

Manufacturing Test Strategy Cost Model User's Guide

NEMI

Board Assembly Technical Integration Group

Test Strategy Project

March 2003

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Test Cost Model Distribution Guideline

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Acknowledgements

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We would like to thank the following individuals for their contributions and participation:

Amit Verma.	<i>Teradyne Inc.</i>
Stig Oresjo.	<i>Agilent Technologies Inc.</i>
James Grealish.	<i>Intel Corp.</i>
Nga Nguyen.	<i>Solectron Corp.</i>
David Mendez.	<i>Solectron Corp.</i>
Brian Chandler.	<i>Delphi Delco Electronic Systems.</i>
Rosa Reinoso.	<i>Hewlett-Packard Co.</i>
Carlos Michel.	<i>Hewlett-Packard Co.</i>

Overview Section.

- [Objective of the user's guide.](#)
- [Objective of the test cost model.](#)
- [About the test cost model.](#)
 - + [Overview](#)
 - + [Inputs](#)
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 - + [Outputs](#)
- [Limitations of the Test Cost Model.](#)

Objective of the User's Guide. The objective of the present document is to provide the users of the economic model with a complete guide of definitions, recommendations and instructions on the use of the NEMI Test Cost Model.

Objective of the Test Cost Model. The objective of the Inspection and Test Strategy Cost Model is to enable a user to understand the financial impact of selecting a manufacturing test strategy. The model uses a spreadsheet format and is intended for post-reflow PCA test strategies.

About The Test Cost Model. The Model is divided in 6 Sections: Overview, Inputs, DPMO/Yield/TTM, Defaults, Calculations and Outputs. The model compares two different test strategies, each strategy can contain up to 10 inspection or test stages; the user must enter information about the product (PCA) and about the test strategies into the model. The more complete and accurate is the information entered by the user, the more accurate will be the outputs driven by the model, however, if an input is unknown to the user (due to lack of data because of a new test strategy for example) they can utilize the values provided on the defaults section. For reasons of accuracy, it is strongly recommended to keep at the minimum the usage of default values. You can find more information about the different sections of the model further on this document or you can refer to the summary described below.

- + **Overview.** The overview section of the model contains the scope and objective of the test cost model, a brief description of each of the sections and acknowledgements of the companies and individuals participants on this project.

- + **Inputs.** The inputs section requires the user to enter detailed information about the product (PCA) and its test strategy. In this section the user will select to use DPMO or Yield for the model calculations, to include Time To Market savings and Return Of Investment Metrics. There are 6 steps to follow when entering the inputs on the test cost model, these steps are:
 - [Step 1](#): Select Model Options
 - [Step 2](#): Enter General Information
 - [Step 3](#): Yield or DPMO Inputs
 - [*Step 3b](#): Time To Market Inputs
 - [Step4](#): Test Strategies Inputs
 - [Step5](#): Test Strategy 1 Inputs
 - [Step6](#): Test Strategy 2 Inputs

If you want to learn more about the inputs of the test cost model or on how to start entering information to the model or about the different steps and their inputs please go to the [inputs section](#) in this document.

- + **Defaults.** The user can utilize default values (provided with the model) for some of the inputs, these default values are based on medium complexity boards manufactured in the US. In order to have accurate and realistic outputs, it is important to keep to a minimum the usage of default values in the model. The default values are on a separate sheet of the model workbook, that way the user can modify at any time the default values according with the data from their manufacturing site. The default values (if exist) can be called at any time when entering the [inputs](#). If you want to learn more about the defaults on the test cost model, please go to the [defaults section](#) in this document.

- + **Calculations.** A user normally will not modify the calculations sheet of the model workbook. However, this section explains the formulas (and the concept behind) used in the model to calculate the results shown in the [outputs section](#). The following are the calculations made in the model:

- Yield	- Re-Test Cost	- Yield Costs
- Defect escapes	- Field Return Cost	- Effectiveness
- Scrap Cost	- Programming Cost	- Yield enhancement savings
- Repair Cost	- Maintenance Cost	- Time to Market Savings
- False Reject Cost	- Equipment Cost	- Return of Investment metrics.
- Diagnostic Cost	- Test Operator Cost	- Overall savings with strategy 2

If you want to learn more about the formulas used in the model please go to the [calculations section](#) in this model.

- + **Outputs.** The Outputs section provides a summary of costs and savings for each test strategy. A comparison of the strategies, including test flow with defect escapes, costs and savings, is shown in the Outputs section. If you want to learn more about the outputs of the test cost model please go to the [outputs section](#) in this document.

Limitations of the Test Cost Model. The test strategy cost model described in this document models test coverage of each test stage in multi-stage test such that test coverage always overlaps from one stage to another. This model will not accurately represent results when multiple test stages are used in a complementary manner.

For example, If test stage 1 had 100% coverage of all defects on 60% of the board that it can access and test stage 2 had 100% coverage of all defects on 40% of the board that it can access, the model would not deliver accurate results.

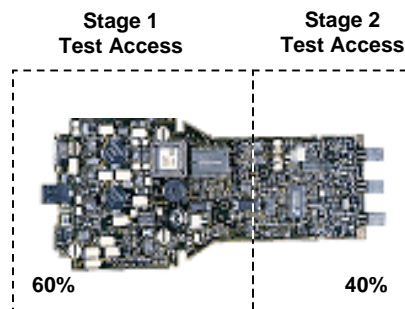
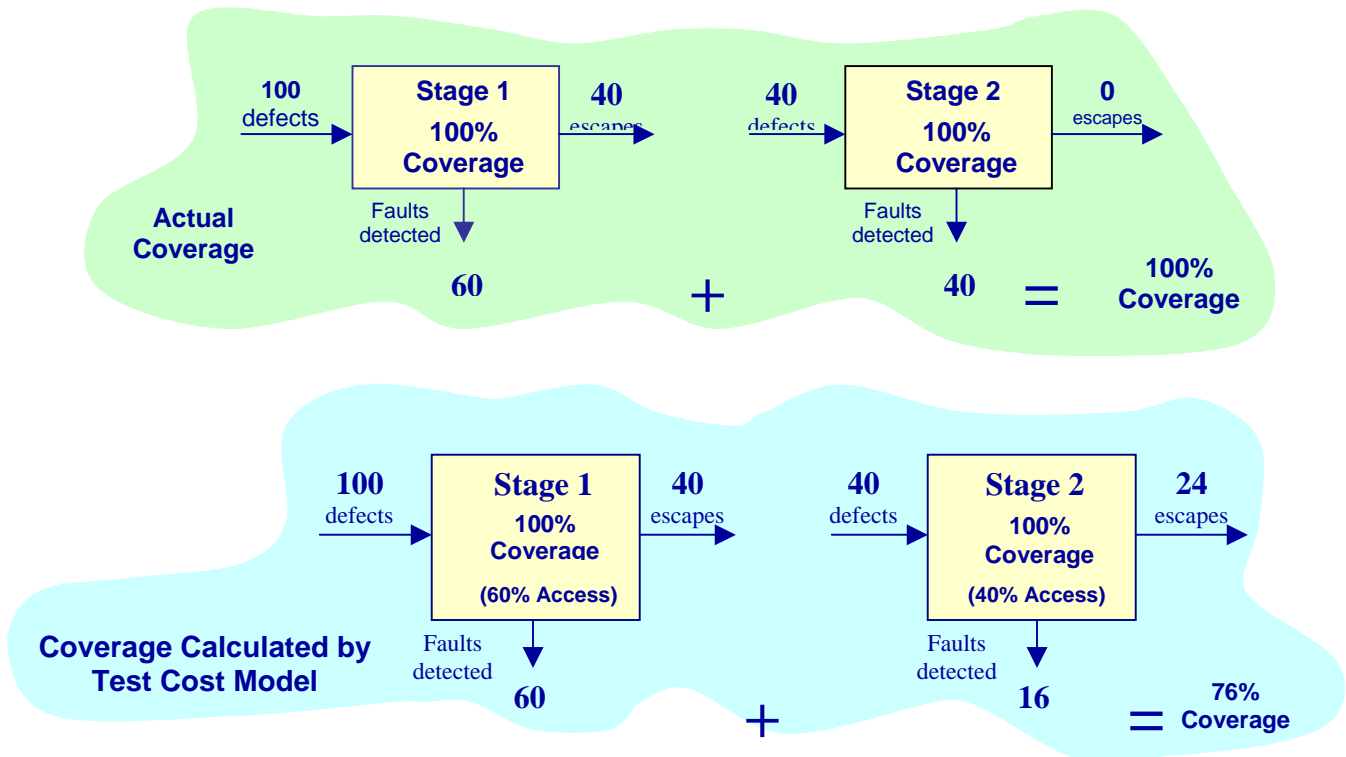


Figure 1: Stage 1, 60% access - 100% coverage. Stage 2, 40% access - 100% coverage.

Instead of giving a result that represents 100% coverage, the model would deliver only 76% coverage of the board.



The model was constructed this way in order to simplify computations. The computations when test coverage is complementary would be beyond the scope of the team that constructed this model. Users of the model need to understand these limitations in multi-machine test strategies with complementary coverage.

Another limitation of the test cost model is around the diagnostic process. In a test process there are true failures and false failures. When we have a diagnostic process, the following things can happen with the failures detected at a particular test station:

1. A *true failure* diagnosed as a *true failure*.
2. A *true failure* diagnosed as a *false failure*.
3. A *false failure* diagnosed as a *true failure*.
4. A *false failure* diagnosed as a *false failure*.

In this test cost model we are assuming a 100% diagnostic yield, which means that the diagnostic is always accurate. In other words, in the present tool we are only considering cases 1 and 4.

The economic impact of the false failures (case 4) is reflected on the test cost model in the calculation of the diagnostic and re-test costs.

Inputs Section.

- [Overview.](#)
- [Step1: Select Model Options.](#)
- [Step2: PCA General Information.](#)
- [Step3: Yield or DPMO Inputs.](#)
- [Step3b: Time To Market Inputs.](#)
- [Step4: Test Strategies Inputs.](#)
- [Step5: Test Strategy 1 Inputs.](#)
- [Step5b: Test Strategy 1 Inputs \(continued\).](#)
- [Step5c: Test Strategy 1 Inputs \(continued\).](#)
- [Step6: Test Strategy 2 Inputs.](#)
- [Step6b: Test Strategy 2 Inputs \(continued\).](#)
- [Step6c: Test Strategy 2 Inputs \(continued\).](#)

Overview. The inputs section requires the user to enter detailed information about the product (PCA) and its test strategy. In this section the user will select to use DPMO or Yield for the model calculations, to include Time To Market savings and Return Of Investment Metrics. To begin entering the information into the inputs section of the test cost model, press the 'Run Model' button that appears on the Menu Bar of Excel, as shown in Figure 1.

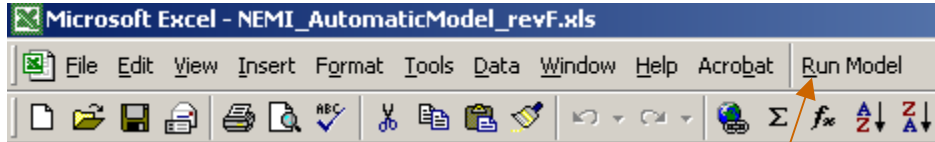


Figure 1. 'Run Model' button

Click here to start entering the inputs

There are 6 steps to follow when entering the inputs on the test cost model. Pressing the 'Run Model' button will open the window of the first step (Figure 2).

Step 1: Select Model Options

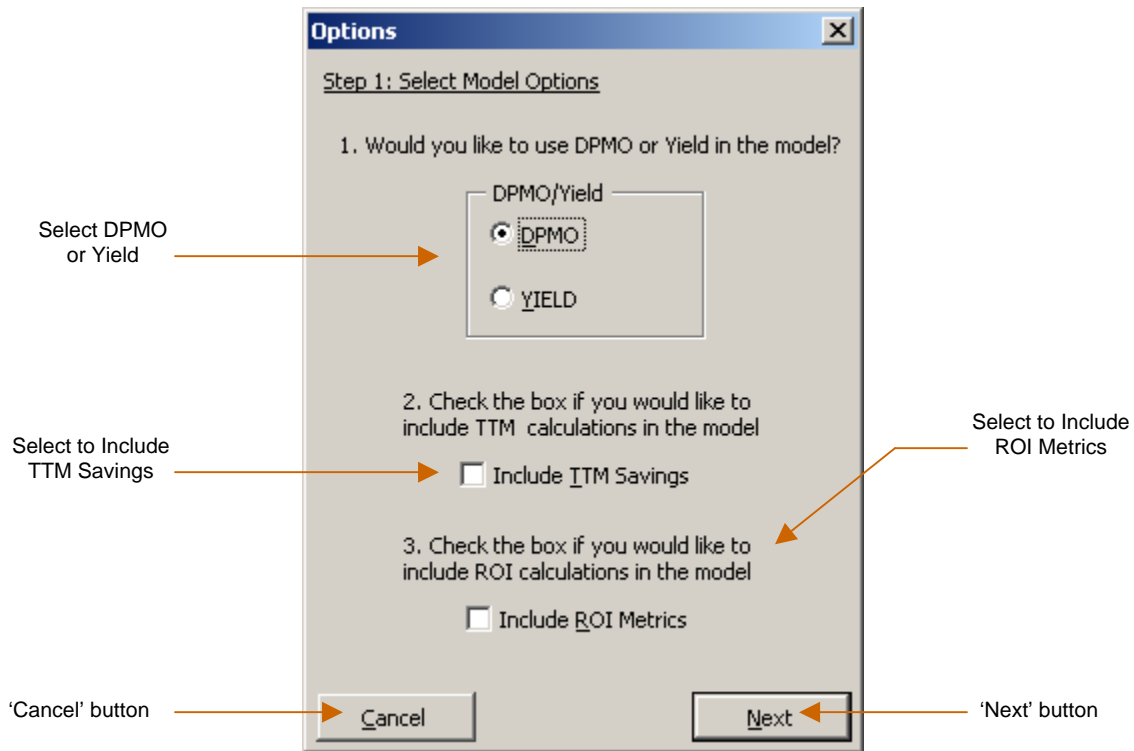


Figure 2. Pressing the 'Run Model' button will open the window of the first step.

On Step 1, you have to select if you prefer to use DPMO Inputs or Yield Inputs in the model for the calculations; also you have to select if Time To Market (TTM) savings and Return of Investment (ROI) metrics will or will not be included in the [outputs section](#).

Select DPMO or Yield Select to use DPMO or Yield inputs for the calculations in the model. If DPMO is selected you will be asked to enter information about the PCA (like number and type of components on the board, number of joints per component, etc;). If Yield is selected you will be asked to enter the number of joints and components on the board and the yield of the first test/inspection stage of strategy 1.

Select to Include TTM Savings. Select to include or not Time To Market savings in the model. If TTM is selected you will be asked to enter information about the product (schedule, sales costs, investments, etc;). To include TTM savings in the model check the *'Include TTM savings'* box. If you do not want to include TTM savings in the model, leave unchecked the *'Include TTM savings'* box. The results of the TTM calculations are shown in the [outputs section](#).

Select to Include ROI Metrics. Select to include or not Return of Investment metrics in the model. To include ROI metrics in the model check the *'Include ROI metrics'* box. If you do not want to include ROI metrics in the model, leave unchecked the *'Include ROI metrics'* box. The results of the ROI calculations are shown in the [outputs section](#).

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box (Figure 3) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

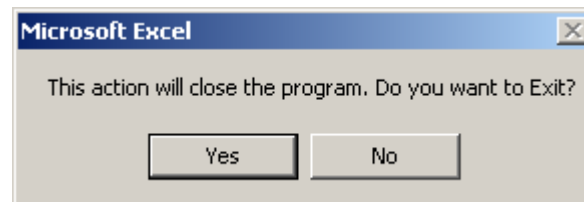


Figure 3. Exit Confirmation

'Next' button. Once you have complete entering all the inputs of step 1, press the Next button. The window of step 2 (Figure 4) will appear.

Step 2: PCA General Information

On Step 2 (figure 4), you have to enter general information of your product (PCA), 3 inputs are required at this step: Production Volume, PCA cost and Field Return Cost (per board).

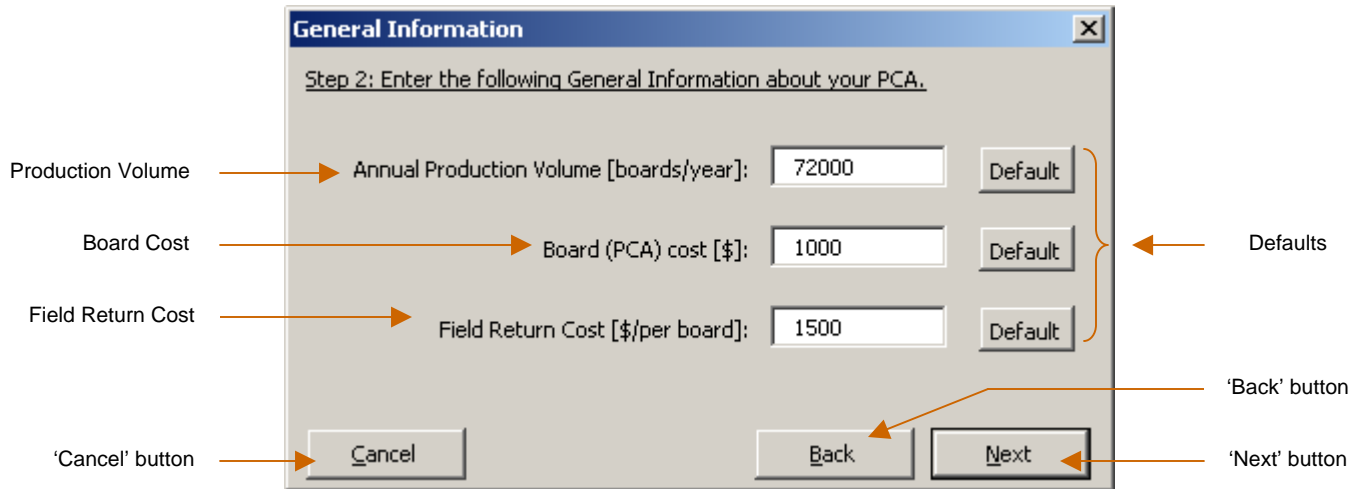


Figure 4. Step 2: General Information Inputs

Annual Production Volume. In this input you have to enter the number of boards manufactured in one year. This could be any number greater than zero. If you enter 0 or anything different than a number, an error message will appear. A default value exists for this specific input. If you want to select the default value of '*Annual Production Volume*' just click the 'default' button at the right of the input box. For more information about the defaults, please go to the [defaults section](#) in this document.

Board Cost. It is the cost of one assembly (board with components) plus the manufacturing cost of one board. This could be any number greater than zero. If you enter 0 or anything different than a number, an error message will appear. A default value exists for this specific input. If you want to select the default value of '*Board Cost*' just click the 'default' button at the right of the input box. For more information about the defaults, please go to the [defaults section](#) in this document.

Field Return Cost. It is the cost of a failed board (PCA) returned by a customer. This input could be any number greater than zero. If you enter 0 or anything different than a number, an error message will appear. A default value exists for this specific input. If you want to select the default value of '*Field Return Cost*' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

'Back' button. If you want to go back to the step 1, click the 'back' button. The Step 1 window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box ([Figure 3](#)) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 2, press the Next button. The window of step 3 ([Figure 5](#)) will appear.

Step 3: Yield or DPMO Inputs.

A) If you have selected to use yield inputs for the calculations on the model, then on Step 3 (figure 5), you will have to enter yield information of your product (PCA), 3 inputs are required at this step: Number of Joints on the board, Number of components on the board and yield at the first test stage of strategy 1.

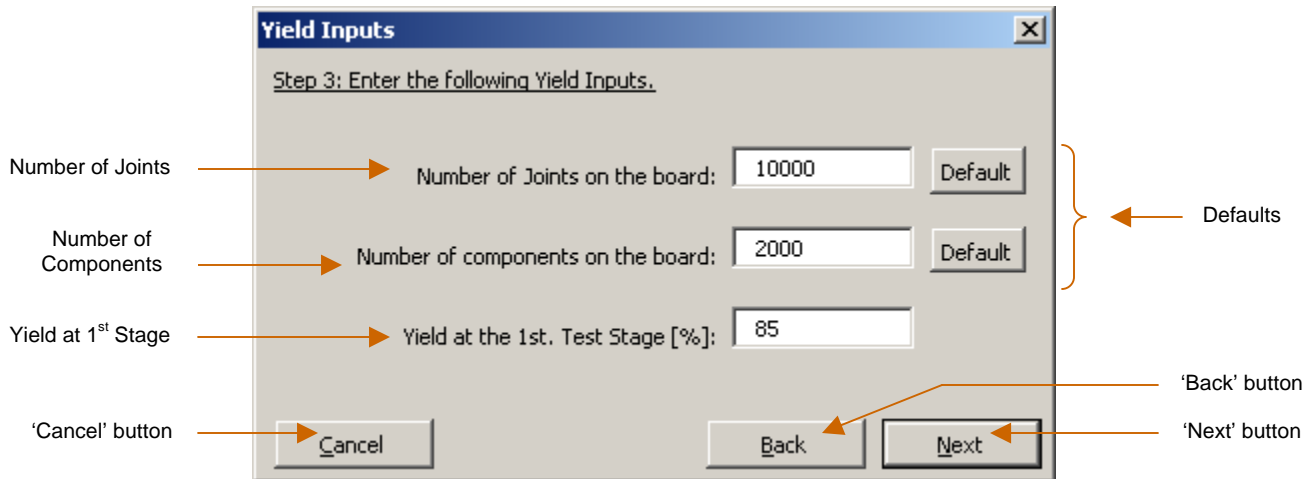


Figure 5. Step 3: Yield Inputs

Number of Joints. It is the total number of joints on the board. This number will be utilized to calculate DPMO, defects & opportunities based on the Yield at the 1st test stage. This input could be any number greater than zero. If you enter 0 or anything different than a number, an error message will appear. A default value exists for this specific input. If you want to select the default value of 'Number of Joints' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Number of Components. It is the total number of components on the board. This number will be utilized to calculate DPMO, defects & opportunities based on the Yield at the 1st test stage. This input could be any number greater than zero. If you enter 0 or anything different than a number, an error message will appear. A default value exists for this specific input. If you want to select the default value of 'Number of Joints' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Yield at the 1st stage. It is the yield at the first test or inspection station in strategy 1. For example, if ICT is the first stage of Strategy 1, then on this input you have to enter the yield at ICT. The yield of the rest of the stations will be automatically calculated. This input could be any number between 0%-100%. No default value exists for this input. The user **MUST** input a value for the yield, if you don't know the yield at the 1st. test stage, return to [step 1](#) and select to use DPMO calculations.

