if not, issues the warning shown in **Figure 6.41**. Independent characteristics can have different samples sizes per lot.

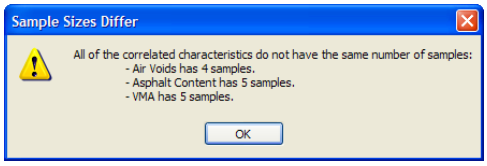
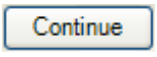


Figure 6.41



Since the **Long Term Expected Payment** analysis uses computer simulation to determine the expected payment, the user also must enter the **Number of iterations** (i.e., the number of lots to be simulated) as an integer less than or equal to 100,000. Selecting **Continue** begins the simulation process and, if any correlated characteristics are involved, pops up the screen shown in **Figure 6.42** where the user enters the correlation coefficients for the correlated characteristics.

PWL*Pay* checks the entered coefficients and if they are not consistent with one another issues the warning shown in **Figure 6.43**.

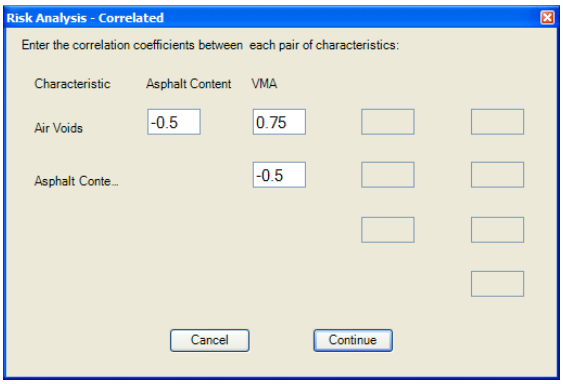


Figure 6.42

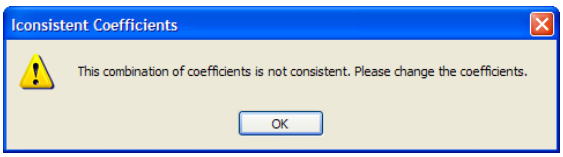


Figure 6.43

Figure 6.44 shows the results screen that is displayed when the simulation analysis from **Figures 6.40** and **6.42** is completed. General information to identify the simulation is shown at the top of the display window.

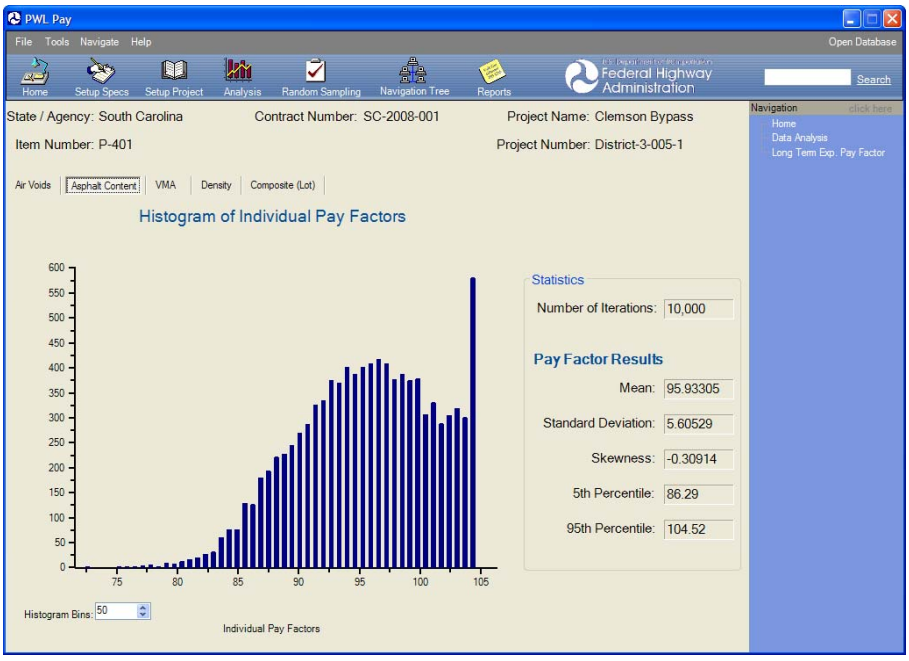


Figure 6.44

The user can select one of the tabs to display the histogram of the distribution of the pay factors for the number of simulated lots (10,000 in **Figure 6.44**) for each characteristic (**Asphalt Content** is selected in **Figure 6.44**) or for the **Composite** (**Lot**) pay factor. The **Histogram Bins:** section in the lower left corner allows the user to select the number of bars (i.e., bins) to use when plotting the histogram. The default value is 100, but a value of *50* has been entered in **Figure 6.44**.

The **Statistics** section displays a number of descriptive statistics for the selected tab. The **Number of Iterations:**, **Mean:**, **Standard Deviation:**, and **Skewness:** values are obvious. The **5th Percentile:** shows the pay factor value for which 5% of the simulated pay factors were less than or equal. The **95th Percentile:** shows the pay factor value for which 95% of the simulated pay factors were less than or equal.

Figure 6.45 displays the simulation results for the **Composite (Lot)** pay factor for the same simulation shown in **Figure 6.44**. The **Mean:** value indicates that the contractor can expect a long term average pay factor of **93.73** percent if its process has the values shown in **Figures 6.40** and **6.42**.

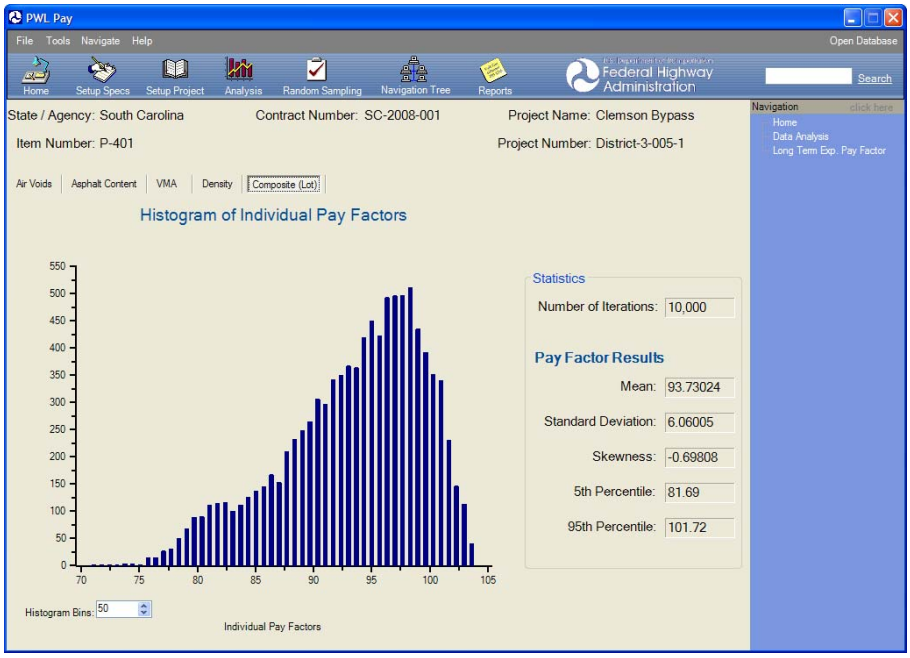


Figure 6.45

Important Note on Computer Simulation Results

Due to the random nature of the computer simulation process that is used in the **Long Term Expected Payment** analysis, the results of each analysis will vary slightly for identical input values. This is the case whenever computer simulation is used.

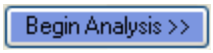
Reference

Thorough descriptions and discussion of computer simulation for risk analysis are well beyond the scope of this user's manual. Discussion of the evaluation of risks for highway materials and construction is presented in detail in *Optimal Procedures for Quality Assurance Specificatons, Publication No. FHWA-RD-02-095, April 2003*.

Saving an Analysis

When working on a project, as new test results become available it is likely that the user will perform the same analyses on a routine basis. To speed up these repetitive analyses, the user can save an analysis, which allows the user

to bypass many of the selection menus associated with some types of analysis.



The screen shown in **Figure 6.46** shows a **Descriptive Statistics** analysis that is ready to be initiated by selecting **Begin Analysis >>**. Before beginning the analysis the user can click on **Save this Analysis** to open the window shown in **Figure 6.47**. The user then enters an easily recognizable name that describes the analysis (Clemson Bypass - Desc Stat in **Figure 6.47**).

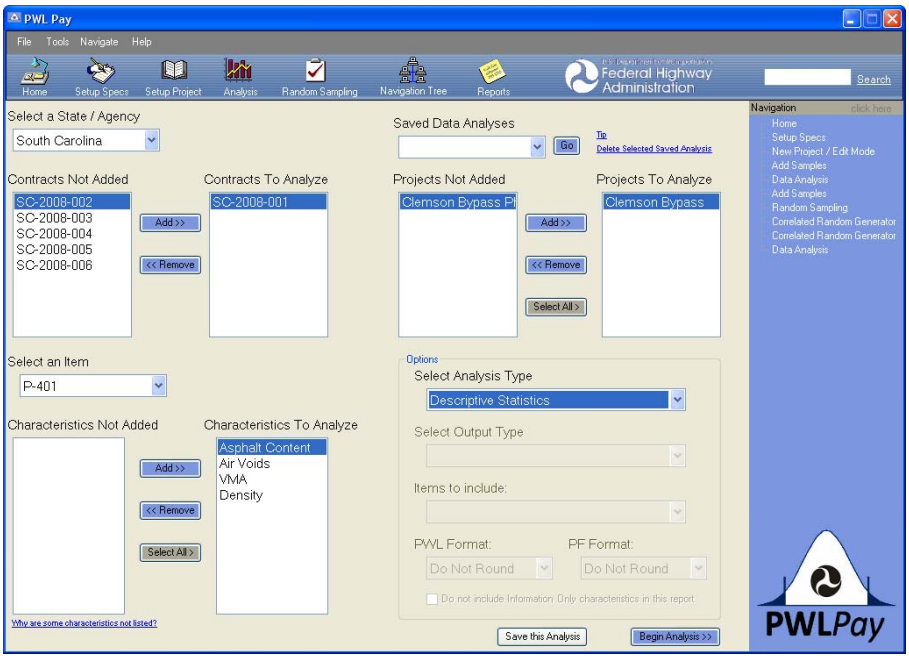


Figure 6.46

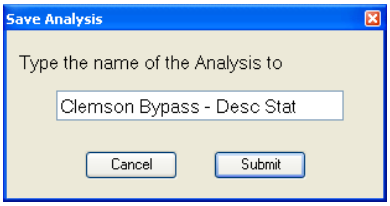


Figure 6.47

Working with Saved Analyses

Any saved analysis will be displayed in the drop down menu that appears by right-clicking on the **Analysis** icon that is at the top of each **PWL***Pay* screen (see **Figure 6.48**). The user can then select the analysis that he or she wishes to run. If Clemson Bypass - Desc Stat is selected in **Figure 6.48**, the user is taken directly to the completed analysis screen shown in **Figure 6.49**.

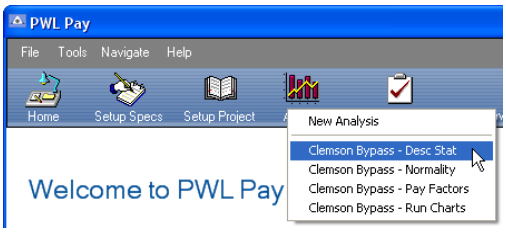


Figure 6.48

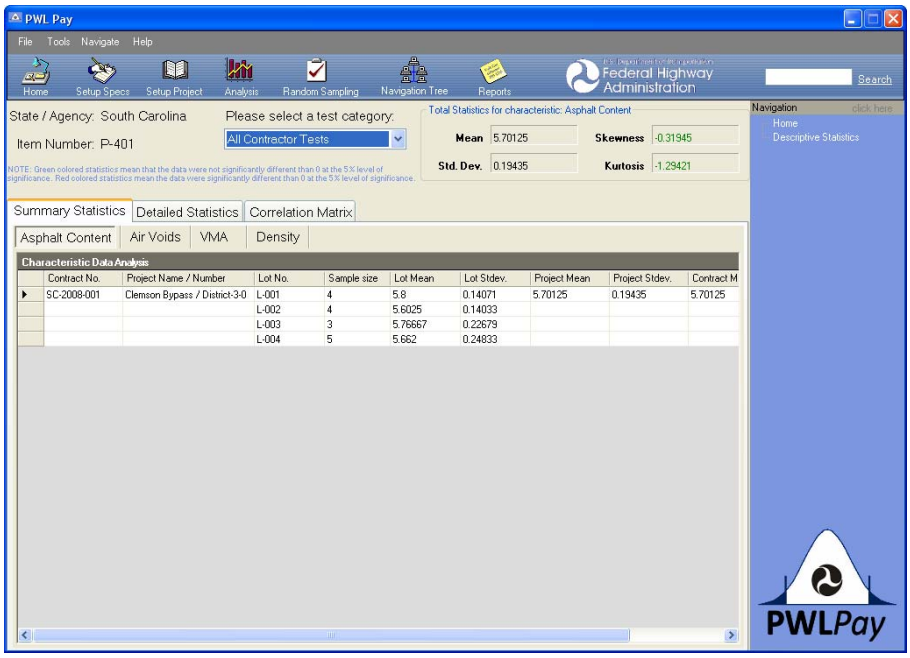


Figure 6.49

Saved analyses can also be accessed from the **Saved Data Analysis** drop down menu in the **Analysis** window (see **Figure 6.50**).

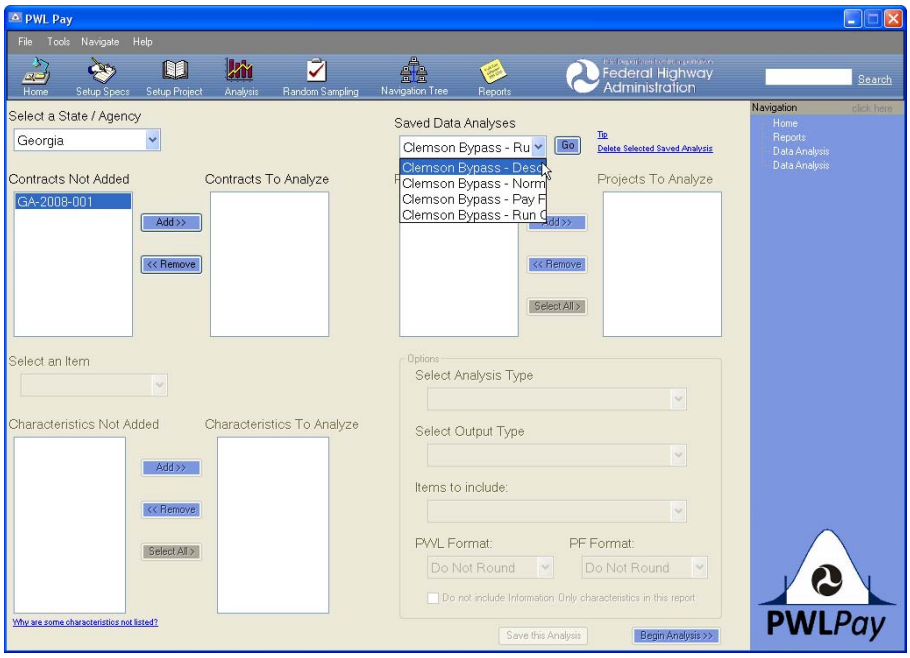


Figure 6.50

Clicking on Tip shown in **Figure 6.50** displays the window shown in **Figure 6.51**. A saved analysis is opened by selecting it from the drop down menu and clicking on **Go**.

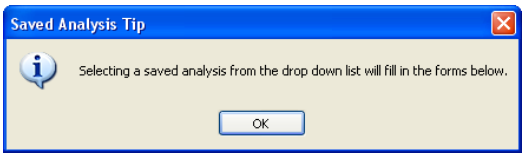


Figure 6.51

Deleting a Saved Analysis

A saved analysis can be deleting by clicking on **Delete Selected Saved Analysis** as shown in **Figure 6.50**.

7 Random Sampling

Background

In most cases locations for samples obtained for testing are selected in some random manner. This has traditionally been done by using a table of random numbers. However, since effective computer algorithms are available for developing lists of random numbers, random sampling locations can easily and quickly be obtained from the computer. The **PWL*Pay* Random Sampling** window allows the user to generate random samples based on location, quantity, or time.

