The Real "Total Cost of Ownership" of Your Test Equipment

White Paper

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Abstract—*Cost of ownership is always a hot topic when making a program decision for any new, upgrade or sustainment option. The criteria for developing a Total Cost of Ownership (TCO) model quickly turns into debates with many facets and lots of emotion. When it comes to the cost of acquiring and operating test equipment, the answer is not any easier to determine. However, if looked at from a Product Life Cycle (PLC) cost or a Performance Based Logistic (PBL) view point, a more accurate cost model can be developed. By understanding and using the attributes of direct and indirect costs for acquiring, operating, maintaining, migrating and disposing of these assets, an accurate model of the total cost of ownership can be obtained. This paper will lay out the PLC/PBL costs of test equipment and walk through a TCO model that can be used for making trade off decisions between different program options.*

Introduction

For many years the acquisition of test and measurement equipment was viewed as a necessarily evil to ensure that electronic products manufactured by companies had zero defects. While there are many reasons for this during the boom of electronics in the 1970's and 1980's, possibly the biggest contributor was the inconsistency in which electronic designs were performed. In many cases designers used home grown spreadsheets or had tables they developed to calculate design margins. As designs became more complicated in the 1990's, it forced most designers into using professionallydeveloped simulation tools. Quickly this proved that a wellsimulated design minimized the performance gap between theoretical design and the actual product. Simulation, combined with contract manufacturers mastering high quality manufacturing methods, led to products with 95%+ yields. Still, the questions continue. Why do we pay so much to test when the level quality is so high? Or a better question: What is the real cost of test?

During the 1990's when we saw outsourced products and more power, control and information built into electronics, consumers were expecting more for less, no deviation from quality and more product variety. The pressure was on for manufacturers to cut costs in a global economy where everyone had access to the same labor pool, parts suppliers and design tools. The result was a new procurement focus, namely Total Cost of Ownership (TCO). TCO first gained popularity with semiconductor equipment users when they wanted to recognize the procurement decision encompassed much more than the initial acquisition (purchase) cost. A semiconductor line could easily cost several tens of millions of dollars to acquire. Further analysis showed that costs associated with owning and operating the asset over its entire useful life could considerably exceed the acquisition costs.

This paper introduces a TCO model for electronic test and measurement equipment and shows how operating costs can be critical drivers in reducing total cost of ownership beyond simply lowering acquisition (capital) costs. The TCO concept will help equipment owners make informed decisions on the purchase decision, and it will show how TCO variables can drastically change the overall cost of ownership for test and measurement equipment throughout the product's life cycle.

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Cost Of Test

Many papers have been written and presented on the topic of Cost of Test (CoT). While there are several models that focus on CoT, almost all of these methods have the same flaw, namely they calculate CoT at a single point in time. That is, although they may take the acquisition costs and depreciate them over a period of years, these models typically look at other expenses (such as preventive and corrective maintenance actions) from an "average" cost standpoint. From studies in Performance Based Logistics (PBL), we have learned the cost of a product is not linear and we cannot measure it at only one point in time. An example of this would be looking at depreciation and repair costs. Depending upon the accounting method used, depreciation can be spread out over three years or five years, and with flat or accelerated schedules for most test and measurement equipment. No matter the method employed, in five years the product has been fully depreciated. During that time the chance of equipment failure is relatively low, however after five years the chance of a failure can be considerably higher and may continue to grow as the equipment ages.

Thus, using a CoT tool can produce very different results depending upon what point in time you decide to model the operation. In Year 1 the primary expense is the acquisition cost, yet in Year 10 maintenance and downtime factors would results in higher expenses. So what numbers do you select? The most accurate number would be represented by the average cost for the equipment over the expected useful life. This would account for the various costs as the equipment ages.

Even using the average cost in a CoT model is misleading when understanding the true TCO. Consider two manufacturing lines using the same type of equipment. Let's say both CoT models arrive at the same cost results with the only difference being that one line has bottlenecked throughput and the other line does not. With CoT modeling, this is usually not a factor that affects the calculated results. In contrast, such bottlenecking would be reflected in the TCO model via input parameters such as reliability and repair turnaround time. In the bottlenecked line, any downtime would affect production and thus revenue.