'Back' button. If you want to go back to the step 2, click the 'back' button. The Step 2 window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box (Figure 3) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 3, press the Next button. The window of step 3b (Figure 7) will appear.

B) If you have selected to use DPMO inputs for the calculations on the model, then on Step 3 (figure 6), you will have to enter DPMO information about your product (PCA). In this step you are required to enter the type of component, number of components and number of joints of every component on the board (PCA).

The screenshot shows a dialog box titled "DPMO Inputs" with the instruction "Step 3: Enter the following DPMO Inputs." Below this is a table with four columns: "Total Number of Packages on Board", "Total Number of Joints on Board", "Total Number of Packages on Board", and "Total Number of Joints on Board". The table contains four rows of component types with their respective package and joint counts. Annotations include "Number of Components" pointing to the first two columns, "Number of Joints" pointing to the last two columns, and "Type of Components" pointing to the component names in the first and fourth columns.

	Total Number of Packages on Board	Total Number of Joints on Board	Total Number of Packages on Board	Total Number of Joints on Board
Leaded (Gullwing) > 0.05/1.27	3	48	0201 SMT	15
Leaded (Gullwing) 0.05/1.27	5	40	1206 Wave	2
Leaded (Gullwing) 0.025/0.64	0	0	0805 Wave	0
Leaded (Gullwing) 0.02/0.5	0	0	0402 Wave	0

Figure 6. Step 3: DPMO Inputs

Number of Components. It is the total number of packages (of the corresponding type: 1st column) present on the board. This input could be any number greater or equal than zero. If you enter anything different, an error message will appear. There is no default value available for this type of input.

Number of Joints. It is the total number of joints present on the board, due to the total number of packages of the corresponding type (1st. Column). This input could be any number greater or equal than zero. If you enter anything different, an error message will appear. There is no default value available for this type of input.

Type of Component. It is the package technology type of the components present on the board. If a component on your board is no listed here, use the "other" type of component to include it on the calculations.

Step 3b: Time To Market Inputs.

On Step 3b you have to enter general information about your product (PCA), 3 main fields are required to be completed at this step: Product & investment (figure 7a), Planned Schedule (figure 7b), and Early schedule (figure 7c). This step is optional and will appear only if you have checked the 'Include TTM savings' box at [step 1](#).

A) Product & Investment Inputs

Label	Field Name	Value	Default Button
Product Life Time	Planned Product Life Time [months]:	36	
Sales Price	Target Sales Price [\$/unit]:	500	
Research & Development	R&D Percentage of Revenue [%]:	10	Default
Cost Of Good Sales	COGS Percentage of Revenue [%]:	45	Default
Sales & Marketing	S&M Percentage of Revenue [%]:	25	Default
General & Admin.	G&A Percentage of Revenue [%]:	10	Default
	Profit [%]:	10	

Figure 7a. Step 3b: Time To Market Inputs (Product & Investment).

Product Life Time. It is the estimated time of life of the product. This input could be any number greater than zero. If you enter anything different, an error message will appear. There is no default value available for this type of input.

Sales Price. It is the market price of the product. This input could be any number greater than zero. If you enter anything different, an error message will appear. There is no default value available for this type of input.

Research & Development. It is the percentage of the revenue invested on Research and Design of the product. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of 'Research & Development' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Cost Of Good Sales. It is the percentage of the revenue invested on Cost Of Good Sales of the product. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of 'Cost Of Good Sales' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Sales & Marketing. It is the percentage of the revenue invested on Sales and Marketing of the product. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of 'Sales & Marketing' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

General & Admin. It is the percentage of the revenue invested on General and Administrative expenses of the product. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of 'General & Admin.' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

B) Planned Schedule Inputs

The screenshot shows a dialog box titled "Time To Market Inputs" with a close button (X) in the top right corner. Below the title bar, it says "Step 3b: Enter the following Time to Market Inputs." The main area is titled "Planned Schedule" and contains three rows of input fields, each with a "Default" button to its right. On the left side of the dialog, three labels with orange arrows point to the input fields: "Time to Peak Sales" points to the first field, "Peak Sales" points to the second field, and "Time to Decline Period" points to the third field. The input values are 6, 1900, and 6 respectively. At the bottom of the dialog, there are three buttons: "Cancel", "Back", and "Next".

Figure 7b. Step 3b: Time To Market Inputs (Planned Schedule).

Time to Peak Sales. It is the time to reach the peak sales (maturity) of the product according with the planned schedule. A default value exists for this specific input. If you want to select the default value of 'Time to Peak Sales' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Peak Sales. It is the maximum number of sales of the product as planned. A default value exists for this specific input. If you want to select the default value of 'Peak Sales' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Time to Decline Period. It is the time from when the product sales begin to decline until it reach 0 sales (obsolescence). If you want to select the default value of 'Time to Decline Period' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

C) Early Schedule Inputs

Time to Peak Sales → Time to reach peak sales [months]: 6 Default

Peak Sales → Peak Sales during maturity [units/month]: 1900 Default

Early Introduction → Early Introduction [months]: 6 Default

Cancel Back Next

Figure 7c. Step 3b: Time To Market Inputs (Early Schedule).

Time to Peak Sales. It is the time to reach the peak sales (maturity) of the product according with the early schedule. A default value exists for this specific input. If you want to select the default value of '*Time to Peak Sales*' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Peak Sales. It is the maximum number of sales of the product as planned. A default value exists for this specific input. If you want to select the default value of '*Peak Sales*' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Early Introduction. It is the difference in time between the planned schedule and an earlier schedule due to a different test strategy. A default value exists for this specific input. If you want to select the default value of '*Early Introduction*' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

'Back' button. If you want to go back to the step 3, click the 'back' button. The Step 3 window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box ([Figure 3](#)) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 3b, press the Next button. The window of step 4 ([Figure 8](#)) will appear.

Step 4: Test Strategies Inputs.

On Step 4 (Figure 8) you have to enter general information about the test strategies (1 & 2) of your product (PCA), 5 inputs are required to be completed at this step: Field Return Rate of Strategy 1, Number of test/inspection stages at Strategy 1, Name of the test/inspection stages at Strategy 1, Number of test/inspection stages at Strategy 2 and Name of the test/inspection stages at Strategy 2.

Field Return Rate

Number of test or inspection stages at Strategy 1

Number of test or inspection stages at Strategy 2

Test Strategies Inputs

Step 4: Please Complete the following Test Strategies Inputs.

Strategy 1 Types of Test/Inspection

Field Return Rate: Default

Number of test/inspection stages on Strategy 1: ◀ ▶

Stage 1 (Name):

Stage 2 (Name):

Stage 3 (Name):

Stage 4 (Name):

Strategy 2 Types of Test/Inspection

Number of test/inspection stages on Strategy 2: ◀ ▶

Stage 1 (Name):

Stage 2 (Name):

Stage 3 (Name):

Stage 4 (Name):

Name of test or inspection stages at Strategy 1

Name of test or inspection stages at Strategy 2

Figure 8. Step 4: Test Strategies Inputs

Field Return Rate. It is the percentage of failed boards returned by costumers. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of 'Field Return Rate' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Stages at Strategy 1. This is the number of test and/or inspection stages or stations for a given strategy. The model can handle up to 10 stages for strategy #1. There is no default value available for this type of input.

Name of Stages at Strategy 1. Enter here the name or type of the Test/Inspection stage (e.g. AOI, AXI, ICT, FT, etc;) for the stages at Strategy 1. There is no default value available for this type of input.

Stages at Strategy 2. This is the number of test and/or inspection stages or stations for a given strategy. The model can handle up to 10 stages for strategy #2. There is no default value available for this type of input.

Name of Stages at Strategy 2. Enter here the name or type of the Test/Inspection stage (e.g. AOI, AXI, ICT, FT, etc;) for the stages at Strategy 2. There is no default value available for this type of input.

'Back' button. If you want to go back to the step 3b, click the 'back' button. The Step 3b window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box (Figure 3) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 4, press the Next button. The window of step 5 (Figure 9) will appear.

Step 5: Test Strategy 1 Inputs.

On Step 5 (Figure 9) you have to enter the information about the test strategy 1 of your product (PCA), 6 inputs per test/inspection stage, are required at this step: Test Effectiveness, Access Multiplier, Test Time, False Reject Units, False Reject Rate and Number of Operators.

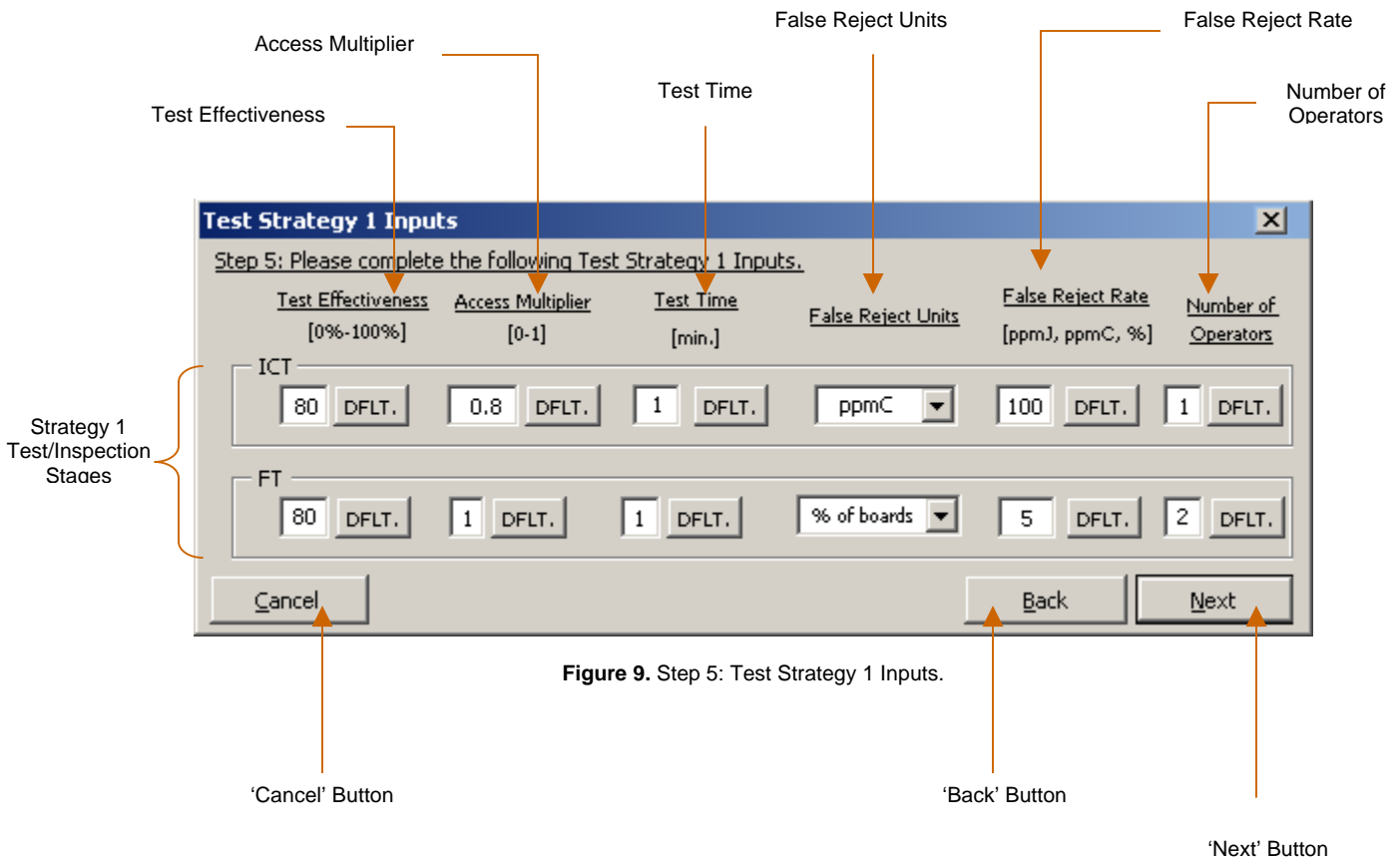


Figure 9. Step 5: Test Strategy 1 Inputs.

Test Effectiveness. It is the effectiveness of the specific test or inspection stage. The effectiveness combined with the access multiplier defines the coverage of the test/inspection station. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of 'Test Effectiveness' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Access Multiplier. This number represents the test or inspection equipment accessibility to the board. A number 1 represents 100% access and 0 means no access at all. This input could be any number between 0 - 1. A default value exists for this specific input. If you want to select the default value of 'Access Multiplier' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Test Time. (Cycle time) is the time required for the test or Inspection stage to test the product (PCA). A default value exists for this specific input. If you want to select the default value of 'Test Time' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

False Reject Units. Different test or inspection equipments may drive false rejects in different units; for example, false rejects at functional test are commonly expressed in percentage of boards units, while AXI used ppmJ as false reject units. This model can handle 3 different units for the false rejects: ppmC (components), ppmJ (joints) or % of boards, you just have to select the correct units from the drop-down menu as shown in figure 9.

False Reject Rate. (False Calls). It is the rate of good boards (% of boards), joints (ppmJ) or components (PPMc) failed by the inspection/test station. A default value exists for this specific input. If you want to select the default value of 'False Reject Rate' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Number of Operators. It is the number of operators (labor) required for that specific test or inspection station. A default value exists for this specific input. If you want to select the default value of 'Number of Operators' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

'Back' button. If you want to go back to the step 4, click the 'back' button. The Step 4 window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box ([Figure 3](#)) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 5, press the Next button. The window of step 5b ([Figure 10](#)) will appear.

Step 5b: Test Strategy 1 Inputs (cont').

On Step 5b (Figure 10a & 10b) you have to enter the information about the test strategy 1 of your product (PCA), 6 inputs per test/inspection stage, are required at this step: Annual Operator Cost, Repair Feedback Loop, Repair Yield, Re-Test Cycles Permitted, Repair Cost and Diagnostic Cost.

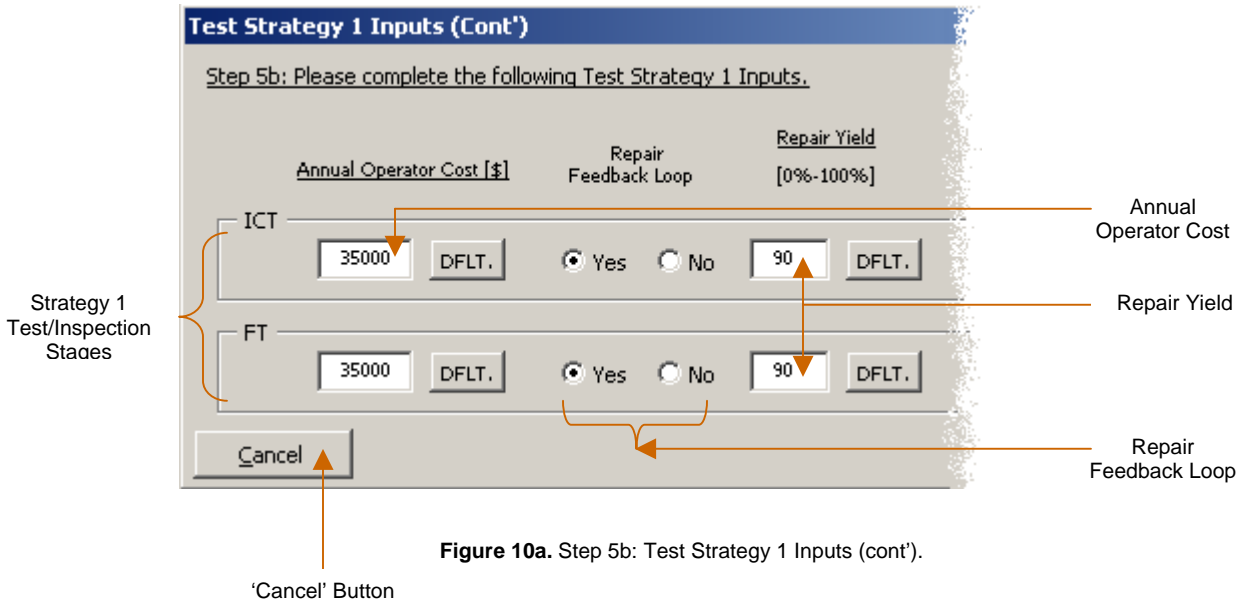


Figure 10a. Step 5b: Test Strategy 1 Inputs (cont').

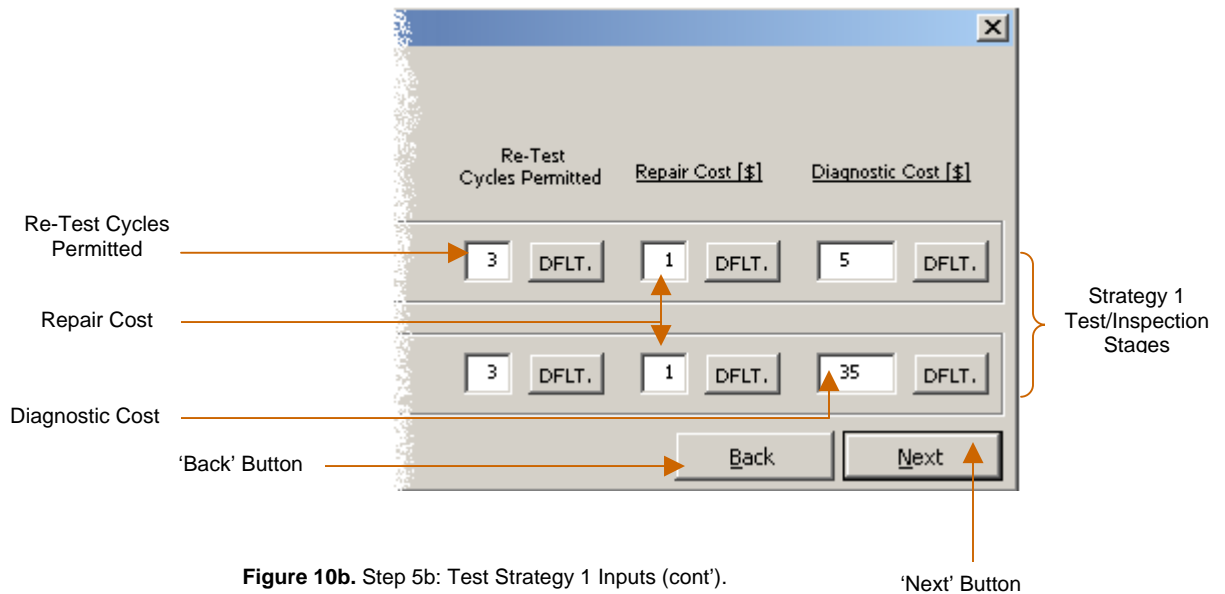


Figure 10b. Step 5b: Test Strategy 1 Inputs (cont').

Annual Operator Cost. It is the cost per year per operator of that specific test/inspection stage. A default value exists for this specific input. If you want to select the default value of *'Annual Operator Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Repair Feedback Loop. Select here if the test/inspection stage will or will not have a diagnostic, repair and re-test process (loop). If 'yes' is selected, the boards failed on that particular test/inspection stage will be repaired, diagnosed and re-tested at that stage. If 'no' is selected the boards failed on that particular test/inspection station will be repaired, diagnosed and passed to the following test/inspection stage.

Repair Yield. It is the percentage of boards successfully repaired at that particular test or inspection stage. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of *'Repair Yield'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Re-Test Cycles Permitted. It is the maximum number of times allowed for a board to be repaired before scraped. If the *Repair feedback loop* for that particular stage is set to 'yes', the *'re-test cycles permitted'* input box will become enabled, indicating that a number should be entered. If the *Repair feedback loop* for that particular stage is set to 'no', the *'re-test cycles permitted'* input box will stay disabled, indicating that no data should be entered. A default value exists for this specific input. If you want to select the default value of *'Re-Test Cycles permitted'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Repair Cost. It is the cost of repairing one single defect at that particular test/inspection stage. A default value exists for this specific input. If you want to select the default value of *'Repair Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Diagnostic Cost. It is the cost of diagnosing one single defect at that particular test/inspection stage. A default value exists for this specific input. If you want to select the default value of *'Diagnostic Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

'Back' button. If you want to go back to the step 5a, click the 'back' button. The Step 5a window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box ([Figure 3](#)) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 5b, press the Next button. The window of step 5c ([Figure 11](#)) will appear.

Step 5c: Test Strategy 1 Inputs (cont')

On Step 5c (Figure 11a & 11b) you have to enter the information about the test strategy 1 of your product (PCA), 6 inputs per test/inspection stage, are required at this step: Equipment Cost, Fixture Cost, Programming Cost, Annual Maintenance Cost, Equipment Depreciation.

The screenshot shows a dialog box titled "Test Strategy 1 Inputs (Cont')". Below the title bar, it says "Step 5c: Please complete the following Test Strategy 1 Inputs." There are two sections: "ICT" and "FT". Each section has two input fields: "Equipment Cost [\$]" and "Fixture Cost [\$]". The "ICT" section has values of 500000 and 20000, both with "DFLT." buttons. The "FT" section has values of 50000 and 15000, both with "DFLT." buttons. A "Cancel" button is at the bottom left. Arrows from external labels point to the "Fixture Cost" field in the ICT section, the "Equipment Cost" field in the FT section, and the "Cancel" button.

Figure 11a. Step 5c: Test Strategy 1 Inputs (Cont')

The screenshot shows a dialog box titled "Test Strategy 1 Inputs (Cont')". It has three input fields: "Programming Cost [\$]", "Annual Maintenance Cost [\$]", and "Equipment Depreciation [Years]". Each field has a value and a "DFLT." button. The "Programming Cost" field has a value of 30000. The "Annual Maintenance Cost" field has a value of 20000. The "Equipment Depreciation" field has a value of 3. At the bottom, there are "Back" and "Next" buttons. Arrows from external labels point to the "Programming Cost" field, the "Annual Maintenance Cost" field, the "Equipment Depreciation" field, the "Back" button, and the "Next" button.

