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BASIC TECHNIQUES OF INVENTORY MANAGEMENT WITH POSSIBLE APPLICATIONS TO IMPROVE THE EXISTING INVENTORY CONTROL OF THE HELLENIC NAVY

by

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Basic Techniques of Inventory Management with Possible Applications to Improve the Existing Inventory Control of the Hellenic Navy

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ABSTRACT

The Hellenic Navy faces many difficulties concerning the finding and supplying of materials due to the variety of causes. The main emphasis of this thesis is to introduce into the Hellenic Navy some basic inventory techniques used by the United States Navy. These techniques could be applied and implemented in the Hellenic Navy after a degree of modification. Application of these techniques would improve and update the inventory control of the secondary (or auxiliary) items. Emphasis has also been placed on minimizing the average annual inventory costs.

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I. INTRODUCTION

Greece is a seafaring nation. Over 80 percent of Greece borders the sea and thousands of islands surround continental Greece. It has a long naval tradition and frequently the "wooden walls," as the ancients called the vessels, secured the independence and the wealth of the country. Even today, the Hellenic Navy has the responsibility of guarding the country's borders.

The present situation in Greece, of course, is different from past years. In older times, naval ships and equipment were internally produced and self-sustained. The wooden walls were manufactured from local material by artistic carpenters and the crews were excellently trained in the nautical arts. Today the nautical tradition continues but the material is very much different. In the sector of material, Greece, as well as most other nations, is no longer self-supporting. Greece has the ability to build ships but does not have the means to arm them, principally because of the rapid advancement of weapons systems and the evolution of electronic warfare.

Competition between different nations manufacturing weapons systems has resulted in a great variety. Thus, Greece, in order to cover its needs must, from time to time, be supplied with material from the United States of America, as well as from various European nations. Supply of material and spare parts depends a great deal on these nations. In the Hellenic Navy, many problems arise that do not exist in the United States Navy. The time needed for search and transport of each individual spare part varies from part to part, from order to order, and from country to country. The cost of purchase of each material is increased greatly by the cost of packaging, loading, transporting, insuring, etc. The problem becomes ever more accute if the wrong item or an unsuitable part is received.

Sources of material required for the support of the Naval Forces are listed as follows:

1. Indigenous or local sources.
2. European sources.
3. U.S.A. sources.

Handling and supplying the materials requires a great deal of attention and carries high responsibility. The limited money available demands that a priority checklist be made of the needs and consequent stock level requirements. A timely forecast will result in the lowering of the cost of supply. Also, the techniques of inventory management, which are discussed in the next chapters, will assist in the control of surpluses (reserve stock), thereby keeping the total yearly cost at a low level.

The major problem in meeting these objectives is that they are basically in conflict. Better customer service can be provided if inventories are at high levels, but a high level of stock results in high inventory cost. Inventories can be kept low if customers are forced to wait for needed supplies.

Most of the problems can be lessened by sound economic judgement, and cost-optimization principles can be used to establish most inventory policies. There is, however, still resistance to the increased use of mathematical and statistical techniques in an area once thought to be governed by experience and common sense.

A. DIFFICULTIES CONCERNING THE FINDING AND SUPPLY OF MATERIALS

As mentioned before, Greece faces many difficulties concerning the finding and supplying of materials due to the variety of their origins. These may be classified in the following categories:

1. Political: Prohibition of sales of materials to countries that do not belong to the same allied coalition.

2. Legal: A nation may have the material, but due to an agreement that it may have signed with other countries, the nation having a potential supply cannot offer the material to a third nation.

3. Anachronistic: Part of the material that is used by the Hellenic Navy is no longer manufactured, anachronistic, and at times almost obsolete. It happens often that the nation or the factory that

prepared the material is discontinuing the manufacture of that material and thus it becomes costly to re-supply.

4. Economic: There is a Greek saying, "Lack of Funds, Stoppage of Runs." Namely, lack of money, may cause the discontinuation of supply.

B. DIFFERENTIATION OF MATERIALS

The materials are differentiated into two major categories:

1. Principal Items
2. Secondary Items

Principal items are items of great value, such as vessels, airplanes, helicopters, weapons systems, radar, electrical apparatus, etc. These items are programmed, ordered and monitored by the Hellenic Navy Staff. Frequently, the principal items of lesser importance and value are monitored by the Hellenic Navy Center of Supply under authorization of the Hellenic Navy Staff. Secondary items are items that are not categoried as principal items.

The secondary items are broken down into two categories:

1. General items
2. Reserved items

The one label we can use for the remunerated items is that these items have a specific purpose. What the Hellenic Navy calls Main Items are those items which the United

States Navy terms as Principal Items, while both Navies use the term Secondary Items.

The main emphasis of this thesis is to develop some basic inventory techniques that could improve the inventory control of the secondary items in the Hellenic Navy. The secondary items are stored in various areas in different parts of Greece. It is from these various places that vessels and services order and receive the items necessary for their needs.

C. PROCEDURES TRANSACTIONS

The Naval Supply Center is the appropriate source for the re-supply of the stock of items for all Naval Stores Depots. The re-supply of the stock depends on data obtained from the historical file and future requirements projection files. Based upon this information, the items may be classified as demand-based or non-demand-based items. This classification will be discussed later.

Naval Stores Depot procedure for providing timely information to the Naval Supply Center concerning stock status is described in the following paragraphs.

The vessels and services submit their paper work concerning the items they need to the Naval Stores Depot. The Depot, if it has the items to satisfy the customer orders, sends them to the customer and at the same time sends a copy of the customer's request, including the quantity of items received, to the Naval Supply Center for their records. If the Depot does not have the item, it informs the customer and sends a request to the Navy Supply Center requesting that item. The Navy Supply Center, according to the degree of priority of the request, will proceed to an immediate purchase or spot procurement, or will inform the customer that a waiting period is needed until the item arrives.

When the Navy Supply Depot receives the item, they draw up a document of arrival, or receipt of delivery, of the items. A copy of the receipt of delivery is submitted to the Navy Store Center to enable the current level of stock to be specified. In the future, this procedure will take place at a center of computer terminals at the Navy Supply Depot.