Consider another scenario where we must outfit a new production line by choosing between two test equipment manufacturers. One test asset could have a higher purchase price and a lower failure rate and the other test asset might have a lower purchase price and a higher failure rate. So while the CoT may favor the asset with lower purchase price, when TCO is considered in the purchase equation the decision may be to spend more money upfront on a more reliable asset. While the differences between CoT and TCO modeling are many, there are other scenarios where the two methods are complimentary. The fact is, to build an accurate CoT model over a production life cycle or to compare two different pieces of test and measurement equipment to get an accurate PBL cost, TCO becomes a foundation for deep understanding. Let's take a look at factors that go into the TCO methodology.

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Total Cost Of Ownership

TCO Defined

TCO is defined to be the total cost to own and operate a piece of equipment over its useful life. Agilent Technologies has developed a TCO model for the Test & Measurement industry comprised of the two core elements of capital expenses (acquisition costs) and operating expenses. Modeling of capital expenses is fairly straightforward with depreciation schedules being the principle area of variation. Capital expenses are costs (Ca) incurred to acquire and install the equipment. Operating expenses provide an area for much greater latitude in terms of what is included in the TCO model and how the cost components are represented. The TCO model presented in this paper structures operating expenses in the following manner:

- Preventive Maintenance – C_{pm}
- Repair – C_r
- Downtime Mitigation – C_{dm}
- Technology Refresh – C_{tr}
- Training & Education – C_{te}
- Resale value or disposal cost – C_{rv}
- Facilities – C_f
- Other – C_o

The Total Cost of Ownership equation is given by

$$TCO = C_a + C_{pm} + C_r + C_{dm} + C_{tr} + C_{te} + C_{rv} + C_f + C_o$$

TCO Cost Components

Calibration of the equipment (i.e. metrology) is usually the largest cost component of preventive maintenance expenses. In this regard, calibration cycle period is the single largest lever to pull on to reduce such metrology costs. Other important variables beyond just the cost to perform a calibration include cal turnaround time (TAT), logistical costs and any "repair" costs required to adjust the product back into calibration. Preventive maintenance costs would also include other periodically scheduled actions such as proactive replacement of subassemblies that tend to exhibit wear out phenomena.

Repairs, sometimes also called as corrective maintenance actions, generally refer to unplanned downing events such as equipment failure. For the purposes of this TCO model, corrective maintenance costs are represented by the cost to perform the repair, re-calibrate after the repair, remove/ship/re-install (logistics), and verify performance of the equipment. The cost to perform the repair can be represented by either a contracted repair agreement or, if the owner wishes, to "self-insure" on a Per Incident (P.I.) basis. Annual P.I. repair expenses are modeled as the expected annual value calculated by multiplying the P.I. cost times the probability of failure occurring over a one year period. While at first glance it may appear that a P.I. strategy is the lower cost option, one must also consider that a repair contract usually results in a lower repair TAT and therefore lower downtime.

A downtime cost penalty must be applied to recognize the fact that the equipment was unavailable for use by the owner. This is accomplished by applying a cost driver variable, such as a weekly rental rate proxy, to the cost equation such that: Cost of Unavailability = (purchase price) x (rental rate proxy) x (repair TAT)

Weekly rental rates for performance measurement equipment typically run in the range of 2-5% of the purchase price.

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The consequences of unplanned corrective maintenance events such as equipment failure can be extremely costly, even disastrous, for the enterprise. For instance, if a test system goes down in a volume manufacturing environment or in a critical R&D application, the impact can be lost sales and missed business opportunities that may cost the enterprise millions of dollars. Because of difficulties in quantifying and predicting the outcome of such events, the TCO model does not place this aspect of the cost element under the heading of repair. Instead, these sort of "catastrophic" costs are addressed through cost avoidance measures and strategies, collectively referred to as Downtime Mitigation strategies. Examples would include investments in high reliability equipment, lower repair turnaround times and increased test capacity.

Technology Refresh (sometimes termed Product Migration) refers to situations where equipment owners wish to upgrade their assets to products with increased levels of measurement capability or increased levels of measurement speed. Typically the largest component of product migration cost is the investment required by equipment owners to ensure backward/forward compatibility of the new piece of equipment in their test process. Costs associated with developing and editing test code to ensure compatibility in the test process can be quite high. These are one-time expenses that should be amortized over the installed base of equipment that derive the benefit.

Facilities costs include electricity to operate the equipment and floor space to utilize the equipment.

At the end of the equipment's useful life, the asset is disposed of either by selling, trading in for credit, or having the equipment recycled. The first two options are treated as a negative cost in the TCO model. High resale value becomes a strategic advantage for suppliers of superior quality products when one looks at the TCO equation.