Figure 11b. Step 5c: Test Strategy 1 Inputs (Cont')

Equipment Cost. It is the cost of the test or inspection equipment for that particular station. (This cost will be depreciated in the calculations). A default value exists for this specific input. If you want to select the default value of *'Equipment Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Fixture Cost. It is the cost of the test or inspection fixture for that particular station. (This cost will be depreciated in the calculations). A default value exists for this specific input. If you want to select the default value of *'Fixture Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Programming Cost. (Test program development cost) It is the cost of programming the test or inspection equipment for that particular station. A default value exists for this specific input. If you want to select the default value of *'Programming Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Annual Maintenance Cost. It is the yearly cost of maintaining the test or inspection equipment and fixture of that particular station. A default value exists for this specific input. If you want to select the default value of *'Annual Maintenance Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Equipment Depreciation. It is the number of years to depreciate the fixture and equipment costs. A default value exists for this specific input. If you want to select the default value of *'Equipment Depreciation'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

'Back' button. If you want to go back to the step 5b, click the 'back' button. The Step 5b window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box ([Figure 3](#)) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 5c, press the 'Next' button. The window of step 6 ([Figure 12](#)) will appear.

Step 6: Test Strategy 2 Inputs.

On Step 6 (Figure 12) you have to enter the information about the test strategy 2 of your product (PCA), 6 inputs per test/inspection stage, are required at this step: Test Effectiveness, Access Multiplier, Test Time, False Reject Units, False Reject Rate and Number of Operators.

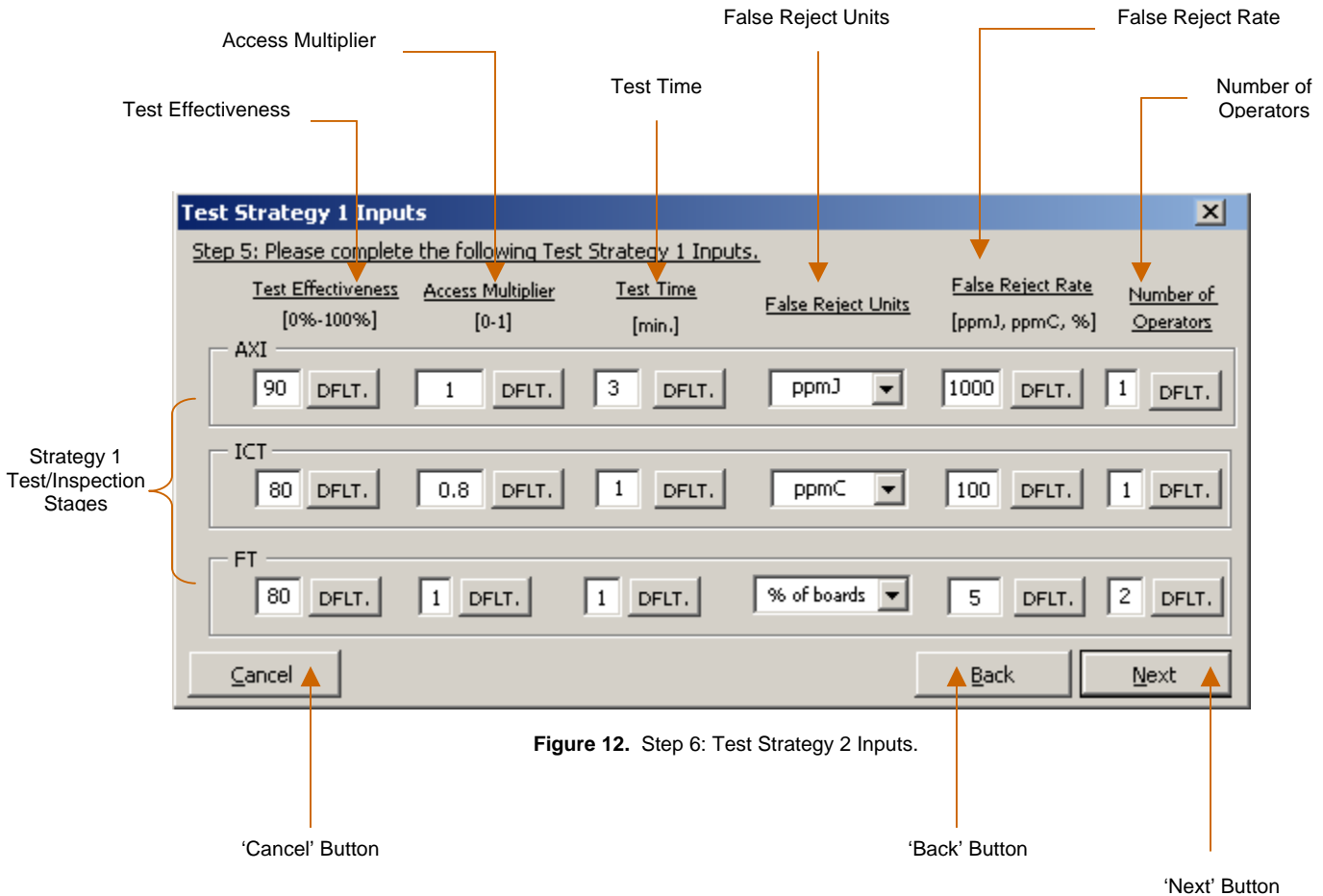


Figure 12. Step 6: Test Strategy 2 Inputs.

Test Effectiveness. It is the effectiveness of the specific test or inspection stage. The effectiveness combined with the access multiplier defines the coverage of the test/inspection station. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of 'Test Effectiveness' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Access Multiplier. This number represents the test or inspection equipment accessibility to the board. A number 1 represents 100% access and 0 means no access at all. This input could be any number between 0 - 1. A default value exists for this specific input. If you want to select the default value of 'Access Multiplier' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Test Time. (Cycle time) is the time required for the test or Inspection stage to test the product (PCA). A default value exists for this specific input. If you want to select the default value of 'Test Time' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

False Reject Units. Different test or inspection equipments may drive false rejects in different units; for example, false rejects at functional test are commonly expressed in percentage of boards units, while AXI used ppmJ as false reject units. This model can handle 3 different units for the false rejects: ppmC (components), ppmJ (joints) or % of boards, you just have to select the correct units from the drop-down menu as shown in figure 12.

False Reject Rate. (False Calls). It is the rate of good boards (% of boards), joints (ppmJ) or components (PPMc) failed by the inspection/test station. A default value exists for this specific input. If you want to select the default value of 'False Reject Rate' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Number of Operators. It is the number of operators (labor) required for that specific test or inspection station. A default value exists for this specific input. If you want to select the default value of 'Number of Operators' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

'Back' button. If you want to go back to the step 5c, click the 'back' button. The Step 5c window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box ([Figure 3](#)) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 6, press the Next button. The window of step 6b ([Figure 13](#)) will appear.

Step 6b: Test Strategy 2 Inputs (cont')

On Step 6b ([Figure 13a](#) & [13b](#)) you have to enter the information about the test strategy 2 of your product (PCA), 6 inputs per test/inspection stage, are required at this step: Annual Operator Cost, Repair Feedback Loop, Repair Yield, Re-Test Cycles Permitted, Repair Cost and Diagnostic Cost.

Annual Operator Cost. It is the cost per year per operator of that specific test/inspection stage. A default value exists for this specific input. If you want to select the default value of 'Annual Operator Cost' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Repair Feedback Loop. Select here if the test/inspection stage will or will not have a diagnostic, repair and re-test process (loop). If 'yes' is selected, the boards failed on that particular test/inspection stage would be repaired, diagnosed and re-tested at that stage. If 'no' is selected the boards failed on that particular test/inspection station will be repaired, diagnosed and passed to the following test/inspection stage.

Test Strategy 2 Inputs (Cont')

Step 6b: Please complete the following Test Strategy 1 Inputs.

Test Stage	Annual Operator Cost [\$]	Repair Feedback Loop	Repair Yield [0%-100%]
AXI	28000	No	90
ICT	35000	Yes	90
FT	35000	Yes	90

Labels and arrows in the image point to: 'Cancel' Button, Strategy 2 Test/Inspection Stages, Annual Operator Cost, Repair Yield, and Repair Feedback Loop.

Figure 13a. Step 6b: Strategy 2 Inputs (cont').

'Cancel' Button

Test Strategy 2 Inputs (cont')

Test Stage	Re-Test Cycles Permitted	Repair Cost [\$]	Diagnostic Cost [\$]
AXI	1	1	1
ICT	3	1	5
FT	3	1	35

Labels and arrows in the image point to: Re-Test Cycles Permitted, Repair Cost, Diagnostic Cost, Strategy 2 Test/Inspection Stages, 'Back' Button, and 'Next' Button.

Figure 13b. Step 6b: Strategy 2 Inputs (cont')

Repair Yield. It is the percentage of boards successfully repaired at that particular test or inspection stage. This input could be any number between 0%-100%. A default value exists for this specific input. If you want to select the default value of 'Repair Yield' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Re-Test Cycles Permitted. It is the maximum number of times allowed for a board to be repaired before scraped. If the *Repair feedback loop* for that particular stage is set to 'yes', the 're-test cycles permitted' input box will become enabled, indicating that a number should be entered. If the *Repair feedback loop* for that particular stage is set to 'no', the 're-test cycles permitted' input box will stay disabled, indicating that no data should be entered. A default value exists for this specific input. If you want to select the default value of 'Re-Test Cycles permitted' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Repair Cost. It is the cost of repairing one single defect at that particular test/inspection stage. A default value exists for this specific input. If you want to select the default value of 'Repair Cost' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Diagnostic Cost. It is the cost of diagnosing one single defect at that particular test/inspection stage. A default value exists for this specific input. If you want to select the default value of 'Diagnostic Cost' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

'Back' button. If you want to go back to the step 6, click the 'back' button. The Step 6 window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box ([Figure 3](#)) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 6b, press the Next button. The window of step 6c ([Figure 14](#)) will appear.

Step 6c: Test Strategy 2 Inputs (cont')

On Step 6c ([Figure 14a & 14b](#)) you have to enter the information about the test strategy 2 of your product (PCA), 6 inputs per test/inspection stage, are required at this step: Equipment Cost, Fixture Cost, Programming Cost, Annual Maintenance Cost, Equipment Depreciation.

Equipment Cost. It is the cost of the test or inspection equipment for that particular station. (This cost will be depreciated in the calculations). A default value exists for this specific input. If you want to select the default value of 'Equipment Cost' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Fixture Cost. It is the cost of the test or inspection fixture for that particular station. (This cost will be depreciated in the calculations). A default value exists for this specific input. If you want to select the default value of 'Fixture Cost' just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Test Strategy 2 Inputs (Cont')

Step 6c: Please complete the following Test Strategy 1 Inputs.

Station	Equipment Cost [\$]	Fixture Cost [\$]
AXI	450000 [DFLT.]	0 [DFLT.]
ICT	500000 [DFLT.]	20000 [DFLT.]
FT	50000 [DFLT.]	15000 [DFLT.]

Buttons: Cancel

Figure 14a. Step 6c: Test Strategy 2 Inputs (cont')

Test Strategy 2 Inputs (cont')

Station	Programming Cost [\$]	Annual Maintenance Cost [\$]	Equipment Depreciation [Years]
AXI	10000 [DFLT.]	25000 [DFLT.]	3 [DFLT.]
ICT	30000 [DFLT.]	20000 [DFLT.]	3 [DFLT.]
FT	30000 [DFLT.]	20000 [DFLT.]	3 [DFLT.]

Buttons: Back, Next

Figure 14b. Step 6c: Test Strategy 2 Inputs (cont')

'Next' button

Programming Cost. It is the cost of programming the test or inspection equipment for that particular station. A default value exists for this specific input. If you want to select the default value of *'Programming Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Annual Maintenance Cost. It is the yearly cost of maintaining the test or inspection equipment and fixture of that particular station. A default value exists for this specific input. If you want to select the default value of *'Annual Maintenance Cost'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

Equipment Depreciation. It is the number of years to depreciate the fixture and equipment costs. A default value exists for this specific input. If you want to select the default value of *'Equipment Depreciation'* just click the 'default' button at the right of the input box. For more information about the defaults, please review the [defaults section](#) in this document.

'Back' button. If you want to go back to the step 6b, click the 'back' button. The Step 6b window will appear.

'Cancel' button. If you want to exit from the 'Inputs window' press the 'Cancel' button. A message box ([Figure 3](#)) will appear to confirm that you really want to exit. If select 'yes' you will exit from the 'Inputs window' and will return to the spreadsheet (you will not exit from Excel). If select 'no' you will return to the 'Inputs window'.

'Next' button. Once you have complete entering all the inputs of step 6c, press the 'Next' button. The last window of the inputs section ([Figure 15](#)) will appear.

When you have completed the 6 steps of the Inputs section, a confirmation window ([figure 15](#)) will appear. If you want to modify the inputs you just have entered, click the 'back' button. If you feel comfortable with your inputs click the 'Done' button. The results will be automatically displayed in the outputs sheet of the workbook. For more information about the outputs, go to the [outputs section](#) in this document.

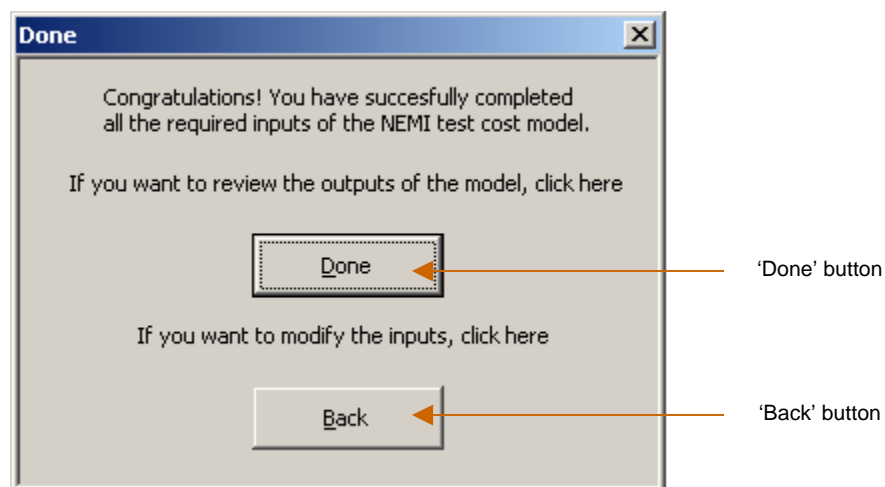


Figure 15. End of the inputs section

Defaults Section.

- [Overview.](#)
- [General Information.](#)
- [DPMO Defaults.](#)
- [Yield Defaults.](#)
- [Time To Market Defaults.](#)
- [Test Strategy Defaults.](#)
 - + [Test Effectiveness.](#)
 - + [Test Access Multiplier.](#)
 - + [Test Time.](#)
 - + [False Reject Rate.](#)
 - + [Number of Test Operators.](#)
 - + [Annual Operator Cost.](#)
 - + [Repair Yield.](#)
 - + [Re-Test cycles permitted.](#)
 - + [Repair Cost.](#)
 - + [Diagnostic Cost.](#)
 - + [Equipment Cost.](#)
 - + [Fixture Cost.](#)
 - + [Programming Cost.](#)
 - + [Annual Maintenance Cost.](#)
 - + [Equipment Depreciation.](#)

Overview. The user can utilize default values (provided with the model) for some of the inputs, these default values are based on medium complexity boards manufactured in the US. In order to have accurate and realistic outputs, it is important to keep to a minimum the usage of default values in the model. The default values are on a separate sheet of the model workbook, that way the user can modify at any time the default values according with the data from their manufacturing site. The same default values (if exist) can be called at any time when entering the [inputs](#).

There are 5 sections in the ‘defaults’ sheet of the workbook. Those sections are: General Information, DPMO, Yield, Time To Market and Test Strategy defaults.

General Information Defaults:

These are the defaults for the second step of the inputs section: The General PCA Information. There are 3 defaults values available for this step (Figure 1): Annual Production Volume, Board (PCA) Cost and Field Return Cost. The default values are:

GENERAL			
1	Annual Production Volume [boards/year]:	72,000	Default Value of the Annual Production Volume
2	Board (PCA) cost [\$]:	\$1,000.00	Default Value of the Board Cost
3	Field Return Cost [\$/per board]:	\$1,500.00	Default Value of the Field Return Cost

Figure 1. General Information Default Values.

72,000 boards per year is the default value for the annual production volume. The default value of the cost of the PCA is \$1,000 USD and for the Field Return Cost is \$1,500 USD. All of these default values* can be changed at any time by the user and can be called during the [inputs section](#).

*Note: these default values are based on medium complexity boards manufactured in the US.

DPMO Defaults:

The defaults for the DPMO section (Figure 2) are used to calculate the defect opportunities and DPMO of the board (PACA) and then to calculate yield, escapes, etc; these defaults are the structural DPMO Joints, structural DPMO component and electrical DPMO component for every component present on the board.

Several components are listed on the DPMO default table (Figure 2) and there is room for other 3 components that could be present on your product (PCA) but not listed in the table.

	DPMO	Structural DPMOJ	Structural DPMOC	Electrical DPMOC		
Type of component	4	Leaded (Gullwing)	200	100	100	Defaults for electrical DPMO component
	5	Leaded (Gullwing)	500	100	100	
	6	Leaded (Gullwing)	700	100	100	
	7	Leaded (Gullwing)	1000	100	100	Defaults for structural DPMO component
	8	Leaded (Gullwing)	10000	100	100	
	9	Leaded (Gullwing)	15000	100	100	
	10	Jlead	300	100	100	Defaults for structural DPMO Joints
	11	Eutectic BGA	100	100	100	
	12	Eutectic BGA	150	100	100	
	13	NonEutectic BGA	150	100	100	
	14	CSP	100	100	100	
	15	Column Grid	100	100	100	
	16	1206 SMT	400	200	100	
	17	0805 SMT	150	300	100	
	18	0402 SMT	150	400	100	
	19	0201 SMT	200	400	100	
	20	1206 Wave	400	500	100	
	21	0805 Wave	150	1000	100	
	22	0402 Wave	150	2000	100	
	23	SMT Connector 1	2000	100	100	
	24	SMT Connector 2	2000	100	100	
	25	Res/Cap Pack 1	100	200	100	
	26	Res/Cap Pack 2	100	200	100	
	27	PTH/Wave 1	2000	200	100	
	28	PTH/Wave 2	2000	200	100	
	29	PTH/Wave 3	2000	200	100	
	30	PTH/Wave 4	2000	200	100	

Figure 2. DPMO Default Values.

These default values* cannot be called during [step 3](#) on the [inputs section](#), but are considered on the [calculations](#). On [step 3](#) the inputs required are related with the number of components and the number of joints per component on the board.

*Note: these default values are based on medium complexity boards manufactured in the US.

Yield Defaults:

These are the default values corresponding to the third step of the inputs section: Yield Inputs. There are 3 default values available for this step (Figure 3): Yield at the 1st stage of Strategy 1, Number of Components on the board and Number of Joints on the board.

YIELD			
31	Yield at the 1st Test Stage of Strategy 1	85.00%	
32	Number of packages on board:	1,000	
33	Number of Joints on board:	10,000	

Figure 3. Yield Default Values

85% yield is the default value for the yield at the 1st stage for strategy 1. The default value of the Number of Components is 1,000 and for Number of Joints is 10,000. All of these default values* can be changed at any time by the user and can be called during the [inputs section](#).

*Note: these default values are based on medium complexity boards manufactured in the US.

Time To Market Defaults:

These are the default values corresponding to step 3b of the inputs section: Time To Market Inputs. There are 3 main areas in the TTM defaults with values available for this step (Figure 4): Product & Investment, Planned Schedule and Early Schedule.

TIME TO MARKET			
34	R&D Percentage of Revenue [%]:	10%	
35	COGS Percentage of Revenue [%]:	45%	
36	S&M Percentage of Revenue [%]:	25%	
37	G&A Percentage of Revenue [%]:	10%	
<u>Planned Schedule</u>			
38	Time to reach peak sales [months]:	6.00	
39	Peak Sales during maturity [units/month]:	1,900	
40	Time for decline period [months]:	6.00	
<u>Early Schedule</u>			
41	Time to reach peak sales [months]:	6.00	
42	Peak Sales during maturity [units/month]:	1,900	
43	Early Introduction [months]:	6.00	

Figure 4. Time To Market default values

Product & Investment: The default value for the Research & development Investment is 10%. For Cost Of Good Sales is 45 %, 25% for Sales and Marketing investment and for General and Admin. Investment is 10%.

Planned Schedule: The default value for the Time to reach peak sales is 6 months, for the peak sales during maturity is 1,900 units per month and for the time to decline period is 6 months.

Early Schedule: The default value for the Time to reach peak sales is 6 months, for the peak sales during maturity is 1,900 units per month and for early introduction is 6 months.

All of these default values* can be changed at any time by the user and can be called during the [inputs section](#).

*Note: these default values are based on medium complexity boards manufactured in the US.

Test Strategy Defaults:

These are the default values corresponding to steps 5 and 6 of the inputs section: Test Strategy Inputs. There are 5 test or inspection stages with 17 inputs each, with values available (Figure 5).

TEST STRATEGY						
44	Field Return Rate [%]:	1.00%				
		MMV	AOI	AXI	ICT	FT
45	Test Effectiveness [%]:	50.00%	75.00%	90.00%	80.00%	80.00%
46	Test Access Multiplier:	0.90	0.90	1.00	0.80	1.00
47	Test Time [min]:	5.00	1.00	3.00	1.00	5.00
48	False Reject Units:	2	0	0	1	2
49	False Reject Rate:	20.00	1000.00	1000.00	100.00	5.00
50	Number of Test Operators:	3	1	1	1	2
51	Annual Test Operator Cost (per operator) [\$]:	28,000	28,000	28,000	35,000	35,000
52	Repair feedback loop [1 or 0]:	1	0	0	1	1
53	Repair Yield [%]:	90.00%	90.00%	90.00%	90.00%	90.00%
54	Re-test Cycles Permitted:	3	0	0	3	3
55	Repair Cost [\$]/per defect:	\$1.00	\$1.00	\$1.00	\$1.00	\$1.00
56	Diagnostic of Defects Cost [\$]/per defect:	\$0.00	\$1.00	\$1.00	\$5.00	\$35.00
57	Equipment Cost [\$]:	\$0	\$200,000	\$450,000	\$500,000	\$50,000
58	Fixture Cost [\$]:	\$0	\$0	\$0	\$20,000	\$15,000
59	Programming Cost [\$]:	\$0	\$10,000	\$10,000	\$30,000	\$30,000
60	Annual Maintenance Cost [\$]:	\$0	\$15,000	\$25,000	\$20,000	\$20,000
61	Equipment Depreciation (years):	0	3	3	3	3

Figure 5. Test Strategy Default Values.