D. SYSTEM OF ORDERING ITEMS: WHEN SHOULD WE ORDER? HOW MANY SHOULD WE ORDER?

The ordering of items is usually on an annual basis, but when a need arises, it may be more frequent, usually quarterly.

The quantities that will be ordered are based on

1. an average use
2. annual analysis of the five past years, called an Average Annual Consumption (M.E.A. in Greek).

The information on consumption derives from the existing electronic calculator or computer-based records. The quantity that will be ordered and is forecast to cover the needs for the coming year is determined as follows:

The figure representing the total consumption of the fifth and most recent year is multiplied by five. The figure representing the sum of the fourth year is multiplied by four, the third year's by three, the second year's by two and the figure of the first year, by one. The sum of the five year items after the above mentioned multiplications is divided by the sum of the multipliers of the five years, and thus the final figure represents the quantity of items that will be ordered for the next year.

For example, let us suppose that we are at the end of 1985 and we wish to calculate a consignment for 1986; the consumption of the last five years respectively was:

- for 1985, 10 items
- for 1984, 14 items
- for 1983, 8 items
- for 1982, 16 items
- for 1981, 8 items

Consequently, the consignment for 1986 will be 12 items:

$$\frac{10 \cdot 5+14 \cdot 4+8 \cdot 3+16 \cdot 2+8 \cdot 1}{5+4+3+2+1} = \frac{170}{15} = 12 \text{ items}$$

Of course, the consignment is placed when the average of the stock sits at a pre-determined level of re-ordering, based on a determination of a lead time and some degree of safety, or emergency, stock.

E. OBJECTIVES

The Naval Supply System of the U.S. Navy is similar to the operations of large corporations of the private sector in providing goods and services to a variety of customers. One of the primary objectives of both the private sector and the Naval Supply System is the attainment and retention of satisfied customers. Satisfied customers in the Navy system equates to enhanced combat readiness of our national defense forces. In order to achieve this objective, the supply system tries to maintain a proper mix of items in the inventory of the Naval Stores Depot. The accomplishment of these objectives is charged to the Naval Supply Center in our Navy.

The Naval Supply Center is responsible for the secondary items as well as for the requirements determination and stocking at all Naval Stores Depots to meet the requisitions of the customers.

In the U.S. Navy, such items managed by the Naval Supply Center are categoried as consumables or repairables. As the term implies, consumable items are consumed in use or cannot be repaired economically when they fail to function. On the other hand, repairables are permanent in nature and can be repaired economically by either the base repair facility or the customer.

F. INVENTORY TECHNIQUES

Many people believe that inventory techniques consist only of keeping records of commodities and stock levels. They think an inventory problem is the determination of which details to record, who should make the entries into the records, where and when to make the entries, etc. [Ref. 1:pp. 1-2]

Others take an overall point of view when looking at inventory techniques. They view inventory techniques, not as dealing with specific commodities, but rather with the totality of the commodities and investments in all the stock's inventory. For them, the problems are inventory turnover, financing investments tied up in stock, etc. Their concerns lie with inventories which are too large and the problem of reduction. [Ref. 1:pp. 1-2]

Still others have another point of view, concerning what items to stock, when to stock them, how much to stock, etc. Other concerns of these individuals are labor stability, utilization of equipment and facilities, and customer relations. [Ref. 1:pp. 1-2]

Because there is such a wide variety of viewpoints regarding this subject, it is necessary to provide definitions of inventory terms. [Ref. 1:pp. 1-2]

An inventory technique in which the following costs are significant and where two or more are subject to control will serve as the definition of inventory techniques in this thesis:

1. The cost of carrying inventories, or holding cost. This cost consists of the investment in inventories, cost of storage, handling items in storage, obsolescence, theft, and other related costs. Carrying cost is usually expressed as a percentage of the on-hand-inventory dollar value.

2. The cost of incurring shortages, stockout cost, or backorder cost includes costs due to lost sales, loss of good will, overtime payments, special administrative efforts, etc. The stockout cost is the actual cost, conceptually, of not having an item in stock in the Navy, including the non-availability of a vessel for exercises due to lack of materials. It is impossible to calculate the damage such an occurrence would have on the Navy. In a military operation, all demands must be satisfied eventually. [Ref. 1:pp. 1-2]

3. The cost of replenishing inventories, or ordering cost. This cost is primarily administrative, consisting of salaries for personnel in inventory control and contracting, costs for supplies and data processing in order to determine and process purchases, and the storage costs of the materials. [Ref. 2:pp. 1-9]

4. The procurement cost, or cost of buying the inventories. While the above costs are considered variable, depending on the circumstances, this cost is fixed. The sum of all the costs is called the total cost. Inventory techniques are intended to keep total annual inventory costs as low as possible. [Ref. 2: pp. 1-9]

Before implementing an inventory technique of any level of sophistication or complexity, the knowledge base of all who will be involved with the technique must be developed. Obtaining cooperative responses from the various levels of the hierarchy when introducing a new technique may be quite difficult and a great potential exists for alienating those who perhaps are not motivated towards the technique. Thus, the benefits of the new system may be offset by a lack of receptiveness, or hostility, towards the technique on the part of those who will be implementing the system. [Ref. 2: pp. 1-9]

G. DEVELOPMENT OF INVENTORY MODELS

There has been a rapid growth of interest within the last four decades in what is referred to as scientific inventory control, generally understood to consist of using mathematical models to determine the rules of operation for inventory systems. Such is the popularity of, and interest in, this subject that some knowledge of inventory models is expected from every serious student in management science or industrial engineering.

