FUNDAMENTALS OF BUILDING A TEST SYSTEM

Modeling the Total Cost of Ownership of an Automated Test System

CONTENTS

Introduction

Most organizations do not consider production test a top priority, but it is a necessity to prevent major quality issues in the products that represent the company brand in the hands of customers. The costs, however, can be significant and are often greatly misunderstood, especially when there's no easy way to quantify the positive business impact of high-quality products or shortened time to market. But best-in-class organizations are unfazed by this "necessary evil" viewpoint, because they seek to understand the total cost of developing, deploying, and maintaining test systems to get ahead of this perception. And the cost of automated test, in reality, is far more complex than the capital cost of a test rack or even the operator's hourly rate.

In this guide, learn about the tools and insight you need to evaluate your test organization, propose changes where significant cost savings are available, and improve the profitability of your company year over year with smarter investment decisions.

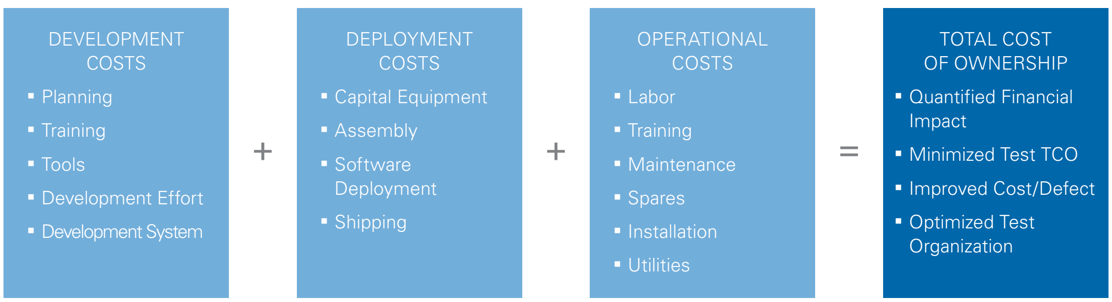

Figure 1. Proper modeling of total cost of ownership uncovers all the lifetime costs of certain test assets and provides a financial framework for justifying future strategic investments.

Development Costs

For most applications, the development costs associated with building a customized automated test system are the smallest in relation to the deployment and operation and maintenance costs. This is typically because only one system is built to serve as a proof of concept for performance benchmarking and test coverage assessment. However, the total cost for developing a test system can vary significantly, depending on the end goal. An organization that is creating a new product often develops and compares multiple test systems with different architectures and instrumentation to identify the optimal approach.

The R&D (engineering) team responsible for a product designs and builds the majority of development systems, and the costs, therefore, are rolled into this budget or cost center. More mature test departments work with their R&D teams to influence the design of products, often referred to as design for test, or DFT, and also work to develop the test systems. This is a best practice but not always possible for test organizations.

For test systems built to test the functionality of a single device or component, the level of effort involved with requirements gathering, instrumentation selection, fixturing, and software development are relatively finite. If, however, a test department is designing a multipurpose, standardized test system to verify the functionality of multiple devices or components, development costs can be greater. You must spend more time identifying all permutations of functionality that the system must accomplish, device under test (DUT) fixturing must be flexible, and the software must be more scalable to make it easy to implement changes when adding new devices to the product portfolio.

Other efforts, such as writing a hardware or measurement abstraction layer or mass interconnect system, require significantly more upfront development cost, but should pay a return on investment for test organizations that either deal with rapid technology change or face instrumentation end-of-life (EOL) issues for long life-cycle systems.

The main costs associated with developing an automated test system are:

- **Planning Effort—**Entails the time and expenses required to properly identify all viable options for the test system. It includes time spent at vendor websites, product demonstration sessions, evaluations, trade shows, and discussion forums.
- **Developer Training—**Includes the time and training course fees associated with learning a new set of software development tools (integrated development environment [IDE] or test executive) and hardware platforms (for example, rack and stack with SCSI or PXI).
- **Development Tools—**The cost associated with purchasing development licenses for the test software (IDE or test executive).
- **Development Effort—**The time associated with the hardware and software development of a proof-of-concept test system.
- **Development System—**The capital cost associated with purchasing the initial proof-of-concept or demonstrator test system for benchmarking against current or other new systems.

