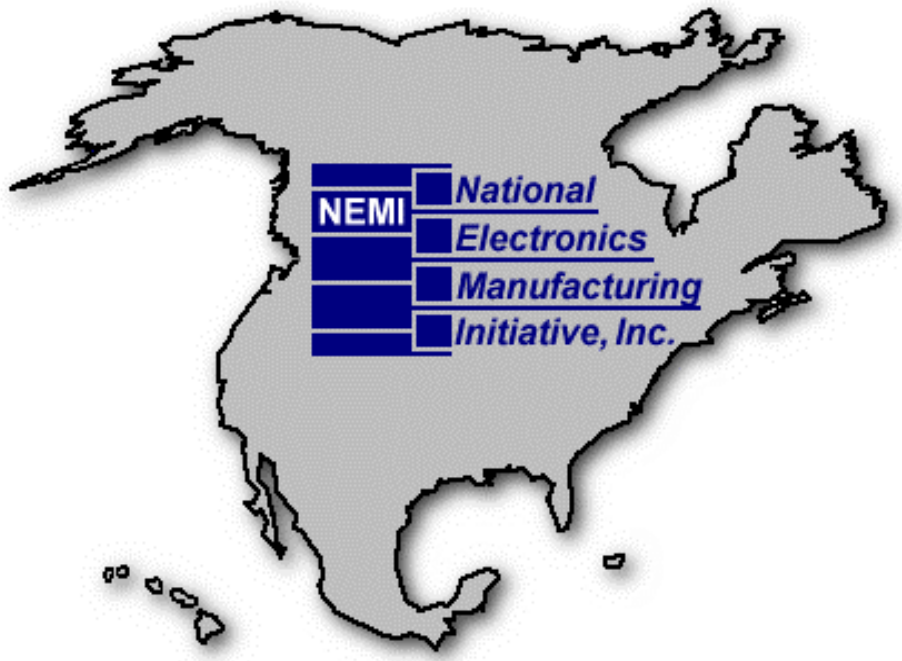


Test Strategy Working Group
Project 3 – Test Cost Model

Test Strategy Project 3
Test Cost Model
April 1, 2003

Project 3 - Introduction

"It is believed that an economic model is an important part of the Test Strategy Working Group investigation in order to help communicate the potential need and benefits of automated inspection and test methods".

Project 3 Objective:

To develop a simple test strategy cost modeling tool that could be used to define a manufacturing PCA test strategy by estimating the cost of finding and repairing manufacturing assembly defects using various types of test and inspection strategies. This economic model would help communicate the potential needs and benefits of each test technique and would help users understand the impact of removing test stages vs. sampling strategies vs. 100% inspection or test methods.

Test Cost Model development process

- **6 participant companies represented in group 3:**
  - –Teradyne, Inc. (Amit Verma)
  - –Agilent Technologies, Inc. (Stig Oresjo)
  - –Solectron, Inc. (David Mendez, Nga Nguyen)
  - –Delphi Electronics, Inc. (Brian Chandler)
  - –Hewlett-Packard Company (Rosa Reinosa, Carlos Michel)
  - –Intel Corporation (James Grealish)
- **All project 3 participant companies shared their test cost models and ROI best practices.**
- **Analysis of each of the tools presented focusing on:**
  - Key Drivers
  - Assumptions
  - Likes/Dislikes.

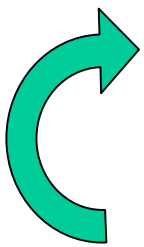
Test Cost Model development process

- **Agreement of all group 3 participants on the inputs and outputs that the NEMI test cost model would have - The voting list.**

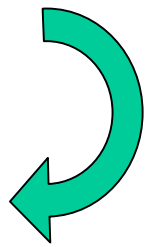
  - Define default inputs and outputs.
  - Each company voted on desired inputs and outputs.
  - Inputs and outputs with majority of votes to be included in the test cost model.

Test Cost Model development process

- **Development of the Test Cost Model tool**
  - Utilizing the best concepts and formulas of each of the presented models and including the inputs and outputs selected (voting list) by the group.
  - Conference calls (each other week) with all group 3 participants to revise the progress of the tool development and to provide feedback.
- **Recurrent Activities**



  - Release of a new version of the test cost model
  - All participant companies to review the new version of the test cost model and provide feedback.