The Random Sampling Window

The **Random Sampling** window allows the user to establish random locations, quantities, or times for obtaining samples. Clicking on the **Random Sampling** icon on any screen opens the **Random Sampling** window shown in **Figure 7.1**. Identifiers, including **State / Agency**, **Contract Number**, **Project Name**, **Item Number**, and, optionally, **Characteristic**, are selected from dropdown menus on the left side of the window.

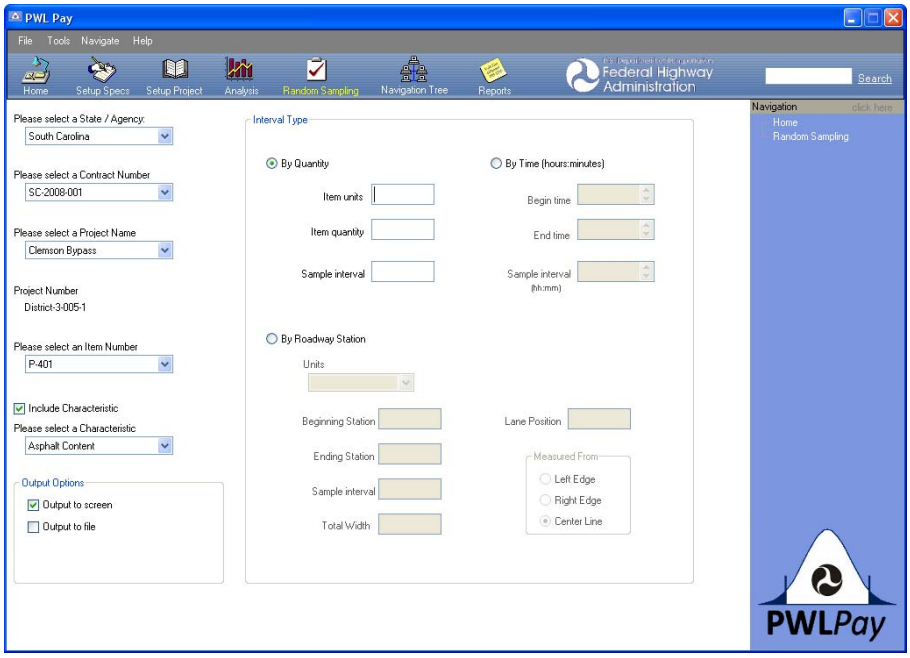


Figure 7.1

Identifying the Sample

When the state or agency has been selected from the **Please select a State / Agency:** dropdown menu, the **Please select a Contract Number:** menu is populated with all contract numbers that have previously been assigned to the state or agency selected. An example of this is shown in **Figure 7.2a**. Similarly, once the contract number is selected, the **Please select a Project Name** dropdown menu is populated with all projects associated with that

contract number. The **Project Number** is automatically displayed for the project name that was selected. An example of this is shown in **Figure 7.2b**. The **Please select an Item Number** dropdown menu is populated with all items that are associated with the selected project (see **Figure 7.2c**).

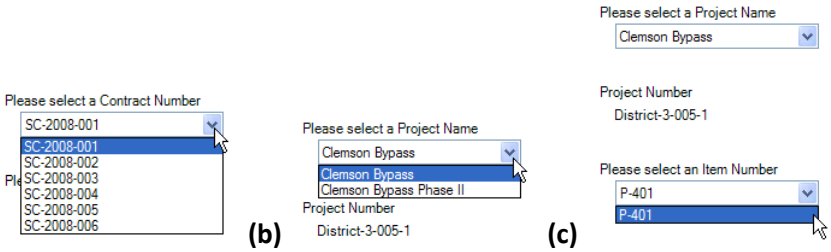


Figure 7.2 **(a)** **(b)** **(c)**

Based on the chosen item number, the user also has the option of selecting a specific characteristic from the **Please select a Characteristic** dropdown menu. If the **Include Characteristic** box is not checked, the screen appears as shown in **Figure 7.3a**. If the **Include Characteristic** box is checked, the user must select a characteristic from the **Please select a Characteristic** dropdown menu and the screen appears as shown in **Figure 7.3b**.

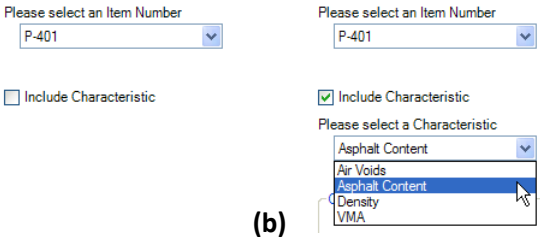


Figure 7.3 **(a)** **(b)**

Output Options

As shown in **Figures 7.4a** and **7.4b**, the user can choose to have the random numbers **Output to screen**, **Output to file**, or to both. If **Output to file** is selected, the user can then select whether or not to have the file open in Excel upon completion of the random number calculations.

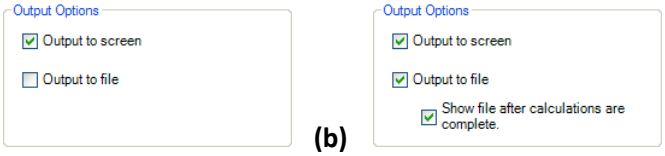


Figure 7.4 **(a)** **(b)**

Interval Type

The **Interval Type** section of the **Random Sampling** window allows the user to select the sampling format as well as the sampling interval. As shown in **Figure 7.5**, random samples can be selected **By Quantity**, **By Time (hours:minutes)**, or **By Roadway Station**.

By Quantity

If **By Quantity** is selected as the **Interval Type,** the user must enter the **Item units**, **Item quantity**, and **Sample interval**. For the example shown in **Figure 7.6**, the units for sampling are tons, the quantity to be sampled is 2500 tons, and one sample is to be randomly obtained from each 500-ton increment.

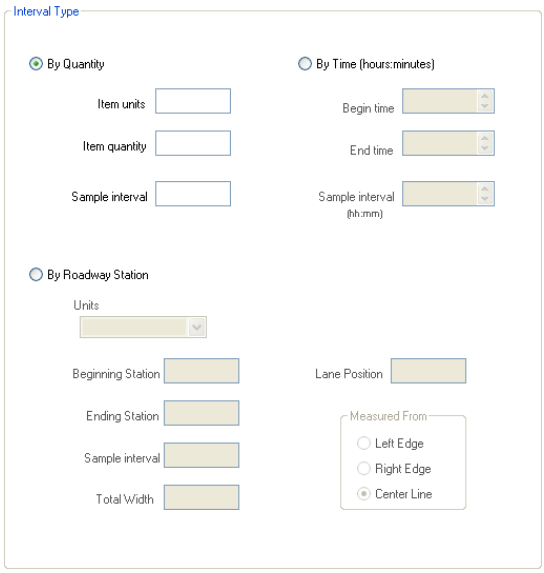


Figure 7.5

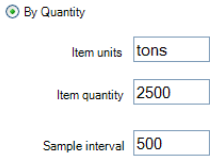
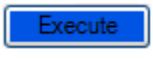
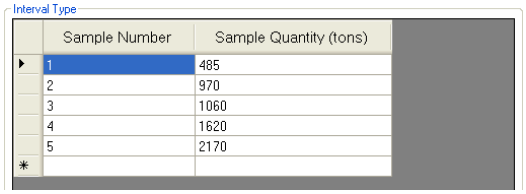


Figure 7.6



Once the unit, quantity, and interval values have been entered, the user selects the **Execute** button to obtain the random sampling locations shown in the screen output in **Figure 7.7**. If the user had also selected the option to send the output to a file, then a CSV file also would have been created. The CSV output file for the example in **Figure 7.7** is shown in **Figure 7.8**.



Sample Number	Sample Quantity (tons)
1	485
2	970
3	1060
4	1620
5	2170

Figure 7.7

	A	B
1	State/Agency: South Carolina	Item Number: P-401
2	Contract Number: SC-2008-001	Item Units: tons
3	Project Name: Clemson Bypass	Item Quantity: 2500
4	Project Number: District-3-005-1	Characteristic: Asphalt Content
5		Sample Interval: 500
6		
7	Sample Number	Sample Quantity (tons)
8	1	485
9	2	970
10	3	1060
11	4	1620
12	5	2170

Figure 7.8

Once the random numbers have been output, the **Execute** button changes to **Start Over**. Clicking on this button allows the user to start over with a new set of options.

By Time

If **By Time** is selected as the **Interval Type,** the user must enter the **Begin Time**, **End Time**, and **Sample interval (hh:mm)**. For the example shown in **Figure 7.9**, the beginning time is 7:00 AM, the ending time is 5:00 PM, and one sample is to be randomly obtained from each 2-hour time interval.

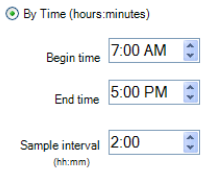
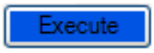


Figure 7.9



Once the beginning time, the end time, and sample interval values have been entered, the user selects the **Execute** button to obtain the random sampling times shown in the screen output in **Figure 7.10**. If the user had also selected the option to send the output to a file, then a CSV file also would have been created. The CSV output file for the example in **Figure 7.10** is shown in **Figure 7.11**.

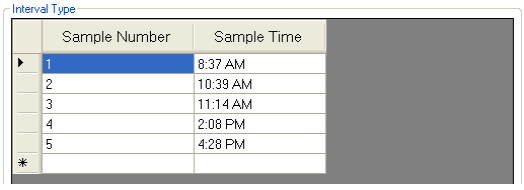


Figure 7.10

	A	B
1	State/Agency: South Carolina	Item Number: P-401
2	Contract Number: SC-2008-001	Begin Time: 7:00 AM
3	Project Name: Clemson Bypass	End Time: 5:00 PM
4	Project Number: District-3-005-1	Characteristic: Asphalt Content
5		Sample Interval: 2:00 (hh:mm)
6		
7	Sample Number	Sample Time
8	1	8:37 AM
9	2	10:39 AM
10	3	11:14 AM
11	4	2:08 PM
12	5	4:28 PM

Figure 7.11

By Roadway Station

If **By Roadway Station** is selected as the **Interval Type,** the user must first select whether the **Units** are in **hundred feet + feet** or **kilometers + meters**. Next, the **Beginning Station**, **Ending Station**, **Sample interval**, and pavement **Width** are entered. The user also has the option to make an entry for **Lane Position**. This could be used to enter information such as the lift, e.g., *surface course*, or some descriptor such as *Westbound Lane*. Finally, the user must indicate the reference for the transverse distance for locating the sample. That is, the user indicates whether the distance is measured from the **Left Edge**, the **Right Edge**, or the **Center Line** of the pavement.

For the example shown in **Figure 7.12**, the beginning station is 100+00, the ending station is 150+00, and one sample is to be randomly obtained from each 500-foot increment. The transverse distance is measured from the Right Edge of the 24 foot pavement, and for a Surface course.

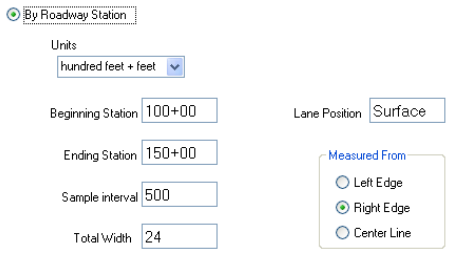


Figure 7.12

Once all of the information has been entered, the user selects the **Execute** button to obtain the random sampling locations shown in the screen output in **Figure 7.13**. If the user had also selected the option to send the output to a file, then a CSV file also would have been created. The CSV output file for the example in **Figure 7.13** is shown in **Figure 7.14**.

Interval Type

	Sample Number	Roadway Station	From Right Edge
▶	1	101 + 86	0.8
	2	107 + 13	9.1
	3	110 + 86	8.0
	4	119 + 02	11.5
	5	121 + 40	2.8
	6	127 + 15	10.9
	7	134 + 93	5.0
	8	136 + 16	6.8
	9	141 + 35	9.1
	10	145 + 36	6.7
*			

Figure 7.13

	A	B	C
1	State/Agency: South Carolina	Item Units: hundred feet + feet	
2	Contact Number: SC-2008-001	From Right EdgeProject Name: Clemson Bypass	Width: 24
3	Project Number: District-3-005-1	Lane Position: Surface	
4	Item Number: P-401	Sample Interval: 500	
5	Characteristic: Asphalt Content	Beginning Station: 100+00	
6		Ending Station: 150+00	
7			
8	Sample Number	Roadwy Station	From Right Edge
9	1	101 + 86	0.8
10	2	107 + 13	9.1
11	3	110 + 86	8
12	4	119 + 02	11.5
13	5	121 + 40	2.8
14	6	127 + 15	10.9
15	7	134 + 93	5
16	8	136 + 16	6.8
17	9	141 + 35	9.1
18	10	145 + 36	6.7

Figure 7.14

Partial Intervals

For some materials the sample intervals may not divide evenly into the total material quantity or time to be sampled. For example, if the sample interval is 500 units and the total quantity to be sampled is 2,400 units, then there will be 4 full sample intervals of 500 units, with an additional 400 units remaining for the last sample interval.

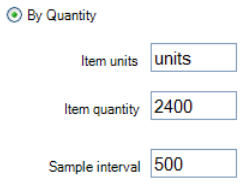
There are a number of different ways that might be used by different owners to handle the situation of uneven sample intervals. Sample intervals are often referred to as sublots. Some possibilities for handling unequal sublots include:

- treating the partial sublot as its own sample interval.
- combining the partial sublot with the last complete sublot to make a larger final sublot.
- dividing the total quantity to be sampled into a desired number of complete sample intervals. For example, if the owner wanted a sample size of 4, then the 2,400 units could be divided into four 600-unit sublots.

There are additional provisions that could be incorporated into the three options above. For example, the owner might have a policy to treat the partial sublot as a full sublot if it is over some threshold quantity, but to combine it with the last complete sublot if the partial sublot is below the threshold quantity.

PWL*Pay* does not attempt to account for all of the possible combinations of ways to deal with partial sublots. **PWL*Pay*** treats any partial sublot as a complete sublot when it generates random sampling locations. Therefore, in the above example, **PWL*Pay*** would provide 5 random sampling locations—one within each of the four 500-unit sublots, and one within the last 400-unit sublot. Examples of the input and output for this example case are shown in **Figures 7.15a** and **7.15b**, respectively.

Figure 7.15 **(a)**



(b)

	Sample Number	Sample Quantity (units)
▸	1	460
	2	835
	3	1155
	4	1740
	5	2100
*		

As shown in **Figure 7.15b**, **PWL*Pay*** has developed 5 sample quantities. The first 4 are each within one of four complete sample intervals or sublots. That is, 460 is between 0 and 500, 835 is between 500 and 1,000, 1155 is between 1,000 and 1,500, and 1740 is between 1,500 and 2,000. The final sample quantity, 2100, is within the last partial interval from 2,000-2,400.

If necessary, the user can choose to make adjustments in the random sample quantities, times, or locations. For instance, if the user desired exactly four tests in the previous example, then the sample interval could have been entered as *600 (i.e.*, 2400/4), rather than *500*. Or, if the user wished to combine the partial sublot with the last full sublot, then the sample could be taken at either 1740 or 2100 units. This approach would more likely be chosen when the partial sublot was a relatively small quantity in comparison to the full sublots. In the above example, it is more likely that the last 400-unit sublot would be treated as a separate sublot as shown in **Figure 7.15b**.

8 Navigating **PWL*Pay***

Navigation Options

There are two different methods by which the user can navigate quickly to the desired location within **PWL*Pay***. These are the **Navigation Tree** and the **Navigation** pane. The **Navigation Tree** icon appears at the top of any screen, as shown in **Figure 8.1**. The **Navigation** pane appears on the right hand edge of any screen, and is the shaded region on the right side of **Figure 8.1**.

