Maximizing Your Test Equipment Investment: An Inventory Modeling Approach

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Abstract

Manufacturing companies often have a great deal of money tied up in measuring equipment. Regardless of the size of the company, manufacturing requires testing to verify product conformance. This testing, whether in-process or post-process, requires the use of calibrated instruments. Test equipment can range in cost from the hundreds of thousands of dollars per instrument, to the one hundred dollar range. Typically the complexity of the product, and the associated testing requirements, drive the per-piece cost of measuring equipment. Additionally, there is a general correlation between complexity and the cost of assets. This is true in absolute terms for labor and material.

Factors driving the test environment are the factors that drive the procurement and maintenance of the test equipment inventory. How do we know if our company's inventory of test equipment is the right size? Do we have the right amount and the right mix to support our products? Perhaps we have too much money tied up in the inventory and in the systems that support it. Perhaps we have too little inventory and our failure to invest in this infrastructure is actually increasing costs.

The purpose of this paper is to analyze the factors that influence the inventory of test equipment within the typical manufacturing environment, and to propose a change in the paradigm for managing this inventory. A model emphasizing system cost minimization, through the use of stratified "ABC inventory management" techniques, will be proposed as the solution to right sizing test equipment inventories and minimizing costs.

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Introduction

New and Improved?

Whenever one proposes a "new and improved" approach to anything, one runs the risk of being criticized for either misrepresenting or misunderstanding the status quo. The danger herein lies in drawing inferences from the general and applying them to unique situations. In proposing a "new approach" to managing test equipment (TE) inventories, one faces a couple of obvious questions. The first question that might occur to you is – "what is the old and unimproved approach?" The second question follows quickly on the heels of the first – "if we aren't currently using a prescribed method for test equipment inventory management (TEIM), how can you claim to provide an improved one?"

The answer to these questions is of course, a disclaimer – the authors do not pretend to know the exact methods or process by which you currently manage your TE. We are generalizing from our experiences and suggesting a method that proves itself conceptually, mathematically, and practically. If it works for your inventory, feel free to use it. If your company's inventory is dramatically different than the typical inventory of a manufacturing company, or if the underlying assumptions of how you procure and manage these inventories is significantly different, you may want to proceed carefully.

Having issued the disclaimer we wish to issue a caution. If you have a TE inventory, you are engaged in the management of that inventory. You are either applying a disciplined approach to that process or managing through laissez faire. Arguing against a particular approach or technique of inventory management is not an argument against inventory management. Though some approaches are arguably better than others, any effort to apply a discipline to the management of TE inventories is better than doing nothing.

The authors wish to acknowledge the importance of the field of Operations Research (Technical Management) to which many of the ideas discussed in this paper are related. It is difficult to appreciate, let alone solve complex operations problems without acknowledging the importance of Queuing Theory, Capacity Planning, and Inventory Management Theory. The authors are indebted to the pioneers in these fields and have leaned heavily upon their expertise.

In Defense of Test Equipment Inventory Management (TEIM)

The most fundamental goal of any inventory management system is to ensure that the right object ends up at the right place, at the right time, and in the right quantity. In manufacturing this is especially critical. For retail operations that manage product inventory to generate sales, an out-of-stock condition represents a lost opportunity cost. You might lose the sale to a competitor. While this is serious and smart companies try to avoid it, for a manufacturing company, an out-of-stock condition can bring your operations to a grinding halt. The consequences to manufacturing of poor inventory management are so severe, and managers so fearful of not having the necessary stock, that many companies have much more than they need of practically everything.
In the long term, this waste of business capital makes companies less competitive. Companies that are more effective in operating closer to the right inventory margin will

have a competitive advantage over those that don't. It's not surprising that business philosophies such as "Lean Manufacturing" and "Just-In-Time" have become so popular. They are valuable techniques for reducing the capital tied up in inventory.

TE is not an exception to the inventory management dilemma of too much or not enough. TE is as critical to manufacturing as is a ready supply of fasteners. The demand to never be without a piece of TE, places an extreme amount of pressure on the TE support structure. In the past the way to relieve this pressure was to enlarge your TE inventory with redundant items. Unfortunately, as the TE inventory grew, so did the cost of maintaining it.

With constant cost-cutting pressure on support functions, the efficiency of these processes shrink while cycle-times grow. This in-turn creates a pressure to further increase the level of redundancy in the system. The economist's law of unintended consequences is at work here. We increase TE inventory to ensure we are never without. As TE inventory rises, our efficiency of servicing it drops. This creates the pressure to increase the inventory further. It is indeed the proverbial vicious circle.

This discussion is an illustration for those who may see TE as simply a technical problem rather than a business inventory problem. It is both. Managers cannot focus exclusively on technical needs without risking excessive cost. Nor will an exclusive focus on cost allow us to meet our technical requirements. As in many things, it requires a balancing of sometimes competing objectives. TE managers must be competent in the same business techniques that inventory managers use in other aspects of our business. We must provide the right TE, at the right place, at the right time, and in the right quantity.