This recurrent process went on until the release of the final version of the test cost model (Rev H) on October 2002. The development of the tool lasted one year

Test Cost Model development process

- Team decided to release the test cost model to the public domain after APEX 2003 in order to:
  - Allow participant companies to utilize the test cost model before public release as a competitive advantage.
  - Perform tool validation.

- The NEMI Test Strategy Working Group decided that the test cost model would be released after APEX with minimum restrictions. It was decided, however, that the test cost model should be password protected and copyrighted only to prevent others to use the model for commercial purposes.

- The Test Strategy Cost Model is being copyrighted only by the Project 3 participating companies.

Test Cost Model Overview
Introduction

Objective: To develop a PCA manufacturing test strategy cost model that will enable a company to determine the financial impact of selecting a particular test strategy.

- ***What do we hope to accomplish with the test cost model?***
  - – Enable a company to estimate the ROI on a particular manufacturing test strategy.
  - – Make tradeoff analysis and decisions based in the financial impact that a strategy may have on an organization.
  - – Provide visibility to decide key test strategy drivers.

- ***What is expected of industry adoption?***
  - – Adopt this test strategy cost model as a standard tool to determine the financial impact of selecting a particular test strategy.
  - – Would like for companies to select this tool as their tool of choice to drive test strategy decisions.
  - – Drive standardization of the economic analysis of test strategies.

Test Cost Model Overview
Introduction

The NEMI Test Strategy Cost Model has the ability to compare two different PCA test strategies and provide the strategies cost, yield enhancement savings, defects escaping out of the strategy, DPMOs/yield for each test stage, ROI metrics and time to market savings. The model uses a spreadsheet format and is intended for post-reflow PCA test strategies:

The following variables were considered in the model:

- Programming Cost
- Equipment Cost
- Fixture Cost
- Maintenance Cost
- Test operators Cost
- Scrap Cost
- Re-test (false rejects) Cost
- Repair & Diagnostics Cost
- Field Return Cost

The following metrics were considered on the ROI analysis in the model:

- Investment
- Payback
- Net Present Value
- Internal Rate of Return

The following investments were considered on the Time To Market analysis in the model:

- R & D revenue
- COGS
- Sales and Marketing
- General and Administrative

Test Cost Model Sections

The NEMI Test Strategy Cost Model is divided in 4 sections:

- **Overview Section.**
- **Inputs Section.**
- **Defaults Section.**
- **Outputs Section.**

Test Cost Model Overview
Overview Section

Overview Section. This section contains a high level description of the test cost model, the copyright disclaimer and the names of the companies and the participants in the development of the tool.

OBJECTIVE

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.