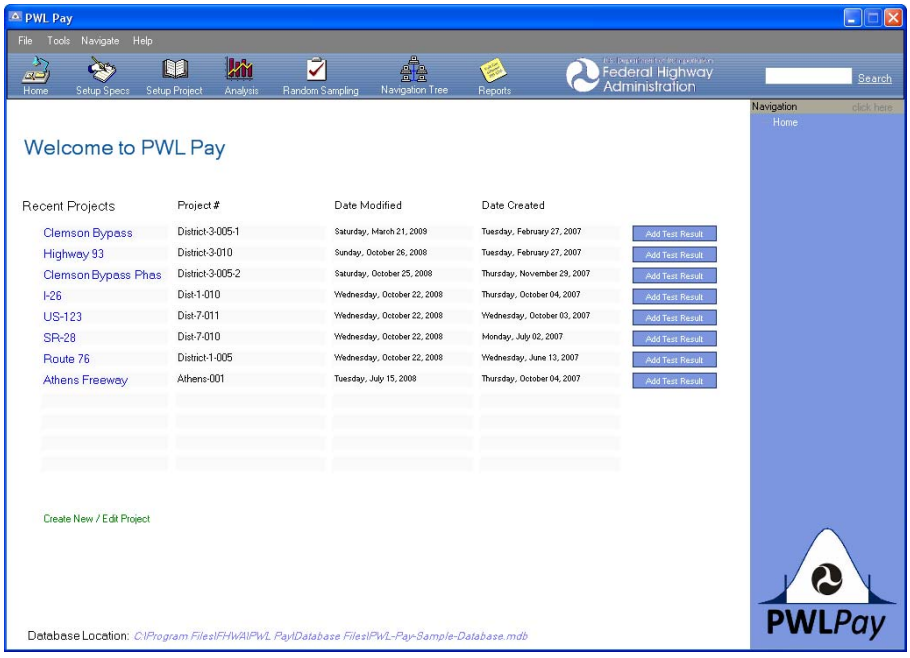


Figure 8.1

The Navigation Tree

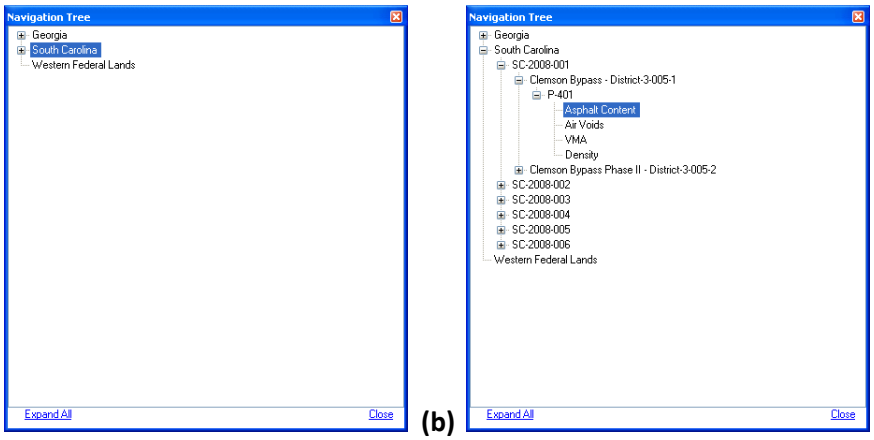
The **Navigation Tree** window allows the user direct access to most locations within **PWL*Pay***. Clicking on this icon opens the **Navigation Tree** window shown in **Figure 8.2a**.

The Display Format

The first level shows all states and/or agencies that have been entered. Clicking on ⊞ opens the next level, showing all contract numbers assigned to the selected state or agency. The user can continue expanding the tree until all item numbers have been displayed. For example, the following selections have been made to arrive at the screen shown in **Figure 8.2b**:

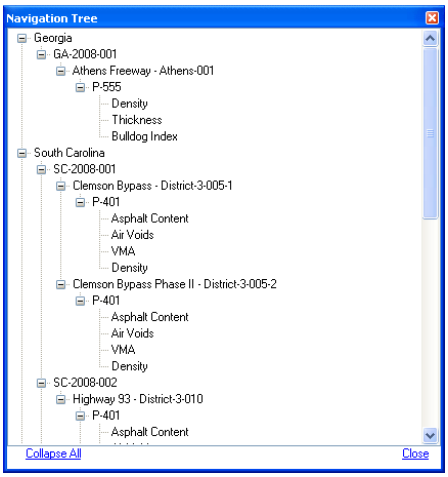
State:	**South Carolina**
Contract Number:	**SC-2008-001**
Project Name - Number:	**Clemson Bypass - Distrtict-3-005-1**
Item Number:	**P-401**
Characteristic:	**Asphalt Content.**

Figure 8.2



The user can quickly show all of the navigation tree by selecting Expand All shown at the bottom of the windows in **Figure 8.2**. This results in the window shown in **Figure 8.3**. Note that Expand All has been replaced by Collapse All as an option at the bottom of the window. Selecting Collapse All would collapse the tree to the one shown in **Figure 8.2a**. The user can also collapse any individual tree level by clicking on the corresponding ⊟ box.

Figure 8.3



Navigating

The user can double click on any level of the navigation tree to go directly to a specified location. If the user clicks on either the state/agency level or the contract number level, he or she is taken to the **Setup Project** screen. If the user clicks on any level below the contract number, he or she is taken to the **Add Samples** window for the selected project.

For example, for the tree shown in **Figure 8.3**, double clicking on a state/agency, such as **South Carolina**, or on a contract number, such as **SC-2008-001**, takes the user to the **Setup Project** screen shown in **Figure 8.4**. Double clicking at the project level, such as **Clemson Bypass - District-3-005-1**, or below, takes the user to the **Add Samples** window shown in **Figure 8.5**.

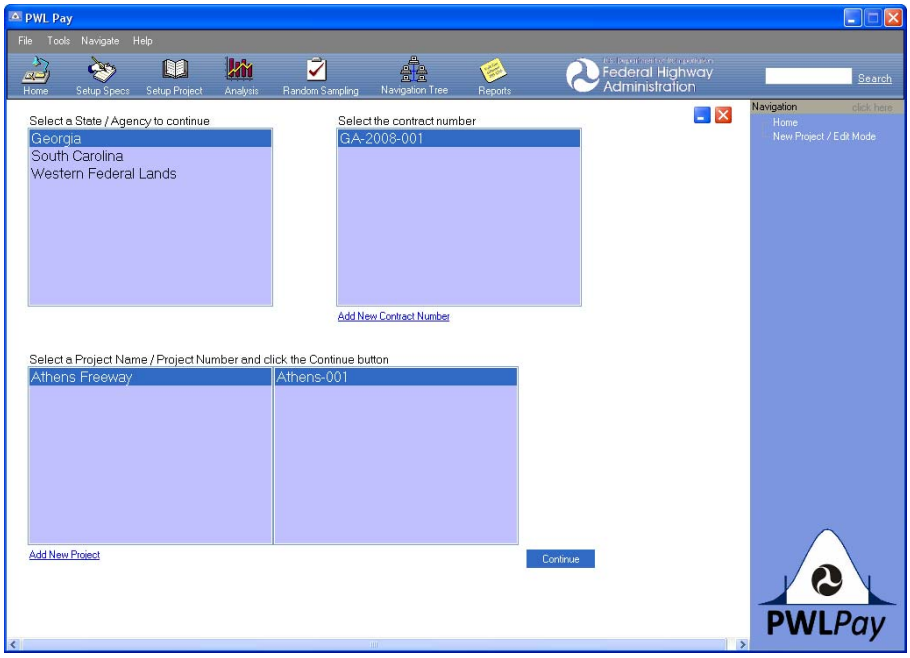
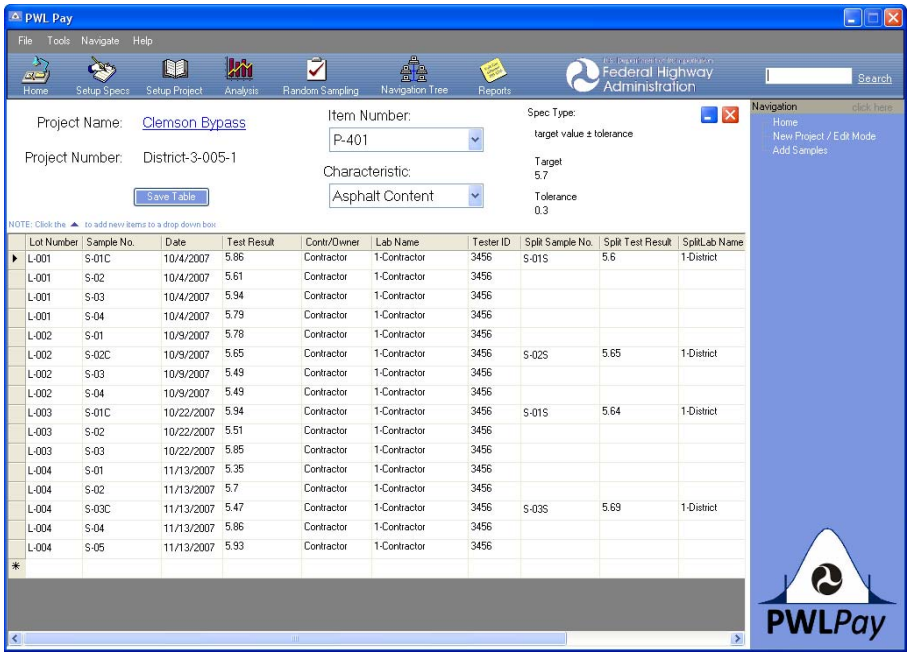


Figure 8.4



Lot Number	Sample No.	Date	Test Result	Contr/Owner	Lab Name	Tester ID	Split Sample No.	Split Test Result	SplitLab Name
L-001	S-01C	10/4/2007	5.86	Contractor	1-Contractor	3456	S-01S	5.6	1-District
L-001	S-02	10/4/2007	5.61	Contractor	1-Contractor	3456			
L-001	S-03	10/4/2007	5.94	Contractor	1-Contractor	3456			
L-001	S-04	10/4/2007	5.79	Contractor	1-Contractor	3456			
L-002	S-01	10/9/2007	5.78	Contractor	1-Contractor	3456			
L-002	S-02C	10/9/2007	5.65	Contractor	1-Contractor	3456	S-02S	5.65	1-District
L-002	S-03	10/9/2007	5.49	Contractor	1-Contractor	3456			
L-002	S-04	10/9/2007	5.49	Contractor	1-Contractor	3456			
L-003	S-01C	10/22/2007	5.94	Contractor	1-Contractor	3456	S-01S	5.64	1-District
L-003	S-02	10/22/2007	5.51	Contractor	1-Contractor	3456			
L-003	S-03	10/22/2007	5.85	Contractor	1-Contractor	3456			
L-004	S-01	11/13/2007	5.35	Contractor	1-Contractor	3456			
L-004	S-02	11/13/2007	5.7	Contractor	1-Contractor	3456			
L-004	S-03C	11/13/2007	5.47	Contractor	1-Contractor	3456	S-03S	5.69	1-District
L-004	S-04	11/13/2007	5.86	Contractor	1-Contractor	3456			
L-004	S-05	11/13/2007	5.93	Contractor	1-Contractor	3456			

Figure 8.5

The Navigation Pane

The **Navigation** pane allows the user direct return access to screens that he or she has previously visited in **PWL*Pay***. All of the visited screens appear as a list in chronological order, from top to bottom, on the shaded right edge of any **PWL*Pay*** screen. An example is shown in **Figrue 8.6**, although, since it appears on every screen, the **Navigation** pane is visible in many of the figures in this manual.

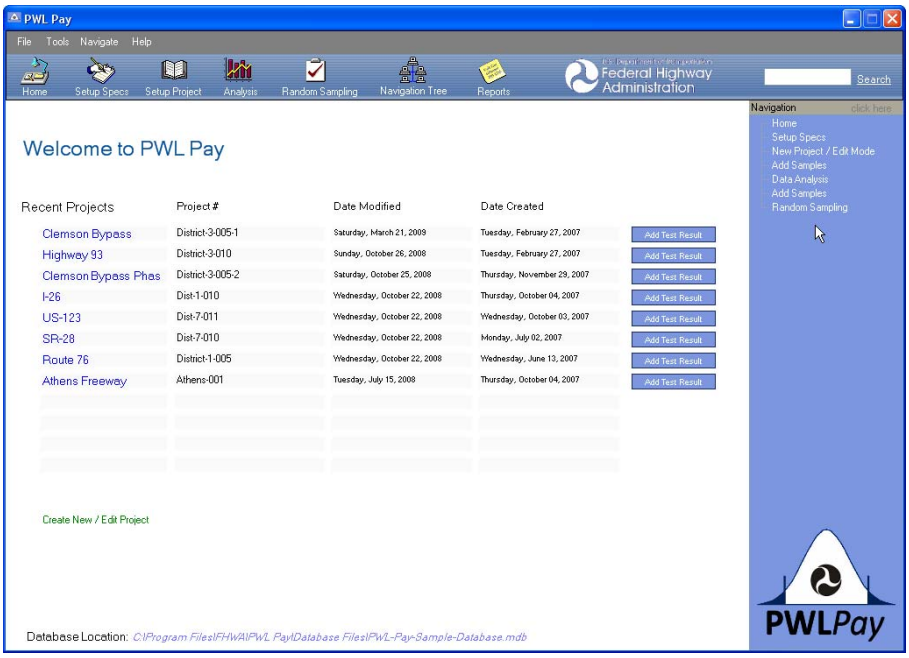
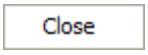


Figure 8.6

Navigating

As can be seen in the list (above the arrow cursor) in the **Navigation** pane in **Figure 8.6**, the user has visited six different locations in addition to the **Home** screen that automatically appears when **PWL*Pay*** is opened. These include the **Setup Specs**, **New Project / Edit Mode**, **Add Samples** (twice), **Data Analysis**, and **Random Sampling**. The two **Add Samples** locations could have been for different projects or items, or could have been the same screen twice.



If the user wishes, locations can be removed from the **Navigation** pane by right clicking the mouse on the location and then selecting **Close** in the window that pops up. This process is shown in **Figure 8.7a**. If desired, the user can open the **Navigation Tree** from the **Navigation** pane by clicking anywhere in the title region at the top of the **Navigation** pane. As shown in **Figure 8.7b**, this opens a window that allows the user to select to go to the **Home** page or to **Open Navigation Tree**.

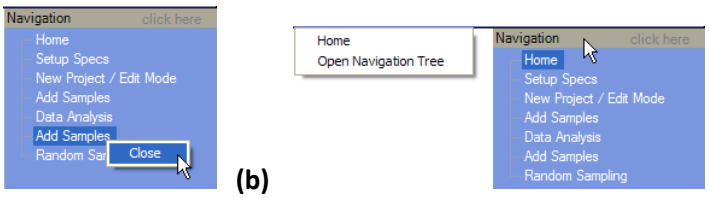


Figure 8.7

Clicking on a location in the **Navigation** pane returns the user to the selected screen as it appeared when the user left that screen. That is, any selections that had been made or data that had been entered will be on the screen when it is re-visited. For example, **Figure 8.8** shows what the screen might look like if **Data Analysis** is selected from the **Navigation** pane in **Figure 8.6**.

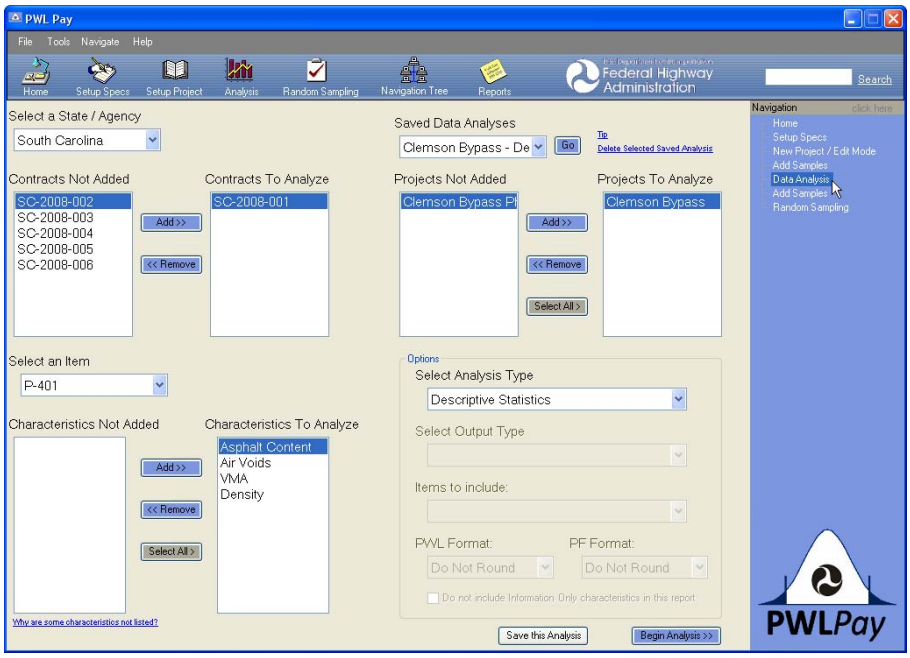
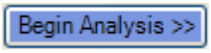


Figure 8.8

Figure 8.8 shows that a **Descriptive Statistics** analysis was either set up or performed on item **P-401** for the **Clemson Bypass** project on contract **SC-2008-001** in **South Carolina** when the user was on this screen. The user can now select a different analysis procedure or modify any of the other selections before again selecting **Begin Analysis**.



