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Agilent Technologies Fault Detective: Revolutionary Automation for Fault Diagnosis in Functional Test

Agilent Technologies Fault Detective is a revolutionary advancement in fault diagnosis in electronic manufacturing functional test. Historically, engineers have used many artificial intelligence (AI) technologies to automate fault diagnosis, with varying degrees of success. These efforts required substantial development time and produced mixed results.

Agilent researchers set out to create a new approach to fault diagnosis based on three practical goals:

- the modeling process should be simple;
- the application in a manufacturing environment should be flexible and adaptable to many existing tools and processes; and
- the technology should be efficient, as measured by execution time and clarity of results.

Agilent achieved these objectives and more by basing Fault Detective -- the first product in Agilent's Diagnostic Technologies family -- on Bayesian (probabilistic) modeling. What follows is a description of the solution's technical details, its manufacturing and cost implications, and associated Agilent support and services.

Technology Primer

The implementation of Fault Detective requires a model that describes the relationship between the product, the Fault Detective model elements and the functional test suite characteristics. The choice of model elements is typically at the component or subcomponent level for large digital devices such as ASICs, and at the functional block diagram level for analog and optical devices, such as amplifiers, mixers and modulators. The selection of modeling elements is based upon the circuit complexity and practical limits imposed by the test suite.

Two parameters must be specified for each element of the Fault Detective model: the tests that interact with the model element, and the degree of coverage that the test suite provides for each element. Although the degree of coverage could be expressed as a percentage between 0 to 100 percent, it is sufficient to describe the coverage using low, medium or high terminology. Table 1 provides a simplistic example of a model with six elements and three tests. As illustrated, each test exercises only a limited number of the components in the circuit, each to a different degree.

Fault Detective takes these inputs, combines them with the *a priori* failure rates of the individual components -- failure rates that have been established in advance -- to calculate a probabilistic weighting, and then ranks the components in order from the most probable to the least probable cause of the failure. The diagnostic result as shown in the Model Development Environment in Figure 1 is given as a weighted list of probable components. In the production environment, the interface to the Fault Detective diagnosis tool is by way of a set of DLL calls in the Microsoft® Windows® environment.

The Model Development Environment is a Microsoft Windows application. Figure 1 displays the three primary interaction windows. Within this environment, the model developer describes the relationship between the functional test and the modeled components. Also, the *a priori* failure rates are specified along with other pertinent facts about each element involved. The development environment also supports a number of extended capabilities for enhancing the diagnostic models. These include sharing functions, which create relationships between components, and dividing functions of complicated components such as ASICs into subcomponents or logically cohesive functional parts.

The time required to develop a Fault Detective model varies based on the complexity of the product. Model development for an RF consumer product such as a PDA or cell phone is typically completed in two days to a week, while the product model for a more complicated router, switch or communications system usually requires two to four weeks. Model development requires only one person with test engineering knowledge, and limited input (hours) from the product developer and the manufacturing process owners.

The act of model development provides unique insights to the actual diagnostic fault coverage provided by the functional test suite. For example, in Figure 2 an automated feature of Fault Detective called the “Debug Adviser” indicates where additional test or coverage is required to improve individual diagnoses of the product. In addition, the model developer gains practical insights by the careful consideration of the intersection of tests and circuit elements.

Component	Test 1 (Pass)	Test 2 (Pass)	Test 3 (FAIL)	Diagnosis
U1	**H**		**M**	**Low Probability**
U2	**H**	**M**		***not possible***
U3		**M**		***not possible***
C1		**H**	**M**	**Low Probability**
D1		**H**	**L**	**Low Probability**
Q1	**L**		**H**	**High Probability**

Table 1: Simplified Fault Detective model inputs, test results and diagnosis.