Other TCO costs that a business may wish to incorporate into the calculation include consumable materials such as connectors and cables.

Mitigating Catastrophic Downtime Costs

As mentioned earlier, unplanned downing events (failures) are probabilistic in nature with the potential for catastrophically high costs to the business. This makes it difficult to attach a cost estimate that is both accurate and believable. A better approach is to develop and implement operational strategies that mitigate (or eliminate) the effects of unplanned downing events. Engineering and management have a number of downtime mitigation strategies to select from, including

1) High Reliability
- Select a product that offers leading edge reliability.

2) Low Repair TAT
- Select a return-to-depot service provider that offers lowest possible repair TAT.
- Perform on-site repair, either by contracting with a service provider or by developing the capability internally.
- Purchase extended warranty service contracts to reduce or eliminate logistical, administrative and procurement delays.

3) Additional Capacity
- Purchase extra manufacturing test capacity and hold in reserve.
- Purchase spare equipment.
- Purchase spare parts (for self-maintainers)

TCO Cost Elements Vary Over Time

Some factors at work in the TCO algorithm will cause costs to vary over time. For instance, reliability of the equipment (influencing repair costs and downtime costs) typically follows the classic reliability bathtub curve. This curve is characterized by a period of improving failure rate (infant mortality), followed by a period of generally constant failure rate, and then followed by a period of increasing failure rate (wear out). In electronic measurement equipment, electromechanical devices are prone to wear out mechanisms. Another driver of varying TCO costs is the calibration cycle period (influencing metrology and preventive maintenance costs). In order for businesses to properly plan for future operating costs, it is important that TCO costs be modeled over time as shown in Figure 1.

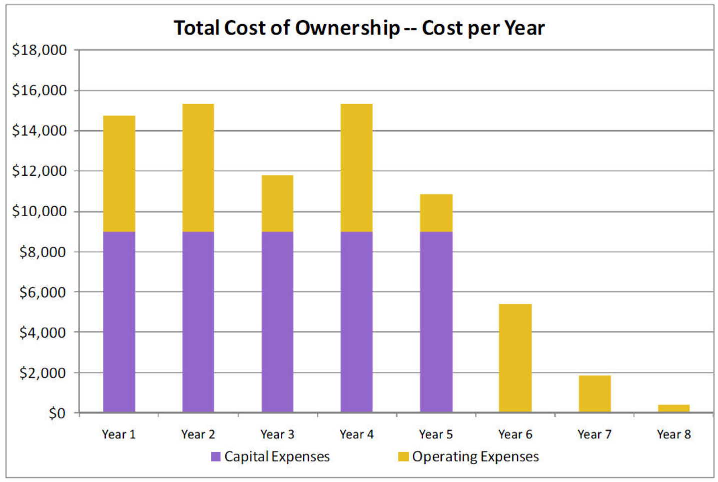

Figure 1. Total Cost of Ownership over time.

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TCO Is More Than Purchase Price

Often times the purchase price is viewed as the single most important cost element in the TCO equation. Indeed, purchase price is all too often the only factor in the equation. Let's take a look at one example where performance, metrology and reliability factors play an important role in affecting the TCO calculation.

Product A is a higher cost test solution. At a price tag of $100,000, it offers higher measurement speed, longer cal intervals, superior reliability and better code compatibility. Because of its superior reliability, the user of Product A is comfortable holding less test capacity in reserve to guard against unplanned downing events such as equipment failure (captured as Downtime Mitigation in the table below). Supplier of Product A also provides on-site repair, a service that supplier of Product B cannot offer. The on-site service contract commands a price premium, however repair TAT is substantially reduced as compared with a return-to-depot contract.

Product B cannot match many of these ownership factors, however the purchase price for the product is 25% less. Industry views Product A as having higher intrinsic value and this is borne out by a higher resale value on the open market. Table I shows the summary of key differences in ownership factors.