Deployment Costs

When you put a product into production, you must scale up the proof-of-concept or demonstrator test system to meet the volume demands of the product. The throughput (units tested per amount of time) of the test system directly impacts the number of systems required to meet demand, and product management and the sales channel determine the forecasted volume. Alongside coverage of test functionality, the required number of test systems is the factor that you should consider most during the development phase because this directly impacts the total deployment cost.

Another factor that increases a test system's deployment cost is shipping. Smaller organizations find this less challenging because the manufacturing test and R&D departments can be collocated in the same building or at least in close geographic proximity. However, even some smaller companies opt to contract the manufacturing and test of their products if they lack the ability or expertize to manufacture and test their devices or components. Larger companies, however, can have manufacturing test and R&D departments located in separate regions within the same country, and even in a completely different country. This can increase deployment costs dramatically, especially if the manufacturing test system is large and/or heavy. Slower freight shipping methods can help to reduce this cost, but only in circumstances where time is not a factor. A best practice is to consider the physical size and weight of any test system during the development phase, especially when comparing two options, as this can bear a significant downstream cost.

Figure 2. When selecting between two test systems with similar performance, select the smaller, lighter test system to reduce deployment costs.

The main costs associated with deploying an automated test system are:

- **Capital Equipment—**The number of test systems required, which is determined by the product demand and test system throughput, directly impacts this cost.
- **System Assembly—**The time required to assemble the individual components into a test system, which includes building a 19 in. or 21 in. instrumentation rack or other mechanical enclosure, installing all test instrumentation, connecting cabling and wiring, installing switching and mass interconnect, and fixturing.
- **Software Deployment—**These costs are associated with compiling or building a collection of software components and then exporting these components from a development computer to target machines for execution.
- **Shipping and Logistics—**The size and weight of the test system as well as the quantity of test systems required for the production or manufacturing facility directly impact this cost. The distance travelled and the time window required to receive the shipment also impacts the cost. Depending on the ruggedness of the system, special packaging may be necessary.

Operation and Maintenance Costs

The final and often overlooked or underappreciated costs associated with a test system are the operation and maintenance costs. These are typically not attributed to the R&D team that originally designed the product or device but almost always roll up to the manufacturing or production team; this separation of cost centers makes cross-department collaboration a common pain-point. In situations where a company chooses to contract out the manufacturing and test of its products, the contract manufacturer incurs the individual costs and negotiates a flat or hourly rate for the service.

The costs associated with operating and maintaining an automated test system are:

- **Hourly Operation—**The labor costs for test system operators and support technicians to ensure the systems are up and running during manufacturing. The number of test systems and the skill level required to operate the system directly impact this amount.
- **Operator Training—**The time required for each operator to learn how to use a test system. Costs typically are limited to the amount of time that each operator must attend training, regardless of format (manual, online, or in-person). Companies with a variety of test systems must decide on their staffing strategy between a model of every operator can operate every test system and each operator specializes on a single test system.
- **Maintenance—**The cost associated with keeping the test system and instrumentation in working order. It often includes the cost for annually calibrating equipment, as well as a forecasted cost for replacing instrumentation upon failure. How easy the system is to service can also impact this.
- **Spare Inventory—**The cost required to keep spare instrumentation in the event of unplanned downtime (for example, instrument failure) or planned downtime (for example, calibration). Each test system requires spare instrumentation; companies with multiple unique test systems, because of high product mix, require a larger set of spare instrumentation and parts for their test fleet to ensure high uptime.
- **Installation—**Test systems that consume a lot of power or produce a lot of heat need special, high-power electrical work or cooling towers to be installed to ensure proper performance.
- **Utilities—**The cost associated with powering, cooling, and housing (floor space) the test system. The price per square foot of the manufacturing floor and electricity rate can vary significantly based on geographic location.