Originally, practical applications were the immediate goals of inventory control models and this is still true to a large extent. However, with greater development and exploration in this area, the theoretical problems of mathematics involved in inventory models are increasingly becoming the primary interest for many individuals. Such people are contributing greatly to the future of inventory management by providing a greater number of more versatile applications for inventory-related models. Today, work on inventory models is being carried on at many different levels, from a concentration solely on practical problems, to a focus on the purely mathematical properties of the models and projecting for future needs. [Ref. 3: preface, v]

While inventory problems have existed throughout history, attempts to apply analytical techniques in the study of these problems dates only to the turn of the century. The simultaneous growth of the various branches of engineering, especially industrial engineering, and the manufacturing industries seems to have provided the initial impetus for the application of mathematical models to inventory analysis. The first, real, recognized need for inventory analysis occurred in industries which had a combination of problems with production scheduling and inventory, e.g., in situations where items were produced in lots with a fairly high cost of set up and where the items were then stored at a factory warehouse. [Ref. 3:p. 2]

In 1915, Ford Harris of Westinghouse Corporation developed the earliest derivation of what is usually called the simple lot size formula. Since then, this formula has been developed by many individuals, apparently independently. Another often-used name for this formula is the Wilson Formula because H. Wilson also derived it as an integral part of an inventory control plan which he sold to many organizations. F.E. Raymond wrote the first full-length book about inventory problems while he was at M.I.T. The book contains no theory or derivations, but rather, attempts to explain practical uses for various extensions of the simple lot size model. [Ref. 3:p. 3]

It was only after World War II, when the operations research and management sciences fields emerged, that attention was focused on the variable nature of inventory problems. Problems had been treated as if they were deterministic up until that time, with the exception of a few isolated cases, as in the work of Wilson, where some probabilistic considerations were incorporated. [Ref. 3:p. 3]

Analytical techniques for solving inventory problems were first required in industry where engineers were looking for the solution for practical problems. Economists, interestingly enough, were not the first to take an active interest in inventory problems, in spite of the important role played by inventories in the study of dynamic economic models. It was because of the very real "need to know" on the part of the engineers that interest in inventory problems evolved. However, now, both schools are actively participating in contributing to the field of inventory management. [Ref. 3:p. 3]

The development and application of inventory models became, with time, quite widespread. A significant role in the applications of inventory models is played by computers in tasks ranging from the military's very innovative and progressive uses to those of inventory management's early pioneers, the manufacturing and retail industries. [Ref. 3: p. 3]

The United States Navy, having as a basic starting point, the Harris Wilson formula, has developed formulas that correspond more efficiently to its needs and various categories of materials. The United States Navy spends large amounts of money in operation research. The policy that has been developed is a product of long and detailed examination, analysis, and a trial and error process for every condition and problem. This work is executed by expert task groups, more specifically by the joint efforts of a group of qualified experts who establish and develop uniform criteria for a more efficient management policy.

Each of the military services provides data to this working group. The working group reviews the supply management practices and makes recommendations for management improvements which are considered compatible with current technology. The working group also produces directives and instructions, which are reviewed by the services and are formally signed by the Office of the Secretary of Defense (O.S.D.). Because the inventory policy is not static, but dynamic, and differs not only from one geographic location to another, from one type of a vessel to another, and, more importantly, from peacetime periods to wartime periods, it is necessary that the different models and techniques that are applied in the inventory policy express a specific policy that is applied accordingly. The milestone for such an application is found in the existing historical facts.

H. INVENTORY CONTROL

Inventory control is the scientific art of ensuring that sufficient inventory or stock is held by an organization in order for it to economically meet both its internal and external demand commitments without holding any more stock then is absolutely necessary. Both too large and too small holdings of inventory are disadvantageous. Therefore, the primary goal of Inventory Control is to obtain the optimum balance or compromise between the two extremes. [Ref. 4:p. 97]

There are important applications for inventory control in virtually all facets of business, including non-profit organizations. The basic tenets of controlling inventory remain the same for all applications. The changes occur in the magnitude of responsibilities and the range of variables, or, in other words, the range of the inherent complexities. The technique of maintaining stock at optimum levels is also a function of Inventory Control, whether the items be raw materials, work-in-progress, or finished goods.

Much as in top management in multinational corporations, top commands in most military services are becoming cognizant of the existing inventory situations within the organization, and their links to the overall efficiency of the operation of the command or service. Thus, the services have an increasing need for personnel with a knowledge of mathematical inventory theory for the analyzing and controlling of stocks.

I. SCOPE OF THE THESIS

This thesis will explore and describe some pertinent techniques of inventory management which were taught during the course of studies at the Naval Postgraduate School. These techniques could be applied and implemented in the Hellenic Navy with certain modifications and adjustments. Application of these techniques would improve and update the inventory control systems. For this purpose, both the discussion and the approach have been kept as simple as the elements of inventory theory will allow. Effort has been made to keep away from complex day-to-day inventory management problems and address only the foundations of Inventory Management as applicable to the Hellenic Navy.

II. DEVELOPMENT OF ABC ANALYSIS

There is a plethora of materials* that move in the Navy, according to inventory management techniques, for the support of various units in the Navy. Because of that, a detailed and updated follow-up of the movements of every piece of material is not only difficult, but also expensive.

The daily follow-up of all the transactions of materials and the maintenance of the stock at the greatest level of efficiency requires a great deal of personnel, sophisticated inventory models and, consequently, a great expense.

Therefore, for effective management that will yield favorable and cost-effective results for efficient control, the inventory should be classified into categories in accordance with the priority of the materials. The techniques used must isolate items which require precise and extremely detailed control from items which do not need to be controlled as strictly.

In relation to this problem, Pareto's Principle of Maldistribution is important. This principle is as follows:

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*When the writer uses the term "materials," it will encompass items such as components, instruments, and other equipment.

> Very often a small number of important items dominate the results while at the other end of the line are a large number of items whose volume is so small that they have little effect on the results. [Ref. 5:p 20]

This principle is illustrated in Figure 1 and is the basis for the ABC analysis. [Ref. 5, p: 21]

ABC Analysis has never been used fully in spite of the fact that it is an old technique. Many specialized inventory management techniques are based on this method. It allows items to be classified according to stockout costs, cash flows, relative sales volume, and lead time. [Ref. 5:p. 7]

The methodology of any inventory management technique should avoid overselling formulas and must leave a systems base that does not lock the operating management into a rigid system, but allows for minor variations based on judgement.