	Product A	Product B
Purchase Price	$100,000	$75,000
Test Time per DUT (seconds)	75	100
Throughput (DUT's per week)	4400	3300
Calibration Interval (years)	2	1
Annual Fail Rate	8%	13%
Annual Contracted Repair Cost	$2,200	$1,300
Downtime during Repair (days)	2.0	30.0
Downtime Mitigation (Reserved Capacity)	4%	7%
Cost for Code Development	$10,000	$50,000
Resale Value	$25,000	$10,000

The test equipment is operated 96 hours per week in a manufacturing environment. Useful life of the equipment is eight years and the depreciation method is five year straight line. A downtime cost penalty (4% of purchase price per week) is assigned to reflect the cost of the equipment being unavailable during repair, calibration or other preventive maintenance actions. Cost of test software development to ensure code compatibility is amortized across an installed base of 20 test systems.

A TCO analysis is performed and the lifetime cost to own and operate Product A is $137,000 compared with a lifetime cost of $160,000 for Product B. The case of Product A becomes even more compelling when its speed advantage is taken into consideration. The TCO of Product A is 10.1 cents per device tested compared with Product B's TCO of 14.8 cents per device tested as shown in Figure 2. Not only are total operating costs lower with Product A, but the capital expenses associated with Product A are also lower than Product B when costs are normalized to the number of devices tested.

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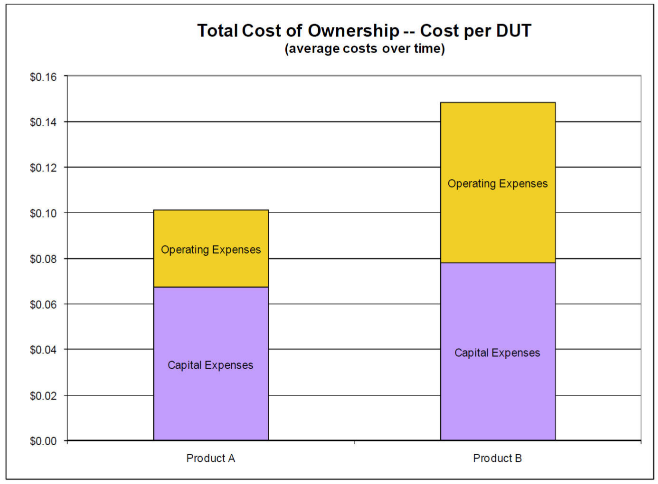

Figure 2. TCO represented by cost per tested device (DUT).

It is instructive to understand the key differences in operating expenses. Figure 3 shows that Metrology costs and Repair costs are the two primary drivers for differences seen in the OpEx costs of Product A and Product B. The longer calibration interval of Product A in the single largest TCO lever to pull, and this is reflected in lower Metrology costs. The lower Repair costs seen in Product A are a result of superior reliability and lower downtime experienced during repair. In fact, these two factors more than offset the lower contracted repair cost offered by Product B.

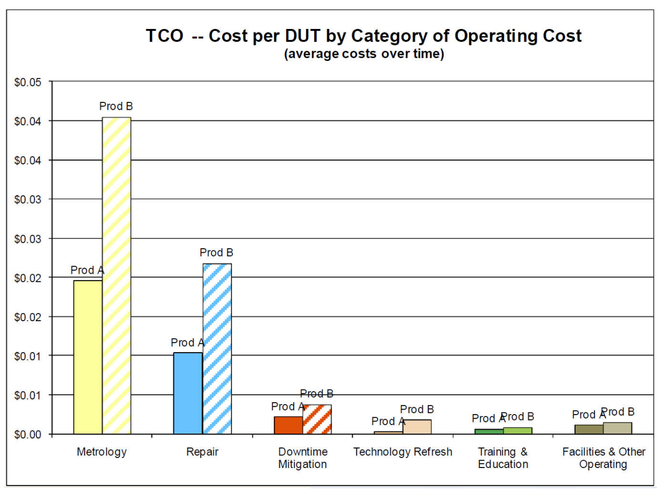

Figure 3. Operating expenses represented by cost per tested device (DUT).

Conclusion

This paper compared and contrasted Cost of Test and Total Cost of Ownership models. While the two techniques are complimentary in nature and some overlap does exist, one of the shortcomings with CoT is it's typically used to calculate costs at a single point in time. The TCO methodology presented here helps bridge this gap by providing a model to calculate cost of key ownership factors over the entire life of the equipment.

As technologies becomes less of a differentiator between competitors and as purchasing departments tend to make decisions primarily based on acquisition costs, understanding the true cost of ownership becomes more critical to the success of the business. Lower upfront costs for acquiring an asset do not necessarily translate into lower total costs to own and operate the piece of equipment over its useful life, and thus do not mean a lower CoT for the products being manufactured.

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