Simplifying the Economics of Test and Repair in Both the Factory and Depot

Abstract

When it comes to understanding the Cost of Test, we all tend to start philosophizing on the multitude of factors that must go into such an equation. In fact, the Office of the Secretary of Defense, Cost Analysis Improvement Group took over 149 pages to layout all the attributes and assumptions in 1992\(^1\). This paper explores a different way of approaching the problem. Instead of developing algorithms and defining attributes bottoms-up for every and all factors of a test strategy, this approach looks at a top down methodology. Taking a systems view of the process, and associated costs of test, a minimum set of data and related cost are all that are needed to get a 90% understanding of the cost of test. More importantly, these models can show gaps in strategies and leverage areas for eliminating test and process steps and thus associated costs.

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\(^1\) Office of the Secretary of Defense Cost and Analysis Improvement Group, Operating and Support Cost-Estimating, 1 May 1992
Introduction

The cost to convert material into a product has always been a chore for the financial world, program manager, designers and those in production. Questions like how should it cost and then the real question of how much does it really cost, how much is in fixed versus variable costs, and how do we allocate cost when sharing resources or equipment? What accounting methods should we use, how will we depreciate costs, what do we count as overhead, or what level of detail do we want? All these factors are important in understanding what something costs and what level of detail needs to be reported. The real question is what you really need to know to make a decision to design, manufacture or repair a product.

With all the focus on the financial aspects of programs there is a renewed emphasis to look at what is the cost of test. Why suddenly the interest? If we look at this phenomena there are several driving factors that would seem to explain it.

The first is the advent of integrated circuits and surface mount technology. Both of these technologies have driven down the cost of individual parts and the assembly of electronic circuit assemblies (boards). This has been quite dramatic, it is estimated that raw material costs have gone from 70% of the total cost of a product in the ‘70s to over 90% in the ‘90s, especially for electronic products like cell phone and computers. Therefore the total cost of assembly and test has dramatically decreased. Although this is true, the real issue is that the percentage of reduction between assembly and test has gone down but as a percentage of reduction in non material cost, test as a percentage of total cost has stayed constant and now has become one of the largest non material expenses in the cost of building a product.

To illustrate this trend Figure 1 is a chart that shows the breakdown, on average, of all non material costs compared to the cost of test for a GSM cell phone.

![Figure 1. Conversion cost compared to test cost over time](chart.png)
As you can see, although the non material costs has dramatically decreased, the cost of test or verifying the product is designed and assembled correctly has stayed virtually the same over the ten year period.

An additional effect of integrated circuits and surface mount components is size and thus complexity of the product. This has enabled designers to take what once took 5-6 circuit boards and reduce it to a single card with mixed digital and radio frequency (RF) signals. Therefore, what was tested functionally on 5-6 different cards now has to be tested all on a single card.

This complexity expands to diagnosing and repairing failed boards. Now people not only need to be able to understand all the possible functions of a product they need to be able to replace parts that sometimes are as small as a grain of sand or may have solder joints that are unseen because of ball grid array technology.

Therefore, with the technology getting more complicated has the understanding of test and its associated cost become more complicated? Not really.

The Elements of Test

As any person that has done any financial work with manufacturing will tell you there are two major buckets that cost must be broken into, fixed and variable. Although there is some debate on certain items, for this paper we will make some assumptions but the methodology is still the same.

The easiest way to determine a fixed cost from a variable cost is that a fixed cost is independent of the volume of product that is being produced. Variable cost changes correlate with the volume of product volume. It should be noted that some variable costs may move in step functions versus a one for one correlation with volume.

As we move through this methodology for determining the cost of test there are very few true fixed costs associated with test. The truth is that most costs are variable. But they are variable in steps. A simple example of this is a test that costs you $100 a day to run and can test 10 units a day. If you test 1 unit a day it will cost you $100, 10 units a day would cost you $10 and 11 units would cost $18.18. This is because you would need two testers ($200) to be able to meet the demand of 11 units per day ($200/11=$18.18).
To simplify the elements that make up the cost of test, you must separate the function of test from the mechanics of test in the process. For developing a model of test the function of what it does rarely matters. From a high level there are four major buckets of test costs; cost associated with the actual test step, diagnostics and repair, overhead and constants, and the cost of product waiting (work in process, WIP).