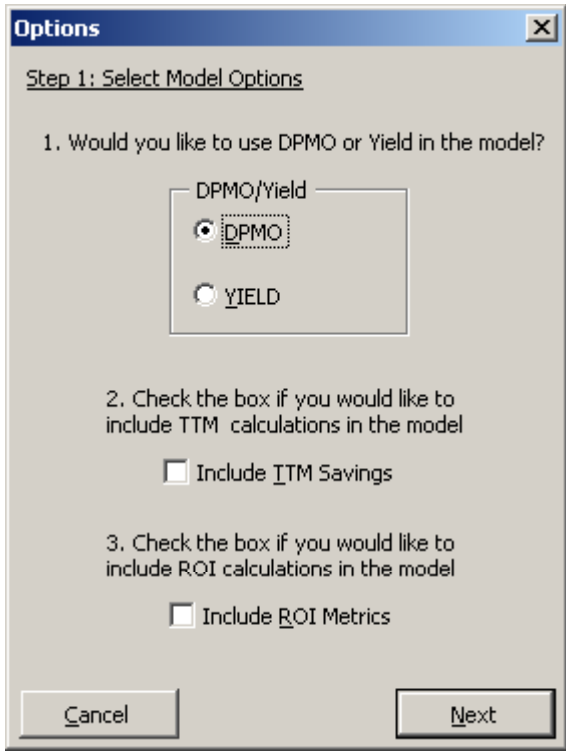
ACKNOWLEDGEMENTS

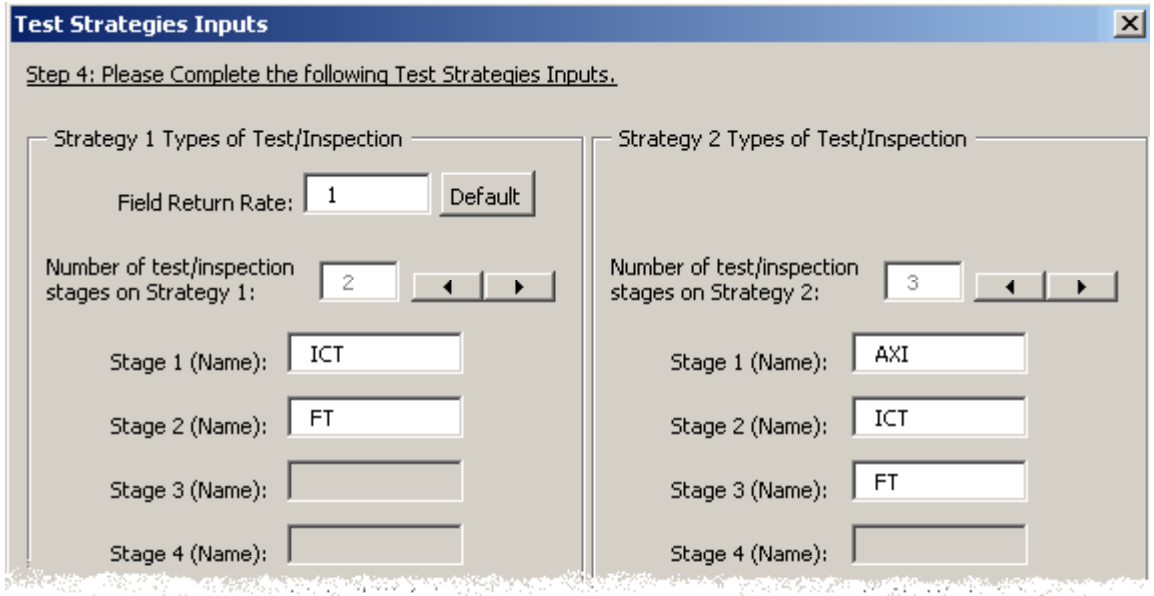
We would like to thank the following individuals for their contributions and participation:

Amit Verma	-------	Teradyne
Stig Oresjo	-------	Agilent
James Grealish	-------	Intel
Nga Nguyen	-------	Solectron
David Mendez	-------	Solectron
Brian Chandler	-------	Delphi Delco
Rosa Reinosa	-------	Hewlett-Packard
Carlos Michel	-------	Hewlett-Packard

Test Cost Model Overview
Inputs Section

Inputs Section. This is the section where the users needs to enter all the information related with their PCA and their test strategies, up to 50 inputs are required to be completed in this section.





Test Cost Model Overview
Defaults Section

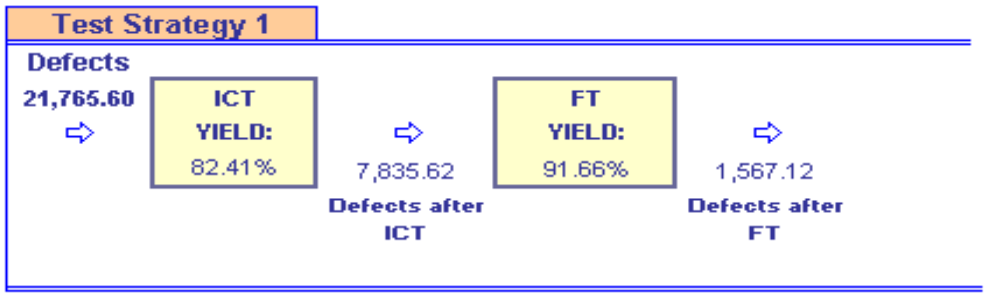
Defaults Section. This section provides a default value for each of the inputs on the inputs section, if an input is unknown to the user, he or she can select a value for that particular input from the defaults section. These defaults values are based on medium-high complex board manufactured in US.