The authors acknowledge that many companies are already moving in this direction. Even without a universally accepted theory of TEIM, they are methodically applying techniques (e.g. direct user cost accountability) to drive equipment inventories toward optimum levels. This paper isn't a challenge to those companies, rather it is a continuation of the discussion of the theory behind the day to day practice. We pay tribute to those companies that have advanced our knowledge. There is value in both the theory and the practical experience.

Definitions and Concepts

Test Equipment Defined

For clarity, when we refer to test equipment (TE) we intend the following definition. Any "…measuring devices needed to provide evidence of conformity of product to determined requirements." (ISO 9000:2000). There is certainly room to debate what types of equipment should be subject TEIM, but for simplicity we are including it all in this definition. The decision of what types of control to extend to the inventory are economic decisions. We will discuss this in greater detail later.

Right-Sizing TE Inventories

Right-sizing means taking a holistic look at your TE inventory, as well as the methods by which you currently manage it. It involves an assessment of where you are today and where you should be tomorrow. It does not necessarily mean down-sizing. Down-sizing is the often interpreted meaning of the phrase right-sizing. But in this case it literally means what it sounds like. It is an evaluation of that which you need in comparison to what you have. The goal is to establish correct inventories without waste (excessive redundancy), and with an acceptable level of risk to manufacturing processes. In some cases right-sizing will mean increasing stock levels of certain equipment, while in many cases it will mean reductions. It may also mean adjusting your support staffing up or down. In this respect, TEIM represents a scientific approach. Inventory levels are set, monitored, and adjusted based on the results achieved. But it is not a hard science. Often inventories and starting points must be initially set based upon the experience and knowledge of the current practitioners. A keen eye for what works is necessary.

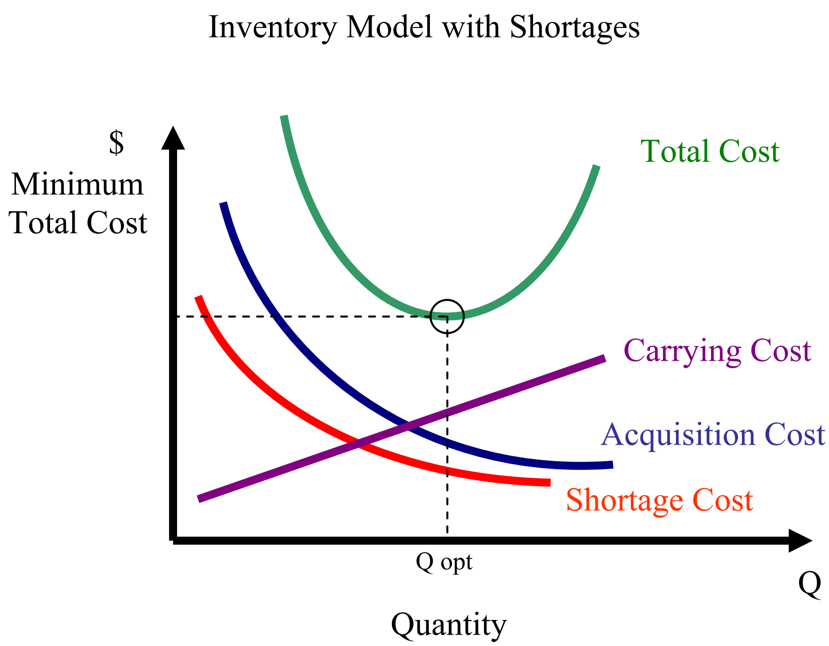
Borrowing from Inventory Management

Inventory management is a discipline used in many factories by operations research specialists. Though our goal is not to turn the TE manager into an operations specialist, we can certainly borrow some techniques. The primary technique we wish to borrow and apply to TEIM is the technique of ABC Inventory Analysis, but prior to discussing ABC Analysis let's review some concepts from the field of asset and inventory management.

Asset Management in General

Manufacturing costs are the sum of labor, material, and overhead. Most emphasis on inventory management occurs within the material aspect of manufacturing. This is generally because raw material and purchased parts are direct costs associated with the product and are highly distinguishable as discrete costs. Within the overhead aspect of manufacturing there is also an inventory indirectly associated with the product (e.g. tools, consumable materials, test equipment). Though direct material costs typically represent a larger overall material investment than the indirect overhead aspect, both are present in your company's balance sheet and tie up a significant portion of your company's operating capital. It is this second category that TE usually falls into, but the principles for managing this inventory are remarkably similar to the other. Regardless of how your company accounts for TE, it represents an inventory of company owned assets and it can and should be managed as such.

Classical Inventory Modeling
Typical inventory models indicate that too much or, on the other hand, too little inventory can lead to increased cost. Each asset in an inventory can be made up of three basic components, 1) acquisition cost, 2) carrying costs and 3) cost of having a shortage of inventory. This concept suggests that a business should drive to a balance point in their inventory. This balance point is also known as the Total Cost Function and represents the optimum (minimum) cost of the inventory. Moore, Lee and Taylor use a figure similar to Figure 1.0 to illustrate the concept of the Total Cost Function with respect to the optimal inventory levels.