Similarly, **Figure 8.9** shows what the screen might look like if **Random Sampling** is selected from the **Navigation** pane in **Figure 8.6**.

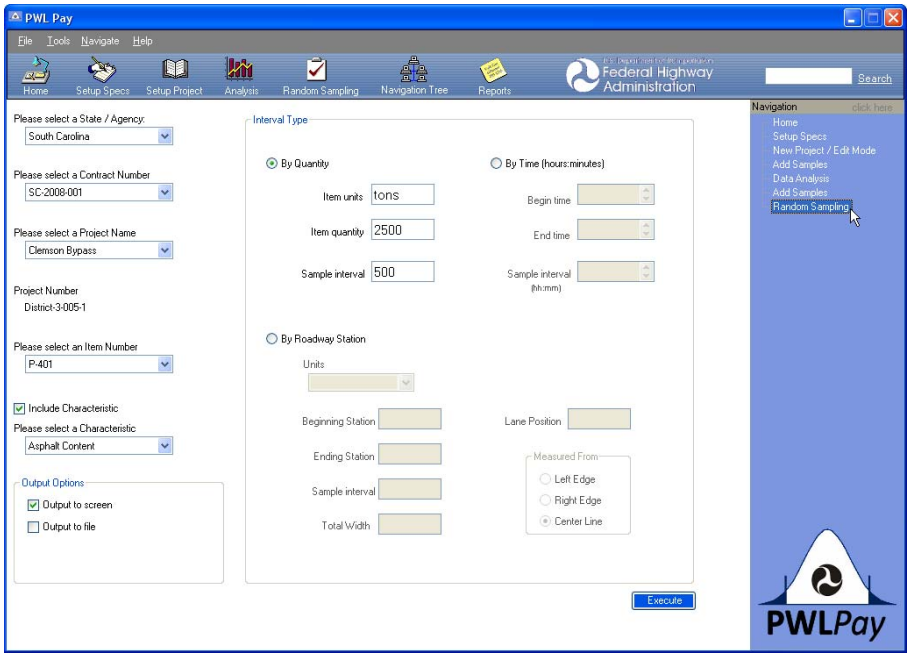


Figure 8.9

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9 Reports

Saving Reports

As seen in Chapter 6, an analysis can be saved so that it can be run with just one click of the mouse. This is an important and time saving capability since some analyses may be run repeatedly throughout the course of a project. The **Reports** icon extends this one-click capability to multiple analyses.

Creating a Report

Before a report can be created the user must have saved at least one analysis as explained in Chapter 6. The **Reports** window can be reached by clicking on the **Reports** icon at the top of any screen and selecting **New Report** from the drop down menu as shown in **Figure 9.1**.

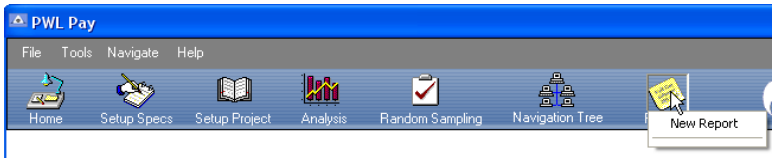
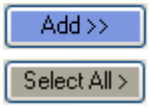


Figure 9.1

The **Reports** window is shown in **Figure 9.2**. Any previously saved reports will appear in the **Saved Reports** drop down menu. In **Figure 9.2** this window has defaulted to **..Add New Report**, signifying that no reports have previously been saved. The user can create a new report by entering a **Report Name:** and using the **Add >>** or **Select All >>** button to move saved analyses from the **Analyses Not Added** window to the **Analyses Included in Report** window.



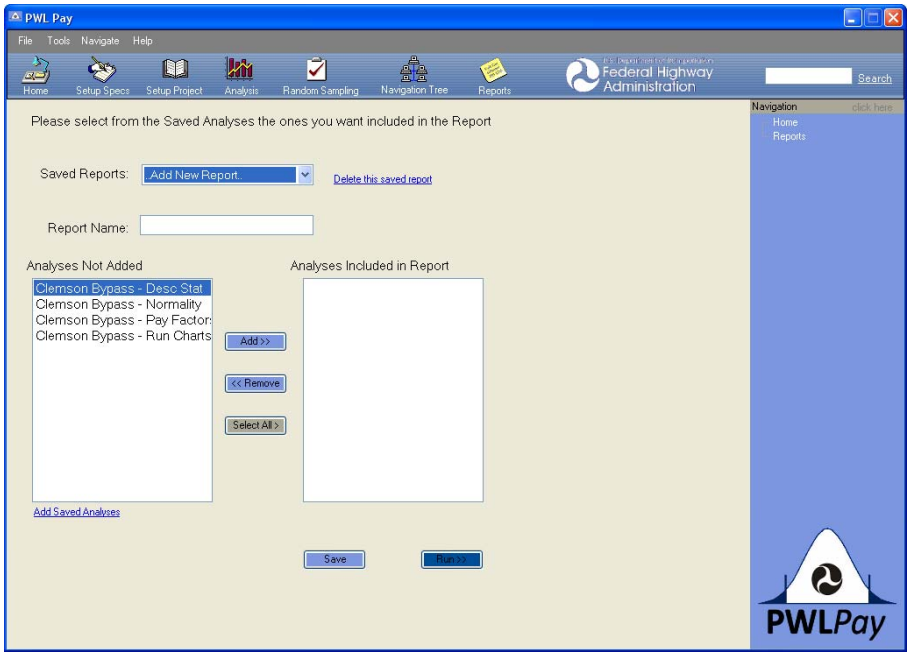


Figure 9.2

Figure 9.3 shows a report named **Clemson Bypass** that is ready to be saved by clicking on Save.

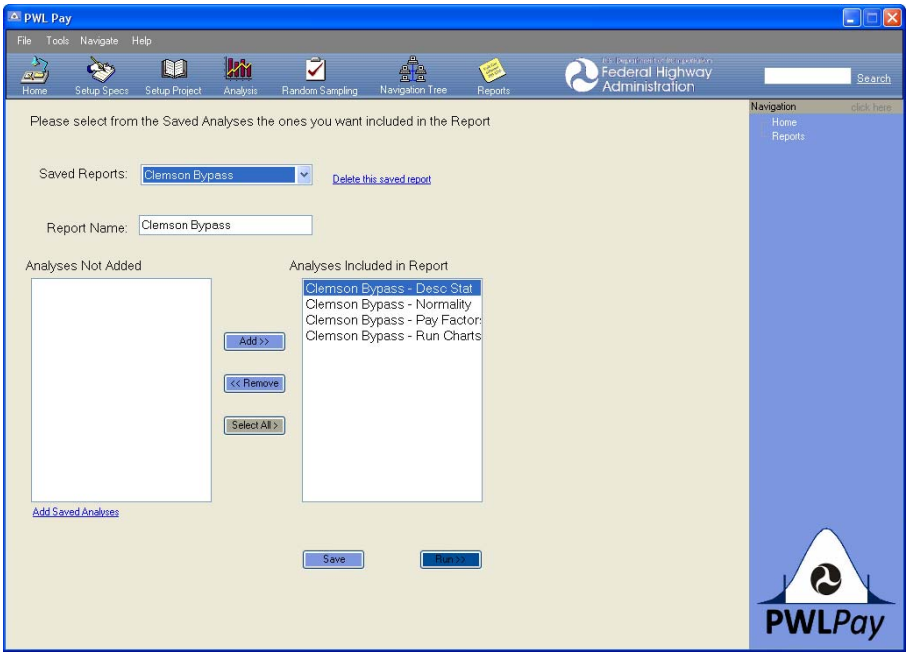
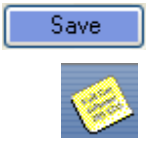


Figure 9.3



The user selects **Save** to save the report under the name appearing in the **Report Name:** box. Saved reports can be accessed directly from the **Reports** icon, as shown in **Figure 9.4**.

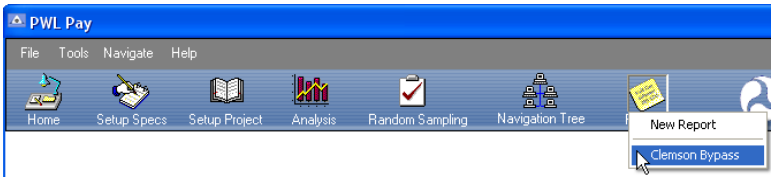


Figure 9.4

Selecting a report in the drop down menu shown in **Figure 9.4** causes all of the analyses assigned to the report to be executed and to appear in the **Navigation** pane for easy access. For example, if **Clemson Bypass** is selected in **Figure 9.4**, the four analyses assigned to it in **Figure 9.3** will be completed and the screen shown in **Figure 9.5** will be displayed.

The four analyses assigned to the **Clemson Bypass** report (see **Figure 9.3**) have been conducted and they now appear in the **Navigation** pane. The last analysis in the list, **Process Control**, is active on the screen shown in **Figure 9.5**. The user can click on any of the analyses in the **Navigation** pane to switch to the selected completed analysis screen.

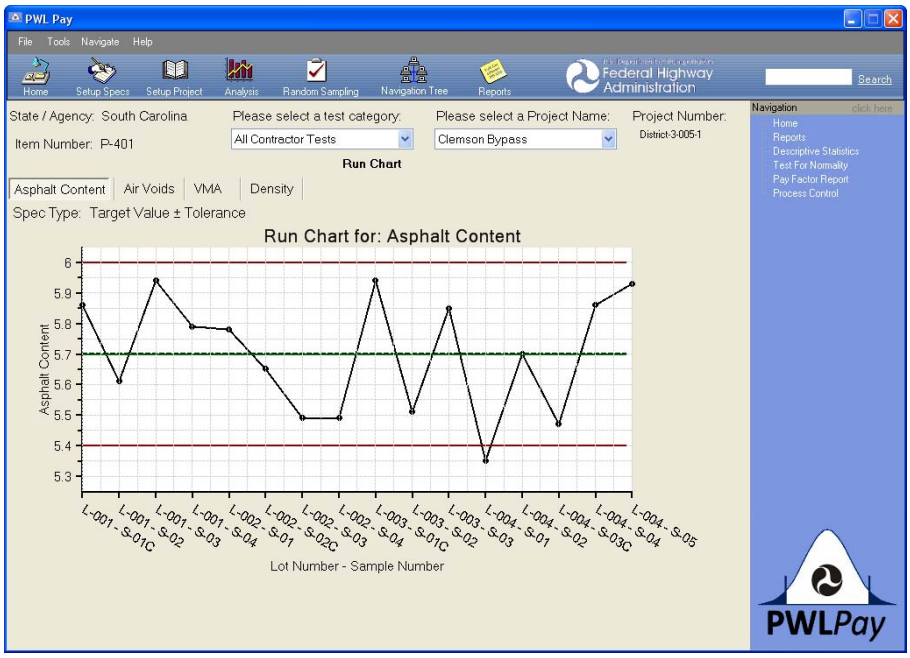


Figure 9.5

Deleting a Saved Report

A saved report can be deleted by clicking on **Delete this saved report** as shown in **Figure 9.3**.

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10 Working with Charts

Printing, Saving, and Copying Charts

As seen in previous chapters, there are many charts (plots) that can be displayed in **PWL*Pay***. Nearly all of these charts can be printed, saved, or modified by clicking the right mouse button while the cursor is over any area of the plot. When this is done, the menu shown in **Figure 10.1** pops up.

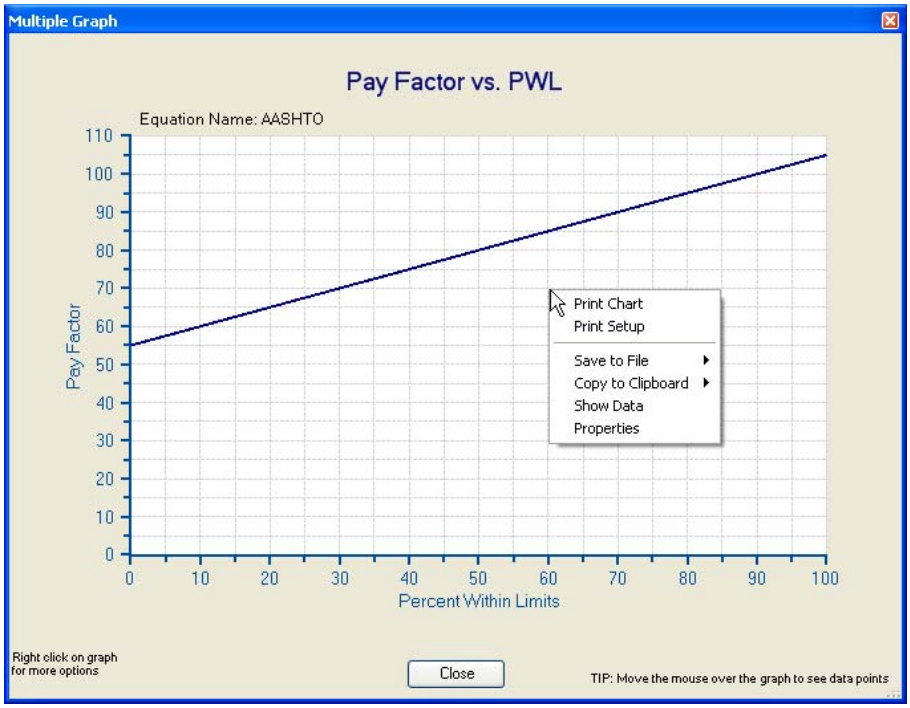

Figure 10.1

Printing a Chart

In the popup menu shown in **Figure 10.1**, clicking **Print Setup** or **Print Chart** opens the Print menu for the default printer associated with the computer on which **PWL*Pay*** is currently running.

Saving a Chart

In the popup menu shown in **Figure 10.1**, clicking **Save to File** opens the submenu shown in **Figure 10.2**. **Save Chart to File** allows the user to save the chart as a picture in an EMF, BMP, GIF, JPG or PNG format. **Save Data to File** allows the user to save the chart data in a CSV file format.

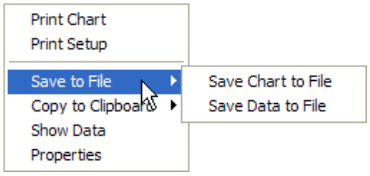

Figure 10.2

Copying a Chart

In the popup menu shown in **Figure 10.1**, clicking **Copy to Clipboard** opens the submenu shown in **Figure 10.3**, and allows the user to copy the chart to the clipboard as a picture in one of the file formats shown. The chart can then be pasted from the clipboard into another program.

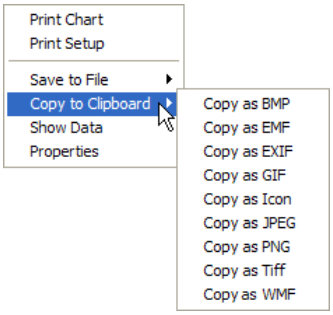

Figure 10.3

Viewing Chart Data

In the popup menu shown in **Figure 10.1**, clicking **Show Data** opens the **Graph Data** window shown in **Figure 10.4**. This window allows the user to see the values of the data points that are plotted in the chart.