Financial Analysis Approaches

Because development and deployment costs are amortized over multiple years and operation and maintenance costs occur in the future, you must use a financial model to determine the total cost of ownership for a test system. For traditional investment scenarios, a project will generate revenue and profit. In this situation, however, there is no revenue or profit but rather a relative savings of one test system in comparison to another. Consider a similar situation that involves investing in high-efficiency lighting or building insulation, which costs money upfront but money will be made through reduced utility expenses in the long run.

- **Payback Period (PP)—**This is the amount of time it takes to recuperate the money you invest in a project. The calculation has two parts. First, you must determine the upfront costs by finding the difference in developing and deploying the new test system and deploying more of the old system. Because the old system has already been developed, there are no associated costs. Second, this difference is divided by the annual savings in operation from the new system's efficiency (throughput).

$$\textit{Payback Period (PP) [yr.]} = \frac{\textit{Upfront Cost [\$]}}{\textit{Annual Savings [\$/yr.]}}$$

- **Return on Investment (ROI)—**This is the ratio of the money earned to the money invested over the life of a project, expressed in a percentage. The calculation is more involved as it requires you to calculate the projected total cost of ownership for both the old and new options, and then find the difference in the two. You then divide this result by the total cost of the more cost-effective option, and subtract 1 (100%) from the quotient to find the resulting percentage.

$$\textit{Return on Investment (ROI) [\%]} = \frac{\textit{Total Net Savings [\$]}}{\textit{Total Cost [\$]}} - 1$$

- **Additional Models—**To determine the viability of projects or financial investments, you can use many additional financial models such as internal rate of return (IRR), net present value (NPV), and modified internal rate of return (MIRR). But most of the advanced modeling that comes with these drops out when comparing two options against one another, and you can simplify the analysis to PP and ROI.

Practical Scenario

The following practical scenario helps demonstrate how you can use financial analysis of total cost of ownership to make an informed decision about purchasing a new test system architecture instead of keeping an old approach.

Overview

Company B is a $200 million manufacturer of IP-based satellite communication systems. Their current production test system is architected using traditional rack-and-stack box instruments. Company B develops and deploys these test systems to a contract manufacturer who charges them a flat rate of $30 per hour to perform product test.

The following best characterizes the current test system:

- Fully functional and full test coverage
- Moderate capital cost
- Organization is fully trained on how to operate
- Throughput is less than optimal

Because Company B recently invested in a larger sales channel and was able to enter new markets for their radar products, their production capacity must increase from 10,000 units to 25,000 units per year.

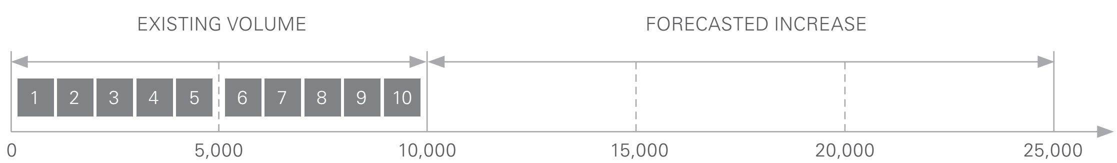

Figure 3. Increase in demand of 15,000 products, year-over-year.

Their engineering team worked with NI to specify a new PXI-based test system that should result in a 3X improvement in test time per DUT. However, a new solution would require upfront development and deployment costs, so the business impact of the migration must be modeled relative to purchasing additional testers based on the previous architecture before a decision can be made.

Existing Rack-and-Stack System

NRE Capital Investment:	N/A
NRE Development Time:	N/A
Capital Expense:	$100,000 per system
# Existing Test Systems:	10
Test Time:	40 minutes per device
Volume/Throughput:	1,000 devices per year

New PXI-Based System

NRE Capital Investment:	$90,000
NRE Development Time:	$150,000
Capital Expense:	$120,000 per system
# Existing Test Systems:	N/A
Test Time:	13 minutes per device
Volume/Throughput:	3,000 devices per year

Other Financial Variables

Amortization Schedule:	5 years
Replace Existing Systems:	No, keep in operation
Operation Cost per Hour:	$30 (contract manufacturer)
Required Throughput:	25,000 units per year

Development and Deployment Costs

The most common assumption during this evaluation process is that it is more economical to buy additional test systems based on the existing architecture, because the organization is already fully trained and there are no incurred development costs. The system is already architected, and it just needs to be replicated. The new system, however, requires planning, architecting, training, and other nonrecurring engineering (NRE) costs during the development period.