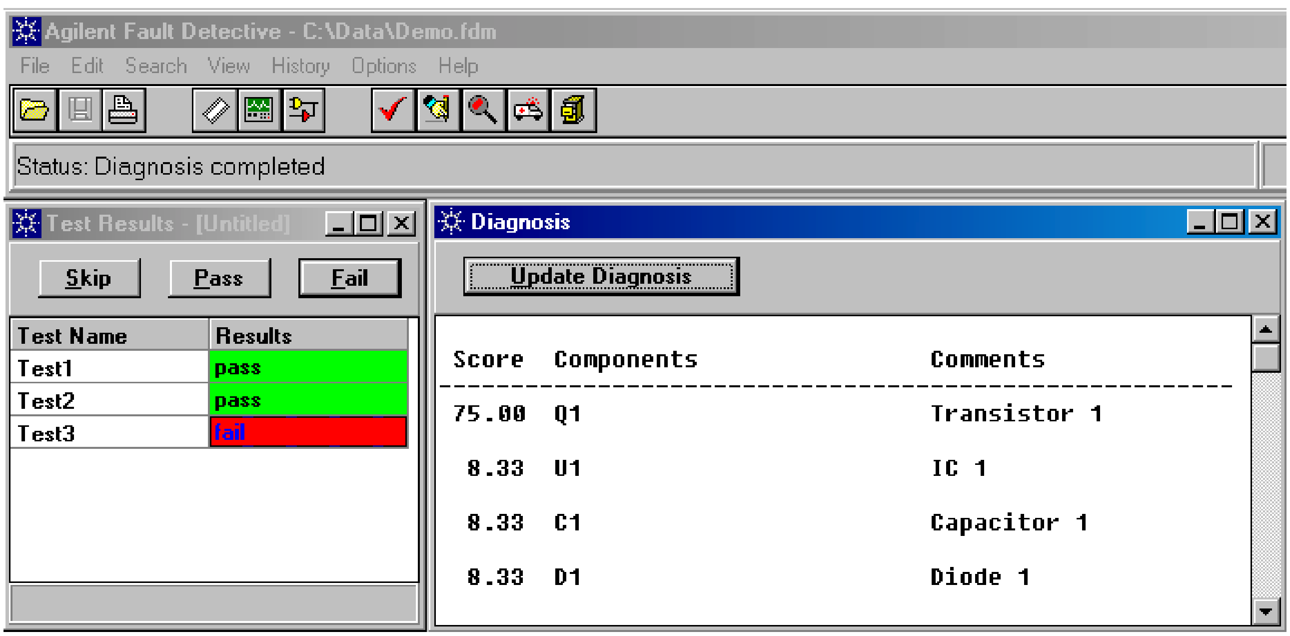

Figure 1: Diagnostic result as shown in the development environment GUI.