Outlined below are many of the elements that go into the cost associated with any given test step.

- Number of Test Stations
- Number of test fixtures per station (#)
- Number of UUTs (unit under test)/fixture
- Number of Test Stations per Operator
- UUT Set-up Time
- UUT Test Time
- UUT Removal Time
- Percent of Maintenance and Support people per shift to Support Test Cell
- Cost of Consumables per Units
- Depreciation

Each of these elements can be broken down to a cost per unit and/or a given period of time easily making them all variable costs.

For diagnostic and repair, the following make up the majority of the cost elements for a given test step;

- Average 1st pass yield
- Average 2nd pass yield
- Average 3rd pass yield
- Average Diagnostic Time
- Average Repair Time
- Depreciation
- Cost of repair material
- Scrap

Depending on the operation process some companies stop after the third repair and then scrap the product. Others will repair until it’s fixed. In the latter process, the 3rd pass yield would be the accumulative average of all the attempts to repair the UUT, this simplifies the model.
Determining the overhead and constant costs tend to be more complicated. Being able to identify them allows the ability to simplify the whole model. Averaging the following costs at high level will not have a discernable effect on the final numbers, while still giving you a workable model.

- Hours per shift (Hrs)
- Number of Shifts per week
- Test Labor Cost
- Diagnostic Labor Cost
- Repair Labor Cost
- Maintenance Labor Cost
- Engineering Support/Test Cost
- Number of Support/Test Engineers
- Material Cost (total direct material)
- Cost of Capital
- Production Months
- Non-reoccurring Engineering Cost

The last element is the cost of product waiting (WIP) for its next process step. There are several areas were these cost matters;

- Average Number units waiting for test
- Average Number units waiting for Diagnostics
- Average Number units waiting for Repair

It would make sense to want to understand how long the units have been waiting in queue to calculate WIP cost. Because this measure is averaged over a long period of time, time does not matter for calculating WIP costs and therefore just the average number of UUTs waiting for a process will work.
Structuring the Model

Simplifying the structure of the model is just as important as simplifying the inputs. We all know that people like to see information in different formats. Some like information in a pictorial form and some in a written form. Some people are more process oriented and some are not. Therefore the ability to structure a model that can be easy understood from a structural standpoint for different types of people is critical.

The first part of structuring the model is to align the various inputs to where they are in the actual process. This would be a fairly easy exercise if all you were modeling a single test step. All that would be needed is getting the data for the elements described above. The fact is that understanding the cost of test for a product means understanding anywhere from as few as three to as many as ten test steps. To complicate this even further, the inputs need to come from many different people and sources.

To remove this complexity the model is broken down to two sections. The first is what is called universal variables. These are inputs that are the same for every test step. Included in these are numbers that may be slightly different but when averaged the overall answer would be the same. Most of these are the elements that are describe as overhead and constants earlier. An example is shown in Figure 2.

Overhead and Constants

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard efficiency</td>
<td>0.95</td>
</tr>
<tr>
<td>Hours per shift (hrs)</td>
<td>8.6</td>
</tr>
<tr>
<td>Number of shifts per week</td>
<td>10</td>
</tr>
<tr>
<td>Test labor cost/hr</td>
<td>$35</td>
</tr>
<tr>
<td>Diag labor cost/hr</td>
<td>$50</td>
</tr>
<tr>
<td>Repair labor cost/hr</td>
<td>$40</td>
</tr>
<tr>
<td>Maintenance labor cost/hr</td>
<td>$45</td>
</tr>
<tr>
<td>Engineering support/test cost/year</td>
<td>$95,000</td>
</tr>
<tr>
<td>Number of support/test engineers</td>
<td>2</td>
</tr>
<tr>
<td>Material cost (total direct material)</td>
<td>$550</td>
</tr>
<tr>
<td>Cost of capital</td>
<td>33%</td>
</tr>
<tr>
<td>Production months</td>
<td>36</td>
</tr>
<tr>
<td>NRE $$</td>
<td>$100,000</td>
</tr>
</tbody>
</table>

Figure 2. Example of overhead and constants inputs
The second section is the test step variables. These are all the variables that are dependent on the actual test set up, the operation of that test and associated support of that test. These are the element described above under cost associated with the actual test step, diagnostics and repair, and the cost of product waiting (work in process, WIP). For each test step modeled, a set of unique inputs for these cost elements will be needed. So even for a simple model this may seem overwhelming. Again to simplify the attainment and the input, the model is set up by test step as shown in Figure 3.