Many managers believe that the most rewarding study technique they have ever used is the ABC Analysis. Such an analysis is applicable to value engineering, sales planning, quality control, cost estimating and other operations, not merely to inventory control. [Ref. 5:p. 20]

Efficient inventory control should effectively control the inventory at the least possible cost. For small, low-cost items which are used in bulk, such as paper clips and rubber bands, it is usually very costly to monitor

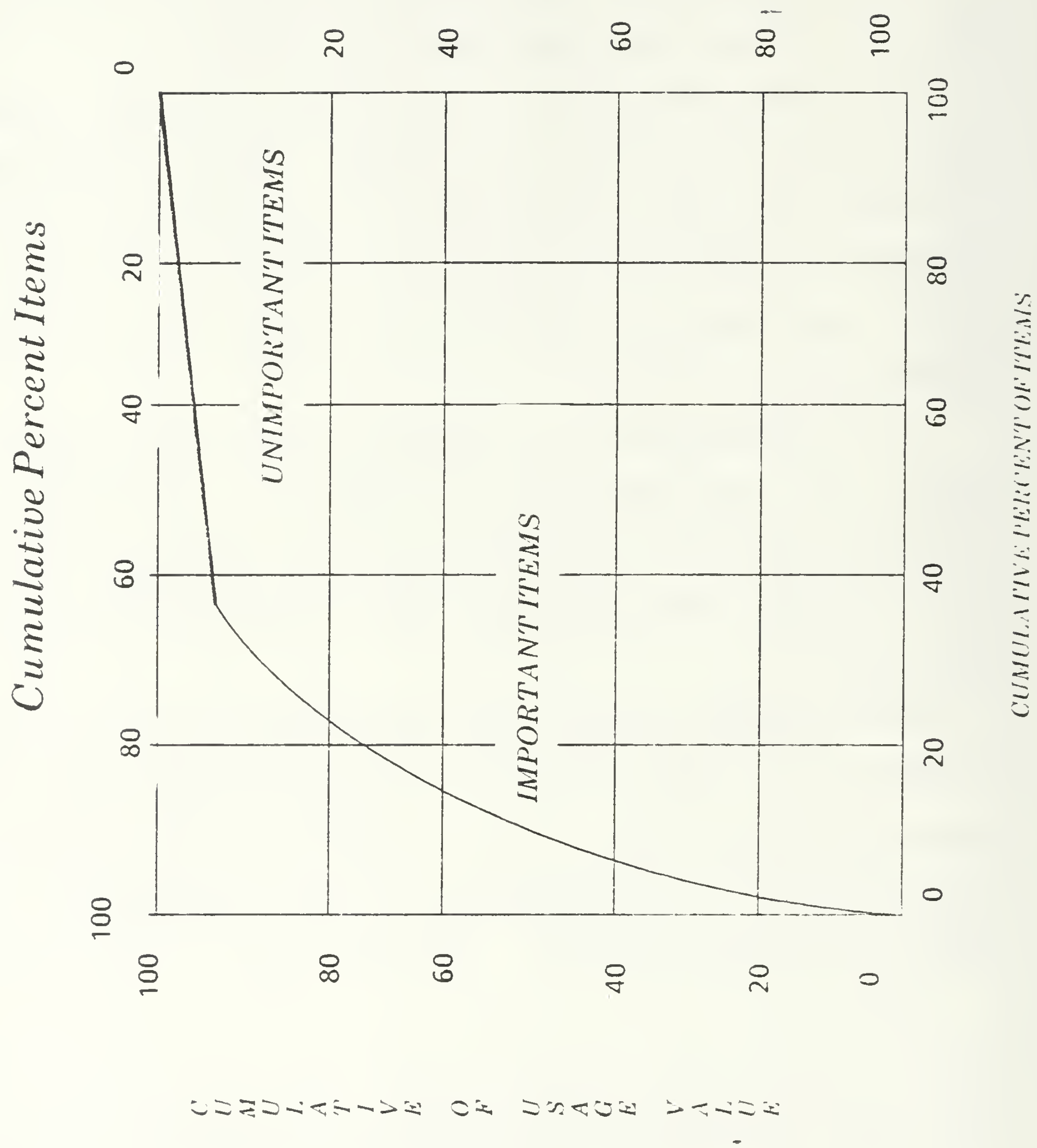


Figure 1.

Pareto's Law of Maldistribution

consumption closely. In such a case, it is more practical to keep a supply on hand at all times and allow people to help themselves. Any waste can be absorbed more easily than the cost of controlling usage. [Ref. 6:p. 173]

Of course, important items should not receive such loose control. Rather, one must make a decision, clarifying which items are unimportant, requiring loose controls, and which need to be monitored more closely. Therefore inventory controllers should carefully check stock records item by item, classifying them into groups. [Ref. 6:p. 173]

The proper classification of items is clear on an ABC curve, which shows that a few of the items are responsible for most of the value of all materials and parts used.

Large investment items fall into category A, the vital few. These ten percent of the items may easily account for 70 percent of the money spent on materials. These are the materials whose usage should be carefully monitored as to the specific quantity needed to support the system. The need should be calculated in advance according to the period of use. The schedule of manufacture or purchase should usually be timed so that they arrive just before they are needed. These are the items which are most suitable for ordering by the computerized MRP methods, which are described in detail in Chapter IV. Usually, inventories of these items should be held down by frequent ordering of small quantities. [Ref. 6:pp. 173-174]

B-category materials are the 15 to 20 percent of the items which make up approximately 15 percent of the investment. These items are expensive enough to require careful records of their use, but are less important than A-category materials and do not require the same degree of careful monitoring. Standard reorder quantities and minimum stock limits may be set and followed for these items. When the stock of an item gets down to its established reorder point, replenishment orders can then be made out. In this case, Economic Order Quantities (see Chapter IV) might be used to advantage. [Ref. 6:p. 174]

The many trivial items which commonly make up 75 percent of the items in inventory while accounting for only ten percent of the value of the materials fall into category C. The items in this category should receive minimal attention and can be carried in large safety stocks. They can often be on a reorder point system, rather than in the computerized MRP system. C-items can be made readily available in the workplace where they may be obtained without the use of requisitions. Usually, these items are charged to an overhead account, rather than to products individually. [Ref. 6:pp. 174-175]

Looser controls of C-category materials and stocking them with large safety margins would increase costs of investment from shelf wear, obsolescence, and wasteful use. However, the costs of controlling them more tightly would be even greater. However, sufficient control must be exercised to be sure not to run out of critical, low-cost items. [Ref. 6:p. 175]

For a summary of the characteristics of each category and its treatment, see Figure 2.