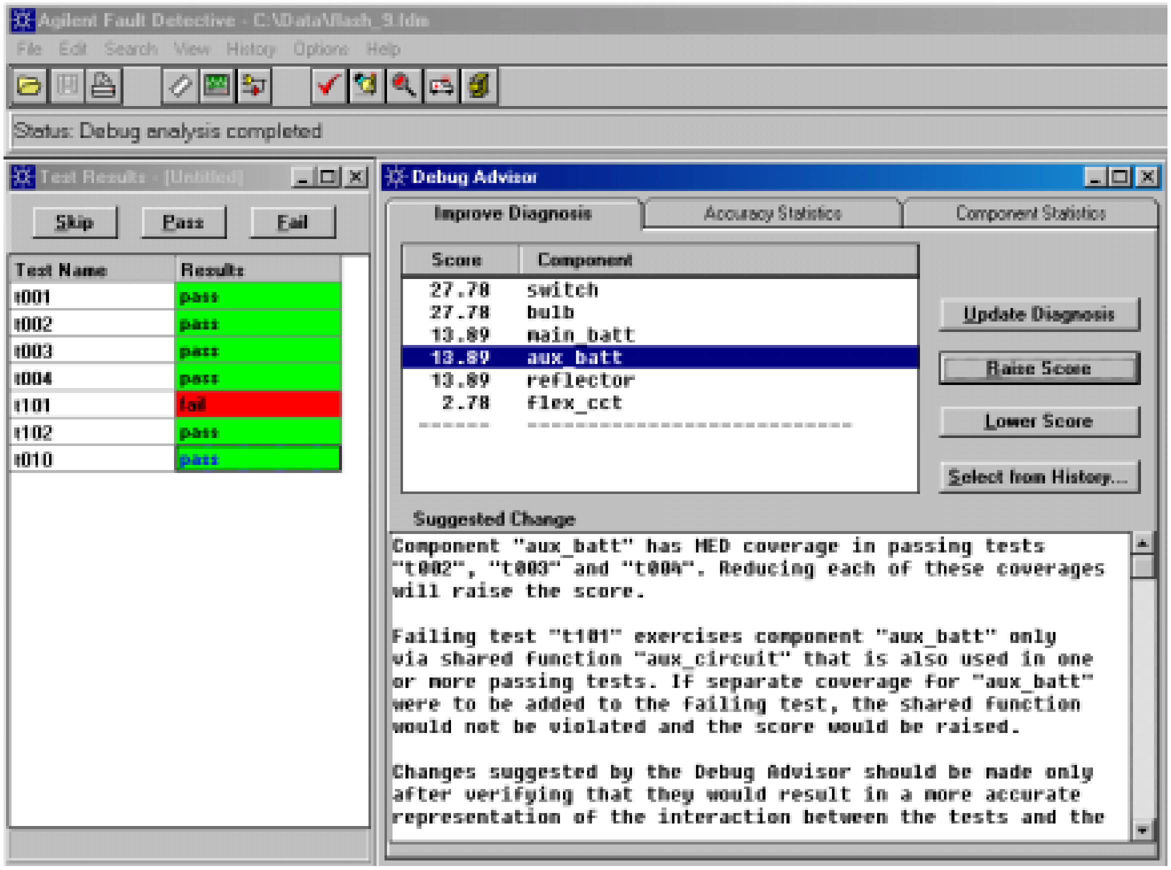

Figure 2: Fault Detective Development Environments GUI, “Debug Advisor.”

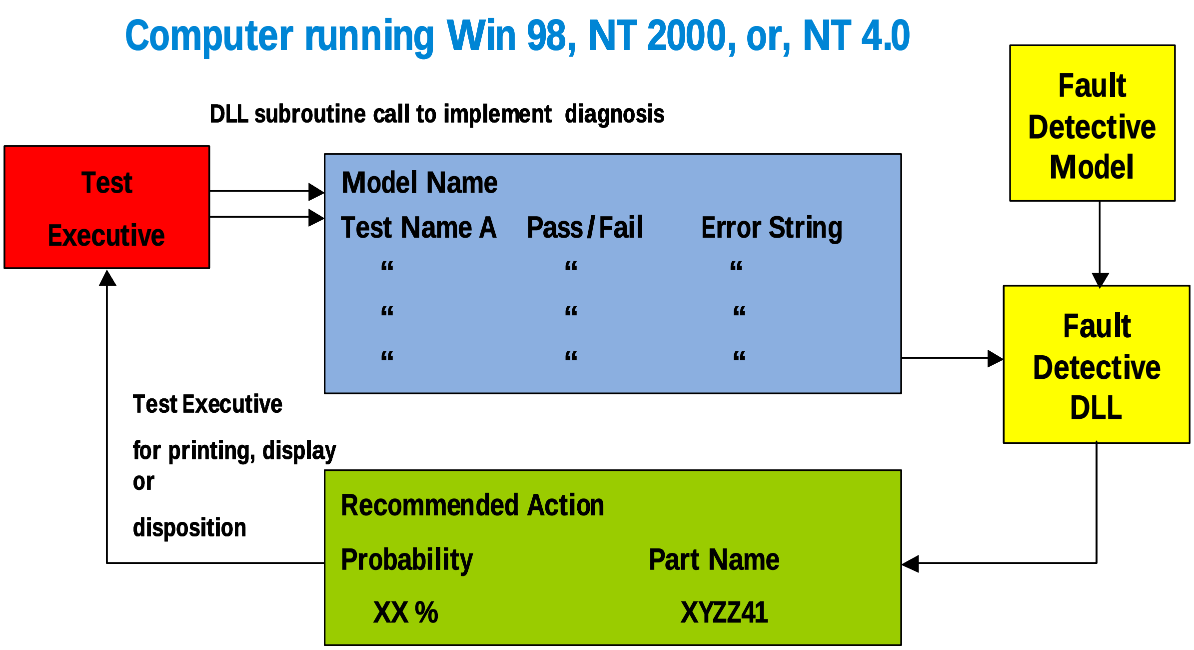

Figure 3: Implementation of Fault Detective DLL in manufacturing.