Inventory Total Cost Function
Figure 1.0

This total cost function is applicable to almost any inventory. The aim is to find the right inventory level and to achieve the minimum cost to maintain this level.

Some Basic Questions -
If managing TE is similar to managing other types of inventory, several questions come to mind.

- What does a typical manufacturer's TE inventory look like?
- Who is responsible for managing it?
- What does this responsibility entail?
- How do we know if we are successful in managing it?

On the surface these appear to be pretty basic questions that one might expect very straightforward answers to. But on a closer examination, you might find that the devil really is in the details. Let's tackle them one at a time.

Describing a Typical TE Inventory
What does a typical manufacturer's TE inventory look like? It contains a mixture of both capital and expense assets. It's comprised of a wide variety of parameters, manufacturers, models, and ranges. The large percentage of the items is common or commonly available, while a number of them are highly unique. Additionally there is likely to be variation in both the perceived quality and reliability of the items. A general lack of uniformity or standardization among similar items might be considered to be the defining characteristics of an inventory that is not being adequately managed.

Management Responsibility
Who is responsible for managing it? Typically, no one or everyone is responsible. Many companies do not have a centralized planning authority managing this inventory. Perhaps it has not been identified as a significant enough economic concern, or because of a lack of knowledge, many companies rely on ad hoc methods for managing the economics of TE investment. It should be noted that we are not saying most companies do not manage TE inventories. Rather we are saying that the management is primarily concerned with technical and/or regulatory aspects of the inventory as opposed to the economic aspects. In effect, engineers and/or administrators usually run the TE end of the business rather than accountants. We are not expecting accountants to become equipment managers. Rather we are emphasizing that TE represents a unique opportunity as a discrete component of business inventory that is often ignored. Many companies focus on standardizing and managing such things as stationary or desktop computers without realizing that their investment in TE may dwarf either of those examples.

The Scope of Responsibility
What does this responsibility entail? Traditionally the focus has been on technical or regulatory compliance. We spend considerable amounts of money assessing and proving the technical validity of our measurements and the degree to which we comply with internal control processes (i.e. incorrect or expired items in use). To an extent this is understandable given the consequences for product quality if we are using the wrong instrument, or if the calibration is invalid. But absent an authority that is accountable for the investment in and sustainment of the inventory, many assume that the current cost of the TE inventory is a fixed expense of doing business. If this is true and the TE inventory

truly represents a fixed cost of doing business, then there is no reason to investigate methods for cost optimization. This is a point that proponents of TE management routinely challenge. **We believe that the gains from a centralized TE function outweigh the costs when all is considered.** TEIM is an attempt to centrally plan, acquire, and manage the TE inventory.

Defining Success

How do we know if we are successful in managing it? This is the key question and the answer to it is the most likely evidence that your company may or may not be managing TE inventories optimally. If you were suddenly asked what your TE inventory replacement value was, how quickly would you be able to answer? If you are unsure of the answer to that question, or if it would take a team of people to get the data, you should probably suspect you have a problem. The short answer to the question of good or bad TE management is this – can you measure your actual TE investment versus your expected investment? Specifically – what you have, versus what you need. If you can't gage your actual current investment, then you are a long way from defining what your expected investment should be. This shouldn't be a cause for despair however, by beginning to question the way in which you are managing TE assets, you are already moving in the right direction.

ABC Inventory Analysis

As you will recall, earlier we referred to a technique we would like to borrow from the field of inventory management. This technique is commonly known as ABC inventory analysis. This approach focuses on the cost of the inventory and classifies the inventory according to three distinct cost levels in a given inventory. It is based on the premise that different management controls applied to the different strata within the inventory, will yield the optimum cost for the inventory concerned. Higher value inventories require the maximum amount of control whereas lower value inventories require less. The challenge of the approach is in determining the different classes of the inventory and the transition areas between these classes.

According to Moore, Lee, and Taylor, *"ABC analysis is a method for classifying inventory according to its dollar value to the firm. Typically thousands of items are held in inventory by a company, especially in manufacturing, but only a small percentage is of such a high dollar value to warrant close inventory control. In general, about 20% of the inventory items will account for 80% of the total dollar value of inventory. These are classified as "A" or "class A" items. "B" items represent another 30% of total inventory units, but only 15% of total inventory dollar value. The last class of items, "C," generally represents about 50% of all inventory units, but represents only a modest 5% of total dollar value. An underlying principle of ABC analysis is that each class of inventory requires different levels of inventory control; that is, the higher the value of the inventory, the tighter the control. Thus, class A items should experience tight inventory control, while Band C require more relaxed (and perhaps minimal) attention."* Refer to figure 2.0 for an illustration of this concept.