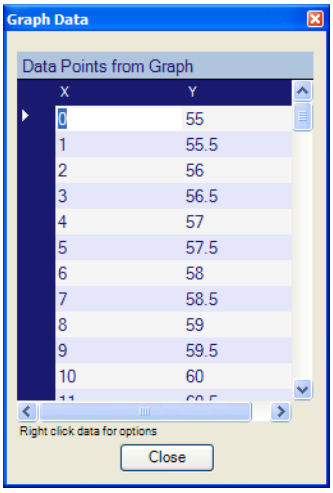

Figure 10.4

Modifying Chart Properties

In the popup menu shown in **Figure 10.1**, clicking **Properties** allows the user to change the properties of the chart with respect to colors, scales, titles, etc. Selecting **Properties** opens the **Chart Properties** window shown in **Figure 10.5**.

The charting module in **PWL***Pay* was licensed from ComponentOne (hence the C1 in the lower left corner of the **Chart Properties** window) and provides powerful charting capabilities. Most of these capabilities are not needed for **PWL***Pay*, but they are still available from the **Chart Properties** window.

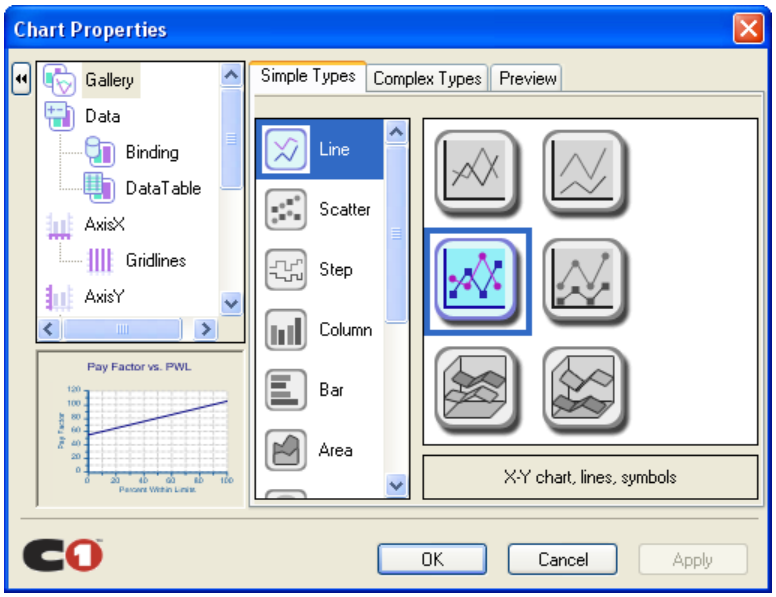

Figure 10.5

Chart Type

Gallery is highlighted in the upper left corner of the **Chart Properties** window shown in **Figure 10.5**. From **Gallery** the user can select from several simple and complex types of charts (e.g., **Scatter**, **Step**, **Column**, **Bar**, **Area**, etc. in **Figure 10.5**). The **Line** chart type is the one of most interest to the user since this chart is used nearly exclusively in **PWL***Pay*. The user might switch to a **Scatter** plot, for example, if they did not want lines connecting the points on a control chart. However, this manual limits its discussion to the properties of **Line** charts since they predominate in **PWL***Pay*.

Chart Properties

Note in **Figure 10.5** that a small preview of the chart is always available in the lower left corner of the **Chart Properties** window. Clicking the **Preview** tab displays a larger preview of the chart (see **Figure 10.6**).

Selecting **Data** in the upper left window (see **Figure 10.5**) allows the user to change the line style, thickness, and color of the lines and/or symbols in the plot. These options are shown in **Figure 10.7**.

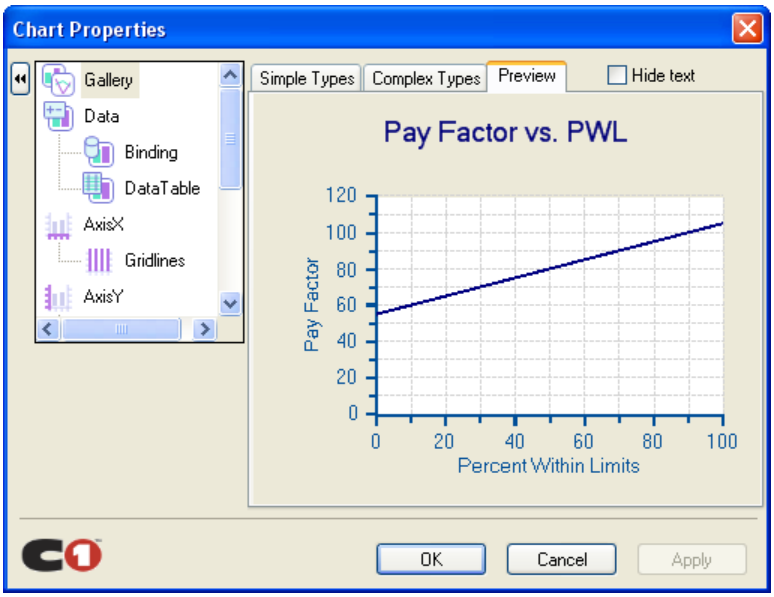

Figure 10.6

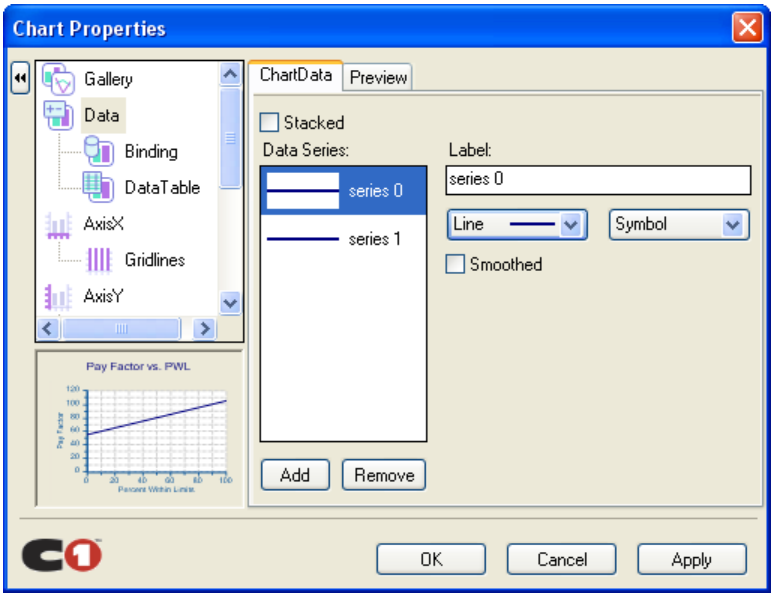

Figure 10.7

Similarly, selecting **AxisX** or **AxisY** in the upper left window allows the user to change the axis title, font style, font size, color, and location. The user can select **Gridlines** to add them to or remove them from either axis. The scale of either axis can be changed by selecting the **Scale** tab. Some of these options are shown in **Figure 10.8**.

Chart Appearance

Selecting **Appearance** in the upper left window (see **Figure 10.9**) allows the user to add or to modify the appearance of a **Header**, **Footer**, or **Legend**, or to modify the appearance of the **ChartArea** or **PlotArea**.

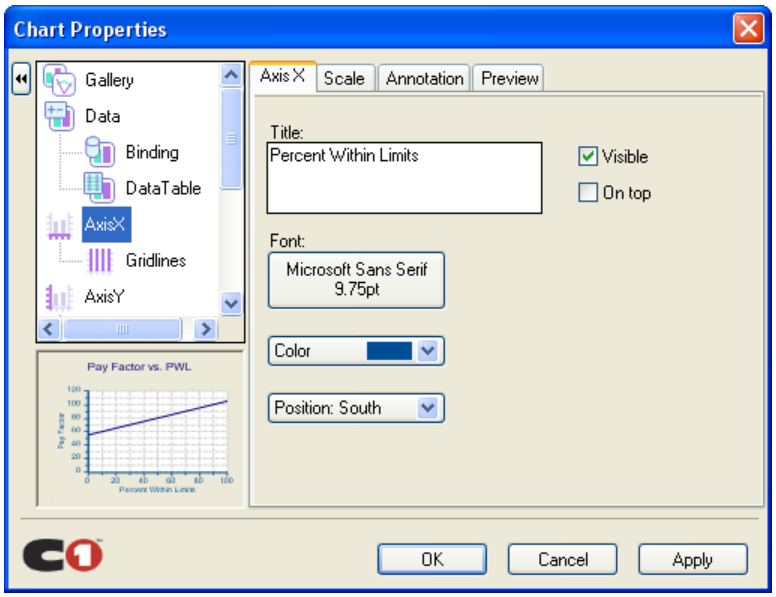

Figure 10.8

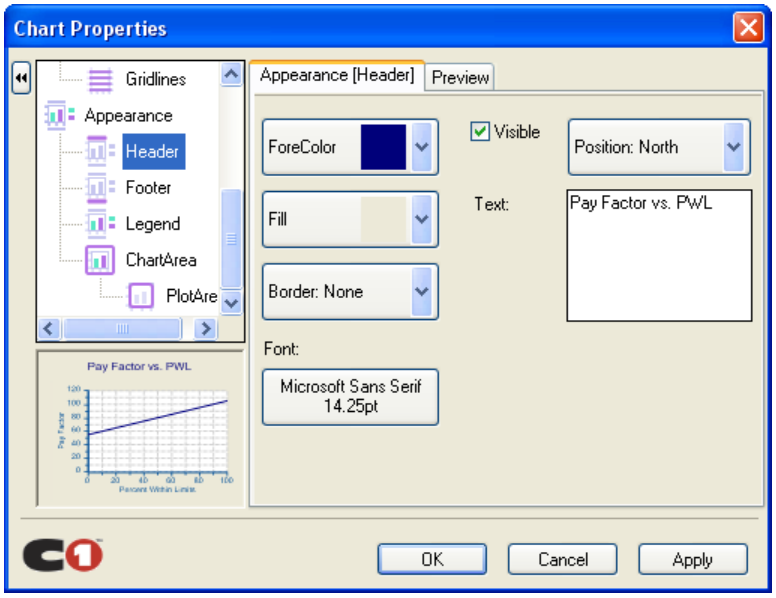

Figure 10.9

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11 Computational Methods

Overview

PWL*Pay* obviously incorporates a number of computational methods in its various analysis modules. Some of these are obvious, while others may not be as obvious to the user of the program. This chapter is not intended to explain in detail the theory that underlies these methods. It does, however, expand on some computational methods that may not be familiar to the typical **PWL*Pay*** user.

Tools is one of the options that appear at the top of every **PWL*Pay*** screen. The drop down menu under **Tools** has **Computational Routines** as one of its options (see **Figure 11.1**). This chapter explains the various options that are available under **Computational Routines**. The chapter also includes a discussion of the various normality testing methods used by **PWL*Pay***.

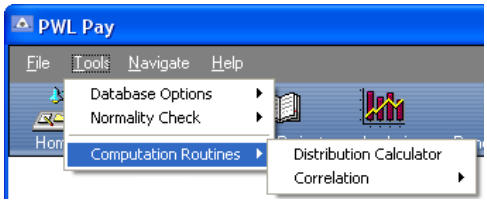


Figure 11.1

Distribution Calculator

PWL*Pay* uses several probability distributions while performing the various analyses of which it is capable. Selecting **Tools** ▸ **Computational Routines** ▸ **Distribution Calculator** opens the **Distribution Calculator** window shown in **Figure 11.2**. This window allows the user to calculate areas under the *t*-, *F*-, and Beta distributions. The critical values corresponding to any selected level of significance can also be calculated for each of these distributions.

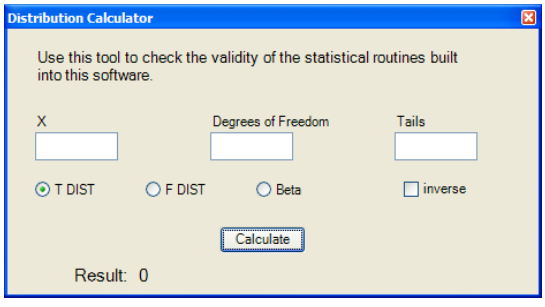


Figure 11.2

There is no need to use these calculations when using **PWL*Pay*** pay. The appropriate calculations are automatically performed by the program. It is included only to allow the user to verify the **PWL*Pay*** calculations if desired. The values calculated using the **Distribution Calculator** can be checked against those calculated by other programs such as Excel.

If desired, the user could use this window as a separate calculation tool when working with these distributions in settings other than using **PWL*Pay***.

T DIST

Selecting the **T DIST** button in **Figure 11.2** allows the user to calculate the *t*-distribution and its inverse. **PWL*Pay*** uses these calculations when performing *t*-tests as part of the verification analysis option. The *t*-distribution and *t*-tests are explained in detail in numerous statistical tests, and are covered in this manual only for illustrative purposes.

The *t*-distribution and the values calculated with **T DIST** are illustrated in **Figure 11.3**.

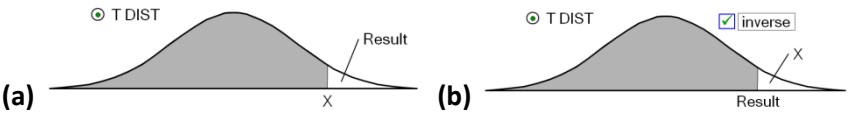


Figure 11.3

Example 1. Suppose that the *t*-statistic from a one-tailed *t*-test is determined to be 1.42 and there are 10 degrees of freedom. The **Result:** in **Figure 11.4** shows that the probability of receiving a *t*-statistic greater than or equal to 1.42 (i.e., the non-shaded area in **Figure 11.3a**) is 0.093.

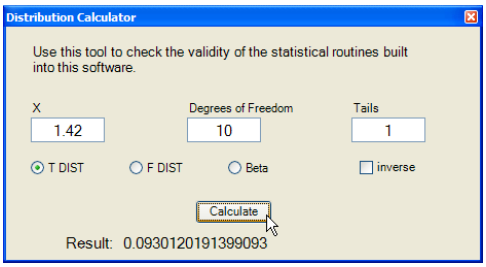


Figure 11.4

Example 2. Suppose that in the previous example the user wishes to know the critical *t*-value that corresponds to a level of significance, $\alpha = 0.05$. In this case the user checks the inverse box and enters *0.05* in the **X** box. The **Result:** in **Figure 11.5** shows that the critical value is 2.228.

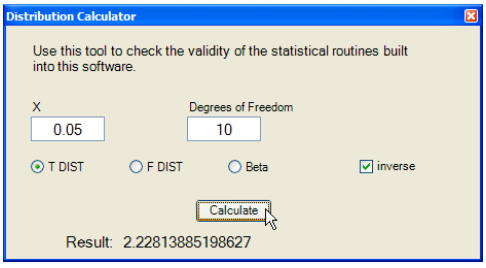


Figure 11.5

F DIST Selecting the **F DIST** button in **Figure 11.2** allows the user to calculate the F-distribution and its inverse. **PWL***Pay* uses these calculations when performing F-tests as part of the verification analysis option. The F-distribution is based on the ratio of variances, and is characterized by the degrees of freedom in the numerator and degrees of freedom in the denominator of this ratio.

In **Figure 11.6**, **Degrees of Freedom 1** is for the numerator, while **Degrees of Freedom 2** is for the denominator. It is important to have these values correct since the degrees of freedom are not interchangeable. That is, for example, the F-distribution with 10 degrees of freedom in the numerator and 12 in the denominator is NOT the same as one with 12 degrees of freedom in the numerator and 10 in the denominator.

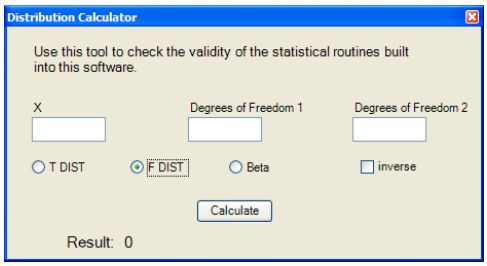


Figure 11.6

The F-distribution and the values calculated with **F DIST** are illustrated in **Figure 11.7**.