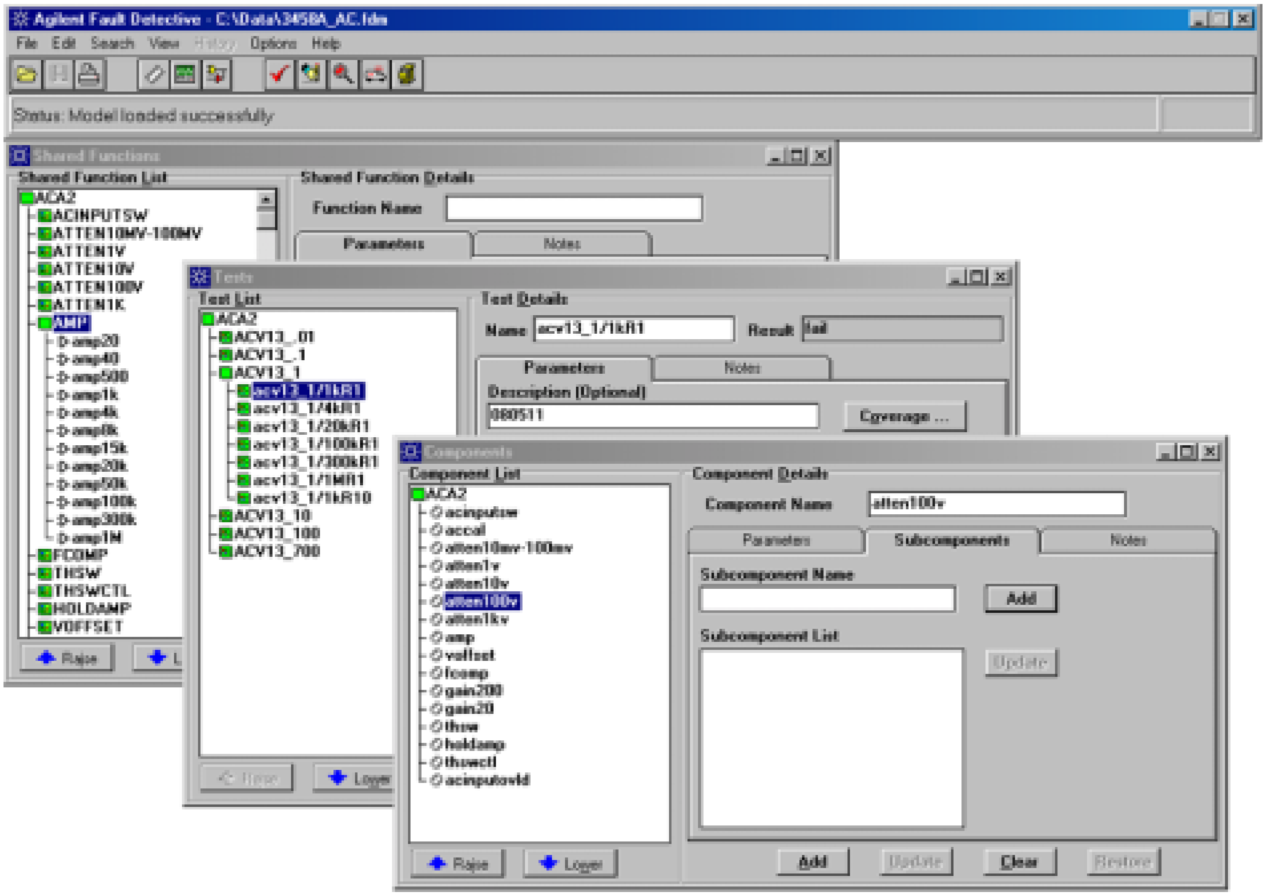

Figure 4: Development Environment GUI.