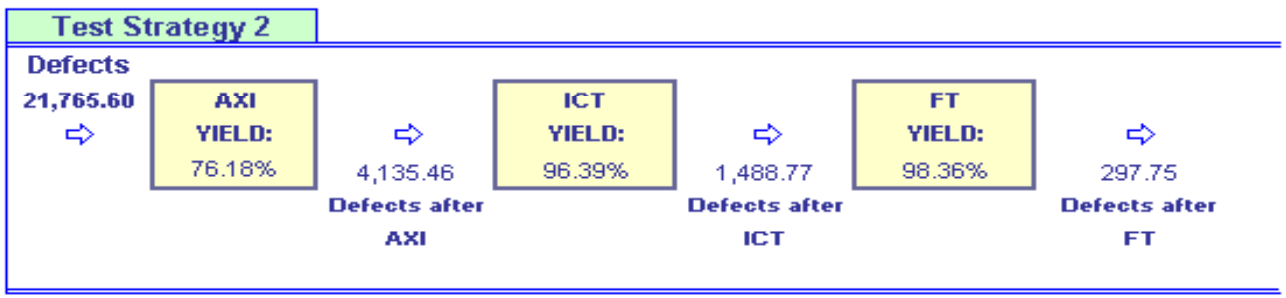
	DPMO	Structural DPMOJ	Structural DPMOC	Electrical DPMOC
4	Leaded (Gullwing)	200	100	100
5	Leaded (Gullwing)	500	100	100
6	Leaded (Gullwing)	700	100	100
7	Leaded (Gullwing)	1000	100	100
8	Leaded (Gullwing)	10000	100	100
9	Leaded (Gullwing)	15000	100	100
10	Jlead	300	100	100
11	Eutectic BGA	100	100	100
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

	TEST STRATEGY					
44	Field Return Rate [%]:	1.00%				
		MVI	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

Test Cost Model Overview
Outputs Section

Outputs Section. This is the section where the test cost model results are presented to the user. It contains a strategy flow of both strategies with the DPMO/yield data of each of the test stages and the defects escaping out of the test stages and out of the strategy, a summary and a graphical cost comparison of the strategies, a section for the ROI metrics and the results of the Time To Market calculations.





Test Cost Model Overview
Outputs Section

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

	Strategy # 1	Strategy # 2	Difference
Effectiveness:	92.800%	98.632%	5.83%
Test Time:	6	9	-3

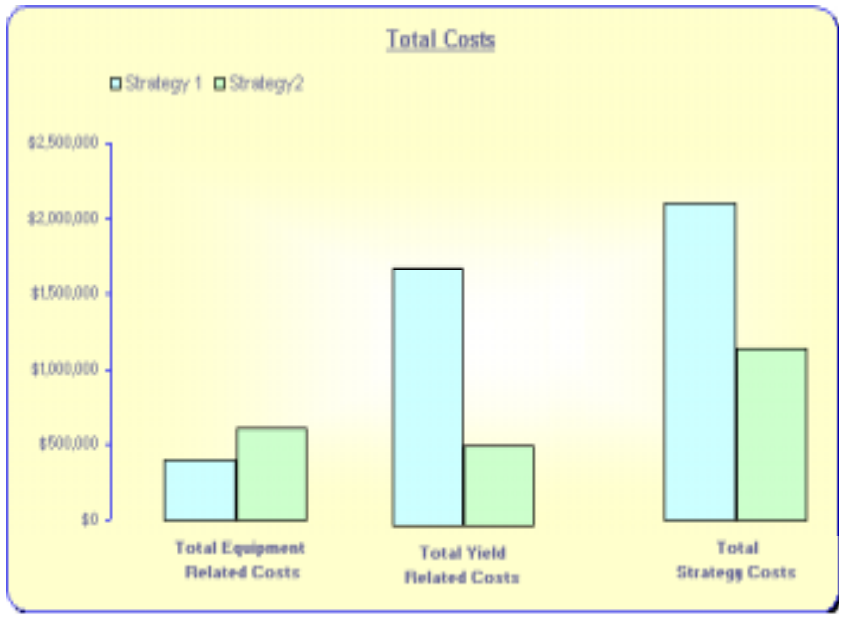
Summary of Savings with Strategy #2

Annual Savings

	Strategy # 1	Strategy # 2	Difference
Test Cost:	$400,000	$613,000	-$213,000

Yield Enhancement Savings:	$1,174,286
Total Savings with Strategy 2:	$961,286

Summary and graphical cost comparison of both strategies



Test Cost Model Overview
Outputs Section

ROI metrics and Time To Market Savings

ROI JUSTIFICATION

Investment	$460,000
Payback [years]	0.39
Net Present Value	$3,515,380
Internal Return Rate	217%