The throughput advantage of the new system, however, cannot be ignored; throughput directly determines the number of additional or new test systems that must be purchased to reach the forecasted increase in volume. In this scenario, scaling up the number of existing test systems requires 15 additional systems whereas buying new PXI-based systems requires only five to meet the production volume.

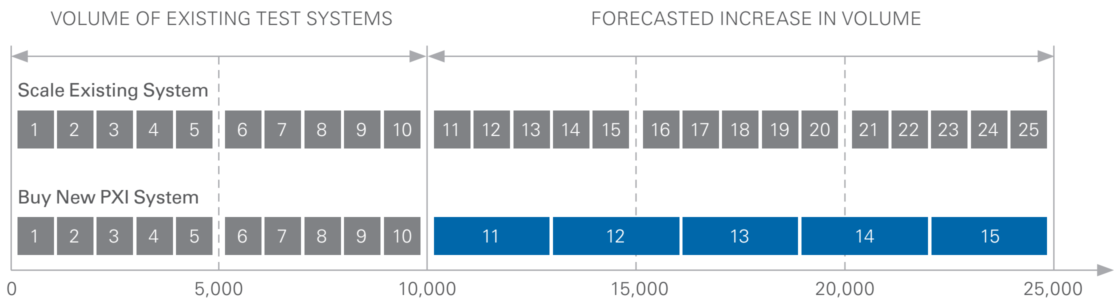

Figure 4. The 3X throughput improvement of the new PXI test system greatly reduces the number of systems required to meet additional product demand.

After determining the number of test systems required for each approach, you can compare the total cost associated with the development and deployment and directly understand the impact of throughput, capital expense, and NRE.

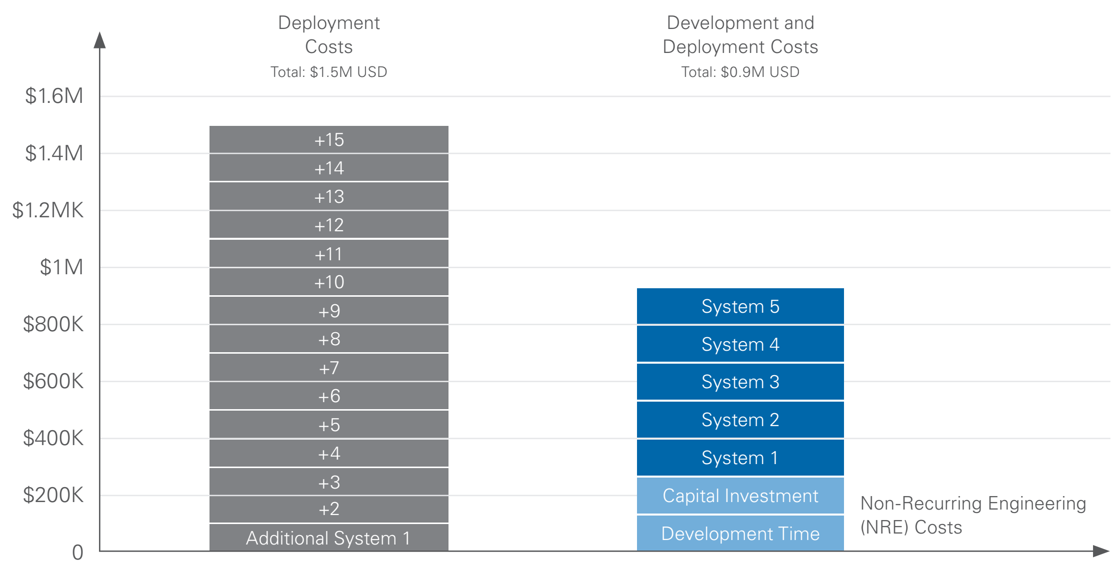

Figure 5. Even though the new PXI-based test system incurs NRE development costs, the total cost of development and deployment for the new system is $600,000 less expensive.