Manufacturing Implementation

The application of Fault Detective is targeted primarily at the functional test diagnostic process. Figure 5 shows a typical manufacturing process for high-density, high-complexity communications boards (5,000 to 30,000 joints and 1,000 to 5,000 parts) and the targeted location in that process for Fault Detective's run-time diagnostic engine.

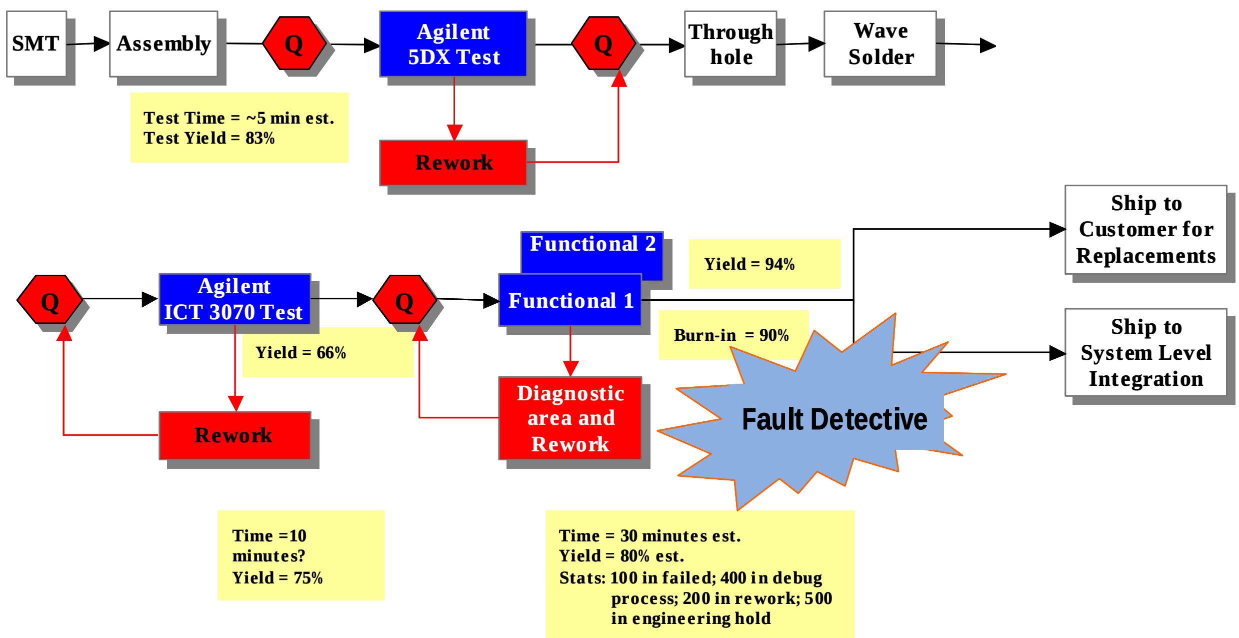

Figure 5: Manufacturing flow for a high-complexity product.

Fault Detective's applicability is not limited to high-complexity product production. Figure 6 shows the typical manufacturing flow for RF consumer products such as cell phones, wireless PDAs and cable modems. Here, Fault Detective is a valuable diagnostic technology at both the board and final test/repair process steps. In this application, the primary cost advantages are the increased plant capacity and a significant reduction in the cost and need for RF technicians to diagnose defective products.