Test Effectiveness: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Test Effectiveness* default value by pressing the 'default' button. The *Test Effectiveness* default value window (Figure 6) will appear.

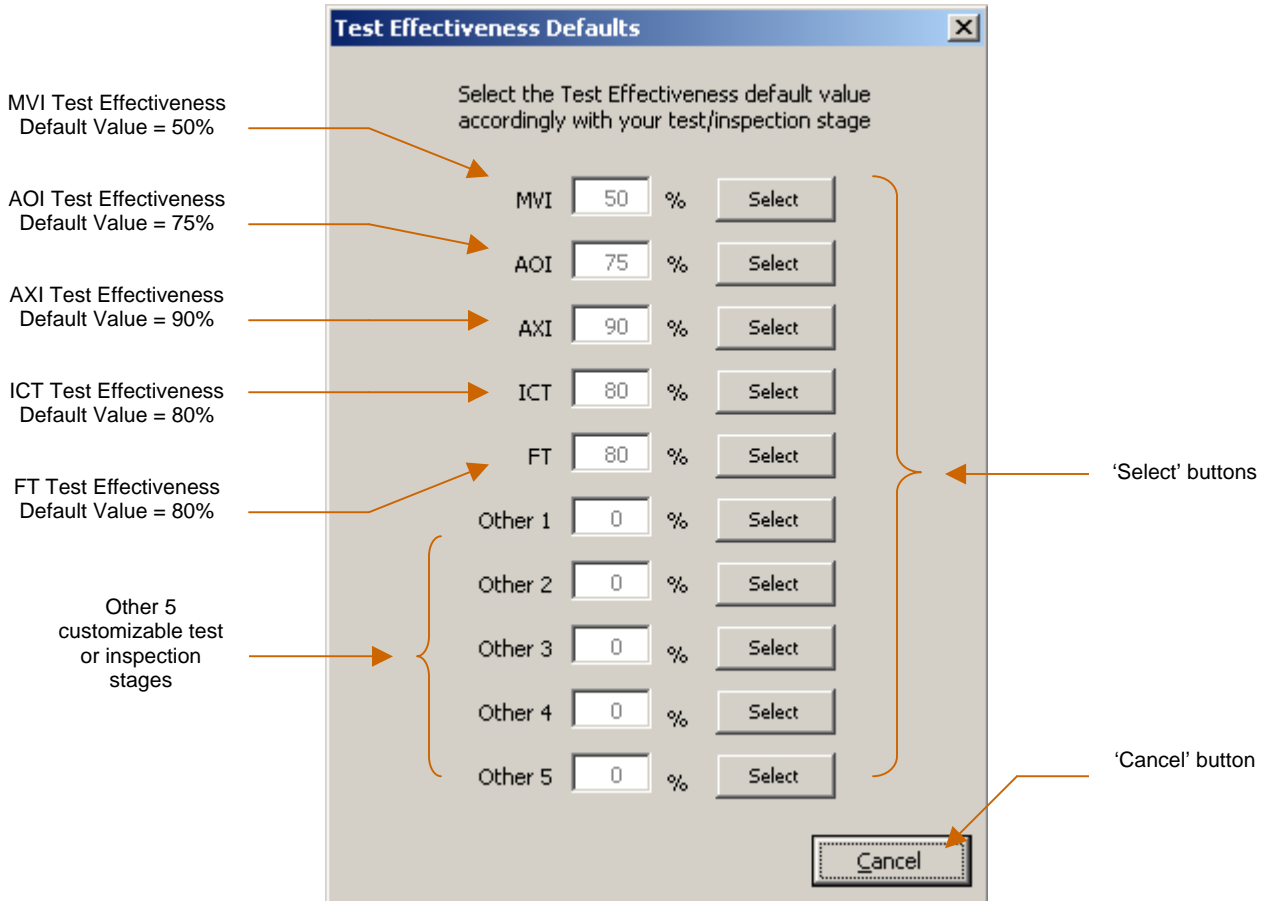


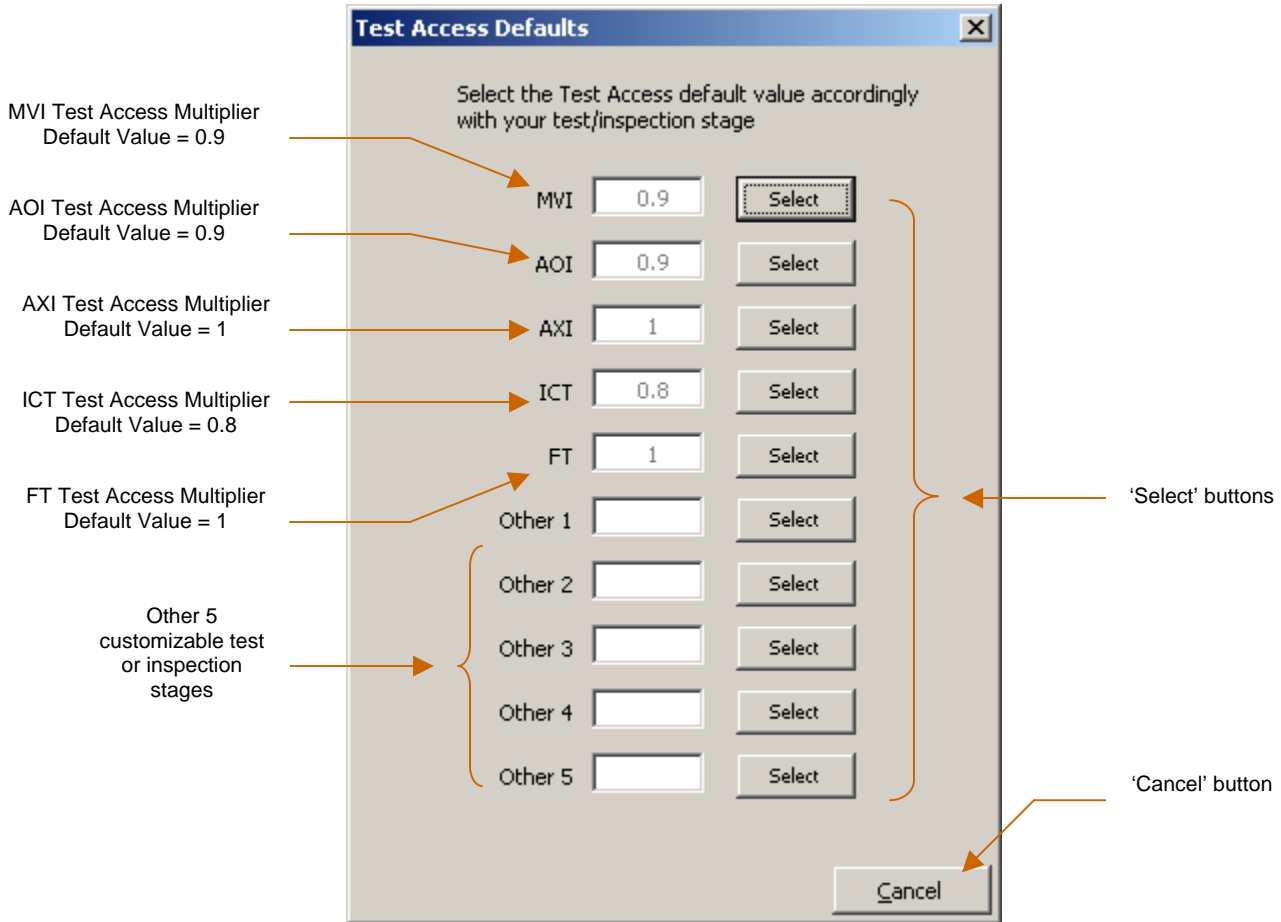
Figure 6. Test Effectiveness Default Values window.

In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 6) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Test Effectiveness* default window (figure 6)

***Note:** these default values are based on medium complexity boards manufactured in the US.

Test Access Multiplier: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Test Access Multiplier* default value by pressing the 'default' button. The *Test Access Multiplier* default value window (Figure 7) will appear.

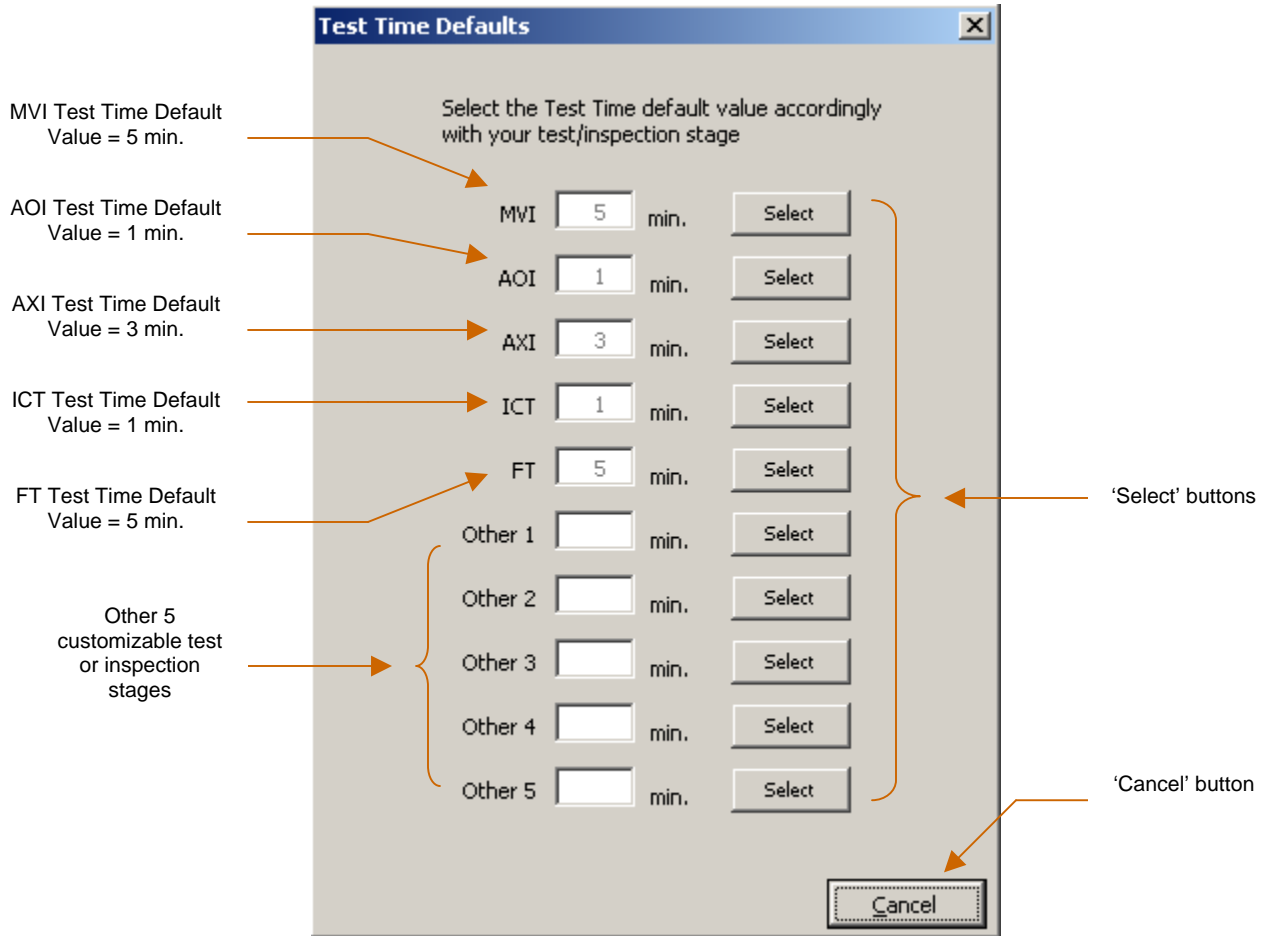


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 7) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Test Access Multiplier* default window (figure 7)

***Note:** these default values are based on medium complexity boards manufactured in the US.

Test Time: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Test Time* default value by pressing the 'default' button. The *Test Time* default value window (Figure 8) will appear.

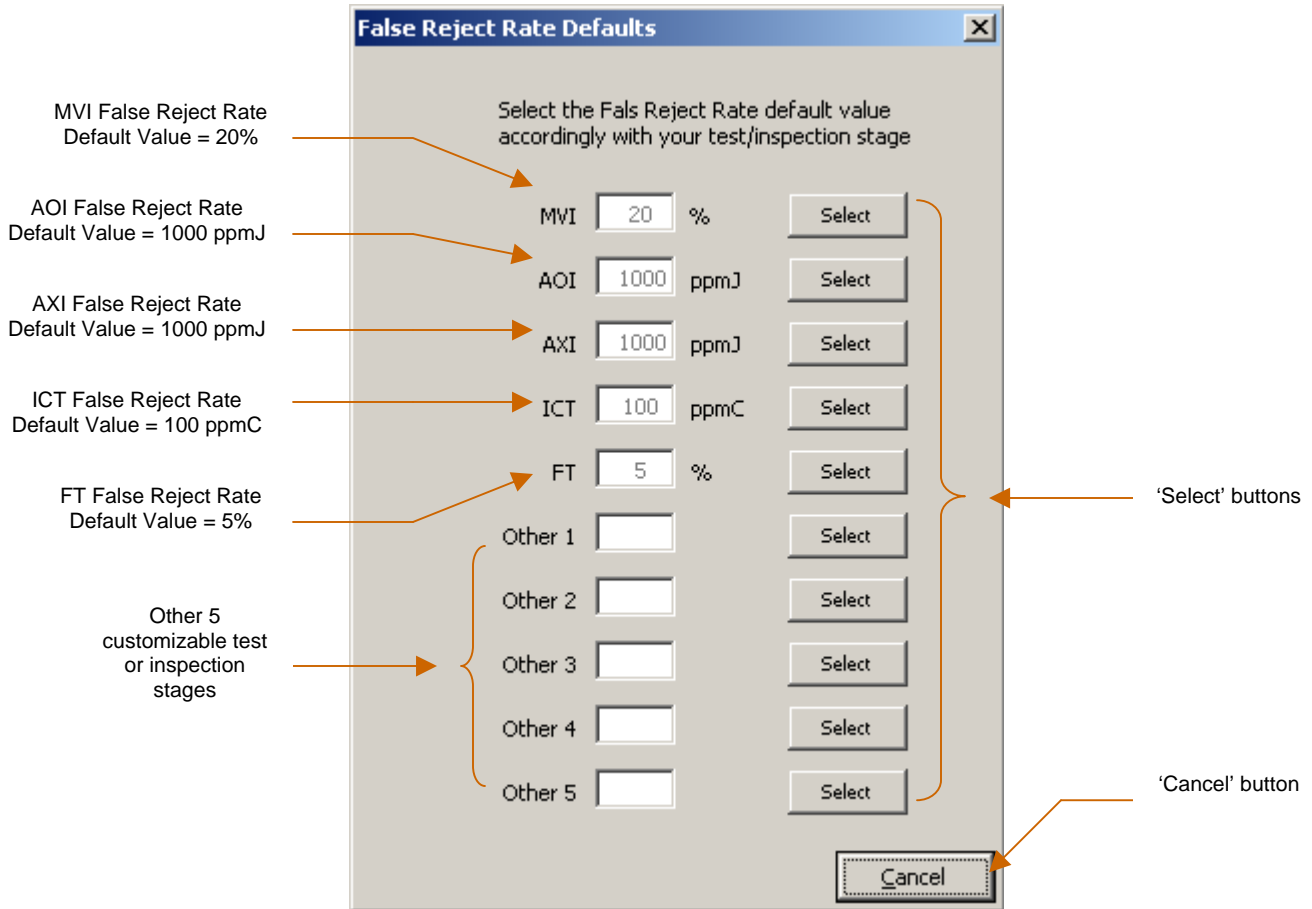


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 8) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Test Time* default window (figure 8)

*Note: these default values are based on medium complexity boards manufactured in the US

False Reject Rate: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *False Reject Rate* default value by pressing the 'default' button. The *False Reject Rate* default value window (Figure 9) will appear.

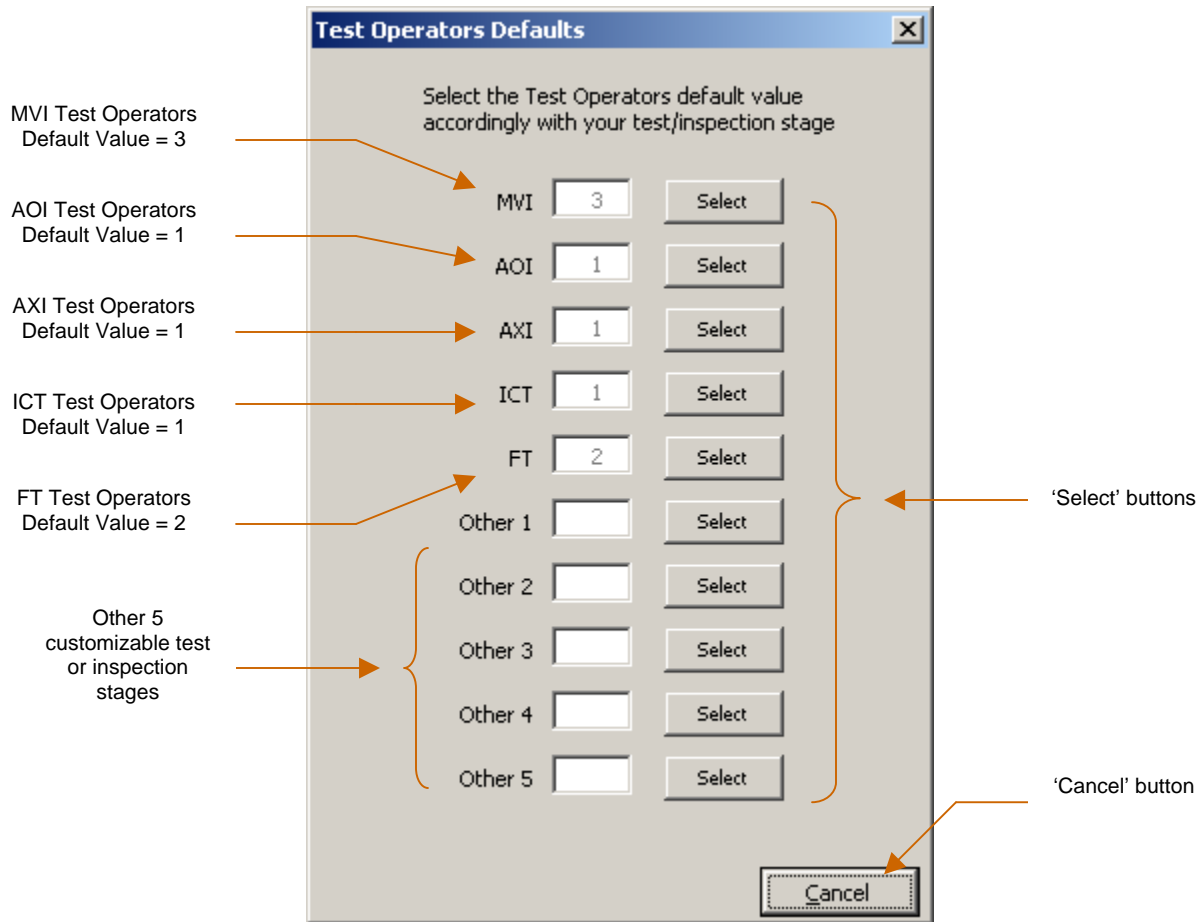


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 9) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *False Reject Rate* default window (figure 9)

***Note:** these default values are based on medium complexity boards manufactured in the US

Number of Test Operators: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Number of Test Operators* default value by pressing the 'default' button. The *Number of Test Operators* default value window (Figure 10) will appear.

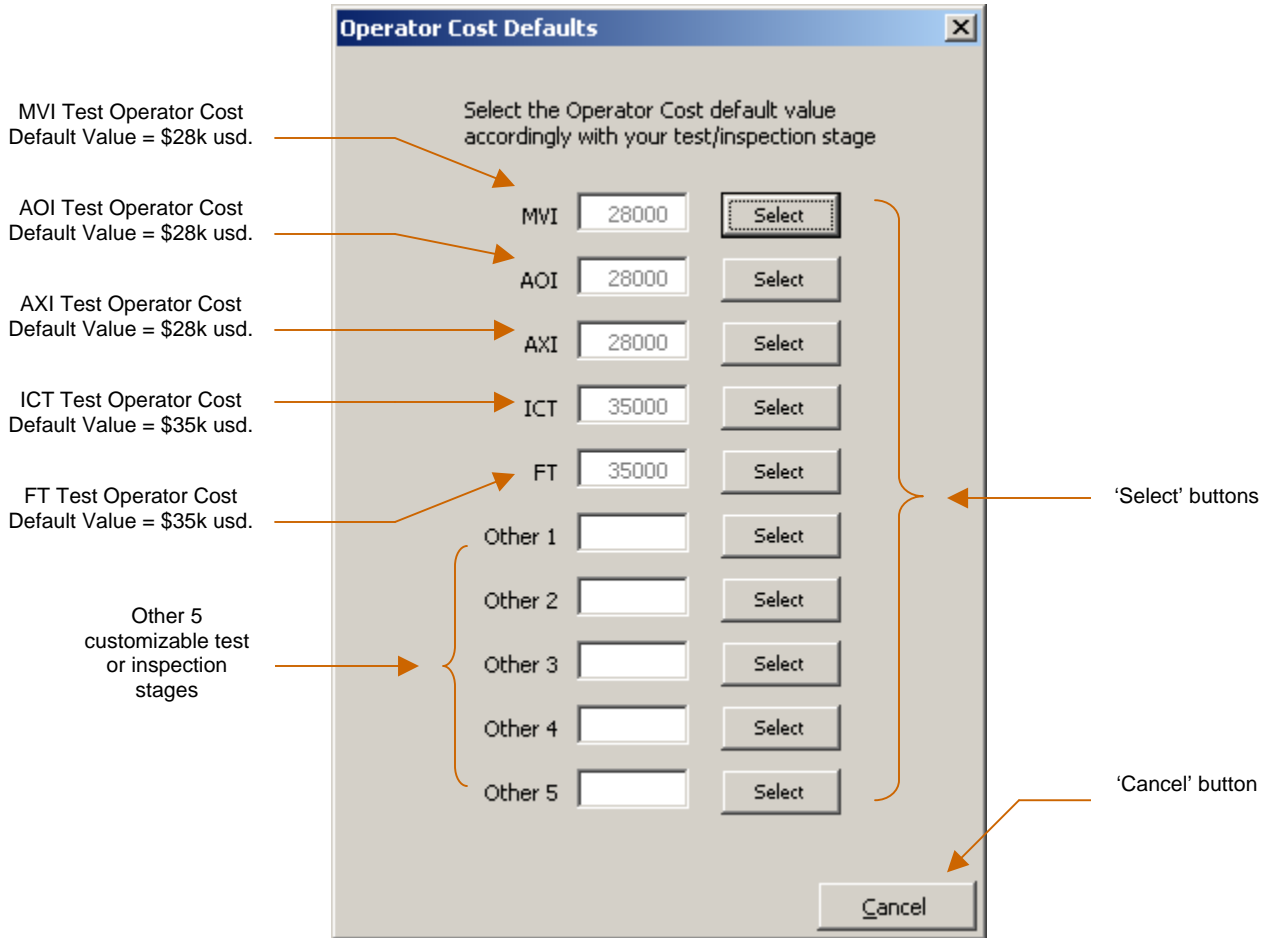


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 10) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Number of Test Operators* default window (figure 10)

***Note:** these default values are based on medium complexity boards manufactured in the US

Annual Operator Cost: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Annual Operator Cost* default value by pressing the 'default' button. The *Annual Operator Cost* default value window (Figure 11) will appear.