For this given scenario, when comparing the development and deployment costs, buying a new solution is more cost-effective than scaling up the existing test system. The biggest driver of the inflated costs for scaling up the existing system is the low throughput of the system. Throughput alone increases the deployment costs by requiring three times as many test systems to meet the required volume.

But what happens if the variables change? Model different what-if scenarios to ensure that it is a profitable outcome, even in the worst-case scenario.

Some hypothetical scenarios to model:

- What if development time of the new system takes twice a long, and is therefore twice as expensive?
- What if the capital expense increases by 10 percent because of currency inflation?
- What if the throughput improvement is only 1.5X instead of 3X?
- What if the sales volume is revised from 25,000 to only 20,000 units?
- What if additional floor space is limited?
- What if additional power or cooling must be installed at the test facility?
- What if the previous instrumentation is now EOL?

Operation and Maintenance Costs

After you have developed and deployed the required number of test systems, you must operate and maintain them over the length of the project or product life cycle. The costs associated with operating and maintaining a test system are normally attributed to the company's manufacturing group, whereas the development and deployment of a test system are attributed to the R&D (engineering) group. Without guidance from leadership, the engineering team will likely default to cost optimize around development and deployment without considering the implications for the operation and maintenance costs.

In the example above where only development and deployment costs are considered, the new test system is more economical than purchasing additional test systems based on the previous architecture. Now analyze the operation and maintenance costs of the two options over the first five years of the project to understand the impact on the total cost of test.

In this situation, Company B has contracted the manufacturing and test of its products. The contract manufacturer charges Company B $30 per hour to operate the test system.

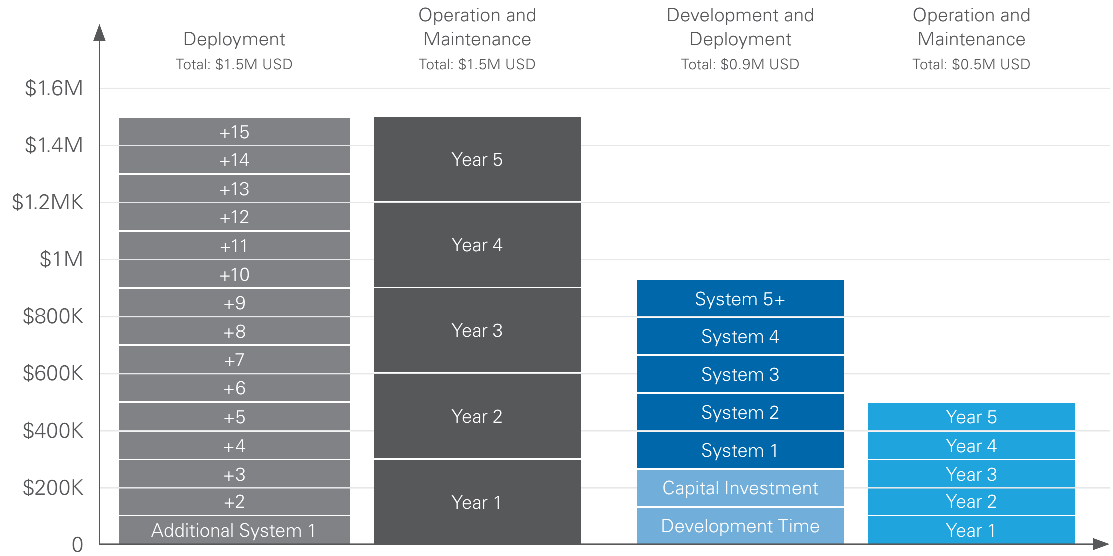

Figure 6. In addition to having much lower development and deployment costs, the operation and maintenance costs of the PXI-based test system are much lower than the previous system's.