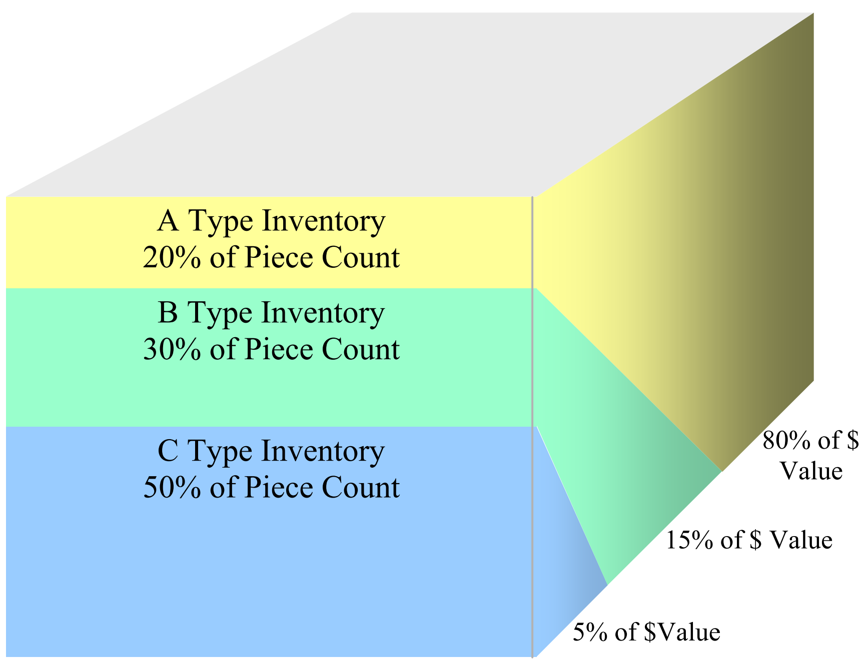


Figure 2.0 - Typical inventory characteristics

As a personal example of this concept, consider how you maintain your own assets. How diligent are you in performing preventive maintenance on the items you own? It is probable that the amount of effort you expend in preventive maintenance is in direct proportion to the value of the asset. You probably do this intuitively. It is likely that you spend a great deal more of your time and money maintaining your vehicle than your lawnmower. Your exposure to financial and personal risk is greater in your car than in your lawnmower. While some of this can be attributed to the greater maintenance demands of cars versus mowers, the majority of your commitment to automotive maintenance is most likely related to the value that you have assigned to the vehicle and its passengers.

When viewed in this light, varying the amount of control and emphasis you place on certain assets is simply a logical reaction to demands on your limited time and funds. In the ABC analysis this is accomplished methodically by categorizing the assets and defining those elements of control for each class. Although there is variation in techniques, ABC inventory analysis is widely discussed within the field of operations research.

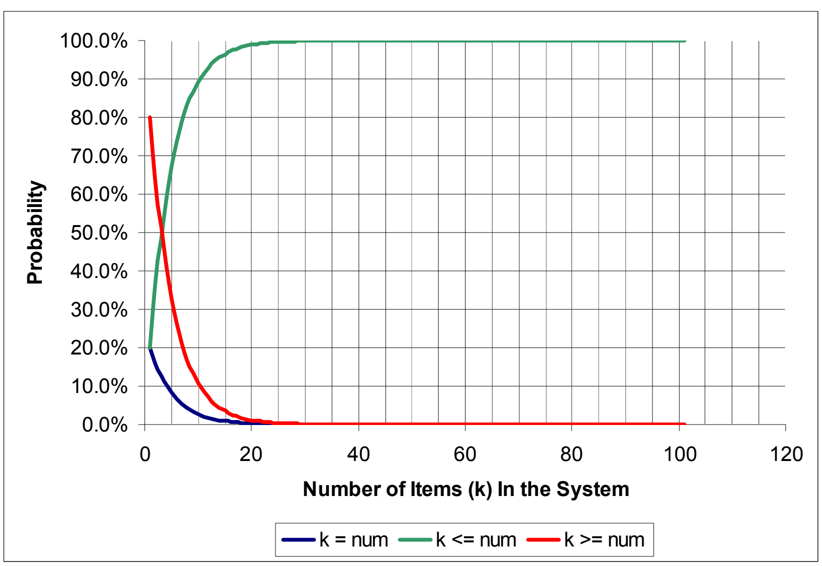
To understand the affect that different cost classifications of TE have on the bottom line of a business, we are now going to examine two hypothetical companies with dramatically different inventories. The fictional companies represent separate ends of the TE valuation continuum. We will first examine Joe's machine tool company which has an inventory of exclusively class "C" (low value) inventory, then Sally's company, an electronics manufacturing firm with an exclusively class "A" (high value) inventory.