The background for the ABC system can be summarized by the "80-20 Rule," where 20 percent of the items account for 80 percent of the value. This rule applies frequently to other situations besides inventory management. For instance, in marketing, 20 percent of customers may account for 80 percent of the sales, or at a university, 20 percent of the courses offered may account for 80 percent of the total student credit hours. [Ref. 5:p. 137]

The decision steps for classifying items into the A, B, and C categories are actually relatively simple. First, one must set the criterion for developing the ranking. This criterion can be sales volume or value of the materials, etc. Items should then be ranked in descending order of importance according to this criterion. Next, the sum of the total value of the ranking criterion should be recorded with the total number of items. Beginning from the most important item, at the top, one must calculate the number and percent of the total ranking criterion represented by each individual item and its total, including all the items above it. This procedure is developed in more detail below. [Ref. 5:pp. 137-138]

Figure 2. Characteristics of ABC Groups

A	B	C
Maintain close control	Maintain moderate control	Maintain looser control
Based on calculated requirements	Based on calculated requirements or past usage	When supply reaches order point, order more
Keep records of receipts and use	Keep records and receipts	Few checks against needs
Close check on schedule revisions	Some checks on changes in mind	
Continual expediting	Expediting for prospective shortages	Little or no expediting
Low safety stock	Moderate safety stock	Large safety stocks

A. CLASSIFICATION OF THE MATERIALS

In order to classify the materials into A, B, and C categories, initially a list that will include all items must be made. This list will include columns of the following elements: (Table 1)

1. Number of item for identification of the material.
2. Item code, stock number, part number, or some sort of description.
3. Number of items used per year.
4. Unit cost of the item.
5. Usage value, which is the number of items times unit cost.

Once this list is completed with all the materials, it is reorganized by arranging the items in order of priority based on the highest demand of annual usage for each item. In addition to the above categories, the following information should now be included: (Table 2)

Cumulative percentage of items.

Cumulative usage value.

Cumulative percentage of usage value.

In the next step, results are plotted on graph paper. The X axis shows the cumulative percent of the total items, and the Y axis the cumulative percent of total usage value. See Figure 3.

The assignment of the materials into their respective ABC groups is the last and most difficult step because there is no simple technique for doing so. Rather, the decision is to a large extent arbitrary, a subjejctive judgement by the decision-maker. Often, significant natural breaks will

TABLE 1

ABC ANALYSIS

(1) Number of Items	(2) Item Code	(3) Number of Items per Year	(4) Unit Cost	(5) Usage Value
1	4710-00-2776101	3	12	36
2	-11-2778703	12	0.25	3
3	-11-2785411	4	4	16
4	-11-5422909	30	0.05	15
5	-11-5422918	20	0.1	2
6	4720-00-2889751	5	0.5	2.5
7	4730-NT-AA21753	14	2	28
8	4730-NT-AA45761	20	60	1200
9	4730-00-1720045	7	9	63
10	4730-00-1874191	600	.50	300
11	4730-00-1892624	16	0.5	8
12	4730-00-1892628	1000	1	1000
13	-11- 1899735	2	60	120
14	-11- 1892552	260	0.5	130
15	-11- 1892583	10	20	200

TABLE 2

ABC ANALYSIS

(1) Number of Items	(2) Item Code	(3) Number of Items per Year	(4) Unit Cost	(5) Usage Value	(6) Cumulative Percent of Itmes	(7) Cumulative Usage Value	(8) Cumulative Percentage of Usage Value %
1	4710-00-2776101	20	60	1200	6.7	1200	38.5
2	-11-2778703	1000	1	1000	13	2200	71
3	-11-2785411	600	.5	300	20	2500	80
4	-11-5422909	10	20	200	27	2700	87
5	-11-5422918	260	.5	130	33	2830	91
6	4720-00-2889751	2	60	120	40	2950	95
7	4730-NT-AA21753	7	9	63	47	3013	97
8	4730-NT-AA45761	3	12	36	53	3049	98
9	4730-00-1720045	14	2	28	6	3077	99
10	4730-00-1874191	4	4	16	67	3093	99.4
11	4730-00-1892624	16	.5	8	73	3101	99.7
12	4730-00-1892628	12	.25	3	80	3104	99.8
13	-11- 1899735	5	.5	2.5	86	3106.5	99.9
14	-11- 1892552	20	.1	2	93	3108.5	99.95
15	-11- 1892583	30	.05	1.5	1000	3110	100