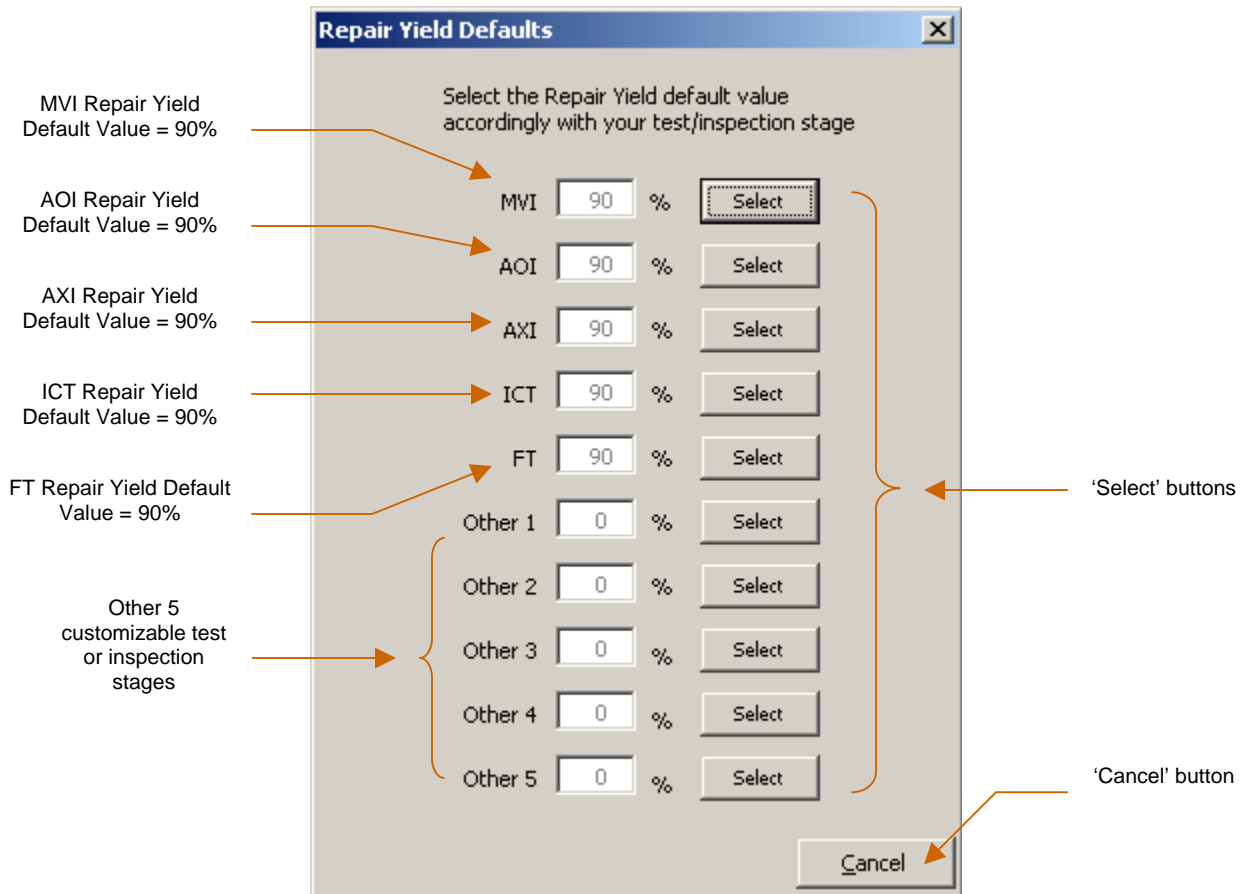


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 11) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Annual Operator Cost* default window (figure 11)

***Note:** these default values are based on medium complexity boards manufactured in the US

Repair Yield: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Repair Yield* default value by pressing the 'default' button. The *Repair Yield* default value window (Figure 12) will appear.

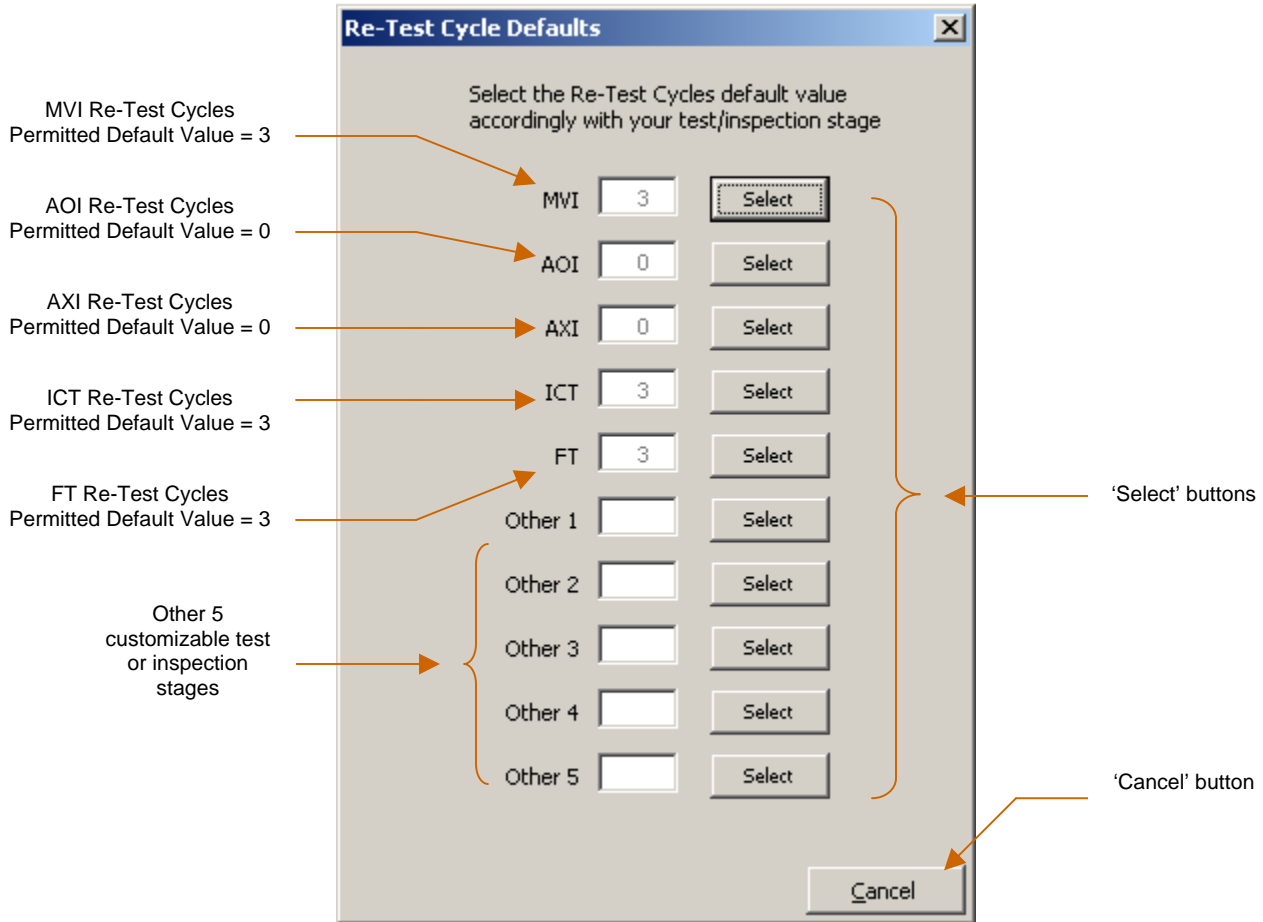


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 12) are exactly the same as those listed on the defaults sheet (figure 5) that means that changing the values of the default sheet will change the values of the *Repair Yield* default window (figure 12)

***Note:** these default values are based on medium complexity boards manufactured in the US

Re-Test Cycles Permitted: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Re-Test Cycles Permitted* default value by pressing the 'default' button. The *Re-Test Cycles Permitted* default value window (Figure 13) will appear.

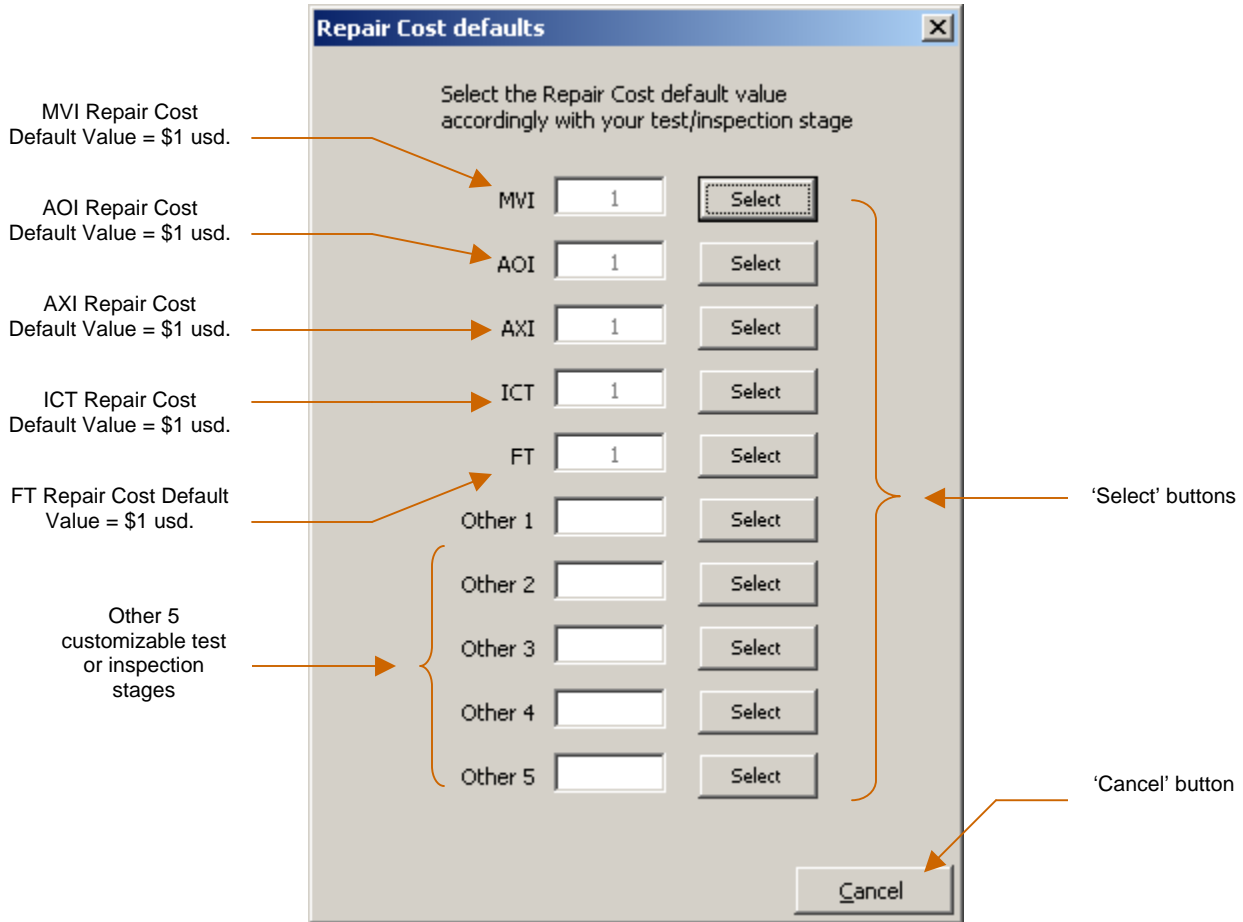


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 13) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Re-Test Cycles Permitted* default window (figure 13).

***Note:** these default values are based on medium complexity boards manufactured in the US

Repair Cost: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Repair Cost* default value by pressing the 'default' button. The *Repair Cost* default value window (Figure 14) will appear.

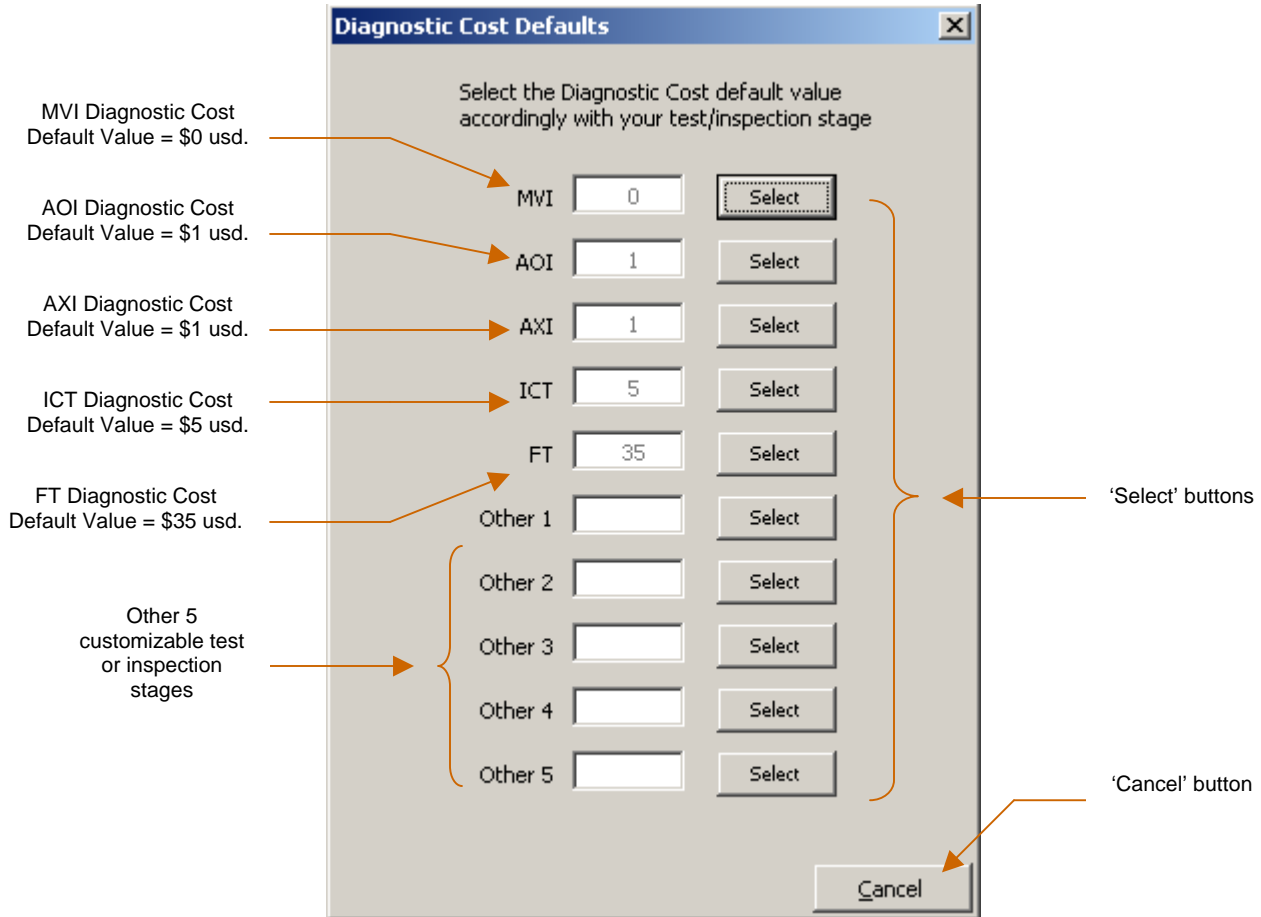


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 14) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet will change the values of the *Repair Cost* default window (figure 14).

***Note:** these default values are based on medium complexity boards manufactured in the US

Diagnostic Cost: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Diagnostic Cost* default value by pressing the 'default' button. The *Diagnostic Cost* default value window (Figure 15) will appear.

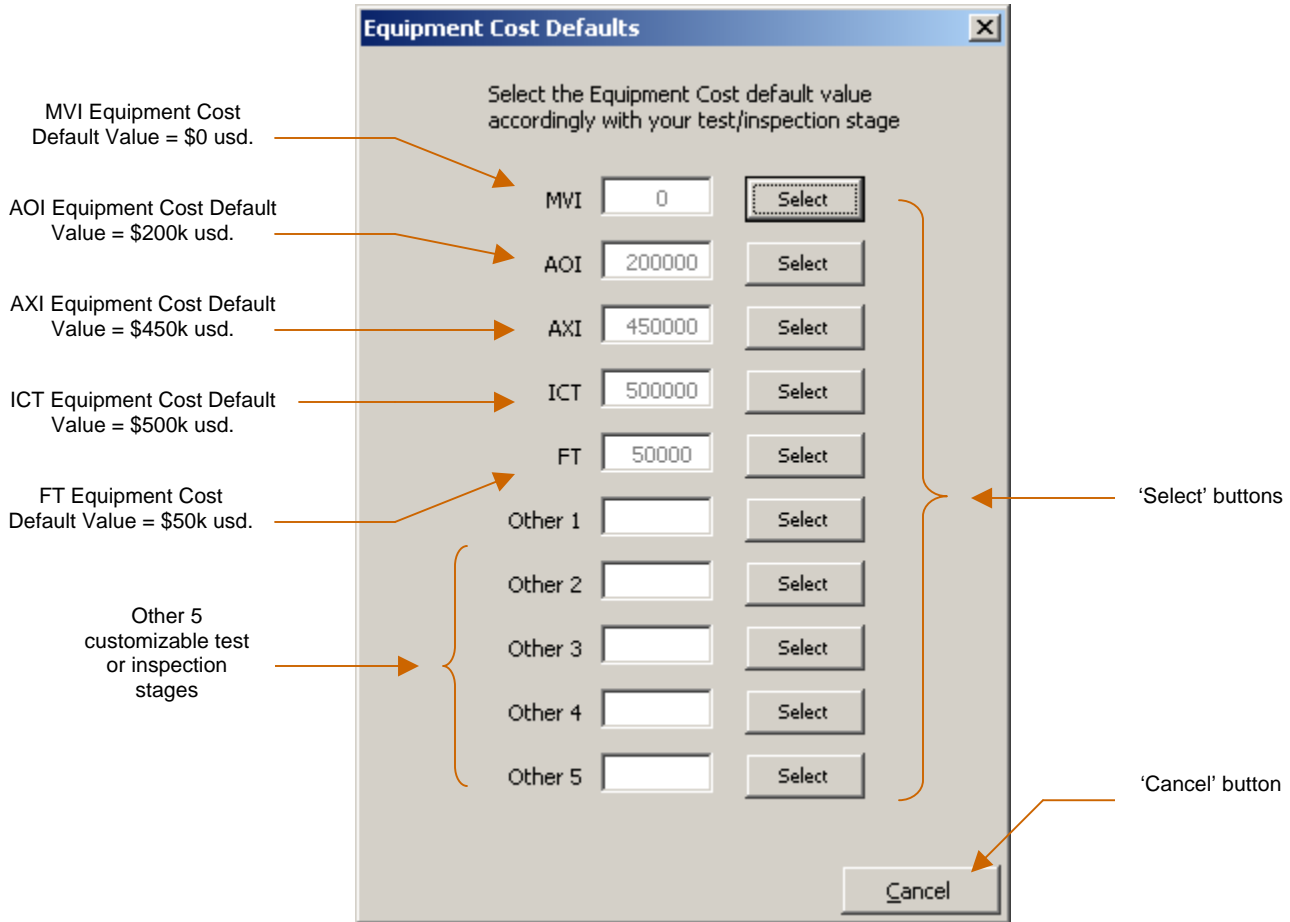


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 15) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Diagnostic Cost* default window (figure 15)

***Note:** these default values are based on medium complexity boards manufactured in the US

Equipment Cost: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Equipment Cost* default value by pressing the 'default' button. The *Equipment Cost* default value window (Figure 16) will appear.