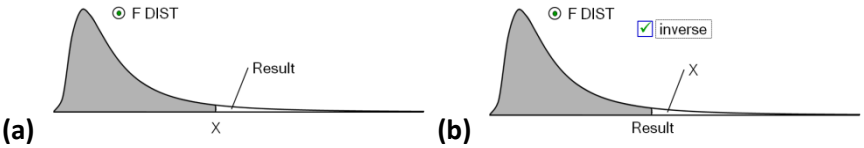


Figure 11.7

Example 1. Suppose that the F-statistic from an F-test is determined to be 2.906, there are 20 degrees of freedom in the numerator, and 5 degrees of freedom in the denominator. The **Result:** in **Figure 11.8** shows that the probability of receiving an F-statistic greater than or equal to 2.906 (i.e., the non-shaded area in **Figure 11.7a**) is 0.120.

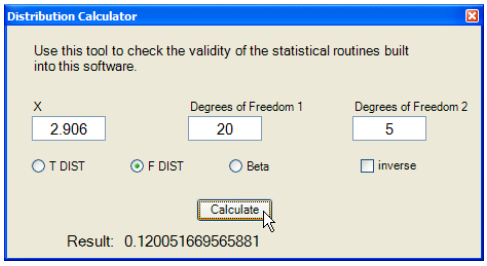


Figure 11.8

Example 2. Suppose that in the previous example the user wishes to know the critical F-value that corresponds to a level of significance, $\alpha = 0.05$. In this case the user checks the inverse box and enters *0.05* in the **X** box. The **Result:** in **Figure 11.9** shows that the critical value is 4.558.

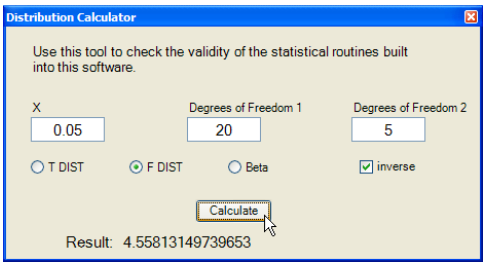


Figure 11.9

Beta

Selecting the **Beta** button in **Figure 11.2** allows the user to calculate the Beta distribution and its inverse (see **Figure 11.10**). **PWL***Pay* uses these calculations when determining PWL values in the payment factor and risk analysis options. The Beta distribution is particularly useful when dealing with percentages since it always ranges between 0 and 1, and because it can take on a wide variety of shapes depending upon the value of its two parameters, **Alpha** (α) and **Beta** (β). **Figure 11.11** illustrates this versatility of shapes.

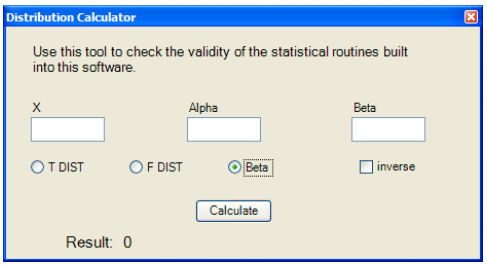


Figure 11.10

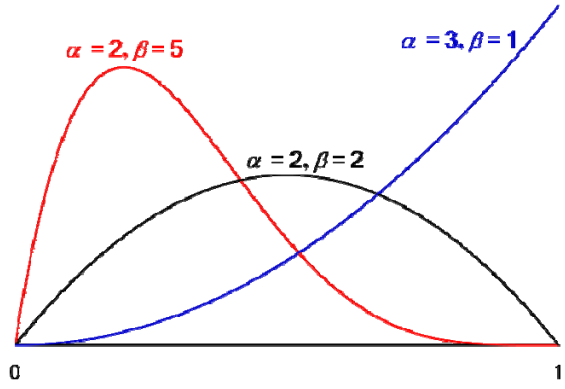


Figure 11.11

A Beta distribution illustrating the values calculated with **Beta** is illustrated in **Figure 11.12**.

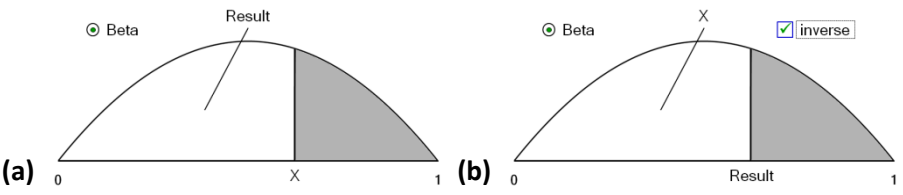


Figure 11.12

Example 1. Suppose that we have a Beta distribution with $\alpha = \beta = 2$. The **Result:** in **Figure 11.13** shows that the percentage of the distribution with values less than or equal to 0.70 (i.e., the non-shaded area in **Figure 11.12a**) is 0.784.

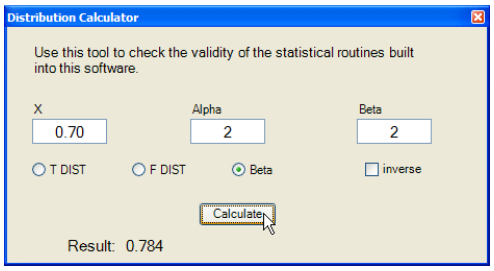


Figure 11.13

Example 2. Suppose that in the previous example the user wishes to know the value for which 60 percent of the distribution is less than. In this case the user checks the inverse box and enters *0.60* in the **X** box. The **Result:** in **Figure 11.14** shows that the value is 0.567.

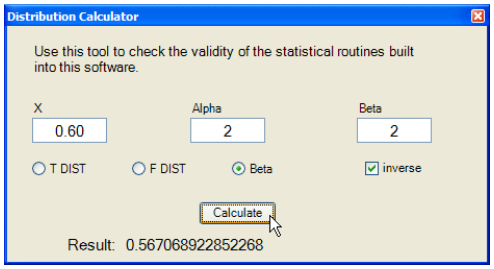


Figure 11.14

Correlation

PWL*Pay* can perform analyses for independent or correlated characteristics. Selecting **Tools ▸ Computational Routines ▸ Correlation ▸** provides the user with the two options shown in **Figure 11.15**. Each of these is discussed in a separate section below.

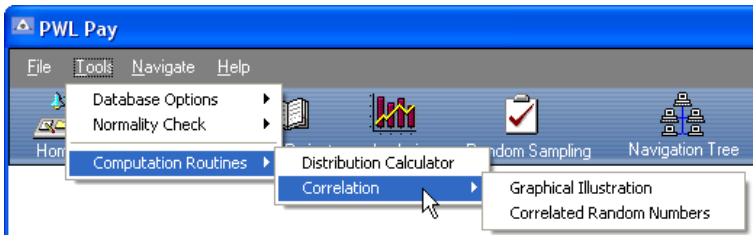


Figure 11.15

Graphical Illustration

Graphical Illustration provides the user visual examples of various levels of correlation between two variables. It also illustrates the effectiveness of the random number generating routines used by **PWL*Pay***. Selecting **Graphical Illustration** opens the **Correlated Illustration** window shown in **Figure 11.16**.

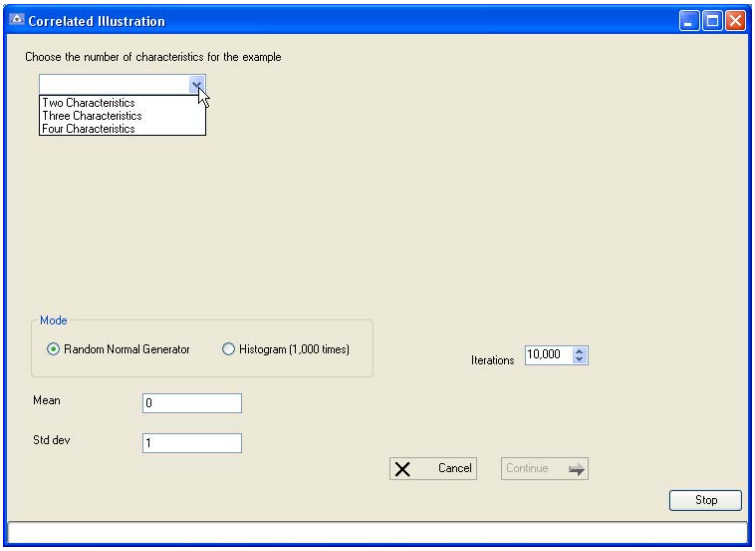


Figure 11.16

As shown in **Figure 11.16**, the **Choose the number of characteristics for the example** drop down menu allows the user to select two, three, or four characteristics for which random numbers will be generated. Also note that in the **Mode** section the user can choose from **Random Normal Generator** or **Histogram (1,000 times)**. These are discussed in separate sections below.

Random Normal Generator

Random Normal Generator results in the computer generation of up to four random normal characteristics with a desired correlation structure that is input by the user. The number of values generated for each characteristic is that shown in the **Iterations** box. The number of **Iterations** is theoretically unlimited. However, for illustration purposes the default value of 10,000 should be quite sufficient in most cases.

Once the user selects the number of characteristics, a correlation matrix (see **Figure 11.17**) is displayed and the user then enters the correlation relationships between each pair of characteristics.

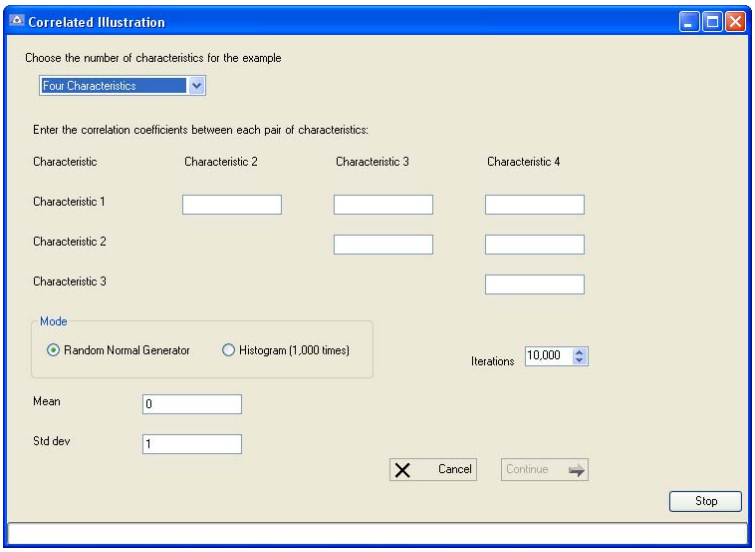


Figure 11.17

PWL*Pay* automatically checks and issues a warning message in the event that there are inconsistencies in the correlation coefficients entered. For example, if Characteristic 1 is positively correlated with both Characteristic 2 and Characteristic 3, then Characteristic 2 and Characteristic 3 could not be negatively correlated. So, if the correlation coefficients shown in **Figure 11.18** were entered, when **Continue** was selected, the warning message in **Figure 11.18** would be displayed.

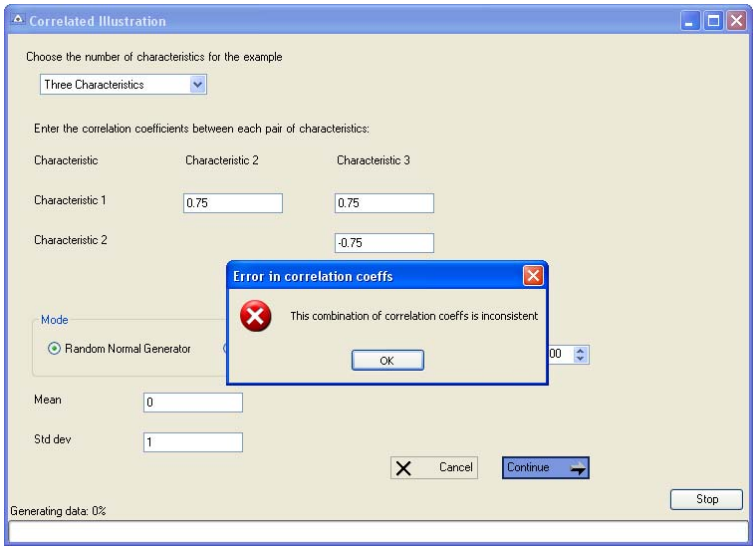


Figure 11.18

The user can use the default values, mean = 0 and standard deviation = 1, or can enter a desired mean and standard deviation. If a consistent correlation matrix has been entered, selecting **Continue** begins the random number generating process and then presents the results, including a plot of the values generated.

Example. Suppose the user has entered the values shown in **Figure 11.19**. Selecting **Continue** results in the screen shown in **Figure 11.20**.

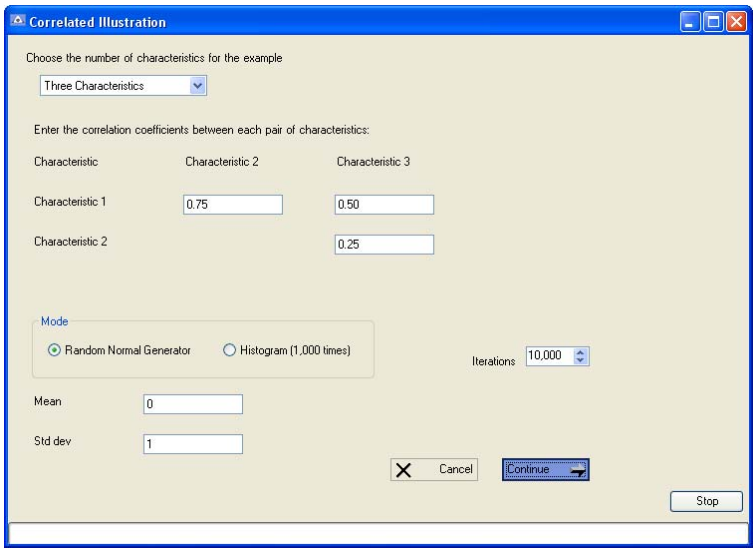


Figure 11.19

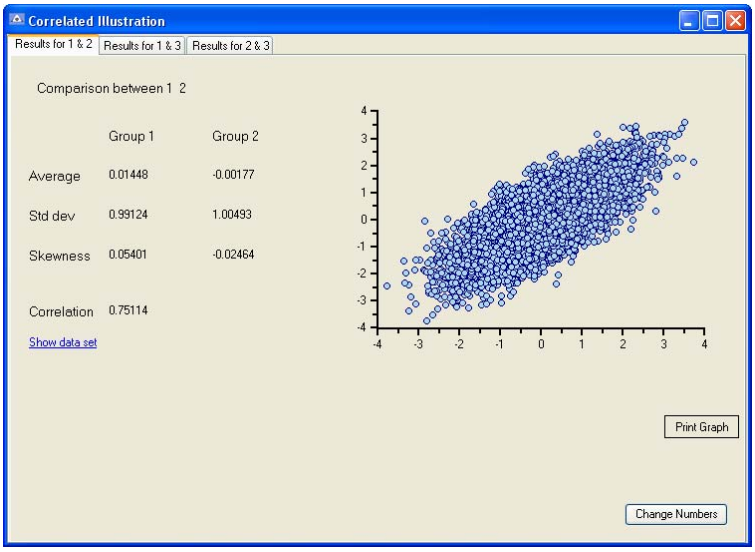


Figure 11.20

Note from **Figure 11.19** that for each characteristic the simulated mean was 0 and standard deviation was 1. Also, the correlation coefficient between Characteristics 1 and 2 was 0.75. **Figure 11.20** shows that the means for the 10,000 random numbers generated (i.e., 0.01448 and -0.00177) were close to the population mean of 0, and that the standard deviations of the generated numbers (i.e., 0.99124 and 1.00493) were close to the population value of 1. Finally, the correlation coefficient for the generated numbers (i.e., 0.75114) was close to the input value of 0.75.

The positive slope of the plot of the generated numbers shows that the two characteristics are positively correlated. The amount of spread around the line that fits the data is consistent with the correlation coefficient of 0.75.

The results in **Figure 11.20** are for the correlation between Characteristics 1 and 2. This is shown by the **Results for 1 & 2** tab that is highlighted at the top left of the window. The user can select the other tabs to see the **Results for 1 & 3** or **Results for 2 & 3**.

Figure 11.21 shows the plots for the generation of two variables with various correlation coefficients.