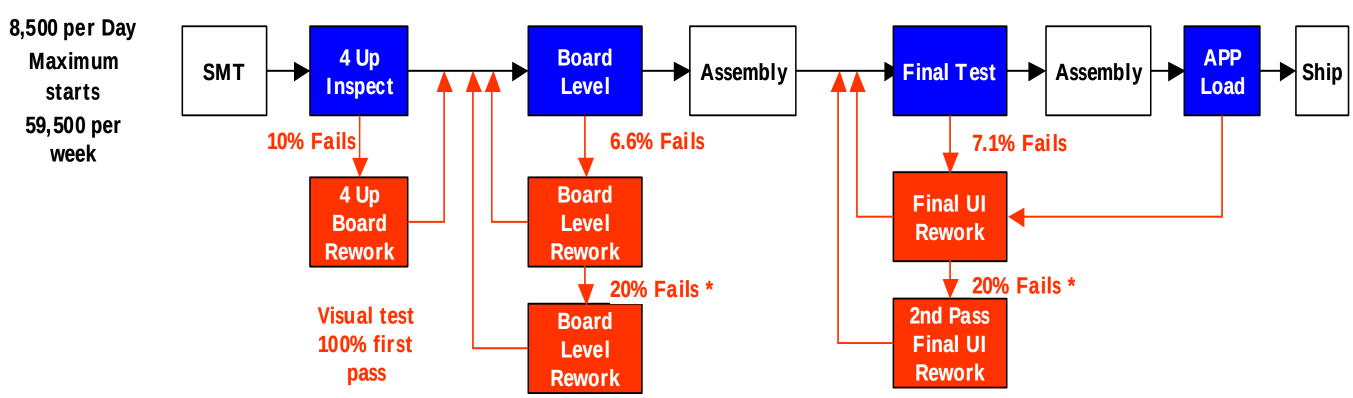

Figure 6: An example of RF consumer product manufacturing process flow.

The actual positioning of the Fault Detective in manufacturing can take on two primary variations. For high-volume manufacturing, most test flows terminate product testing upon a single test failure. This approach maximizes the utilization of the test capacity for good product types. In this case, the implementation of Fault Detective would likely follow the process illustrated in Figure 7. The off-line strategy offers two advantages: the primary test capacity in the forward flow is directed at shipping products; and additional tests not required or used for the primary forward flow can be included in the rework process to increase diagnostic accuracy.