TIME TO MARKET SAVINGS

Time To Market Savings
Planned Schedule vs. Early Schedule

Product & Investment Inputs

Planned Product Life Time:	38
Target Sales Price:	2000
R&D Percentage of Revenue:	10%
COGS Percentage of Revenue:	45%
S&M Percentage of Revenue:	25%
G&A Percentage of Revenue:	10%
Profit:	10%

Planned Schedule

Time to reach peak sales:	6
Peak Sales during maturity:	1900
Time for decline period:	6

Early Schedule

Time to reach peak sales:	6
Peak Sales during early maturity:	1900
Early Introduction:	6

	Planned	Early
Revenue:	$121,600,000	$144,400,000
R&D Investment:	$12,160,000	$12,160,000
COGS :	$54,720,000	$64,980,000
S&M Investment:	$30,400,000	$36,100,000
G&A Investment:	$12,160,000	$12,160,000
Profit :	$12,160,000	$19,000,000

Savings with early Introduction:

$6,840,000

Yearly Savings:

$2,160,000

Test Cost Model Overview
User's Guide

A user's guide was developed to help the users of the model to understand the capabilities of the tool and to learn how to utilize the test cost model. The user's guide is a document with 72 pages of text and images that describes in detail each one of the sections of the test cost model and explains, step by step, how to enter all the required information into the model and how to interpret the results on the outputs section. This user's guide contains also a section called ***calculations section*** that explains in detail all the formulas used in the test cost model.

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).

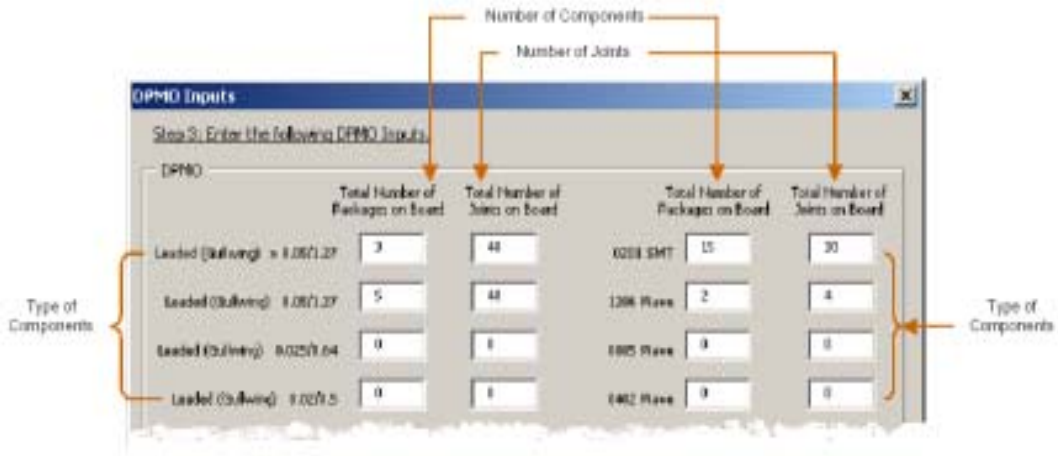


Figure 6. Step 3: DPMO Inputs

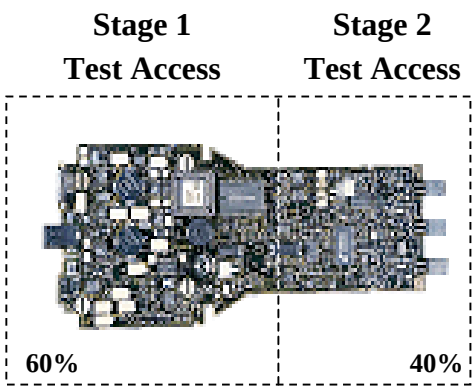
Number of Components. It is the total number of packages (of the corresponding type: 1st column) present on the board. This input could be any number greater or equal than zero. If you enter anything different, an error message will appear. There is no default value available for this type of input.