**Test Step 1**

![Table of Test Step Variables](image)

**Putting It All Together**

Once all the elements and structure are defined, the tying it all together is easy. By associating the elements in the test step to the associated overhead and constant elements, a cost per test step can be calculated. Although this process can be time consuming, once it is done for one test step it is easily copied for the remaining test steps.
For each of the elements in the test step an associated cost and/or time element is calculated using elements of the constants. For example, the cost of loading, testing and unloading a UUT is a function of the time it takes to do each of these steps times the cost of labor of the operator performing the function. This does get a little more complicated if the test station tests multiple UUTs at a time or one operator can operate two stations. Once the algorithm is defined, these differences are automatically taken into account.

To help simplify the overall cost calculation, the top level again is broken down to the major categories of cost, as shown in Figure 4. These are test cost, diagnostics and repair, WIP and scrap cost for each of the test steps and then a cost for all of the fixed and overhead costs of the whole process.

The fixed and overhead costs are those costs that can not be associated with any individual steps. One example might be the total engineering cost that it took to define the test process. These costs would be broken down to the total non-reoccurring engineering (NRE) expense, divided by the number of months it is estimated the product will be in production, divided by the approximate volume per month. This calculation provides the incremental value per UUT for developing the overall process.

<table>
<thead>
<tr>
<th>Cost Matrix</th>
<th>Test step 1</th>
<th>Test step 2</th>
<th>Test step 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total COT</td>
<td>$638</td>
<td>$2,218</td>
<td>$399</td>
</tr>
<tr>
<td>Cost of Test</td>
<td>$604</td>
<td>$2,142</td>
<td>$379</td>
</tr>
<tr>
<td>Diag &amp; Repair</td>
<td>$25</td>
<td>$61</td>
<td>$13</td>
</tr>
<tr>
<td>WIP</td>
<td>$3</td>
<td>$4</td>
<td>$6</td>
</tr>
<tr>
<td>Scrap</td>
<td>$6</td>
<td>$10</td>
<td>$0</td>
</tr>
</tbody>
</table>

**Figure 4. Sample of cost of test model output**

Once the all the individual steps are calculated and assembled by test step and category, it becomes a simple process of adding the numbers together and determining the format in which the numbers will be most useful.

As in all models, after it is completed a reality check is prudent. This can be accomplished in a number of ways. These range from having others look at it to changing variables and ensuring the expected corresponding variables change also.
Modeling for Decision Making

When the model is complete the real value can then be exploited. The model can become a tool for decision making and tradeoffs to be evaluated using consistent data. The model allows people to change one or more variables and then compare them to the as-is model and determine what is the return of the investment. Another use of the model could be determining the cost of test for a program still in the planning stages by using information from a similar or existing program.

Some examples of the tradeoffs that could be looked at might be; what is the tradeoff of upgrading a test station? On one hand it raises the depreciation expense of the equipment and may add NRE costs. On the other hand it may cut down on the speed of testing the UUT. Another tradeoff example could be the savings of removing a test step by adding additional tests and test time to another test step. Perhaps the cost of retooling a test station for a new product and its associated support costs would be better than buying new equipment. There are countless tradeoffs that could be looked at once the model becomes the foundation for the decisions. Modeling creates an opportunity to investigate numerous options before committing to a course of action.

Summary

In summary, in today’s dynamic world of having to be able to predict the future and understanding the complexities of current operations, developing models can help make decisions easier. Because test is such a pivotal part of today’s electronic manufacturing process it would make sense that an easy to develop and use model would be a great advantage for making decisions.

This paper has established a framework to develop a cost of test model for any part of a product life cycle and allow either real-time or proactive decision making.

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