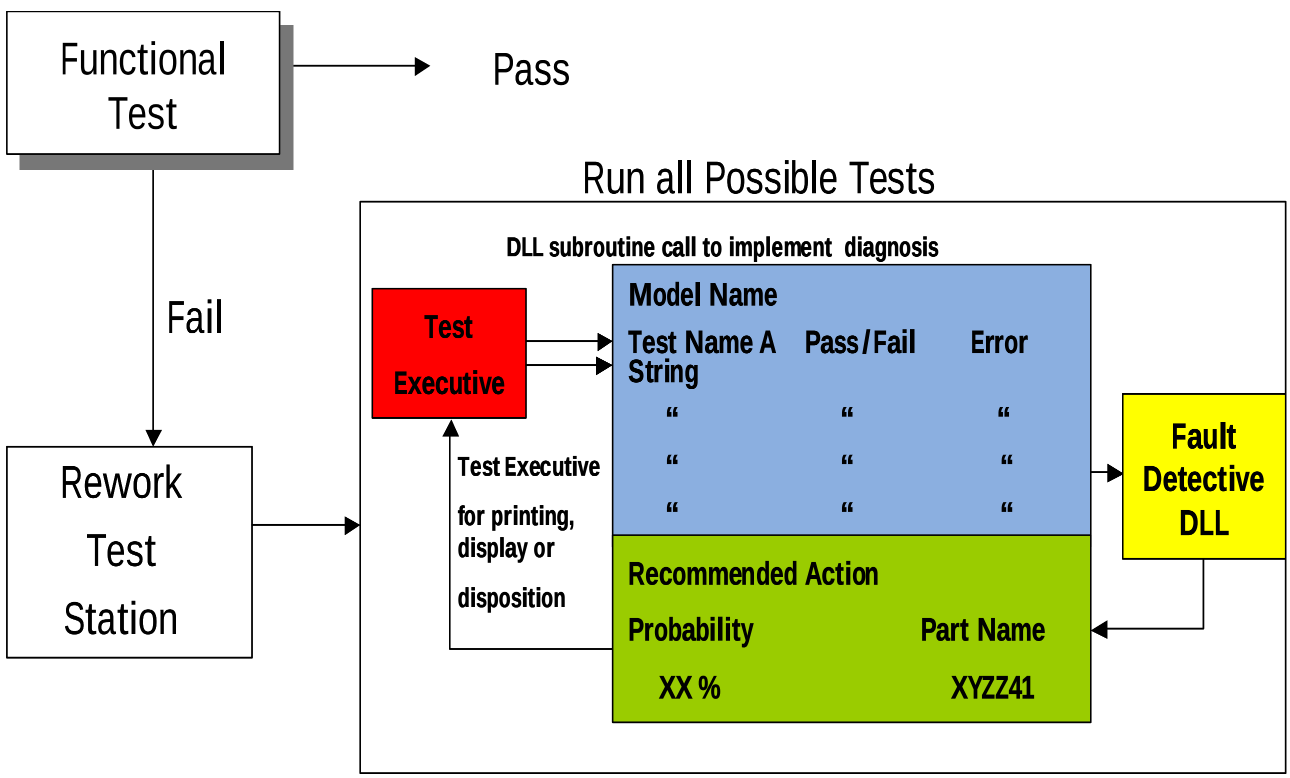

Figure 7: Fault Detective implementation for high-volume products.

For the high-complexity products, the deployment of the diagnostic engine as a DLL is usually integrated into the repair process. It is usually not necessary to rerun the functional test suite, since this was accomplished in the primary forward flow. The only requirement for the diagnostic process is access to the test results (test name, pass or fail result, and a computer running Windows 98, NT 4 or NT 2000).

Financial Impact

For most manufacturers, functional test and functional test diagnosis represent both a bottleneck in the manufacturing process and the single largest opportunity for cost reduction. Based on Agilent's analysis, an average of 10 percent of the total manufacturing cost is devoted to these two areas. Table 2 illustrates this point for eight industries, which represent the production of $2 billion in assemblies. The table identifies two of five cost-saving opportunities impacted by Fault Detective.

Table 2: Complex Board production and associated manufacturing cost.

Complex Boards Segments	# of Failed Units	Material cost	Technician Time	Total Market for the Segment	Rank	% of CM	Rank	Units Made per year	Rank	Failure
Server-Motherboard and CPU	1127039	$281,759,750	$98,615,953	$487,661,158	1	80%	2	8.3M	1	9%
Carrier Class Switches	798862	$199,715,500	$143,795,222	$440,398,362	2	35%	5	2.4M	3	16%
Wireless Basestation	696173	$174,043,250	$83,540,812	$330,235,977	3	60%	3	3.1M	2	12%
Routers	613321	$153,330,250	$42,932,494	$251,618,903	4	95%	1	1.2M	4	14%
NICs	527072	$131,768,000	$23,059,379	$198,496,640	5	80%	2	0.6M	6	10%
Flight Navigation	299615	$74,903,750	$74,903,812	$192,060,977	6	15%	6	.8M	5	23%
WS-Motherboard and CPU	270470	$67,617,500	$40,570,572	$138,702,656	7	45%	4	1.2M	4	11%
Medical Diagnostics	170917	$42,729,250	$53,411,625	$123,257,532	8	35%	5	.5M	7	21%
Total	*4503469*	*$1,125,867,250*	*$560,829,869*	*$2,162,432,204*						

(Source: New Venture Research Company, 1999)

In the table, the two opportunities are material cost and technician labor. In addition, the application of a diagnostic technology can affect functional test and the rework of capital equipment, overall plant capacity, and inventory carrying cost. For manufacturers whose manufacturing capacity is bottlenecked by functional test, the application of an effective diagnostic technology can increase overall plant capacity 1 to 10 percent. The exact impact on capacity is a function of the diagnostic effectiveness of the test suite and the functional test yield. For the complex technologies represented in Table 2, this impact is particularly beneficial for capacity limited firms.

The cost impact of a diagnostic technology is directly related to the diagnostic effectiveness of the functional test suite. Typically, very little emphasis is given to this measure for two key reasons: diagnostic effectiveness is difficult to measure and the financial impact of test effectiveness is seldom calculated.

Agilent Technologies has developed financial models that give critical insight to the importance of these parameters. Figure 8 illustrates this point for a product with an annual volume of 25,000 boards, with a manufacturing cost (material and conversion cost) of $1,500, where the diagnosis time is 30 minutes per board. In this example, the baseline diagnostic accuracy of the board was 50 percent prior to the introduction of Fault Detective. With Fault Detective, the manufacturer was able to achieve a diagnostic effectiveness of greater than 80 percent, which represented a $500,000 savings and an increase in plant capacity of 5 percent.