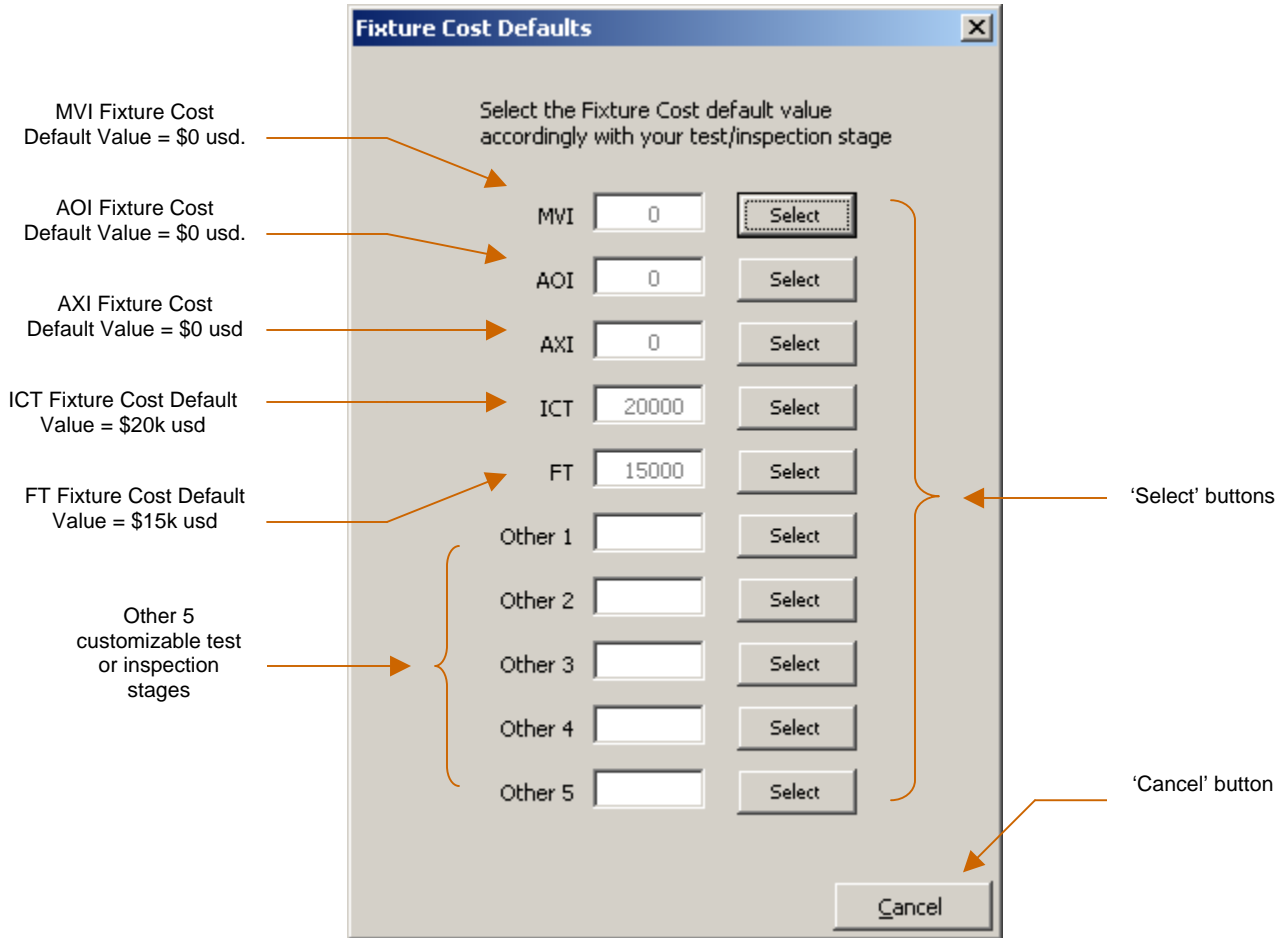


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 16) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Equipment Cost* default window (figure 16)

***Note:** these default values are based on medium complexity boards manufactured in the US

Fixture Cost: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Fixture Cost* default value by pressing the 'default' button. The *Fixture Cost* default value window (Figure 17) will appear.

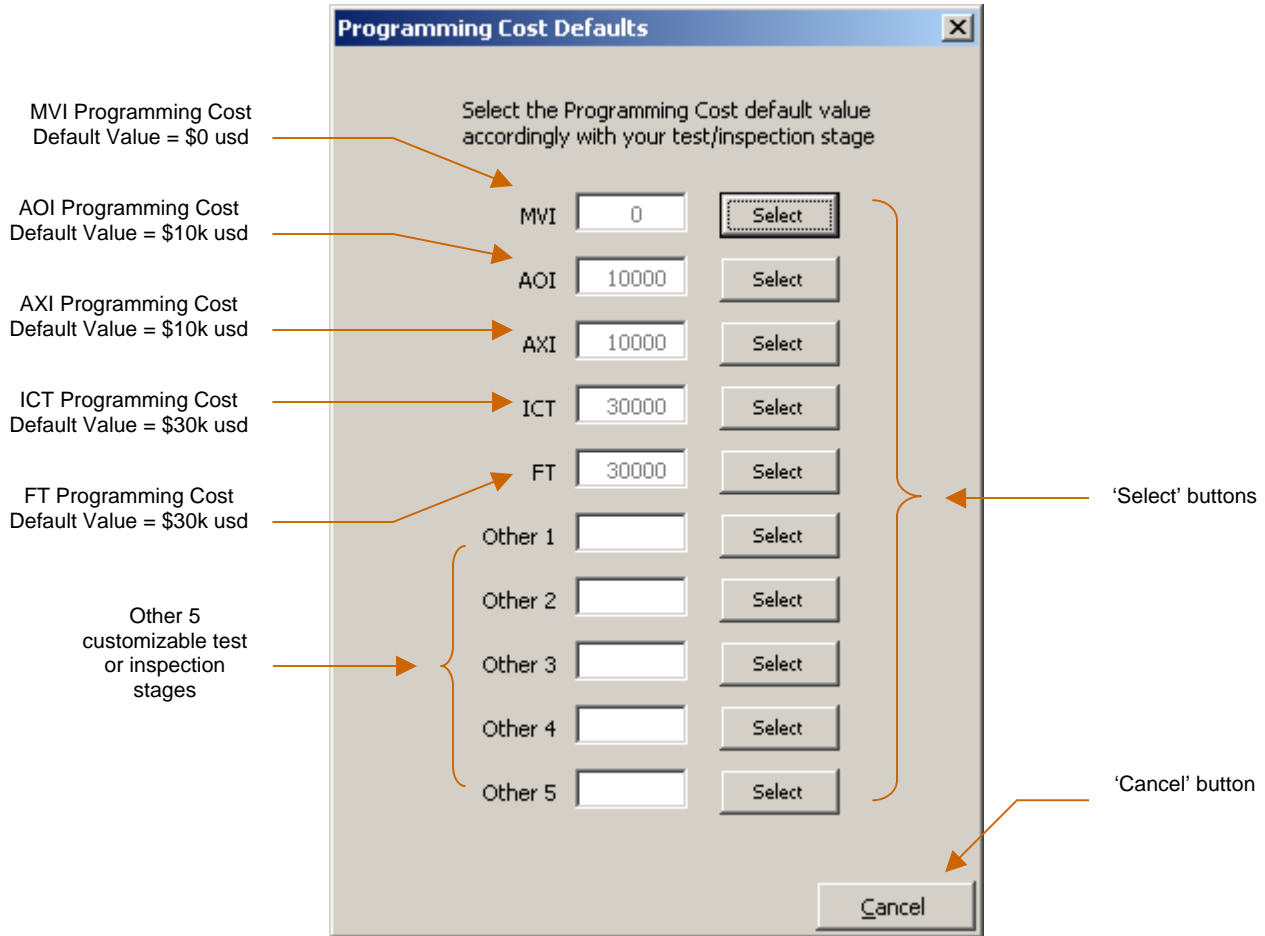


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 17) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet will change the values of the *Fixture Cost* default window (figure 17)

***Note:** these default values are based on medium complexity boards manufactured in the US

Programming Cost: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Programming Cost* default value by pressing the 'default' button. The *Programming Cost* default value window (Figure 18) will appear.

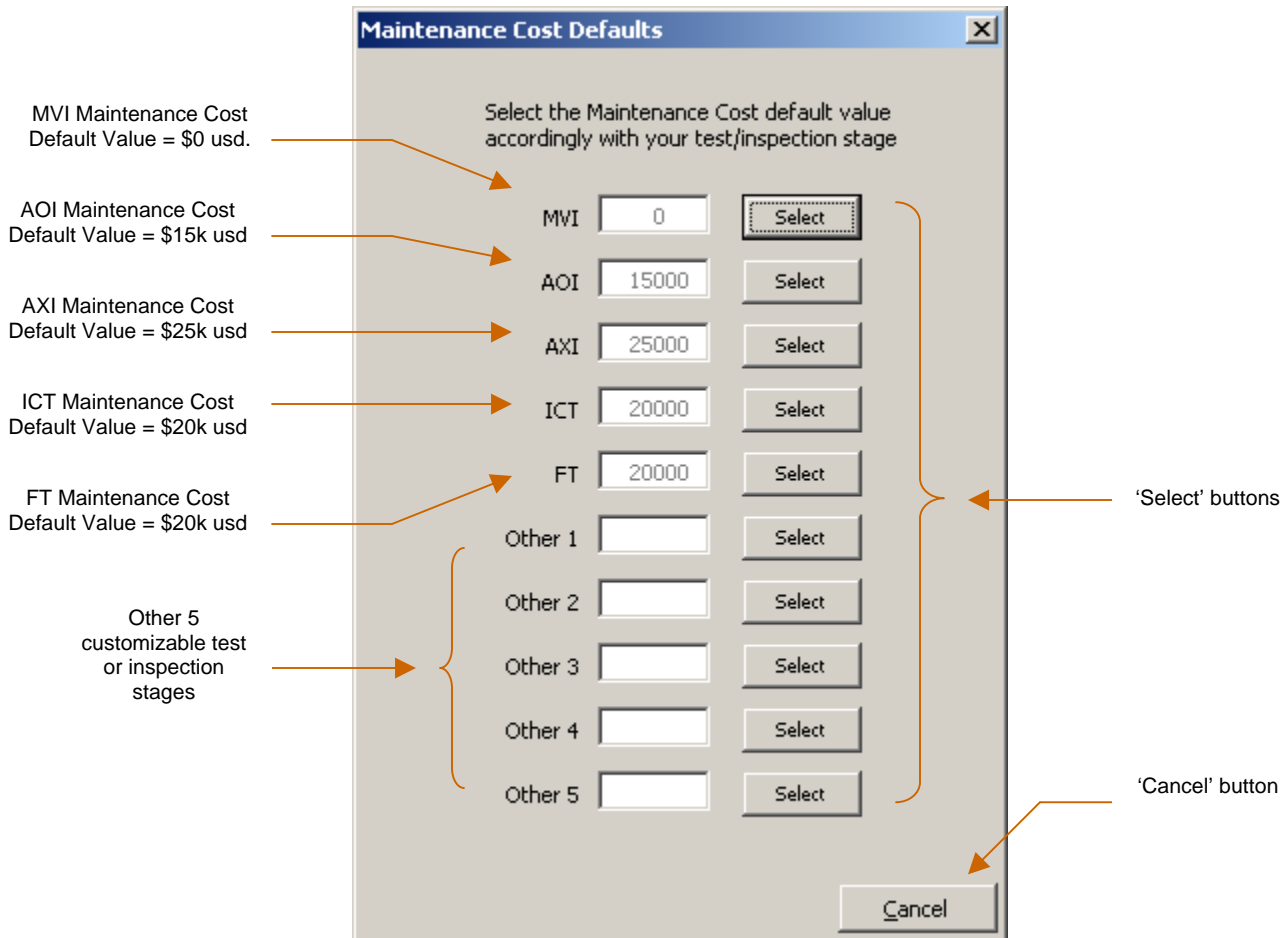


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 18) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Programming Cost* default window (figure 18)

***Note:** these default values are based on medium complexity boards manufactured in the US

Annual Maintenance Cost: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Annual Maintenance Cost* default value by pressing the 'default' button. The *Annual Maintenance Cost* default value window (Figure 19) will appear.

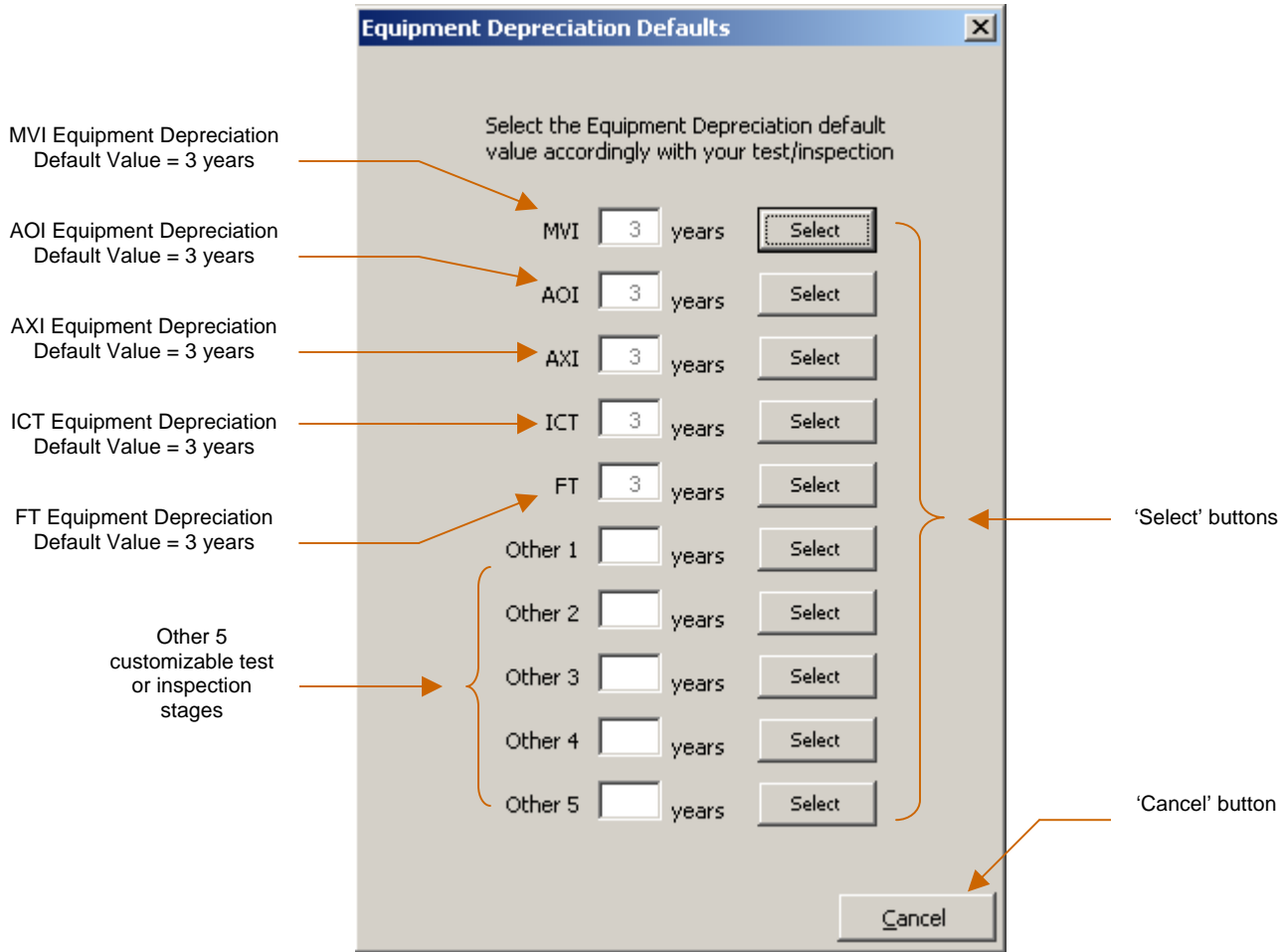


In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 19) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Annual Maintenance Cost* default window (figure 19)

***Note:** these default values are based on medium complexity boards manufactured in the US

Equipment Depreciation: When entering the test effectiveness input for strategy 1 and strategy 2 on steps 5 and 6 of the inputs section, you can call the *Equipment Depreciation* default value by pressing the 'default' button. The *Equipment Depreciation* default value window (Figure 20) will appear.



In this window you can select, by pressing the 'select' button, a default value for your input accordingly with the test or inspection stage of your strategy. 5 test or inspection stages are listed on the default window (Manual Visual Inspection, Automatic Optical Inspection, Automatic X-ray Inspection, Functional Test and In-Circuit Test) but there is room for other 5 test or inspection stages. You can 'customize' any of these 5 'others' test or inspection stages by changing its name and value on the defaults sheet (Figure 5).

The default values displayed on this window (figure 20) are exactly the same as those listed on the defaults sheet (figure 5) which means that changing the values of the default sheet (figure 5) will change the values of the *Equipment Depreciation* default window (figure 20)

***Note:** these default values are based on medium complexity boards manufactured in the US

Calculations Section.

- [Overview.](#)
- [Yield.](#)
- [Scrap Cost.](#)
- [Repair Cost.](#)
- [Diagnostic Cost.](#)
- [Test Operator Cost.](#)
- [Field Return Cost.](#)
- [Programming Cost.](#)
- [Equipment Cost.](#)
- [Fixture Cost.](#)
- [Maintenance Cost.](#)
- [Equipment-related Costs.](#)
- [Test Cost per board.](#)
- [Re-Test costs.](#)
- [Yield-related Costs.](#)
- [Total Test Costs.](#)
- [Yield Enhancement Savings.](#)
- [Total savings with strategy 2.](#)
- [Return of Investment Calculations.](#)
- [Time To Market Calculations.](#)

Overview. A user normally will not modify the calculations sheet of the model workbook. However, this section explains the formulas (and the concept behind) used in the model to calculate the results shown in the [outputs section](#). The following are the calculations made in the model:

- | | | |
|-----------------------|---------------------------|---------------------------------|
| - Yield | - Equipment Costs | - Yield-related Costs |
| - Diagnostic Costs | - Fixture Costs | - Total Test Costs |
| - Repair Costs | - Maintenance Costs | - Yield enhancement savings |
| - Scrap Costs | - Equipment-related Costs | - Total savings with strategy 2 |
| - Field Return Costs | - Test Cost per board | - Return of Investment metrics |
| - Test Operator Costs | - Re-test Cost | - Time To Market Savings |
| - Programming Costs | | |

Yield.

A) Yield Calculation. Yield is the area under the probability density curve between tolerances. From the Poisson distribution, this equates to the probability with zero failures. Mathematically, this relationship is

$$Y = P(x = 0) = \frac{e^{-\lambda} \lambda^x}{x!} = e^{-\lambda} = e^{-\frac{D}{U}} = e^{-DPU}$$

Equation 1. Yield

Where λ is the mean of the distribution and x is the number of failures. This relationship is shown pictorially in Figure 1.

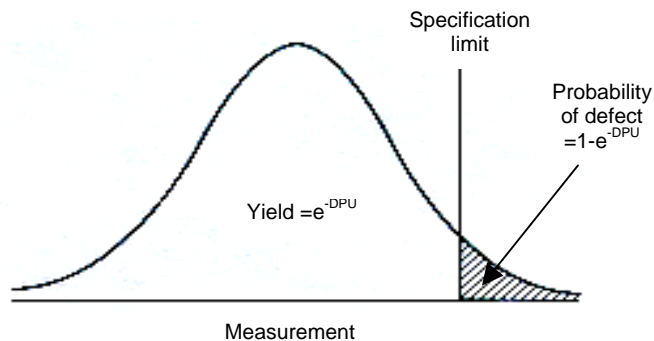


Figure 1. Yield plot.

B) DPMO calculation using DPMO data. Some organizations give focus only to the rate of defects at the end of a process. A defect per unit calculation, however, can give additional insight into a process by including the number of opportunities for failure. A defect per unit metric considers the number of opportunities for failure within the calculations. A Pareto chart of the defects by DPMO can give insight to where process improvement efforts should focus.

An application example of *DPMO* is the soldering of components onto printed circuit boards. For this case, the total number of opportunities for failure could be the number of components plus the number of solder joints (sometimes insertion is also included as a opportunity for failure). A benefit of using *DPMO* for this situation is that many different part numbers pass through a printed-circuit board assembly process. Each of these part numbers typically contain a different number of solder joints and components. With a *DPMO* metric we can now have a uniform measurement for the process, not just for the product. Measurements that focus on the process as opposed to the product, lead more directly to effective process improvement activities.

In the Test Cost Model, in step 3 of the inputs section, the *DPMO* of the process is calculated with the following equation:

$$DPMO = \frac{D}{O} \times 10^6$$

Equation 2. *DPMO* formula.

Where *D* is the defects on board and *O* is the total opportunities for defect. In the spreadsheet, *D* is calculated as the sum of the structural defects (*D_S*) plus electrical defects (*D_E*):

$$D = D_S + D_E$$

Equation 3. Defects on Board

Structural and electrical defects are calculated with the number of components and joints on the board, the structural and electrical *DPMO_C* (components) and *DPMO_J* (joints) and with the structural and electrical multiplier:

$$D_S = \frac{(C_B \times S_C \times M_S) + (J_B \times S_J \times M_S)}{10^6}$$

Equation 4. Structural Defects

$$D_E = \frac{C_B \times E_C \times M_E}{10^6}$$

Equation 5. Electrical Defects

The electrical and structural multiplier can be modified by the user in order to reduce or increase the electrical and structural number of defects on the board. For example, if there is a known design problem with the component, a structural multiplier of 2 or 3 will increase the defects on that component to reflect the design problem.

C) DPMO calculation using Yield data. If a user does not have DPMO information available, but would like to use instead the yield data to backwards calculate the DPMO the formula to use is the same as in equation 2. But the defects on board (D) are calculated different. From equation 1 we know that the yield is:

$$Y_n = e^{-D_F}$$

Equation 6. Yield at stage n.

Where D_F is the number of defects found at test stage n. Test coverage can be defined as:

$$T_C = T_E \times T_A$$

Equation 7. Test Coverage

Where T_E is the test effectiveness and T_A is the test access. The number of defects found on a particular test stage is:

$$D_F = T_C \times D$$

Equation 7a. Defects found.

Where T_C is the test coverage at that particular stage, and D is the number of defects on the board. Substituting equation 7 into equation 7a, we have that:

$$D_F = T_E \times T_A \times D$$

Equation 8. Defects Found at stage n

And substituting equation 8 into equation 6:

$$Y_n = e^{-T_E \times T_A \times D}$$

$$-\ln(Y_n) = T_E \times T_A \times D$$

$$D = -\frac{\ln(Y_n)}{T_E \times T_A}$$

Equation 9. Defects on Board

$$DPMO = -\frac{\ln(Y_n)}{O \times T_E \times T_A}$$

← DPMO calculated using yield data. Y_n is the yield at stage 'n'

Equation 10. DPMO calculated from yield

D) Defect escapes. The *DPMO* calculated on B) or C) is used as the number of defects entering to test strategy 1 and test strategy 2. The yields of the test stages are calculated using the formula of equation 6. The defects entering to following stages are the defects that escape from previous stages.

The defects that escape from a test stage can be defined as the total defects on board minus the defects found at that particular stage:

$$Do_n = Db - Df_n$$

$$Do_n = Db - (Tc_n \times Db)$$

$$Do_n = Db(1 - Tc_n)$$

Equation 11. Defect escapes from stage n.

Do_n is the number of defects that escape from stage 'n', Db is the number of defects on the board, Df_n is the number of defects found at stage 'n' and Tc_n is the test coverage at stage 'n'.