Joe's Machine Tool Company

Joe owns a medium sized machining company. He has just won a new contract and is opening a branch operation in a new city. Rather than duplicate his current calibrated tool inventory, he has decided to try his hand at creating a TE management function. Joe has concluded or assumed the following:

- Joe needs 320 machinists who will each need a set of 5 different calibrated hand tools. This equates to a full time demand for 1600 calibrated hand tools.
- Each tool will be calibrated/serviced once per year.
- Joe's transportation/calibration system has a capacity of processing 1 tool per hour.
- He will maintain one calibration specialist who will perform all maintenance functions on the tools as well as pickup and return.
- His internal burdened labor costs are approximately $50 per hour (for either machinists or calibration specialists).
- Calibrated tool expiration (arrival rate) is/will be normally distributed.
- He expects his calibration specialist to be optimally used at an 80-90% service utilization factor.
- The average cost per new tool is $100.
- A machinist without a necessary tool imposes a 10% opportunity loss burden per hour of labor (locating, borrowing, and returning a nearby tool).
- One man year is 2000 hours.

Using deterministic calculations, Joe concludes that with a population of 1600 tools and annual service interval (2000 hours), on average one tool will expire every 1.25 hours (0.8 arrival rate). Joe realizes that this expiration is subject to a random normal distribution. Joe performs this analysis and comes up with the following expiration distribution. See figure 3.0.



Single Phase Single Channel Model

Mean Arrival Rate (lambda)	0.8
Mean Service Rate (mu)	1

CALCULATED VARIABLES	
Average Number in the system	4
Average Time in the system	5
Average Number in the Queue	3.2
Average Wait Time in Queue	4.00
Utilization factor for system (rho)	80%
Percent Idle Time for system	20%

Figure 3.0 Joe's Arrival Queue Distribution at 80% Utilization

Using this data, Joe attempts to predict the average number of hours that items that will be unavailable to his machinists at any given time. He concludes the following:

- The average number of tools in the transportation/calibration system is 4 tools.
- The average time in the transportation/calibration system is 5 hours.
- Multiplying these figures by his estimated opportunity loss factor and his hourly rate, Joe concludes that were he to buy only the actual number of necessary tools and no extras, he would cost his company $100 per hour as tool shortage cost or $40,000 annually.

Joe reasonably concludes that to avoid the $40,000 shortage cost, he must procure and maintain a limited amount of safety stock. According to Render and Stair, "Safety stock is additional stock that is kept on hand…the main purpose of safety stock is to avoid stockouts when demand is higher than expected." Joe's TE management program must have sufficient redundancy to prevent his workers from being without tools. <u>Joe's challenge is to find the optimum amount of safety stock without significantly increasing his service cost.</u>

At this point let us stop and reflect on what we've observed from Joe's situation. Looking at the high shortage cost calculated by Joe, you can see the temptation to overbuy tools as a defensive posture. But Joe is not done. Let's see what he does next.

Concluding that he must add safety stock, Joe returns to his probability distribution and begins to calculate the impact of additional tools on his:

- Calibration specialist utilization (recall - optimum 80-90%)
- Number of tools in the transportation/calibration system
- Inventory cost

Joe attempts to set the upper boundary first by determining what number of tools would force him to hire an additional calibration specialist. Joe's assumption of an upper 90% utilization factor as the hiring point is helpful in this determination. Joe concludes that adding more than 200 tools would force him past the 90% utilization. Therefore Joe now knows his "do-not-approach" inventory limits based on his current demand. At this point it is a risk based decision. Joe must set his safety stock of calibrated tools at some number between five and two hundred. Refer to figure 4.0 for a graphical depiction of this.