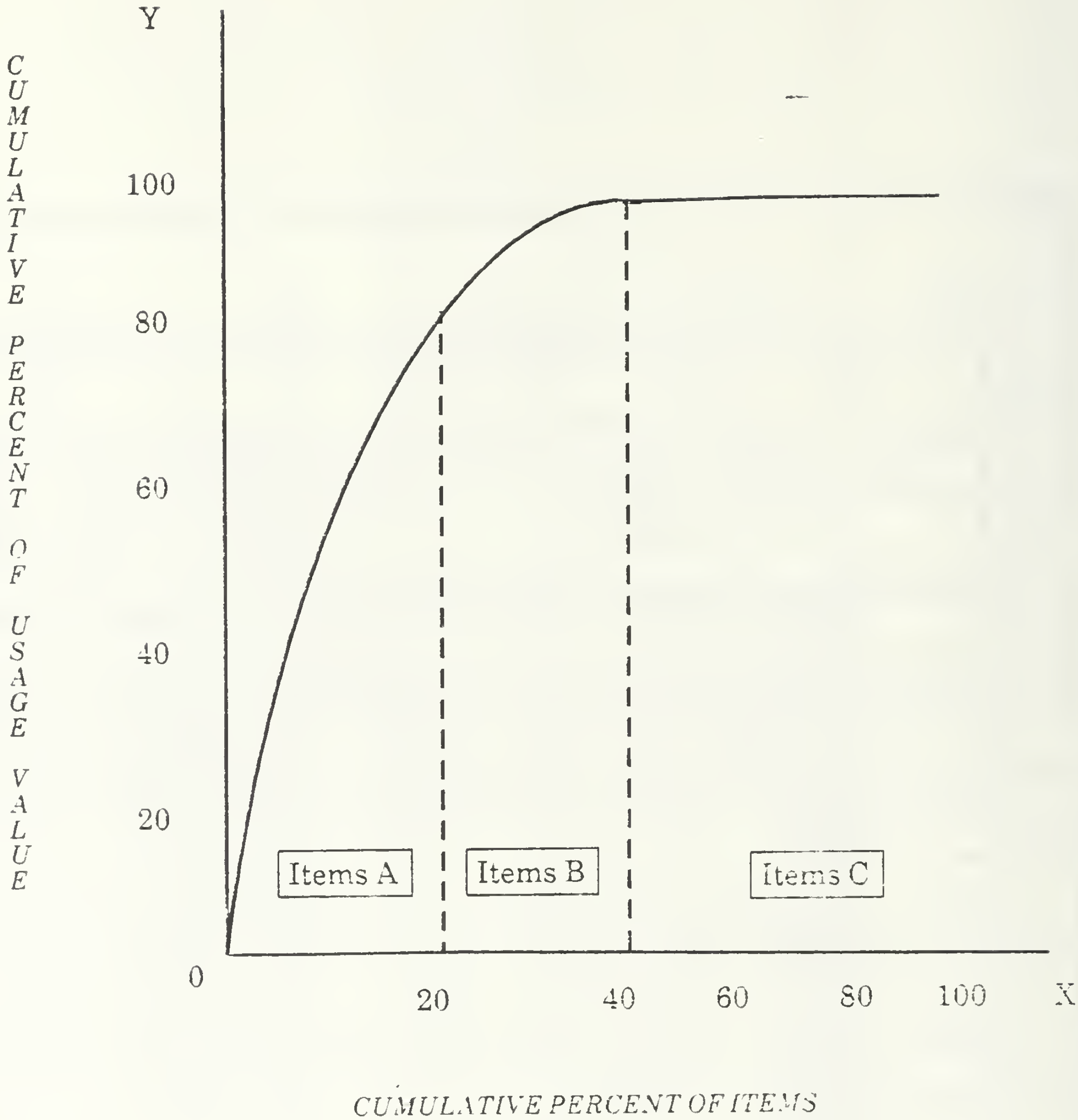


Figure 3

ABC Analysis - The 80-20 Rule

appear during the examination of the rankings. However, this is not always the case, and at such times a decision must be made based on balancing the material's importance with the cost of its control. [Ref. 5:p. 138]

Thomas (1968) proposed a simple method for roughly dividing materials into which of the A, B, and C categories they will most likely belong without the necessity of performing a complete Pareto analysis of all items in stock. He suggested that an item which has a usage value (prime cost x yearly or monthly demand) that is more than six times the average value for all the items probably belongs in category A. Similarly, category C items would have a usage value of less than half the overall average. Therefore, all items with usage values between six times and half of the average value must belong in category B. [Ref. 1:p. 92]

B. CRITICAL VALUE ANALYSIS (CVA)

From an inventory control perspective, the ABC analysis is not always completely satisfactory as some items in category C may not receive as much attention as they merit. These items with low usage values, if lacking, would create serious problems in the sales of a company or in the operations of a weapons system. For example, shoelaces may be classed as a category C item in the inventory of a distributor or wholesaler. However, if a stockout of shoelaces were to occur, a loss of shoe sales could result. A small bolt or similar part may be a category C item for the manufacture of sophisticated consumer products, such as refrigerators or automobiles. But a stockout of that tiny part could close down an entire assembly line, causing greater losses than the cost of maintaining a larger inventory of that part. For that reason, some companies implement a plan, developed by the military, called Critical Value Analyusis. The basic function of CVA is to classify inventory materials on the basis of point values assigned in three to five categories, as in the following example:

1. Top priority: no stockouts--critical items.
2. High priority: essential, but limited stockouts permitted.
3. Medium priority: necessary, but occasional stockouts permitted.
4. Low priority: desirable, but stockouts allowed.

Clearly, the combined usage of both ABC Analysis and CVA could produce a higher degree of control of inventory management. If all items are classified by the ABC and Critical Value Analysis approach, we could classify the low priority and high priority items, with the high priority items as A class items, the medium priority items as the B class items and the low priority items to the C class.

The United States Navy has classified the material that is used by the end of the line consumers (retail, ships and aircraft) into ten categories (VADCATS) according to the Value of Annual Demand (VAD). Items with the highest VAD are assigned to VAD category (VADCAT) A and would have a monthly order cycle, and items in the lowest VAD grouping are assigned to VADCAT J and are expected to be ordered once a year or less.

C. SUMMARY

Finally, one must remember that the ABC method for classifying inventory is subject to limitations as a control technique. On the other hand, as a system, it is easy to implement and allows the user organization to focus more attention on the more important items of inventory in order to more effectively utilize resources. Naturally, a company will wish to use the more sophisticated and therefore more expensive systems of inventory management in the situations where the best returns can be realized, that is, with the items in category A. In this regard, an understanding of the forms of basic inventory models will be helpful.

III. PROVISIONING

A. INTRODUCTION

Initial supply support for complex weapons and equipment begins very early in the acquisition phases of a new weapons system through the provisioning process. In order for the weapons-system's operation, maintenance and supply system replenishments to be as effective as possible, a sort of pump-priming, in the form of initial provisioning must take place.