E) Test Effectiveness. The effectiveness of each test strategy is defined in the model as the relationship of the defects that enter to the strategy and the defects that escape from that strategy.

$$T_{En} = \frac{Di_n - Do_n}{Di_n}$$

Equation 12. Test effectiveness of strategy n.

Where Di_n is the number of defects entering to strategy 'n' and Do_n is the number of defects escaping from strategy 'n'.

Scrap Cost.

Scrap cost is the cost of the failed boards that could not be repaired within the repair cycles permitted. The scrap cost at stage 'n' is defined as:

$$Cs_n = Dr_n \times Fy_n \times Cb$$

Equation 13. Annual scrap cost.

Where Dr_n is the annual defect rate at stage 'n', Fy_n is the number of boards that couldn't be repaired within the cycle times permitted and Cb is the cost of the board. The annual defect rate at stage 'n' (Dr_n) can be calculated as the annual production volume times the complement of the yield at stage 'n' (Y_n):

$$Dr_n = (1 - Y_n)V_A$$

Equation 14. Annual failure rate.

And the rate of unsuccessful repaired boards (Fy_n) can be obtained with the repair yield (Ry_n) complement raised to the power of the repair cycles permitted (Cy_n):

$$Fy_n = (1 - Ry_n)^{Cy_n}$$

Equation 15. Unsuccessful repair rate

Substituting equations 15 and 14 into equation 13:

$$Cs_n = [(1 - Y_n)V_A \times (1 - Ry_n)^{Cy_n}] \times Cb$$

Equation 16. Annual scrap cost.

The total Scrap Cost of the strategy is the sum of the scrap cost of the individual stages:

$$TCs = \sum_{i=1}^n Cs_n$$

Repair Cost

Repair cost at stage 'n' is the cost of repairing the defects found at stage 'n'. If there is no repair feedback loop set for stage 'n', the boards will be diagnosed, repaired and sent forward to the following stage, hence, no re-test cost will occur and the defect escapes from repair (due to repair yield) will be added to the defects entering to the following station.

When there is no repair feedback loop, the repair cost at stage 'n' (Rc_n) is defined as the annual defect rate (Dr_n) times the cost of repairing one defect (Cr):

$$Rc_n = Dr_n \times Cr$$

Equation 17. General Annual repair cost

Substituting equation 14 into equation 17:

$$Rc_n = (1 - Y_n)V_A \times Cr$$

Equation 18. Annual repair cost

Which is the annual repair cost when the repair feedback loop is 0. When a repair feedback loop exists for stage 'n', the repair cost of that stage can be calculated as the cost of repairing the defects found at stage 'n' plus the cost of repairing the defects found after the repair cycle 1, plus the cost of repairing the defects found after the repair cycle 2, etc; until we reach the maximum number of repair cycles permitted that was established on the inputs section. It is important to note that a maximum of 3 iterations are calculated, even when the repair cycles permitted is greater than 3:

$$Rc_{n0} = (1 - Y_n)V_A \times Cr$$

Equation 19. Annual repair cost with cycle times permitted = 0.

$$Rc_{n1} = Rc_{n0} + (Rc_{n0})(1 - Ry_n)$$

Equation 20. Annual repair cost with cycle times permitted = 1.

$$Rc_{n2} = Rc_{n1} + (Rc_{n1})(1 - Ry_n)$$

Equation 21. Annual repair cost with cycle times permitted = 2.

$$Rc_{n3} = Rc_{n2} + (Rc_{n2})(1 - Ry_n)$$

Equation 22. Annual repair cost with cycle times permitted = 3.

Where Rc_{n0} is the repair cost when the repair feedback loop is 0, V_A is the annual production volume, Y_n is the yield at stage n, Ry_n is the repair yield at stage n, Rc_{n1} is the repair cost when the repair feedback loop is 1, Rc_{n2} is the repair cost when the repair feedback loop is 2 and Rc_{n3} is the repair cost when the repair feedback loop is 3. The total Repair cost for a given strategy, is the sum of the repair costs of the stages:

$$TRC = \sum_{i=1}^n Rc_n$$

Diagnostic Cost

Diagnostic cost at stage 'n' is the cost of diagnosing the defects found at stage 'n'. If there is no repair feedback loop set for stage 'n', the boards will be diagnosed, repaired and sent forward to the following stage, hence, no re-test cost will occur and the defect escapes from repair (due to repair yield) will be added to the defects entering to the following station.

When there is no repair feedback loop, the diagnostic cost at stage 'n' (Dc_n) is defined as the annual defect rate (Dr_n) times the cost of diagnosing one defect (Cd) plus the cost of diagnosing the false rejects (Cd_F):

$$Dc_n = (Dr_n \times Cd) + Cd_F$$

Equation 23. General Annual diagnostic cost.

Substituting equation 14 into equation 23:

$$Dc_n = [(1 - Y_n)V_A \times Cd] + Cd_F$$

Equation 24. Annual diagnostic cost.

Which is the annual diagnostic cost when the repair feedback loop is 0.

The cost of diagnosing the false rejects (Cd_F) can be calculated as the number of false calls (N_F) times the cost of diagnosing a defect (Cd):

$$Cd_F = N_F \times Cd$$

Equation 25. Cost of diagnosing false calls.

If using ppmJ as the unit for the false rejects, the number of false rejects will be:

$$N_F = \frac{J_B \times T_A \times Db \times V_A \times Fr}{10^6}$$

Equation 25a. Number of false rejects with ppmJ units.

Where J_B is the number of joints on the board, T_A is the test access, Db is the number of defects on the board, V_A is the annual production volume and Fr is the false reject rate.

If using ppmC as the unit for the false rejects, the number of false rejects will be:

$$N_F = \frac{C_B \times T_A \times Db \times V_A \times Fr}{10^6}$$

Equation 25b. Number of false rejects with ppmC units.

Where C_B is the number of components on the board, T_A is the test access, Db is the number of defects on the board, V_A is the annual production volume and Fr is the false reject rate.

If using % of boards as the unit for the false rejects, the number of false rejects will be:

$$N_F = V_A \times Fr$$

Equation 25c. Number of false rejects with % boards units.

Where V_A is the annual production volume and Fr is the false reject rate.

When a repair feedback loop exists for stage 'n', the diagnostic cost of that stage can be calculated as the cost of diagnosing the defects found at stage 'n' plus the cost of diagnosing the defects found after the repair cycle 1, plus the cost of diagnosing the defects found after the repair cycle 2, etc; until we reach the maximum number of repair cycles permitted that was established on the inputs section.

It is important to note that a maximum of 3 iterations are calculated, even when the repair cycles permitted is greater than 3:

$$Dc_{n0} = [(1 - Y_n)V_A \times Cd] + Cd_F$$

Equation 26. Annual diagnostic cost with cycles permitted = 0.

$$Dc_{n1} = (Dc_{n0}) + (Dc_{n0})(1 - Ry_n) + Cd_F$$

Equation 27. Annual diagnostic cost with cycles permitted = 1.

$$Dc_{n2} = (Dc_{n1}) + (Dc_{n1})(1 - Ry_n) + Cd_F$$

Equation 28. Annual diagnostic cost with cycles permitted = 2.

$$Dc_{n3} = (Dc_{n2}) + (Dc_{n2})(1 - Ry_n) + Cd_F$$

Equation 29. Annual diagnostic cost with cycles permitted = 3.

Where Dc_{n0} is the diagnostic cost when the repair feedback loop is 0, V_A is the annual production volume, Y_n is the yield at stage n, Ry_n is the repair yield at stage n, Dc_{n1} is the diagnostic cost when the repair feedback loop is 1, Dc_{n2} is the diagnostic cost when the repair feedback loop is 2, Dc_{n3} is the diagnostic cost when the repair feedback loop is 3 and Cd_F is the cost of diagnosing the false reject calls. The total Diagnostic cost for a given strategy, is the sum of the diagnostic costs of the stages:

$$TDc = \sum_{i=1}^n Dc_n$$

Test Operator Cost

The total test operator cost at stage 'n' is defined in the model as the number of operators (Op_n) at that stage times the annual cost per operator (Co).

$$Co_n = Op_n \times Co$$

Equation 30. Operator costs at stage n.

The total Test Operator cost for a given strategy, is the sum of the test operator costs of the stages:

$$TCO = \sum_{i=1}^n Co_n$$

Equation 30a. Total Operator Cost for the test strategy.

Field Return Cost

A) Annual Field Return for Strategy 1. The annual field return cost for strategy 1 (FRC_1) is defined in the model as the annual production volume (V_A) times the cost of one field return (FRC) times the field return rate (Rr):

$$FRC_1 = V_A \times FRC \times Rr$$

Equation 31. Field Return cost for strategy 1.

B) Annual Field Return for Strategy 2. The field return rate (Rr) could be a difficult number to get, which is why in the model the field return rate it is only asked as an input for strategy 1. The field return rate for strategy 2 is calculated, then, using a relationship between the defect escapes out of strategy one (Do_1) and the defect escapes out of strategy 2 (Do_2) times the field return costs of strategy one (FRC_1):

$$FRC_2 = \frac{Do_1}{Do_2} \times FRC_1$$

Equation 32. General field return cost for strategy 2.

Then, substituting equation 31 into equation 32:

$$FRC_2 = \frac{Do_1}{Do_2} \times V_A \times FRC \times Rr$$

Equation 33. Field return cost for strategy 2.

Programming Costs

The total programming cost (TCp) is the direct sum of the programming costs of every test/inspection stage in the strategy (Cp_n):

$$TCp = \sum_{i=1}^n Cp_n$$

Equation 34. Total programming costs.

Equipment Costs

The total equipment cost (TCe) is the direct sum of every equipment cost of the test stages on the strategy (Ce_n) depreciated by the number of years entered at the inputs section (Dep_n):

$$TCe = \sum_{i=1}^n \frac{Ce_n}{Dep_n}$$

Equation 35. Total equipment cost.

Fixture Costs

The total fixture cost (TCf) is the direct sum of every fixture cost of the test stages on the strategy (Cf_n) depreciated by the number of years entered at the inputs section (Dep_n):

$$TCf = \sum_{i=1}^n \frac{Cf_n}{Dep_n}$$

Equation 36. Total fixture costs.

Maintenance Costs

The total maintenance cost (TCm) is the direct sum of the programming costs of every test/inspection stage in the strategy (Cm_n):

$$TCm = \sum_{i=1}^n Cm_n$$

Equation 37. Total maintenance costs.

Equipment-related Costs

It is the sum of all the total costs that are related with test hardware, software and labor on the strategy like: test operator costs (TCo), programming costs (TCp), equipment costs (Tce), fixture costs (TCf) and maintenance costs (TCm):

$$Ec = TCo + TCp + Tce + TCf + TCm$$

Equation 38. Equipment-related costs

Test Cost per board

The test cost per board (Bt_c) it is defined in the cost model as the equipment-related costs (Ec) divided by the annual production volume (V_A):

$$Bt_c = \frac{Ec}{V_A}$$

Equation 39. Test Cost per board.

Re-Test Costs

Re-Test cost is the cost of testing boards more than one time due to an unsuccessful repair (repair yield) or to a false reject. As in repair and diagnostic costs calculations, the re-test cost depends on the repair cycle times permitted.

When the repair feedback loop exists for stage 'n', the re-test cost of that stage can be calculated as the cost of testing boards after the repair cycle 1, plus the cost of testing boards after the repair cycle 2, etc; until we reach the maximum number of repair cycles permitted that was established on the inputs section.

$$Rt_{C0} = [(1 - Y_n)V_A \times Bt_C] + Cr_F$$

Equation 40. Re-Test Cost when cycle times permitted = 0

$$Rt_{C1} = Rt_{C0} + Rt_{C0}(1 - Y_n) + Cr_F$$

Equation 41. Re-Test Cost when cycle times permitted = 1

$$Rt_{C2} = Rt_{C1} + Rt_{C1}(1 - Y_n) + Cr_F$$

Equation 42. Re-Test Cost when cycle times permitted = 2

$$Rt_{C3} = Rt_{C2} + Rt_{C2}(1 - Y_n) + Cr_F$$

Equation 43. Re-Test Cost when cycle times permitted = 3

Where Rt_{C0} is the re-test cost when the repair feedback loop is 0, V_A is the annual production volume, Y_n is the yield at stage n, Bt_C is the test cost per board, Rt_{C1} is the re-test cost when the repair feedback loop is 1, Rt_{C2} is the re-test cost when the repair feedback loop is 2, Rt_{C3} is the re-test cost when the repair feedback loop is 3 and Cr_F is the cost of re-testing the false reject calls.

The cost of re-testing the false rejects (Cr_F) can be calculated as the number of false calls (N_F) times the test cost per board (Bt_C):

$$Cr_F = N_F \times Bt_C$$

The number of false calls (N_F) can be obtained with equations 25a, 25b and 25c.

The total Re-test cost for a given strategy, is the sum of the re-test costs of the stages:

$$TRt_C = \sum_{i=1}^n Rt_{Cn}$$

Yield-related costs

It is the sum of all the costs that are related with yield measurements like: Scrap cost (TCs), Repair cost (TRc), Diagnostic cost (TDC) and Re-Test cost (TRt_c):

$$Yc = TCs + TRc + TDC + TRt_c$$

Equation 44. Yield-related Costs.

Total Test Costs

The total test costs for each strategy is the sum of the equipment related costs and yield related costs:

$$Ct = Ec + Yc$$

Equation 45. Total Test Costs.

Yield Enhancement Savings

These are the savings obtained with the implementation of strategy 2, the yield enhancement savings are given by the difference between the yield related costs of strategy 1 and strategy 2:

$$Ys = Yc_2 - Yc_1$$

Equation 46. Yield Enhancement Savings.

Total Savings with Strategy 2

The cost of implementing the test strategy 2 vs. test strategy one is given by the difference between the equipment-related costs of strategy 1 and the equipment-related costs of strategy 2:

$$E_{\Delta} = Ec_1 - Ec_2$$

Equation 47. Equipment-related Costs Delta.

The yield enhancement savings minus the cost of implementing strategy 2 gives the total savings obtained with the implementation of strategy 2.

$$Ts = Ys + E_{\Delta}$$

Equation 48. Total savings with strategy 2.

Return Of Investment metrics

A) Investment. When the user select the ROI calculations option or enable/refresh the ROI metrics in the test cost model, a macro in excel is automatically executed. This macro compares the test / inspection stages between strategy 1 and strategy 2 to determine which stages are 'new' on strategy 2.

The equipment, fixture & programming costs of these 'new' stages on strategy 2 would be the Investment metric on this section. For example, if strategy 1 has 2 stages: IC and FT, and strategy 2 has 3 stages: AXI, ICT and FT the investment required to implement strategy 2 would be the sum of the equipment, fixture and programming costs of AXI since this stage is the only 'new' stage in strategy 2 (ICT and FT already existed in strategy 1).

B) Payback Period. Payback period is the time, in years, in which the money invested to implement the strategy 2 will be repaid due to the savings generated because of the implementation of strategy 2. Mathematically, the payback period is the investment divided by the annual savings:

$$P = \frac{I}{S}$$

Equation 49. Payback period.

C) Net Present Value. The net presented value is calculated in the model within a period of five years, using the following equation:

$$NPV = \left[\sum_{i=1}^5 \left(\frac{S_i - (Cm_i + Dc_i)}{(1 + rate)^i} \right) \right] - I$$

Equation 50. Net Present Value.

Where S is the annual savings, Dc is the yearly depreciation cost, Cm the yearly maintenance cost. I is the investment and $rate$ is the rate of discount over the length of one year. This rate of discount might represent the rate of inflation or the interest rate of a competing investment.

D) Internal Rate of Return. In the test cost model the internal rate of return is the interest rate received for the money invested on the implementation of strategy 2, consisting of payments (the Investment, maintenance and depreciation costs) and income (savings due to yield enhancement) that occur every year over a five year period.

Time To Market savings

There are many studies about time to market savings calculations, for example Louis Ungar and Tony Ambler utilized a Time to Market model for one of their BIST studies*. An abstract of that model is shown in this section:

Getting a product out more quickly has the greatest economic benefit. Product obsolescence is a reality in our fast-changing electronics market. Several sources exist for calculating the market life cycle model. Figure 2 shows one version of a market life cycle model.

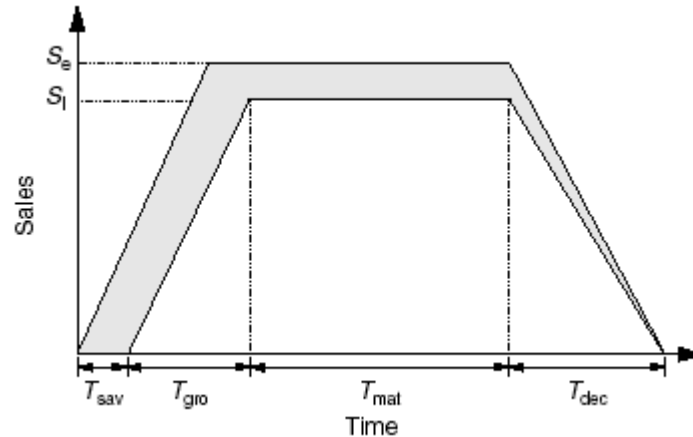


Figure 2. Market life cycle model.

Figure 2 shows two sales patterns. With early product release, the sales pattern maximizes at S_E . With later release, maximum sales are at S_L . The area under each curve represents the revenue generated by that sales pattern. The benefit, B_{EM} , derived from reaching the market early (by time T_{SAV}) is the difference in the revenues produced between the two scenarios:

$$B_{EM} = R_E - R_P$$

Where R_E is the revenue generated by the early release sales pattern and R_P is the revenue generated by the late-release sale pattern. The shaded area in Figure 2 represents this benefit.

We can divide the life cycle market into three phases: growth, maturity and decline. Sales increase during growth phase T_{GRO} maintain a steady rate during maturity phase T_{MAT} and decrease (possibly due to product obsolescence) during decline phase T_{DEC} . The revenues with (R_E) and without (R_P) early to market benefits are:

$$R_P = \frac{S_L}{2} (T_{GRO} + 2T_{MAT} + T_{DEC})$$

$$R_E = \frac{S_E}{2} (T_{SAV} + T_{GRO} + 2T_{MAT} + T_{DEC})$$

* **Economics of Built-In Self-Test.** Louis Y. Ungar and Tony Ambler. IEEE Design & Test of Computers. 2001

To obtain the real profit out of the revenue (R_P and R_E) we must consider other investments done during the product's life cycle, like: Research & Development (RD), Cost of Good Sold ($COGS$), Sales & Marketing (SM) and General & Administrative ($G\&A$):

$$RD = (RD\%) \times (R_P)$$

$$SM = (SM\%) \times (R_P)$$

$$GA = (GA\%) \times (R_P)$$

$$COGS_P = (COGS\%) \times (R_P)$$

$$COGS_E = (COGS\%) \times (R_E)$$

$$SM_P = (SM\%) \times (R_P)$$

$$SM_E = (SM\%) \times (R_E)$$

The total investment in the planned (late in the market) schedule (I_P) is:

$$I_P = RD + COGS_P + SM_P + GA$$

The total investment in the early (in the market) schedule (I_E) is:

$$I_E = RD + COGS_E + SM_E + GA$$

The profit for the planned (late in the market) schedule (P_P) is the difference between the late-schedule (planned) revenue (R_P) and the late-schedule (planned) investment (I_P):

$$P_P = R_P - I_P$$

The profit for the early (in the market) schedule (P_E) is the difference between the early-schedule revenue (R_E) and the early-schedule investment (I_E):

$$P_E = R_E - I_E$$

The time to market savings would be the difference between the early and planned (late in the market) profits:

$$TTMs = P_E - P_P$$

And, finally, the yearly Time To Market savings is the savings divided by the product life cycle in years:

$$Sy_{TTM} = \frac{TTMs}{t}$$

Outputs Section.

- [Overview.](#)
- [Test Strategies Flow.](#)
- [Cost & Savings Summary.](#)
- [Test Cost charts.](#)
- [Return of Investment metrics.](#)
- [Time To Market Savings.](#)

Overview. The Outputs section provides a summary of costs and savings for each test strategy. A comparison of the strategies, including test flow with defect escapes, costs and savings, is shown in the Outputs section.

There are 5 sections on the Outputs sheet of the workbook that shows the results driven by the [inputs](#) entered by the user and the [calculations](#) in the model. These 5 sections are: Test Strategies Flow comparison, Costs & Savings Summary, Test Costs Charts, Return of Investment Metrics and Time To Market savings.

Test Strategies Flow. The first section of the outputs is a comparison of the flows of Strategy 1 and Strategy 2 (figure1). In this section the user can observe the yield on each of the test or inspection stages for both, strategy 1 and strategy 2, the defects entering to each of the strategies, the defects escaping from every test or inspection stage of strategy 1 and strategy 2 and the defects escaping from overall strategy 1 and overall strategy 2.