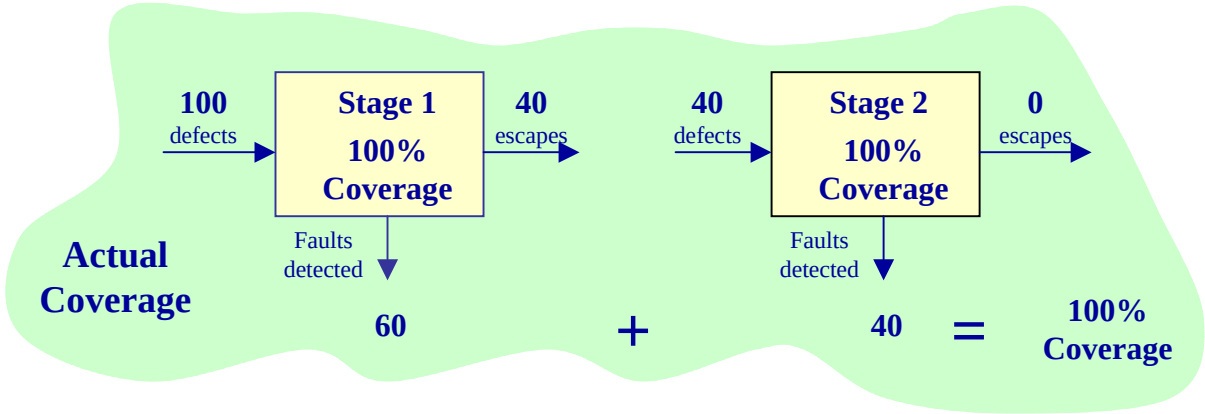
Number of Joints. It is the total number of joints present on the board, due to the total number of packages of the corresponding type (1st. Column). This input could be any number greater or equal than zero. If you enter anything different, an error message will appear. There is no default value available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

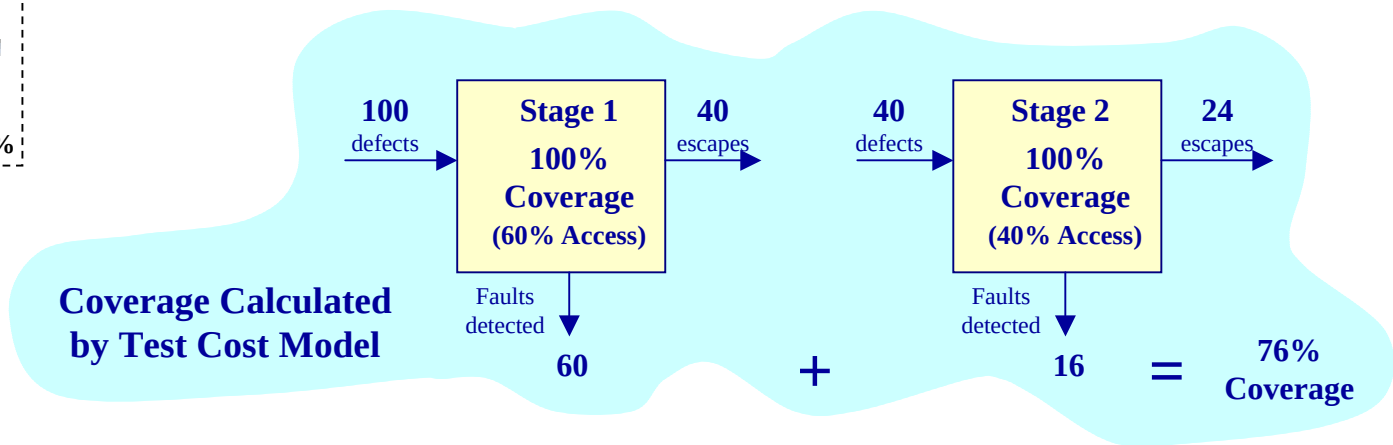
Type of Component. It is the package technology type of the components present on the board. If a component on your board is no listed here, use the "other" type of component to include it on the calculations.

Test Cost Model Overview
Limitations

The present tool 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.