The state of a system's functional readiness at a random point in time is described in terms of Operational Availability, which depends upon the weapons system's reliability, maintainability, and logistic supportability.

For each system, the following elements must be provided and assigned:

1. Maintenance Planning
2. Support and Test Equipment
3. Supply Support, including initial provisioning
4. Transportation and Handling
5. Technical Data
6. Facilities
7. Personnel and Training
8. Funds for Logistic Support Resources
9. Logistic Support Management Information

Initial provisioning brings together, at the right time, in the right combination, material, trained personnel, tools and test equipment in order to maximize operational readines.

B. DEFINITION

Provisioning may be defined as the process of determining the range and depth of the required parts for support of an end item for an initial period. The responsibility for provisioning is shared jointly by the Hardware Systems Commands, the in-service engineering activities, the vendor and the Ships Parts Control Center (SPCC).

Another way to view provisioning is as the front end of Life Cycle Support. The development of an allowance list and the lay-in of material are the culmination of the provisioning process. In fact, the development of the allowance list serves as the bridge between the twin subjects of Provisioning and the COSAL (Coordinated Shipboard Allowance List). The end product of the provisioning process, the allowance list serves as the basic building block for the development of the COSAL.

When an item is purchased, the contractor provides the Provisioning-Technical Documentation, which includes:

- Drawings down to the piece part level
- The contractor's recommended list of spares

- Failure Rate Data down to the piece part level
- Technical Manuals

C. PROVISIONING METHODS

Now the question is, should all the spare parts suggested by the contractor be purchased? There are two systems which could be used to evaluate the contractor's recommendations for parts purchase.

The first system is the manual or explored system, under which a basic maintenance plan or Lead Allowance Part List is used. Developed by the in-service activity, this document provides the basic maintenance plan and basic spare parts requirements to the Supply Center. The maintenance plans and basic spare parts requirements are the same regardless of manufacturer for many types of equipment such as valves, boilers, laundry equipment and the like. Only maintenance-worthy items, as identified by the manufacturer's Provisioning Technical Documentation and verified as being maintenance-worthy by the Lead Allowance Part List, are considered for stocking. The method is only appropriate for equipment that is relatively small and unsophisticated.

For large and more sophisticated equipment, primary electronics, and ordnance, the second method is used. With this sytem, the contractor provides the provisioning technical documentation in a mechanized format, which often identifies thousands of individual parts in a given system. A provisioning conference is usually held to review each item individually, rather than using a Lead Allowance Part List to identify those which are considered maintenance-significant.

Representatives from the Supply Center, the in-service engineering activity, and the contractor participate in the conference. During this provisioning conference, decisions concerning the maintenance philosophy and the classification of specific piece parts as maintenance-worthy are made and the information is subsequently loaded into the files.

D. PROGRAM DATA

The program data is developed by establishing a Preliminary Operational Capability (POC) date for the end item. This date is when repair and spare parts are first needed for the end item.

Other necessary dates are the time to initiate the first replenishment purchase, POC+TR (TR = Time Replenishment), and the time when the first replenishment purchase is received, POC+TR+L (L = Procurement Lead Time).

The primary concern of provisioning is the determination of the required number of units of each component of a system at the time of POC-L and POC. In order to avoid the occurrence of a stockout, the provisioning purchase made at POC-L should be large enough to fulfill all anticipated requirements during the interval from POC to POC+TR+L. The provisioning problem would be fairly simple if the forecasts of demand that are available during that interval and for the time POC, TR, and L were clear and reliable. However, a great deal of uncertainty characterizes the provisioning problem with regard to the failure rates of new equipment, the procurement lead time, and the time TR. Additional units will be installed and the amount of equipment will grow during the interval between POC and POC+TR+L. This will cause an increase in the aggregate failure rates over this interval of concern in the provisioning process. In addition, actual installation schedules can be subject to a great deal of uncertainty. Often the failure rate estimates are only engineers' theoretical guesses of the actual failure rates. Time lags can be very long. For instance, the time interval between POC-L and POC+TR+L may be four years or more. Therefore, the fact that the provisioned quantities often do not meet the demands is not surprising.

E. TIME WEIGHTED AVERAGE MONTH'S PROGRAM

The Department of Defense has developed a standard method for determining the program for requirement forecasts that is called the Time Weighted Average Month's Program

(TWAMP). The amount of program to be used in TWAMP is based on the Program Time Base (PTB), the value of which is dependent on the environment, but is usually twelve months. Simply put, the PTB is the number of months of program to be used in forecasting the demand for the first or following purchases.

In order to compute the TWAMP, one must determine the area under the curve of the total installed population over time from POC to POC+TR+L and then divide it by the length of the PTB. The result is the average number of end items to be supported over the PTB. The designation of this average is the initial TWAMP or TWAMPi.

The formulas below are provided for computing this initial TWAMP. By summing the vertical slices of the area spanning each month, they obtain the total area. The formulas assume that deliveries occur at mid-month, thus the cumulative program buildup (Dm) until and including the last month (m) in the PTB is defined as follows:

For $m=1$, $D1=I1/2$

For $m \geq 2$, $Dm\ (\sum_{k=1}^{m-1} Ik) + Im/2$

where:

m= the number of months after POC

D= the area of the time slice of the curve described above for the month t

Ik= the number of units of the end item to be installed in month K.

TWAMP over an integer PTB is given by:

$$TWAMPi = \sum_{m} DM/PTB \text{ for } m=1,2, \ldots PTB.$$

The initial annual demand rate for any given spare part can be computed with the following formula:

$$Di=TWAMPi \times N \times BRF$$

where:

N= the number of units of a given replaceable part in the end item

BRF=the Best Replacement Factor which is actually the estimated failure rate of a unit over the course of a year.

Initially, the BRF is based on a Technical Replacement Factor (TRF), the contractor's estimate of the attrition rate.