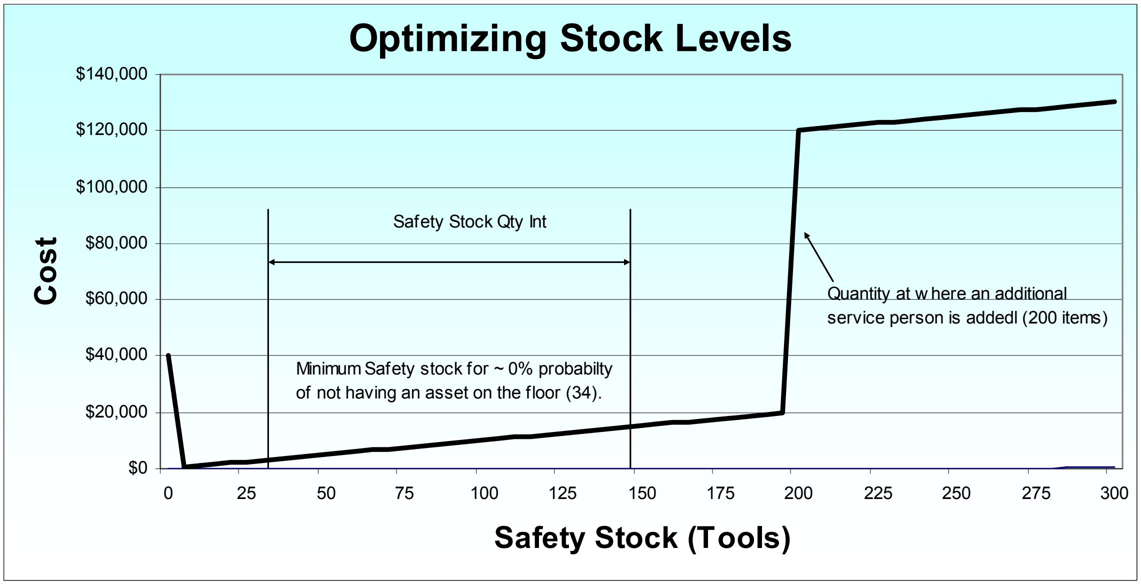


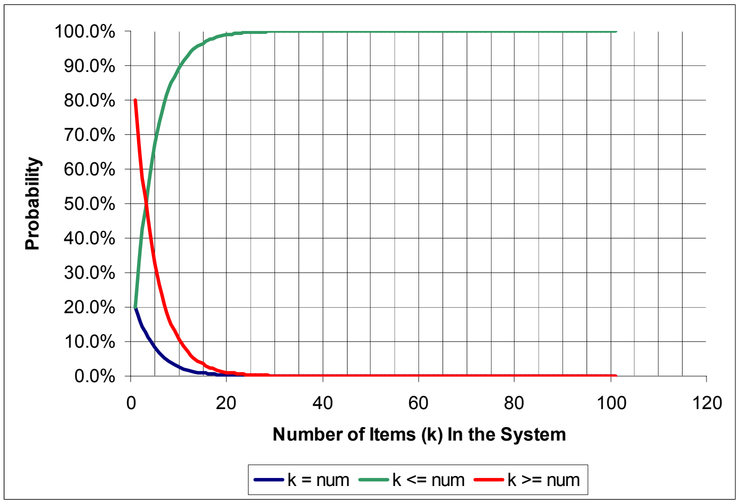
Figure 4.0 - Joe's Machine Tool Co. Cost Function Curve

Sally's GPS Electronics

Sally is the owner of a medium sized electronics firm that makes GPS equipment. Sally and Joe are good friends and she has observed Joe's efforts to implement a TE management program. She believes she can apply some of the same principles that Joe did. Sally has assumed the following:

- Sally has 500 employees, 100 of them are involved in product measurement.
- Sally's inventory of TE is exclusively high-end electronics.
- Sally has estimated her actual demand for calibrated items at 400 items.
- Each instrument will be calibrated/serviced once per year.
- Sally's transportation/calibration system has a capacity of processing 0.25 instruments per hour.
- She will maintain one calibration specialist who will perform all maintenance functions on the tools as well as pickup and return.
- Her internal burdened labor costs are approximately $50 per hour.
- Calibrated item expiration (arrival rate) is/will be normally distributed.
- She has planned for her calibration specialist to be optimally used at an 80-90% service utilization factor.
- The average cost per instrument is $20,000.
- A technician or engineer without a necessary instrument imposes a 50% opportunity loss burden per hour of labor.
- One man year is 2000 hours.

Using the same deterministic calculations as Joe, Sally concludes that with a population of 400 instruments and annual service interval (2000 hours), on average one instrument will expire every 4 hours (0.25 arrival rate). This expiration is also subject to a random normal distribution. Sally performs the analysis and comes up with a distribution almost identical to Joe's. See figure 5.0



Single Phase Single Channel Model

Mean Arrival Rate (lambda)	0.2
Mean Service Rate (mu)	0.25

CALCULATED VARIABLES	
Average Number in the system	4
Average Time in the system	20
Average Number in the Queue	3.2
Average Wait Time in Queue	16.00
Utilization factor for system (rho)	80%
Percent Idle Time for system	20%

Figure 5.0 Sally's Arrival Queue Distribution at 80% Utilization

Using this data, Sally also attempts to predict the average number of hours that items will be unavailable to her technicians and engineers at any given time. She concludes:

- The average number of instruments in the transportation/calibration system is 4.
- The average time in the transportation/calibration system is 20 hours.
- Multiplying these figures by her estimated opportunity loss factor and her hourly rate, Sally concludes that were she to buy only the actual number of necessary instruments, she would cost her company $400 per hour as an instrument shortage cost or $200,000 annually.

At first she is surprised to see that her shortage costs are potentially much higher than Joe's. But on a closer analysis the difference becomes obvious. At the same service utilization (80%), the longer service time per instrument creates longer queues and therefore longer periods of unavailability. This translates into higher costs.

Sally's challenge is similar to Joe's in that she must balance the risk of TE shortage costs against the cost of increased assets. Using the same technique as Joe, Sally returns to the same expiration arrival distribution and calculates the effect of adding additional stock. Like Joe, she plots the results. Sally's "do-not-exceed" limits and the associated cost curve are significantly different than Joe's. See figure 6.0.