Histogram (1,000 times)

The output from **Random Normal Generator** (see, for example, **Figure 11.20**) includes the mean, standard deviation, skewness coefficient, and correlation coefficient for the generated values. Selecting **Histogram (1,000 times)** causes the **Random Normal Generator** function to be repeated 1,000 times. It then plots histograms of the 1,000 means, standard deviations, skewness coefficients, and correlation coefficients. **Note** that when **Histogram** is selected the analysis is always performed using only Characteristic 1 and Characteristic 2, regardless of the number of characteristics showing in the **Choose the number of characteristics for the example** window.

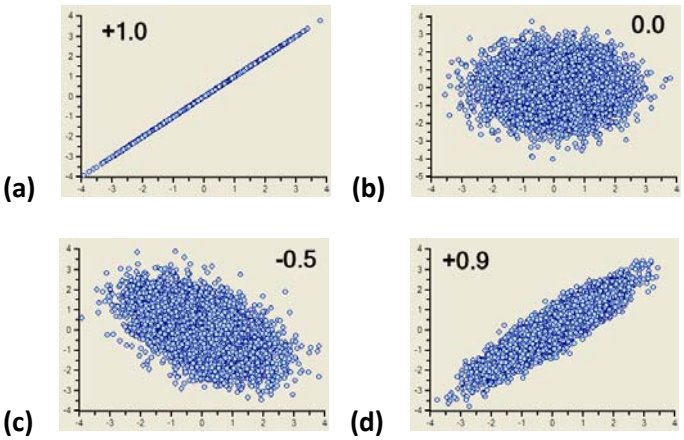


Figure 11.21

Important Note on Number of Iterations

Since **Histogram** repeats the **Random Normal Generator** function 1,000 times, the user should consider carefully the value selected in the **Iterations** window. A large value for **Iterations** can lead to a long wait when repeated 1,000 times. For this reason, the default value for **Iterations** is 10 when **Histogram** is selected. However, the number of iterations can be set to whatever value is desired.

The **Histogram** option allows the user another method to verify that **PWL***Pay*'s random number generating routine is operating properly. This is illustrated and discussed in the following examples.

Example 1. Suppose the user has entered the values shown in **Figure 11.22**. The correlation coefficient has been entered as 0.0, which would be the case if the two characteristics are independent of one another. The default **Mean**, **Std dev**, and **Iterations** values have been used.

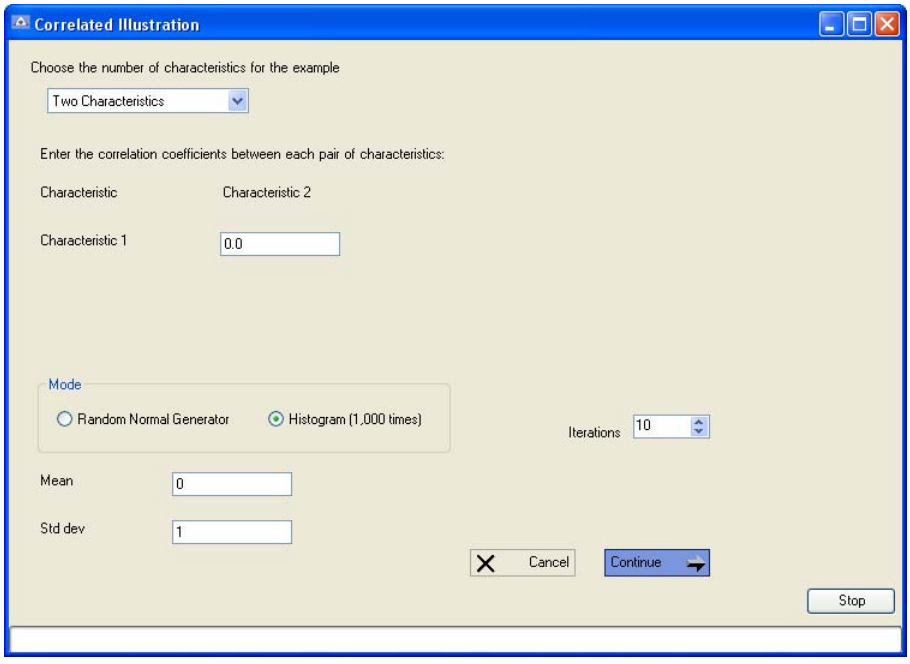
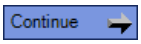


Figure 11.22



Distribution of Sample Means. Selecting **Continue** in **Figure 11.22** results in a screen similar to the one shown in **Figure 11.23**. The histogram shows the distribution of the 1,000 sample means of size n = 10 that were generated from a normal distribution with mean = 0 and standard deviation = 1 (see **Figure 11.22**). A normal distribution should have a skewness coefficient = 0. The simulated values in **Figure 11.23** (i.e., **Mean** = -0.00879, **Std dev** = 0.3179, **Skewness** = 0.02502) compare quite closely with those predicted by theory.

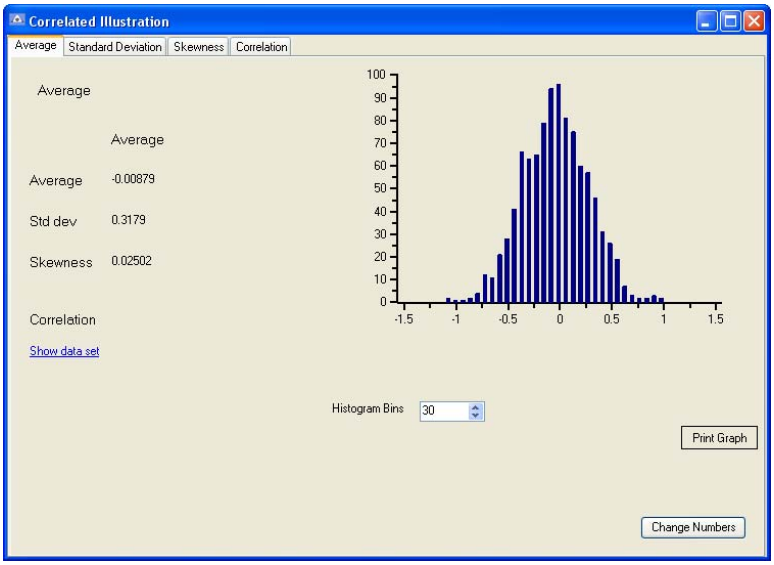


Figure 11.23

The Central Limit Theorem states that the distribution of sample means should be normally distributed with mean equal to the population mean, i.e., 0, and standard deviation equal to the population standard deviation divided by the square root of n, i.e., $1/\sqrt{10} = 0.316$. The shape of the histogram and the **Skewness** coefficient of 0.02502 indicate that it is reasonable to assume the values are normally distributed.

Note that the **Histogram Bins** box shows a value of 30. This is the number of bars in the histogram plot. This value can be set to any number between 1 and 100. However, around 30 bins is usually a good choice for a sample of 1,000 values.

Distribution of Sample Standard Deviations. Selecting the **Standard Deviation** tab in **Figure 11.23** results in the screen shown in **Figure 11.24**. The histogram shows the distribution of the 1,000 sample standard deviations of size n = 10 that were generated from a normal distribution with mean = 0 and standard deviation = 1.

The average sample standard deviation is known to be a biased estimator for the population standard deviation. It can be shown theoretically that the average standard deviation for samples of size n = 10 taken from a population with standard deviation = 1 should equal 0.9727. This compares favorably with the simulated value of 0.97481.

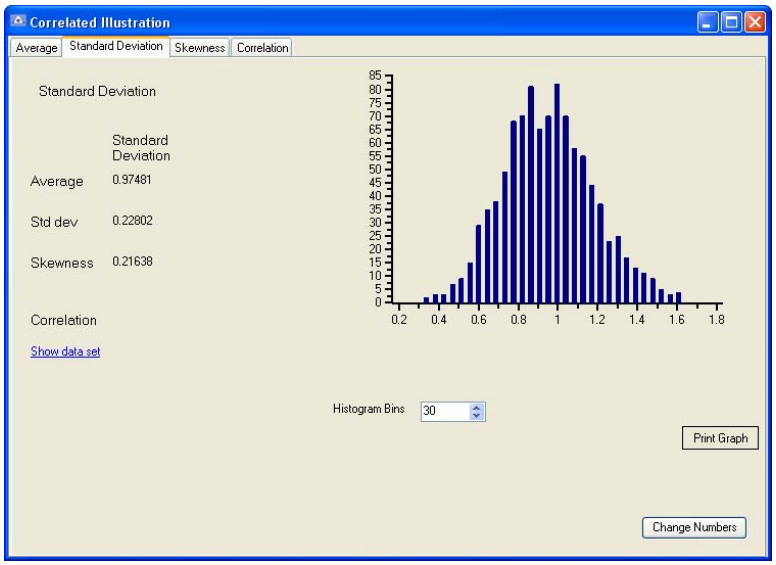


Figure 11.24

Unlike the distribution of sample means, the distribution of sample standard deviations is not normally distributed, but is positively skewed, with the degree of skewness decreasing as the sample size, $n = 10$ here, increases. The skewness of 0.21638 for the simulated values is consistent with what would be expected.

Distribution of Sample Skewness Coefficients. Selecting the **Skewness** tab in **Figure 11.23** results in the screen shown in **Figure 11.25**. The histogram shows the distribution of the 1,000 sample skewness coefficients of size $n = 10$ that were generated from a normal distribution with mean = 0 and standard deviation = 1.

Since the values are simulated from a normal distribution, the average of the 1,000 skewness coefficients should be approximately 0, i.e., the skewness of a normal distribution. In **Figure 11.25**, the average skewness coefficient of -0.03692 compares favorably with the theoretical value of 0. It can be shown theoretically that the standard deviation of the sample skewness coefficients for samples of size $n = 10$ should be 0.687. This compares reasonably well with the simulated value of 0.65425.

Distribution of Sample Correlation Coefficients. Selecting the **Correlation** tab in **Figure 11.23** results in the screen shown in **Figure 11.26**. The histogram shows the distribution of the 1,000 sample correlation coefficients of size $n = 10$ that were generated from a normal distribution with mean = 0 and standard deviation = 1.

Since the values are simulated from two normal variables with 0 correlation, the average of the 1,000 correlation coefficients should be approximately 0. In **Figure 11.26**, the average skewness coefficient of -0.00977 compares favorably with the theoretical value of 0. It can be shown theoretically that the standard deviation of the sample correlation coefficients for samples of size $n = 10$ should be approximately 0.333. This compares favorably with the simulated value of 0.33844.

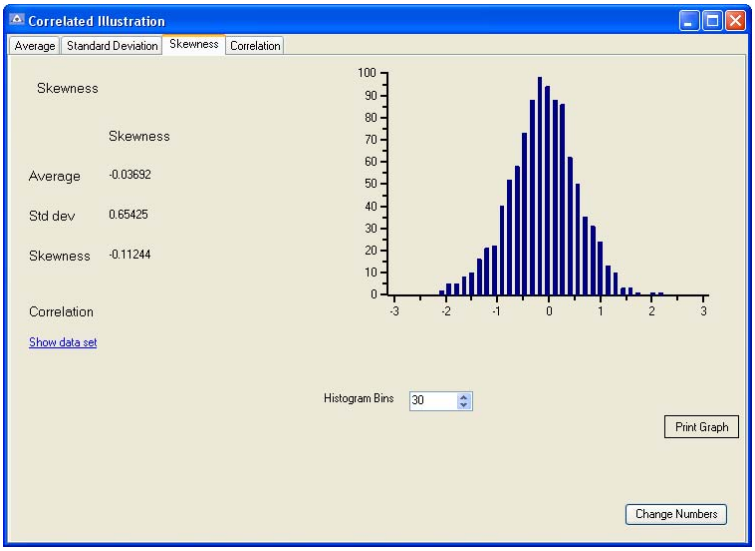


Figure 11.25

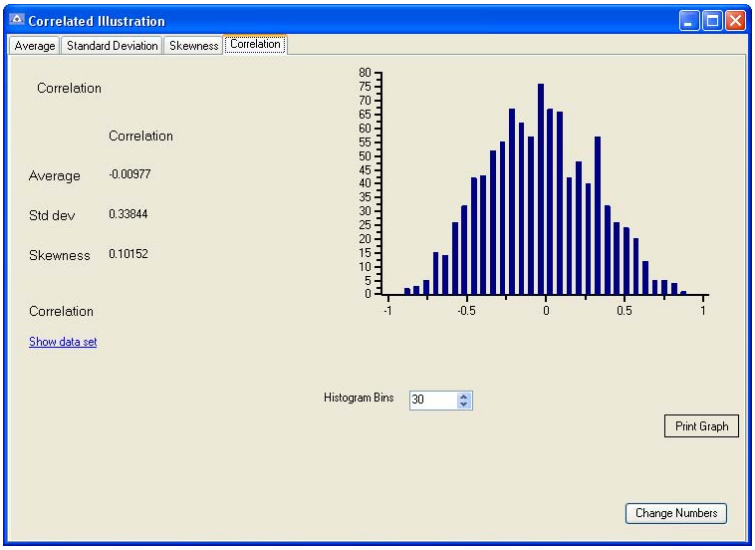


Figure 11.26

In **Figure 11.26**, the histogram is approximately symmetric as evidenced by the skewness coefficient relatively close to 0. This is a unique case that applies when the two populations that are being simulated have 0 correlation. If there is either a positive or negative correlation between the two populations, then the histogram of the sample correlation coefficients will be skewed.

Figure 11.27 shows the input screen for the case where the two characteristics to be simulated have a correlation of +0.5 between them. The resulting histogram of the correlation coefficients is shown in **Figure 11.28**. Note that the histogram is negatively skewed. The maximum possible value for any individual sample correlation coefficient is +1.0. Therefore, the sample cannot over estimate the population correlation by more than 0.5. However, it is possible that the sample could under estimate the population by a much greater amount (-1.5 in this problem). These facts lead to the distribution shape shown in the histogram in **Figure 11.28**.

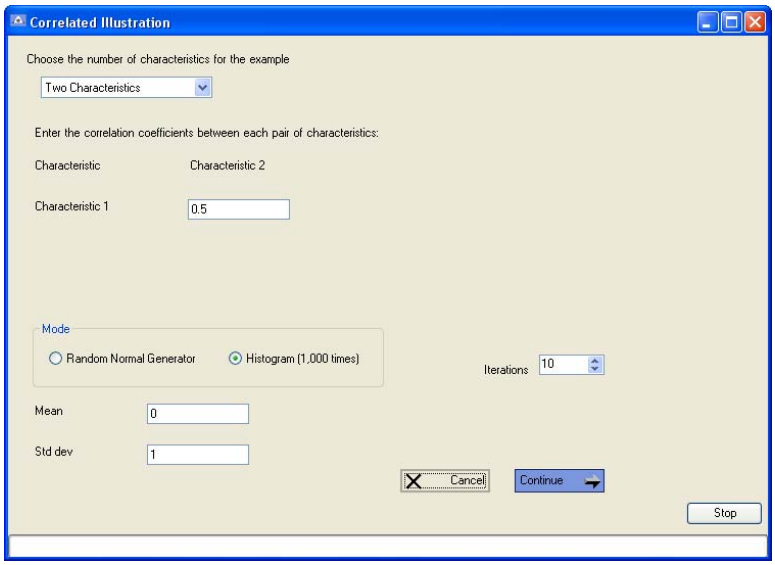


Figure 11.27

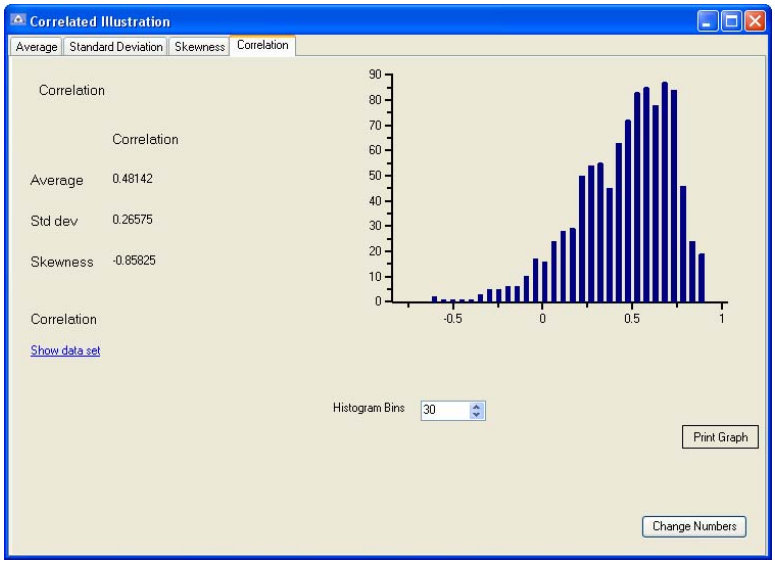


Figure 11.28

If the two populations were negatively correlated, then the histogram of the sample correlation coefficients would be positively correlated for the same reasons. **Figure 11.29** shows the sampling distributions for populations with several different population correlation values.