Total Cost of Ownership

Although in this scenario the PXI option is the best choice, it is still important to determine the total cost of ownership to effectively model the financial benefit of the new system. This five-year analysis provides insight into variables such as PP, ROI, total savings, and reduction in cost of test on a per part basis. For this analysis, the development and deployment costs are amortized equally (flat) over a five-year period.

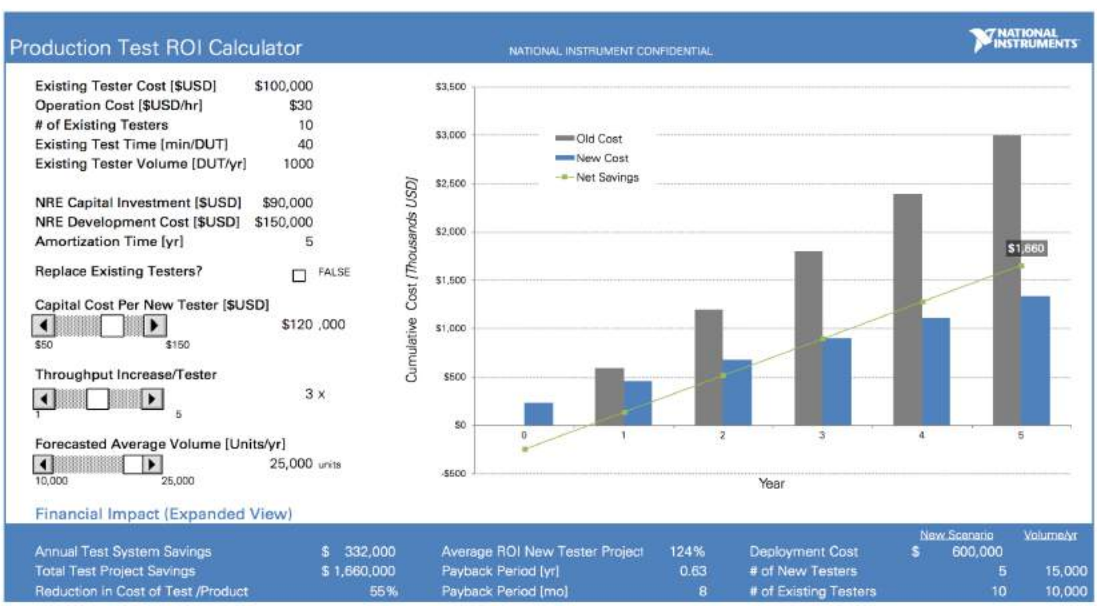

Figure 7. The new test system generates a total savings of $1.66 million in five years with a payback period of 11 months in comparison to scaling up the existing solution.

Scenario Summary

In the case of deciding between these two options for a test system, there are many factors to consider. The common assumption is that scaling up the old solution is easier and cheaper, but further analysis reveals that investing in a newer, higher performance system is a superior financial decision. The biggest factor in the financial advantage of the PXI system is the 3X improvement in throughput—this allowed Company B to purchase one-third as many test systems to accomplish the same task, which saves them money on the capital investment. Over the five-year period, this also reduces the operation and maintenance costs that they pay to the contract manufacturer significantly, resulting in a PP of 11 months and a 124 percent ROI on the project.

Conclusion

As device complexity and time-to-market pressures continue to soar, the total cost of ownership for an automated test system will continue to play an important role in a company's profitability. To realize this goal, you must look beyond the initial capital cost of the test system to ensure that all relevant costs are factored into your purchasing decisions. This guide focuses on automated production test, but you can extrapolate and apply the same concept to other phases of bringing a product from initial concept to the end user, including R&D, characterization, verification, and validation.

As the developers of the PXI platform, LabVIEW graphical system design software, and TestStand test management software as well as a founding member of the PXI Systems Alliance, NI has 40 years of experience helping companies to develop automated test systems for industries ranging from semiconductor production to aerospace and defense. Our direct field engineer team in more than 50 countries worldwide is committed to helping companies, large and small, ensure the highest product quality while reducing the cost of test. To take the next step, contact your local NI representative.