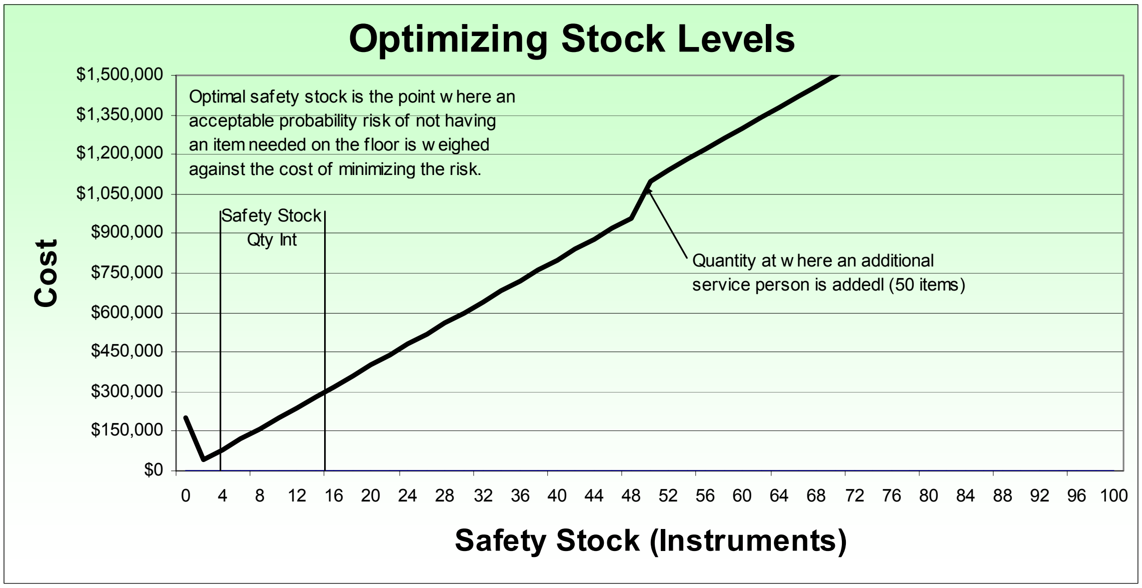


Figure 6.0 - Sally's GPS Electronics Co. Cost Function Curve.

Comparing Joe's analysis to Sally's, a number of points relative to Class "A" and "C" assets become apparent.

For Class "A":

- Potential shortage costs are proportionally much greater.
- The optimum control range for safety stock is narrower.
- The safety stock cost curve is noticeably steeper (unit sensitivity).
- Both adding safety stock and support labor (capacity) are viable mitigation strategies.

For Class "C"

- Potential Shortage costs are easily mitigated with safety stock with little added cost.
- The optimum control range for safety stock is relatively wide.
- The safety stock cost curve looks more like a step function with each major increase in cost associated with additional support labor.
- Adding support labor (capacity) has little effect as a mitigation strategy whereas increased safety stock does.

Criticisms of the Illustrations
Both examples are unrealistic in several senses. First, it is rare that a company would have TE inventory that was exclusively one class of asset. Second, the shortage costs appear to be high. Third, the actual demand for TE is given in the problem whereas in real life it is difficult to estimate.

We acknowledge both the first and third point readily, with the caveat that the illustration is simply to demonstrate the concept of cost stratification, and the different management approaches that might be applied for the different strata. To this end, it is unnecessary that the inventory be a perfect representation, or that the estimates of demand be easy to arrive at.

The second point that the shortage costs appear to be high is more subtle. The calculation of shortage cost is an easy enough task given the stated assumptions. Assigning an hourly loss factor is a matter of some speculation, but once arrived at, its impact is a relatively easy thing to calculate. It seems intuitively improbable that a shortage would cost us that much in either of the examples. However, the reason it seems improbable is because none of us work for a company that would allow such an obvious shortage consequence to occur. In other words, we already carry sufficient safety stock in our inventories that we would never experience that absolute shortage cost demonstrated in the illustration.

This raises additional questions. First, if we have safety stock to prevent shortage costs, where are we keeping it? Second, are our safety stock levels at or near the optimum points for their respective classes? The author's hypothesis is - that if you are not applying a TE management strategy to your inventory, then by default you are keeping your safety stock on the floor, and you have no idea what your level of safety stock should be or actually is. Absent a disciplined approach to TEIM, it is likely that your TE inventories are unnecessarily large and are consuming otherwise valuable funds.

Application

Understanding The Objective

In the illustrations of Joe and Sally, the objective of each was to create a cost function curve that defined the upper and lower boundaries of their respective test equipment inventories. This curve helps to define the range of total cost associated with maintaining the respective inventory. The examples were chosen for conceptual purposes because the inventories in question were largely homogenous. In reality it is unlikely that your company's inventory can generate a realistic single cost function curve. To demonstrate this point, consider if we were to merge the inventories of Joe and Sally's companies. The cost function curves were significantly different and the affect of merging the inventories would distort the results. In companies with diverse inventories the appropriate approach is to stratify the data using the ABC approach and develop separate cost function curves for each stratum.

Estimating Actual Demand

A key point in discussing total system cost is to clearly understand and estimate what actual demand is, versus what TE users typically estimate demand to be. Actual demand represents the absolute minimally necessary quantity of equipment which can be mathematically derived from a given statement of work. It is deterministic versus probabilistic and should not include contingencies. This is easier said than done.