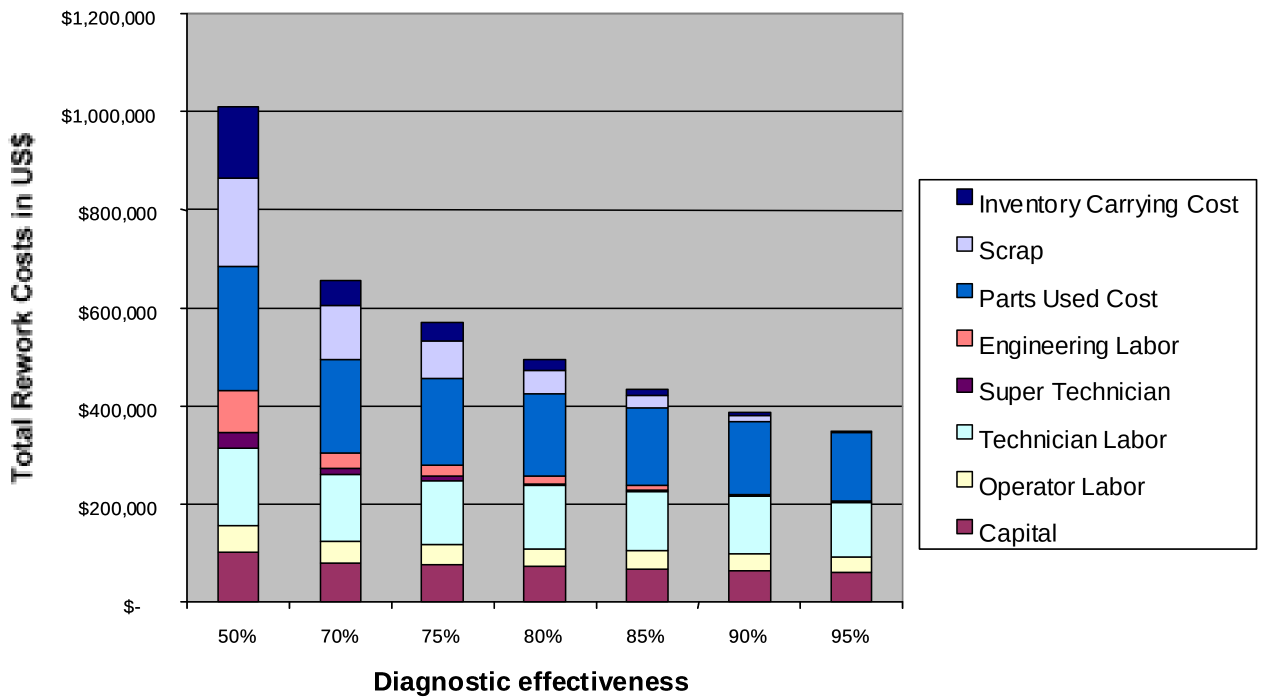

Figure 8: Example of the cost saving derived by implementation of Fault Detective.

Notes: Annual Volume: 25,000, $1,500 board cost including manufacturing, typical technician diagnosis time of 30 minutes per unit.

Development Support and Services

The ultimate success or failure of a revolutionary technology depends critically on the effectiveness of the implementation and acceptance of the receiving entity. To this end, Agilent has created a comprehensive set of development and support services that supplements the Fault Detective technology. The support services take two forms: *à la Carte* and startup services.

Startup services include all the necessary applications support, implementation consulting, licenses and training courses to insure an efficient implementation for the first target product. The critical issues addressed by these services are technology training, model development assistance, model reviews and factory implementation strategies.

The *à la Carte* services menu allows the customer access to these services as needed.

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EDITOR'S NOTE: Agilent Technologies Fault Detective is currently available to customers. This technical backgrounder supplements an Agilent press release to be issued on Jan. 22, 2002.

January 2002