Correlated Random Numbers

Correlated Random Numbers (see **Figure 11.15**) provides the user with a check of how well **PWL***Pay* is able to generate random values with the correlation structure that is desired. It is another way to illustrate the effectiveness of the random number generating routines used by **PWL***Pay*. Selecting **Correlated Random Numbers** in **Figure 11.15** opens the screen shown in **Figure 11.30**.

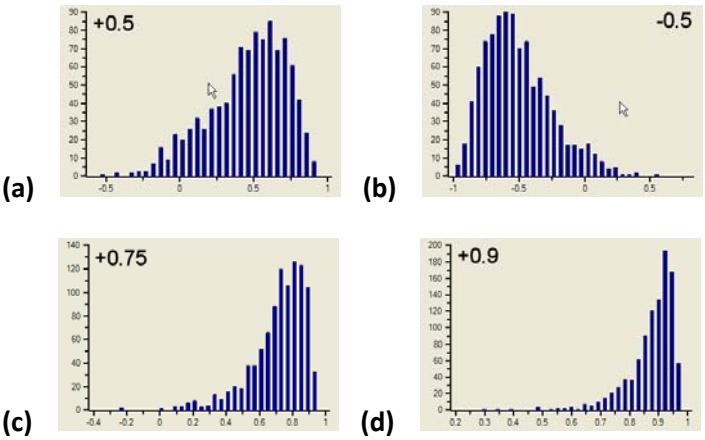


Figure 11.29

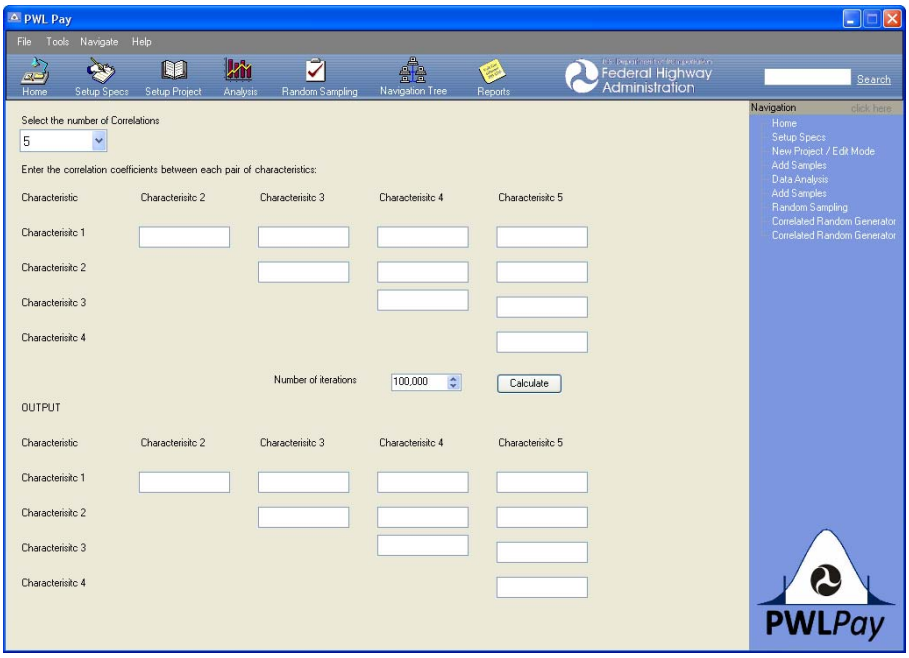


Figure 11.30

The **Select the number of Correlations** drop down menu allows the user to select 2, 3, 4, or 5 characteristics for which to generate correlated random values. **Figure 11.31** shows the screen after the correlation coefficients for 5 correlated characteristics have been entered and **Calculate** has been selected. As can be seen, the simulated values have similar correlation coefficients to those desired.

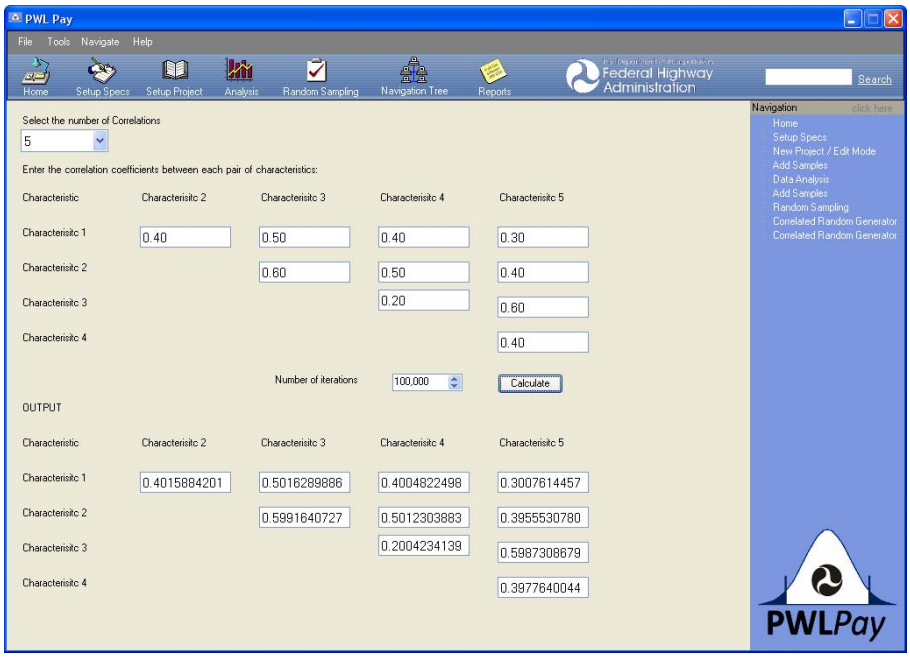


Figure 11.31

Normality Testing

As discussed in Chapter 6, **PWL*Pay*** can be configured to automatically run a quick check for normality whenever new data are entered. **PWL*Pay*** can also perform two more detailed procedures to check for normality. These procedures are illustrated in Chapter 6 and are discussed in more detail in the following sections.

Anderson-Darling Test

There are a large number of statistical goodness of fit (GOF) tests. The typical **PWL*Pay*** user may be familiar with GOF tests such as the Chi-Square or Kolmogorov-Smirnov (K-S) tests. These are general purpose GOF tests that are not particularly powerful for detecting departures from normality.

PWL*Pay* uses the Anderson-Darling GOF test to identify data that do not appear to have come from a normal population. The Anderson-Darling test, like the K-S test, is based on differences between the cumulative distribution of the observed data and that of the theoretical distribution against which the data are being compared. However, unlike the K-S test statistic, which is based on only the maximum individual difference, the Anderson-Darling test statistic, A^2, includes all of the sample values in its calculation.

Important Note on Sample Size for Anderson-Darling Test

PWL*Pay* uses a form of the Anderson-Darling test that has been modified to apply specifically to testing for normality when the true population mean and standard deviation are unknown and are estimated from the sample mean and standard deviation values. ***The procedure for this test is valid for sample sizes ≥ 8***.

Test Procedure. PWL*Pay* performs all necessary calculations and notifies the user whether or not the normality assumption is reasonable. As such, it is not necessary for the user to understand the steps involved in the Anderson-Darling GOF test. The steps are presented only briefly here for users who may be interested. A more thorough description and explanation of the Anderson-Darling test can be found in statistics texts.

Step 1: Arrange the n sample values in ascending order such that
$x_1 \le x_2 \le \ldots \le x_{n-1} \le x_n$

Step 2: For all x_i, calculate the standardized values $y_i = (x_i - \bar{x}) / s$.

Step 3: For each sample value, $i = 1, \ldots, n$, calculate P_i, which is the area under a standard normal curve that is less than or equal to the standard score y_i. This is the cumulative probability of obtaining a value less than or equal to y_i.

Step 4: Calculate the Anderson-Darling test statistic, A^2:

$$A^2 = -\sum_{i=1}^{n}\left[(2i-1)\{\ln P_i + \ln(1-P_{n+1-i})\}/n\right] - n$$

Step 5: Calculate the modified test statistic, A^* (modified specifically for testing for normality when μ and σ are unknown):

$$A^* = A^2\left[1.0 + \frac{0.75}{n} + \frac{2.25}{n^2}\right]$$

Step 6: Reject the null hypothesis of normality if A^* exceeds the critical value for the selected level of significance, α, in **Table 11.1**.

Table 11.1

α	0.15	0.10	0.05	0.025	0.01
Critical A^*	0.561	0.631	0.752	0.873	1.035

Important Note Regarding Level of Significance

Since the Anderson-Darling test is quite sensitive to departures from normality, in **PWL*Pay*** it is always conducted at the 0.01 level of significance regardless of what value has been selected with the **Tools ▸ Normality Check ▸ Alpha Value** option.

qq-Plot

The quantile-quantile (qq-) plot is a general method for determining if two samples come from the same population. The qq-plot can also be used to determine if one sample comes from a specific theoretical distribution (simply replace the other sample by the target distribution), in which case it is sometimes called a *probability plot*, or, particularly, a *normal probability plot* if the target distribution is normal. **PWL*Pay*** can develop and display normal probability plots to evaluate whether or not a set of test data reasonably approximate a normal distribution.

The normal qq-plot plots the sample quantiles against the theoretical quantiles (sometimes called the *expected quantiles*) of the standard normal distribution. Suppose the sample is of size n. First, rank order the sample values from lowest to highest. Take any observation x and record its rank k. Then x is the $p(k)$-quantile of the sample, where

$$p(k) = (k - 0.5) / n$$

In other words, the probability of an observation being below x (or the k-th order statistic) is $p(k)$. This probability is usually taken to be simply k/n, but that would be biased for our purpose (see comments below). The expected quantile associated with x is then the $p(k)$-quantile of the standard normal distribution. For example, the 0.05 quantile of the standard normal distribution is –1.645, i.e., a normal distribution has 0.05 of its area less than or equal to a z value of –1.645. The $p(k)$-quantile values could be looked up from the standard normal table, however, **PWL***Pay* automatically calculates these values for the user.

Important Note Regarding Determining $p(k)$

While **PWL***Pay* uses the method shown above, other methods for determining $p(k)$ are also used. The most natual choice is obviously $p(k) = k/n$, which is obviously biased when $k = n$ since for a standard normal distribution only positive infinity has a quantile of 1.0. Like the equation above, other versions of $p(k)$ attempt in some way to correct this bias.

Example 1: Computing the Expected Quantiles. Suppose the sample size is $n = 50$. After rank ordering the sample the 4^{th} smallest value is $x = 10$ (i.e., the rank for the observation $x = 10$ is 4). Then $x = 10$ is the $[(4 – 0.5) / 50 = 0.07]$ quantile of the sample. Thus the expected quantile associated with $x = 10$ is the 0.07-quantile of the standard normal distribution, which is –1.476.

Drawing Conclusions. If the sample comes from the standard normal distribution, the sample quantiles and theoretical quantiles should be very close and thus the displayed points should fall around the straight line passing through the origin with slope 1. If the sample comes from any normal distribution, the displayed points should approximately fall in a straight line (because any normal distribution is a linear transformation of the standard normal distribution and thus the plot shifts and rotates the previously described straight line, but it remains straight). Thus, a straight line for the qq-plot indicates the sample comes from a normal distribution, while any significant departure from linearity shows evidence against normality.

Example 2: Interpreting qq-Plots. Figure 11.32 shows four probability density functions, one for the standard normal distribution (**Figure 11.32a**), one for the normal distribution with mean 3 and standard deviation 2 (**Figure 11.32b**), one for the t-distribution with degrees of freedom 3 (**Figure 11.32c**), and one for the χ^2-distribution with degrees of freedom 5 (**Figure 11.32d**).

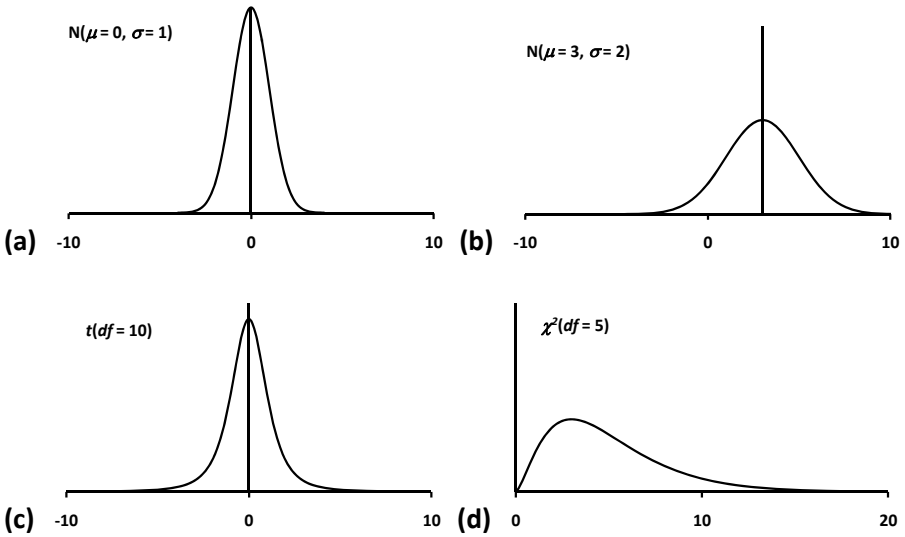


Figure 11.32

Figure 11.33 shows qq-plots for samples of size $n = 200$ drawn from the populations shown in **Figure 11.32**. Clearly **Figures 11.33a** and **11.33b** indicate normality, while **Figures 11.33c** and **11.33d** do not. It should be noted that it is difficult to distinguish a *t*-distribution from the normal using histograms. But the qq-plot is able to detect it. We know that *t*-distributions are flatter and thus have heavier tails than the standard normal distribution. Accordingly, the quantiles for the *t*-distributions depart from those of the standard normal distribution at the lower end and at the upper end, as can be seen from **Figure 11.33c**.

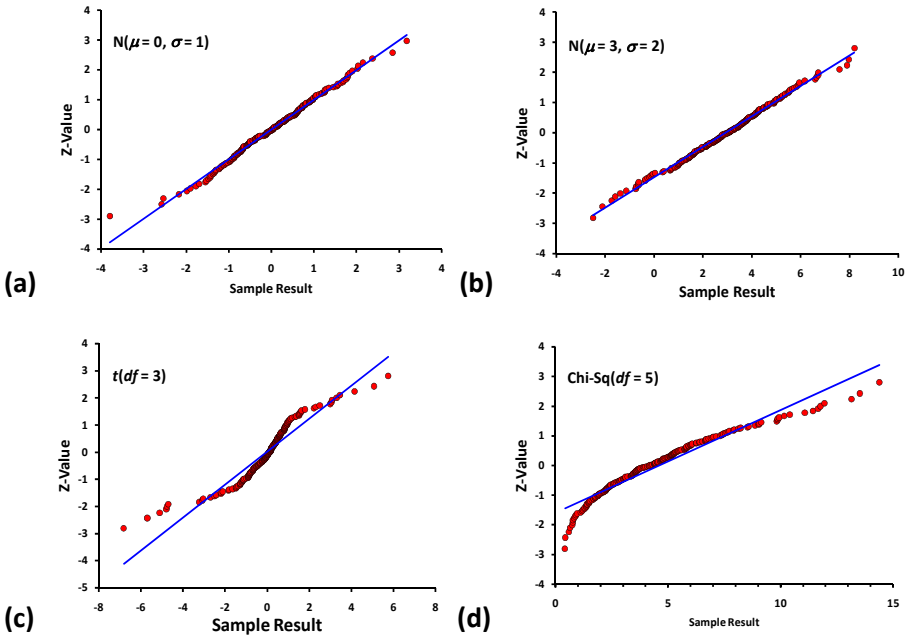


Figure 11.33