For example, Joe knew from experience that each machinist in his company needed a set of five calibrated tools. In estimating this need, he did not include extra tools "just-in-case" one was lost, or failed, or was in for repair or cal. It's not that Joe has discounted the reality of these occurrences, rather he correctly understands that the appropriate place to plan and hold safety inventory is not at the local user level. Determining the appropriate level of safety inventory is the end goal of this exercise and to include safety in the initial demand estimates would subvert this goal.

As the owner, Joe has both the proper respect for this reality and the incentive to not overestimate demand. Consider what might happen if Joe were to query each machinist individually about how many calibrated tools each believed were necessary. Each machinist would certainly say at least five were necessary and likely a good deal more than that as they began to consider contingencies (what might happen if one were lost etc). This number given by the machinists represents the way demand is typically estimated. It is often the uncritically examined estimate of need that is proposed by users when they assume that no one but themselves will look out for their interests by maintaining tool availability. The obvious benefit of trimming these estimates and holding safety stock at a central point versus the point of use, is that it allows for a more economical approach to contingency planning.

In the given scenarios, both Joe and Sally knew the actual demand in absolute terms. As the owners of the respective businesses, they had no reason to inflate or hedge these estimates against the uncertainty of equipment availability. In fact their perspective as owners would probably drive them toward more precise estimation as the costs of excess inventory were just as real to them as the shortage costs. The same cannot necessarily be said of subordinate managers and planners within larger organizations who suffer the direct effects of shortage costs, but not the delayed and indirect effects of excess inventory. They often hedge estimates in order to avoid the very real consequences of unavailable equipment. Fear and "what if" thinking drives inflated estimates which results in "hidden" safety equipment in the system. It is critical for planning purposes that estimated actual demand does not include so called "fudge factors" that will distort the cost function curve. In businesses where the test equipment planners rely heavily on inputs from the using community or are not the purchasing authority for test equipment, identifying actual demand that is not inflated is problematic.

Inputs to the Cost Function Curve
In order to manage your TE inventory you need to create a cost function curve.
The necessary elements to create a cost function curve are:

- An estimate of actual demand for the inventory or inventory strata in question.
- An estimate of annual service interval and the corresponding arrival rate model (probability based versus deterministic)
- Service system capacity (per hour including transportation and handling).
- Estimated hourly service cost.
- Defined optimal server/service utilization boundaries (80-90% boundaries in example)
- The average cost per new item.
- An estimate of opportunity loss burden per hour of labor (locating, borrowing, and returning a nearby tool).

Without these estimates, you cannot generate the cost function curve for the inventory stratum under consideration. The authors have observed that many individuals in the field of Metrology, by nature or training, have an aversion to imprecise estimates. This aversion must be overcome. The process of creating a cost function curve is iterative and sometimes involves educated guesses and approximation. The specific methods for making these estimates is beyond the scope of this paper. Nonetheless rough estimates are better than nothing. The resulting curve (even based on rough estimates) is a better management tool than allowing test equipment users to independently set safety stock levels on an ad hoc basis.

Applying ABC to TEIM
Once you have decided that your inventory is diverse enough to require stratification, you must define the boundaries for each stratum. Applying the ABC analysis to a TE inventory is relatively straight forward. It simply requires that the inventory manager make an assessment of the value of the assets within the inventory and define the boundaries of the three classes A, B, & C. The question of how one assesses the value is less important than consistency of approach. Acquisition value may be the easiest valuation data to find, although using replacement value would paint a more realistic picture in terms of today's dollar values.

In performing this analysis on their test inventory, the authors experimented liberally but settled on the following rules. Anything that required “capitalization” was considered a type A asset. Using the rule of thumb that type C assets generally account for only 5% of the inventory valuation, we applied that percentage to the dollar value of the capital threshold. For example, if your capital investment threshold was $5000, you would end up with a C threshold of $250. By defining the upper and lower boundaries the middle is also defined. In the example, the B type assets would have valuations between $250 and $5000. Once you have defined these classes you may begin creating your cost function curves for each.

Conclusion

This paper has attempted to demonstrate the concept of cost minimization of test equipment inventories through ABC analysis. We have considered a number of factors which influence this inventory, and we have proposed a change in the paradigm for managing it.

Test equipment inventories should be planned and managed to minimize total cost. Test equipment is a cost of doing business but it need not be considered an unmanageable cost. If your strategy for managing test equipment does not identify actual demand, managing to an appropriate inventory level is difficult if not impossible. Once demand is know in actual terms safety stock can be used to keep this demand met. Setting these safety stock levels involves both estimation and practical experience.

Failing to strategically manage your test equipment inventory still results in safety stock, but it is hidden in the system and complicates future efforts at planning and cost control. Developing Cost Function Curves are an effective tool for planning levels of safety stock. Most inventories require the development of multiple CFC’s across different strata of the inventory. ABC Inventory analysis is an approach that can be applied to stratify the inventory and is useful in generating CFC’s. The precision of your equipment management model estimates is less important than making the effort. The models are flexible and can change over time.

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