Test Cost Model Overview
Limitations

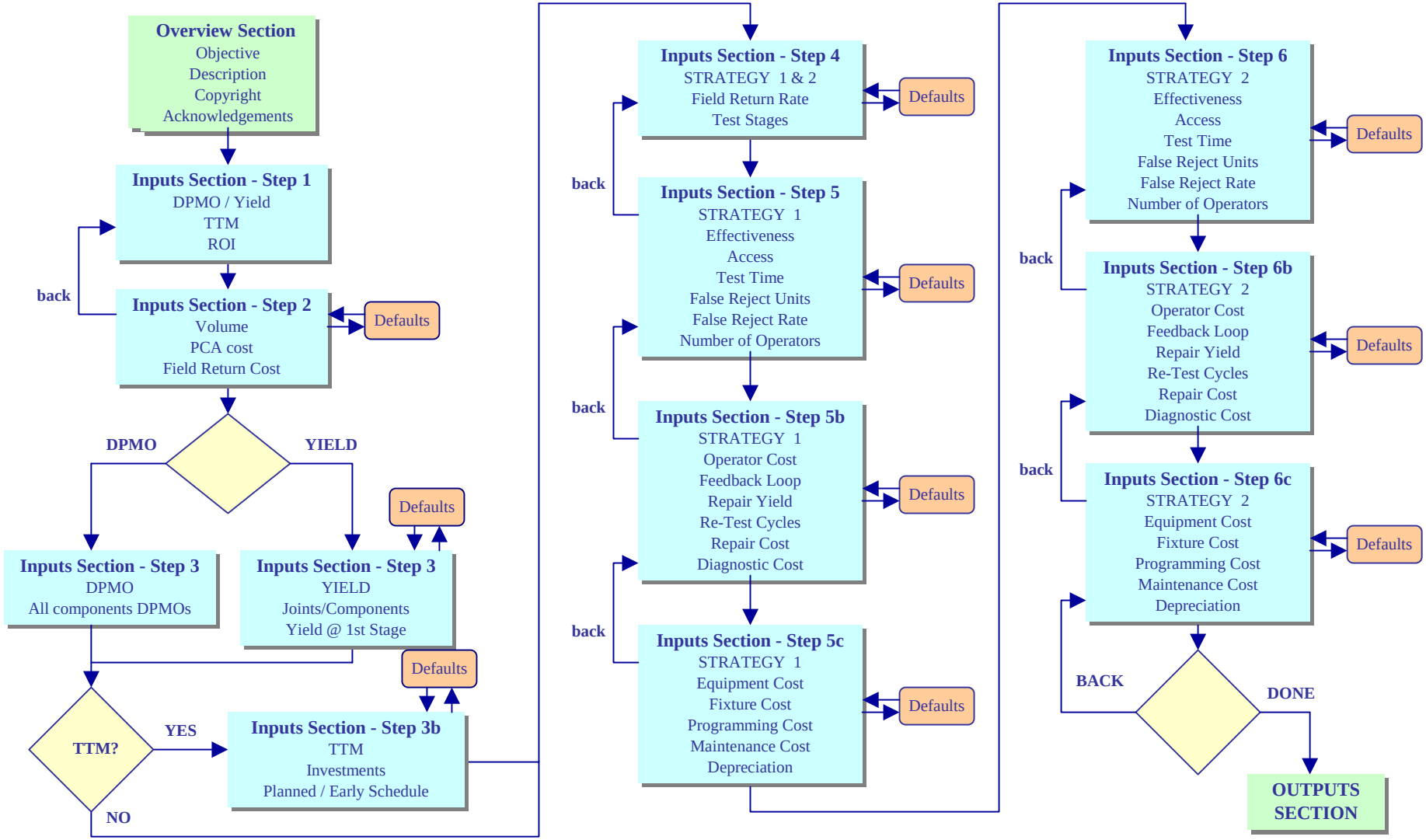
In a test process there are true failures and false failures. When we have a diagnostic process, the following things can happen with the failures detected at a particular test station :

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.

Test Cost Model Flow



Connect with and Strengthen Your Supply Chain

Test Cost Model Example

Objective: Identify what benefit (if any) would have the addition of Automated X-Ray inspection to a current test strategy.

- Current Test Strategy (Strategy 1) has 2 test stages: ICT and FT.
- Proposed Test Strategy (Strategy 2) has 3 test stages: AXI, ICT and FT.