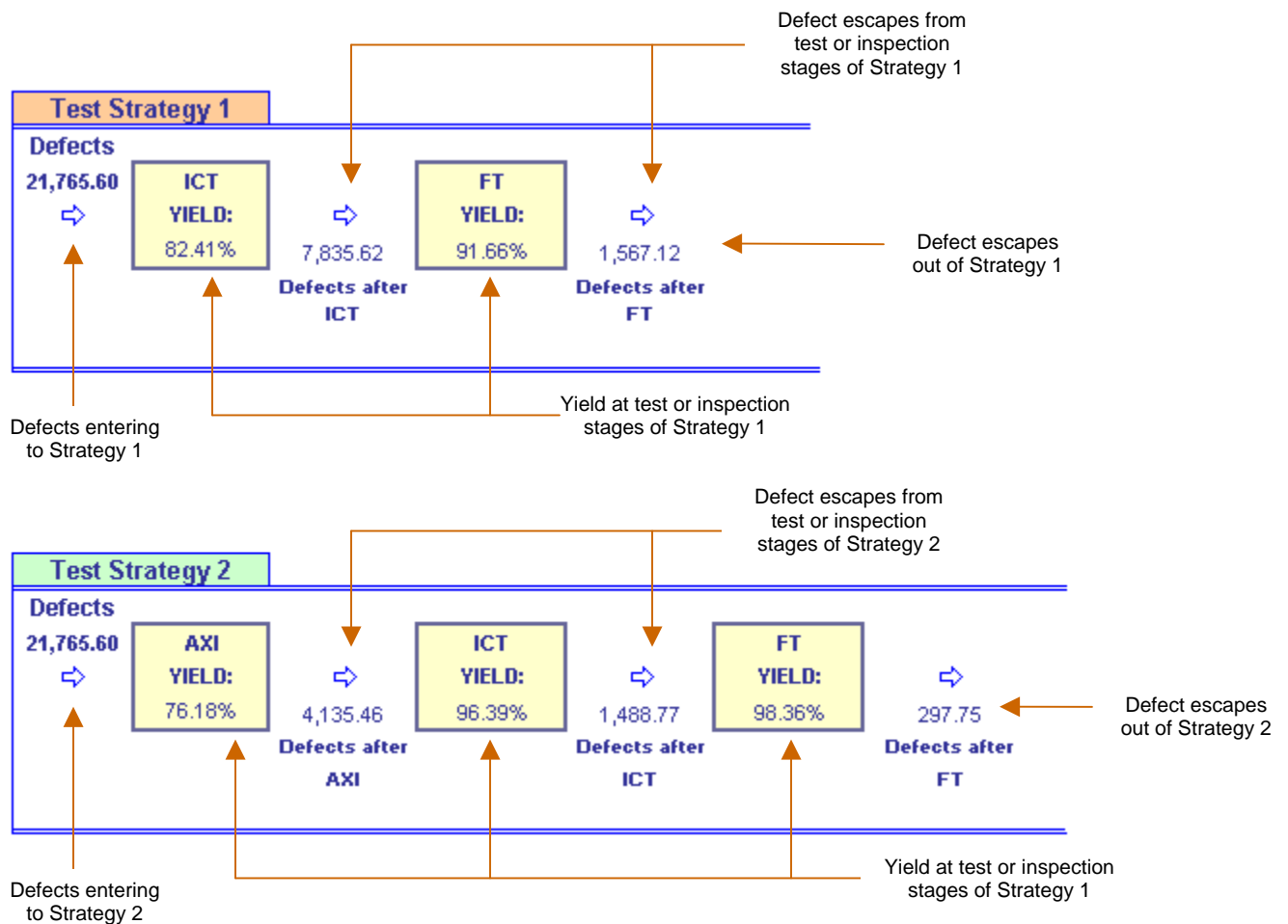


Figure 1. Test Strategies Flow

The user can select the type of units for the defect escapes, there are two options available: Number of defects or DPMOs. To select the units of the defect escapes, click the appropriate button (DPMOs or Defects) on the box (figure 2) at the top of the outputs sheet.

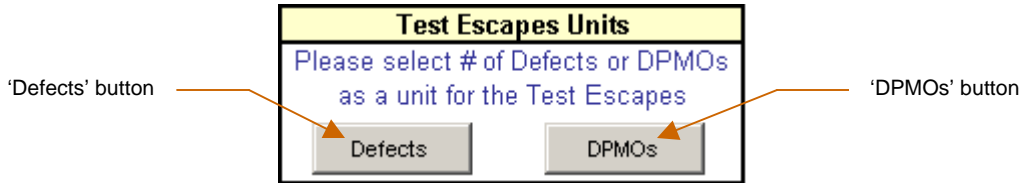


Figure 2. Select Defect Escapes Units

Cost & Savings Summary. A summary of the test costs of each strategy is provided in the outputs section (figure 3). Several costs of the strategies are listed in the summary. These costs are divided in *Equipment-related Costs* and *Yield-related Costs*.

SUMMARY					
Test Strategy 1			Test Strategy 2		
1	Effectiveness:	92.80%	18	Effectiveness:	98.63%
2	Annual Scrap Cost:	\$18,669	19	Annual Scrap Cost:	\$3,780
3	Annual Repair Cost:	\$24,848	20	Annual Repair Cost:	\$22,181
4	Annual diagnostic of defects Cost:	\$489,988	21	Annual diagnostic of defects Cost:	\$216,141
5	Test Operator Cost:	\$105,000	22	Test Operator Cost:	\$133,000
6	DPMO escapes after Test:	21.7656	23	DPMO escapes after Test:	4.135464
7	Annual Field Return Cost:	\$1,080,000	24	Annual Field Return Cost:	\$205,200
8	Programming Costs:	\$60,000	25	Programming Costs:	\$70,000
9	Annual Equipment Cost:	\$183,333	26	Annual Equipment Cost:	\$333,333
10	Annual Fixture Cost:	\$11,667	27	Annual Fixture Cost:	\$11,667
11	Annual Maintenance Cost:	\$40,000	28	Annual Maintenance Cost:	\$65,000
12	Annual re-test Cost:	\$83,314	29	Annual re-test Cost:	\$75,230
13	Total Test Time:	6	30	Total Test Time:	9
14	Annual Equipment Related Costs:	\$400,000	31	Annual Equipment Related Costs:	\$613,000
15	Annual Yield Related Costs:	\$1,696,818	32	Annual Yield Related Costs:	\$522,532
16	Total Costs of Strategy 1:	\$2,096,818	33	Total Costs of Strategy 2:	\$1,135,532
17	Test Cost per board:	\$6	34	Test Cost per board:	\$9

Strategy # 1 vs. Strategy # 2				Summary of Savings with Strategy # 2			
Summary				Annual Savings			
	Strategy # 1	Strategy # 2	Difference	Strategy # 1	Strategy # 2	Difference	
Effectiveness:	92.800%	98.632%	5.83%	Test Cost:	\$400,000	\$613,000	-\$213,000
Test Time:	6	9	-3	Yield Enhancement Savings:			\$1,174,286
				Total Savings with Strategy 2:			\$961,286

Figure 3. Cost & Savings Summary

The *Equipment-related Costs* Includes: Test Operator cost, Programming costs, Equipment cost, Fixture cost and Maintenance cost. The *Yield-related Costs* includes: Scrap cost, Repair cost, Diagnostic cost, Field Return cost and Re-Test cost. Other results listed on the summary are: Effectiveness of the Test Strategy, Defect escapes after test, Test Time, Total Equipment-related costs, Total Yield-related costs, Total cost for the strategy and total cost per board; all of these costs are listed for both strategy 1 and strategy 2. At the bottom of the summary there is a comparison of Strategy 1 and Strategy 2 in terms of test effectiveness, test time and test cost. The 'Difference' cell shows the difference between strategy 1 and strategy 2. Strategy 2 is the reference of the comparison; for example, if Strategy 2 is more effective than strategy 1 then the number on the 'Difference' cell will be greater than 0, if strategy 1 is more effective than strategy 2 the number on the 'Difference' cell will be a negative number. Something similar happens with test time and test cost comparison: if Strategy 2 is more expensive to implement than strategy 1, then the number in the 'Difference' cell will be a negative number as it is in the example shown in Figure 3.

The 'yield enhancement savings' are the savings due to the yield enhancement that a user would see if that user implements the Strategy 2 instead of the Strategy 1. The 'Total Savings with Strategy 2' cell is the total savings that the user would get with strategy 2, that is the 'Yield Enhancement savings' minus the 'Test Cost'. If you want to learn more about how these calculations are made, go to the [calculations](#) section in this document

Test Costs Charts. The results of the summary section are also shown in a graphic style with 3 different charts: *Equipment-related Costs chart* (figure 4a), *Yield-related Costs chart* (figure 4b) and *Total Costs chart* (figure 4c).

Equipment-related Costs chart. This chart compares the costs related with the test equipment of Strategy 1 and Strategy 2.

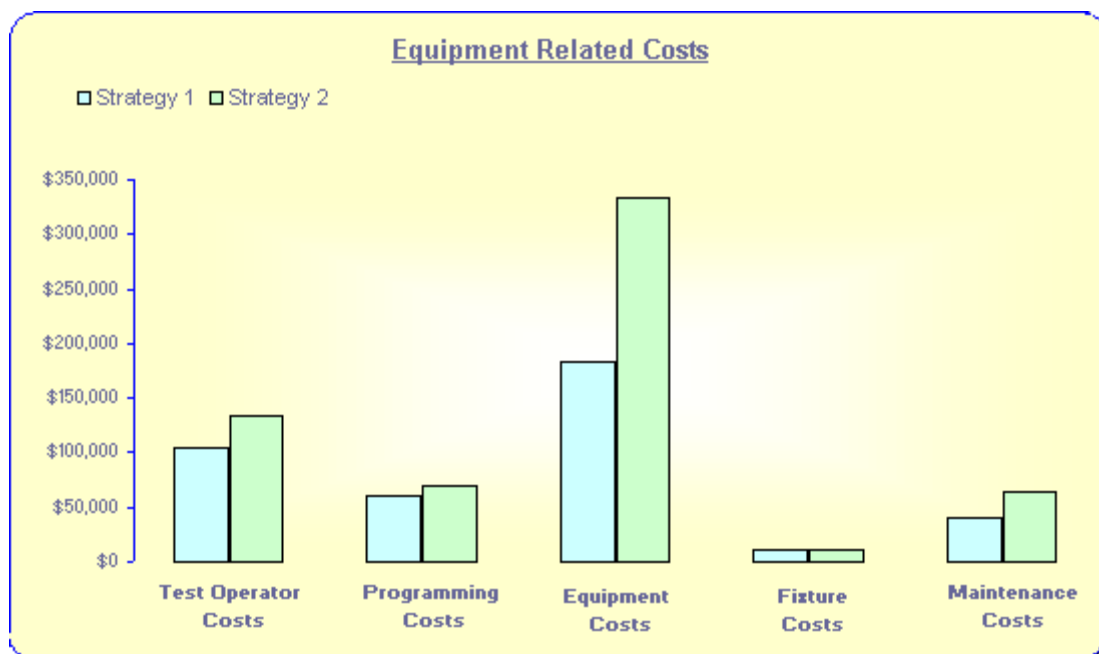


Figure 4a. Equipment-related Costs chart

Yield-related Costs chart. This chart compares the costs related with the test yield of Strategy 1 and Strategy 2.

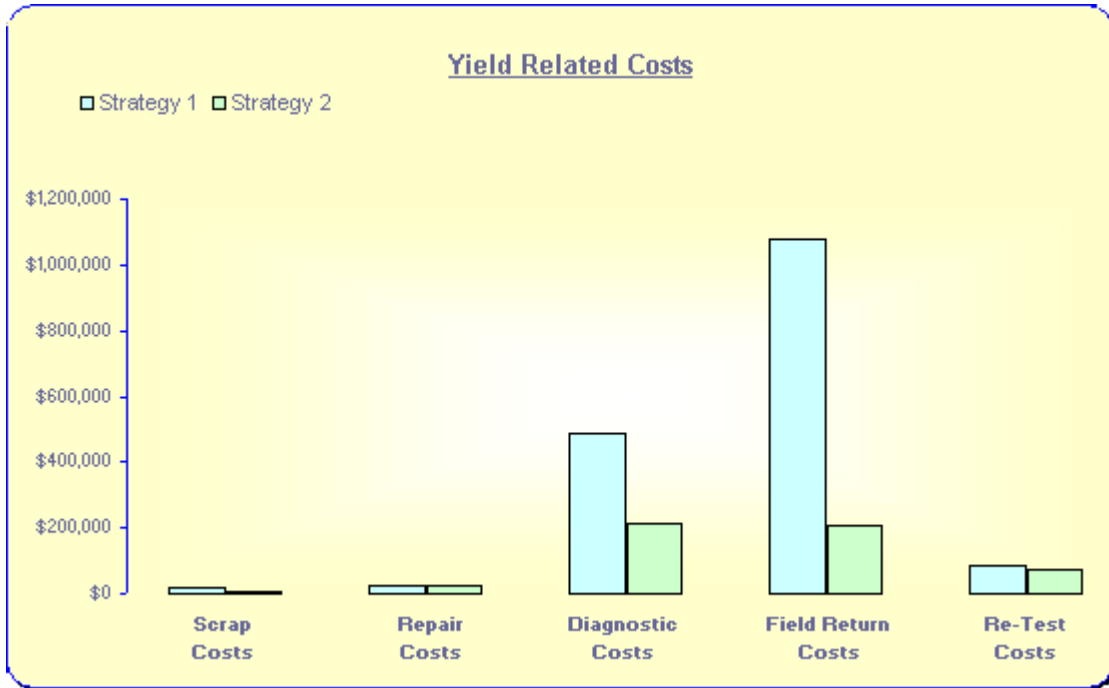


Figure 4b. Yield-related Costs chart

Total Costs chart. This chart compares the total test costs (equipment and yield) of Strategy 1 and Strategy 2.

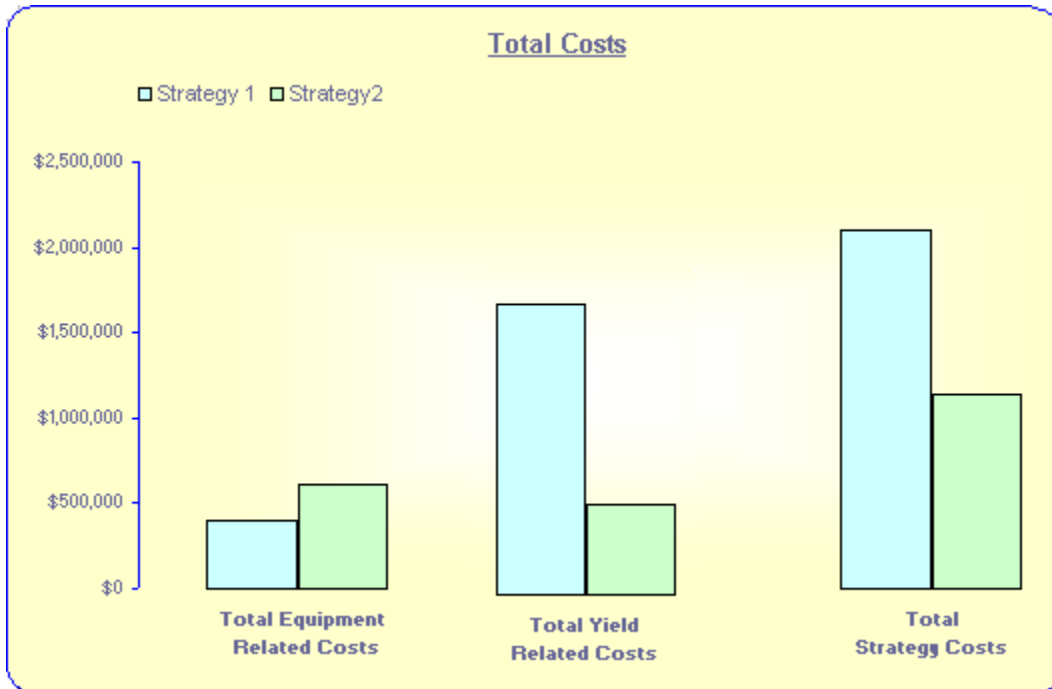


Figure 4c. Total Costs Chart.

Return Of Investment Metrics. A section on the Outputs sheet of the workbook is dedicated to the *Return of Investment Metrics* (figure 5). Four ROI metrics for Strategy 2 are calculated in the model; those metrics are: Investment, Payback, Net Present Value and Internal Return Rate. If you want to learn more on how these metrics are calculated please go to the [calculations](#) section in this document.

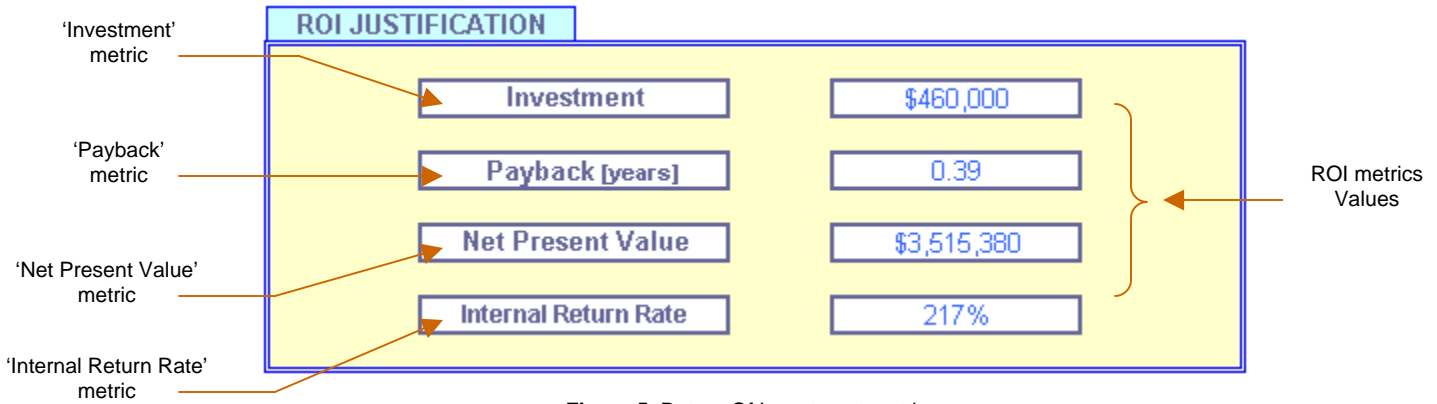


Figure 5. Return Of Investment metrics.

Investment. It is the cost of equipment, programs and fixtures generated by the implementation of a new test strategy.

Payback. The simplest break-even analysis method, payback period, calculates the cost of equipment, programs and fixtures, then deducts the anticipated savings.

Net Present Value (NPV). The net present value (NPV) method assumes an opportunity cost, and then calculates the present value of all cash flows that a project will generate throughout its life, including the initial investment.

Internal Return Rate (IRR). The internal rate of Return technique computes the interest rate that reduces the net present value to exactly zero. In effect, this approach asks the question, "How high would the opportunity cost have to be to make this project not worth doing?"

The Return of Investment metrics outputs can be enabled (refreshed) or disabled at any time during the reviewing of the outputs section by clicking on the appropriate button at the top of the outputs section (figure 6). *The ROI metrics need to be refreshed every time that changes are made to the inputs section.*

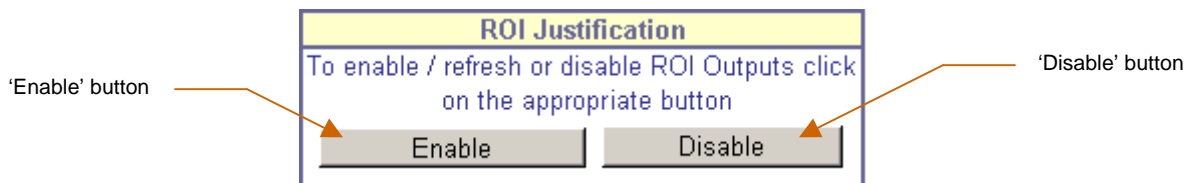


Figure 6. Enable (refresh) or Disable ROI metrics.

Time To Market Savings. The Time to Market savings section of the Outputs sheet of the model workbook (figure 7) it is selected or deselected at the inputs section ([step 1](#)). If selected, the savings of introducing the product to the market earlier than planned are displayed in this section.

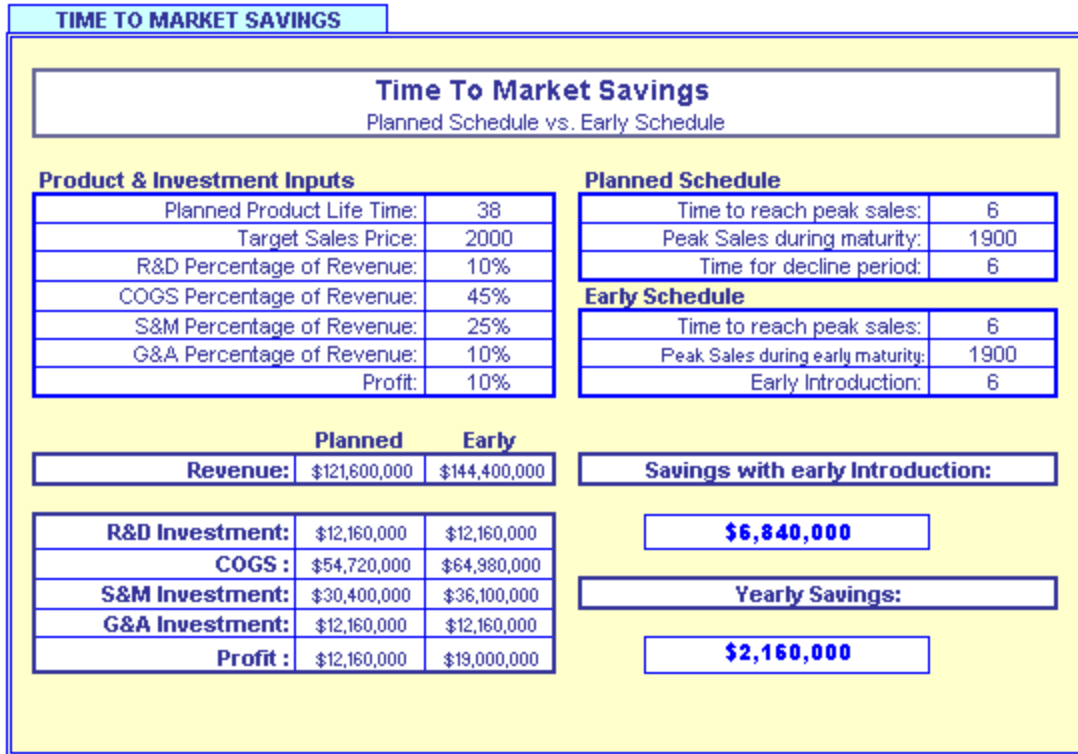


Figure 7. Time To Market Savings summary.

The revenues of the planned and early schedules are listed in this section, as well as the different investments (R&D, COGS, S&M, G&A) for both schedules. The profits of the early and planned schedules are the difference of the investment on each schedule vs. the revenue of each of the schedules.

The total savings with the early introduction is the difference between the profit of the planned schedule and the profit of the early schedule; the yearly savings are obtained when the total savings are divided by the product lifetime. If you want to learn more on how the Time to Market savings are calculated please go to the [calculations](#) section in this document.

It is important to note that the Time to Market section does not have a direct linkage with the inputs entered for the test strategies (1 and 2). This is a separate and optional section of the test cost model.

Contact Information.

The present document and the Test Cost Model described in this document are not a finalized version. Updates and corrections to this User's guide and the test cost model will occur, since they are still under revision by the NEMI working group. For more information about this subject, the user's guide or the test cost model please send a message to the following electronic address:

costmodel@nemi.org

Or visit the website:

http://www.nemi.org/projects/ba/test_strat.html