		AXI	ICT	FT
28	Test Effectiveness [%]:	90.00%	80.00%	80.00%
29	Test Access Multiplier:	1	0.8	1
30	Test Time [min]:	3.00	1.00	5.00
31	False Reject Units:	0	1	2
32	False Reject Rate:	1000.00	100.00	0.05
33	Number of Test Operators:	1	1	2
34	Annual Test Operator Cost (per operator) [$]:	$28,000	$35,000	$35,000
35	Repair feedback loop [1 or 0]:	0	1	1
36	Repair Yield [%]:	90.00%	90.00%	90.00%
37	Re-test Cycles Permitted:		2	2
38	Repair Cost [$/per defect]:	$1.00	$1.00	$1.00
39	Diagnostic of Defects Cost [$/per defect]:	$1.00	$5.00	$35.00
40	Equipment Cost [$]:	$450,000	$500,000	$50,000
41	Fixture Cost [$]:	$0	$20,000	$15,000
42	Programming Cost [$]:	$10,000	$30,000	$30,000
43	Annual Maintenance Cost [$]:	$25,000	$20,000	$20,000
44	Equipment Depreciation (years):	3	3	3

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

Yield at 1st stage of strategy 1	85.00%
Number of packages on board:	1,000
Number of Joints on board:	10,000

Annual Savings

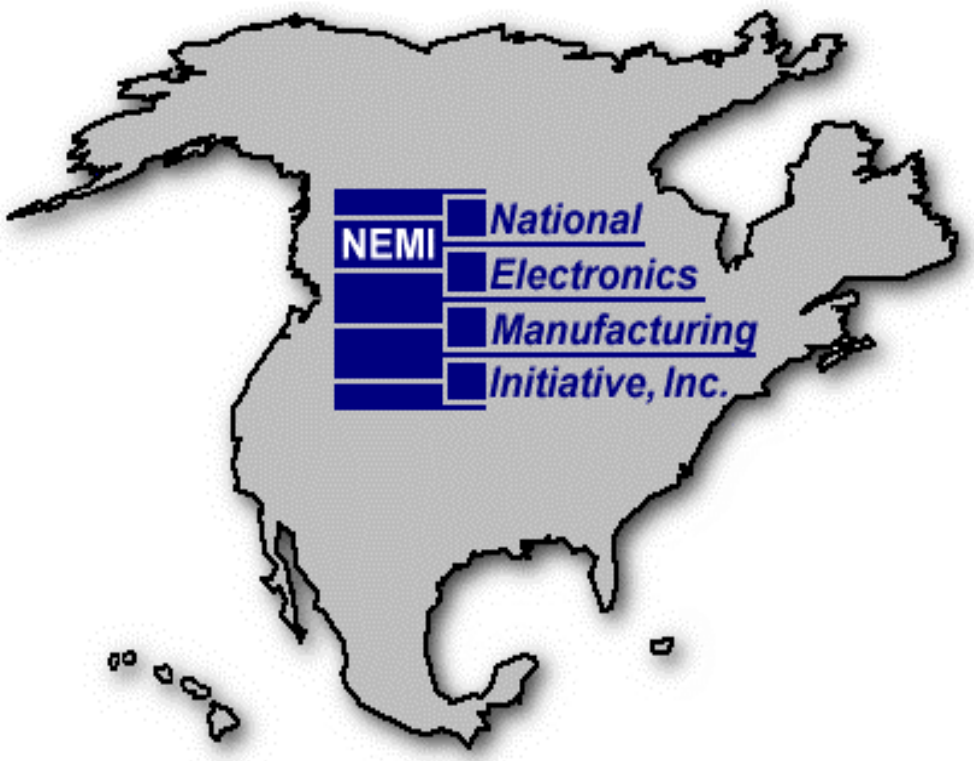
	Strategy # 1	Strategy # 2	Difference
Test Cost:	$400,000	$613,000	-$213,000

Yield Enhancement Savings:	$909,760
Total Savings with Strategy 2:	$696,760

Test Cost Model Next Steps

• The test strategy cost model will be posted on the "NEMI Test Strategy Project" webpage : http://www.nemi.org/projects/ba/test_strat.html The model will be in Excel file format and will be downloadable.

• Feedback and comments about the NEMI Test Strategy Cost Model will be received at the following e-mail address: costmodel@nemi.org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