The Cost Difference (COSDIF) formula, which will be described in a following section (Demand Based Items), requires an initial estimate of the Steady State Annual Demand Rate (Dss), which is computed by determining, first, the total number of end items expected to be installed by the end of the procurement lead time: $Dss=TWAMPss \times N \times BRF$

In order to develop the provisioning budget, which is discussed in a following section, one must compute an estimate of the initial demand during the procurement lead time (L) plus one quarter. The result is the purchase quantity value, which is used to develop the budget. For consumable items, the formula is:

$$D(L+1) = Di \times (L+1)/4$$

F. DEMAND PROPERTIES

Four components are recognized in every inventory system: demand, replenishment, cost, and constraint. Briefly, demands are those things taken out of the inventory; replenishments are those items that are put in; costs are the pertinent measures associated with positive or surplus, and negative or shortage stockout inventories, and with raising the level of inventories; and constraints are the various factors, administrative, physical, and others, which place limitations on the other three components. [Ref. 1:p. 21]

The most important of the properties of an inventory system is the demand property. The reason inventories are kept is in order to meet demands, fill orders, and satisfy requirements. The only reason inventory problems exist is because of demands, otherwise, we would not have any inventory problems. [Ref. 1:p. 21]

For the most part, demands cannot be controlled directly, and often even indirect control is not possible.

Rather, they are generally dependent on decisions made by people outside of the organization that has the inventory problem. In the Navy, many times the demand depends on unweighed factors. While the demands themselves cannot be controlled, in general, it is possible to study their properties.

- When do customers place their orders?
- How much do they require?
- Is the demand greater at the beginning of the month or at the end of the month?
- Is accurate information available, or is it necessary to estimate average demands and the ranges of demands?

These are the significant properties which affect the solutions of inventory problems. [Ref. 1:p. 22]

G. DEMAND SIZE

Demand size is used to denote the quantity necessary to satisfy the demand for inventory. We say the demand size is constant when it does not change from period to period, otherwise it is labelled as variable. The demand size, when we have precise advance information about it, is said to be known. Those inventory systems in which the demand size is known are referred to as deterministic systems. At times when the demand size is not known, we may ascertain its probability distribution. In these cases, we refer to the inventory systems as probabilistic systems.

H. BASIC INVENTORY THEORY

The primary elements with which basic inventory theory begins are historical demand and demand averages. Theory makes the assumption that demand estimates are available. Items may be classified, for Navy purposes, as either demand based or non-demand bases.

I. NON-DEMAND BASED INVENTORIES

Those materials for which the decision to stock is not based on anticipated demand are called non-demand based items. [Ref. 2:pp. 1-4]

The U.S. Navy classifies an item as demand based if it has an expected demand of equal to or greater than one in 90 days. On a destroyer-sized ship, there are approximately 2,300 demand based items. [Ref. 2:pp. 1-4]

A non-demand based item that is essential and will not fail in normal usage is an insurance item if its failure or loss, without an easily-available replacement, would seriously hamper the operation of a weapons system. [Ref. 2:pp. 1-4]

For items whose predicted usage is too low to qualify them as demand based materials, but where the lack of replacement would seriously hinder the weapons system's operation, the Navy establishes Numeric Stock Objective (NSO) stock levels. For non-demand based items, the minimum quantity needed for one maintenance action, or a quantity of one, usually determines the quantity of NSO.

An item becomes an insurance item if it has an expected demand of equal to or more than one every four years (i.e., one fourth of one demand in one year, or ".25"). Aboard a DD-963 class ship, there are approximately 9,800 insurance items stocked. There are, in addition, about 4,100 items in stock on the ship because they are:

- personnel safety items, or
- will satisfy planned maintenance requirements.

The total stock number sequence list for on-board stocking amounts to approximately 16,200 items.

Items also included in the Numeric Stockage Objective (NSO) category are:

1. Items such as set assembly, non-repetitive overhaul programs that are needed to support specific programs that are sporadic or non-recurring in nature and where there is no reprocurement required after the completion of that particular program.

2. Items that are procured on a life-of-type basis, or that are "bought-out" when a production program terminates.

3. Items which should be retained after a one-time or non-repetitive program in which they are not fully consumed, for possible use at a future time on a similar program.

Any item for which the Cost Difference (COSDIF) equation shows that it is more costly to keep it in stock than to not stock it is a non-demand based item.

J. DEMAND BASED ITEMS

For demand based items, the decision on whether or not to stock is based on anticipated recurring demands. Any item which does not fit into this category is a non-demand based item.

K. FUNCTIONS OF INVENTORY

The theory of inventory can be described as a theory of storage. Often, it is impossible to meet the demands for some items if the item has not been stored in anticipation of demands. The following functions of storage identify use of, and reasons for having an inventory.

1. The Decoupling Function

Inventories make reliance on production facilities unnecessary, allowing missions or tasks to be performed independently. In manufacturing, inventory is used to separate or de-couple production capabilities from each other. For the Navy, maintenance of inventories allows for fleet operations to be carried out in remote locations for long periods of time without the need for resupply.

2. Pipeline Inventories

The transportation time of the materials from the producer to the supply center is called the pipeline. If for no other reason, some inventory must be maintained in the inventory system to meet the demands of the customers during the transit, handling, and shipping time of the items. For those items which are not in continuous production, the pipeline inventory must also account for the production lead time.

3. Buffer or Safety Stock Inventories

In many inventory systems, the average demand and average lead time for the inventory pipeline are supplemented by enough stock to provide for a possible higher than average demand during the lead time. In order to determine reasonable or affordable levels of safety stock, the risk of stocking out is assessed including the cost and inconveniences involved.

4. Review Cycle Inventories

Between inventory reviews, the inventory management scheme's order cycle or review time portion must provide enough material to support operations. A consideration of the amount of stock which will be used between inventory reviews must be included when the question of how much stock to order at once in such a periodic review system is decided.

L. THE COST DIFFERENCE FORMULA (COSDIF)

Demand-based items are identified by means of a cost equation referred to as the Cost Difference (COSDIF) equation, a probabilistic approach for comparing the forecasted cost of keeping an item in stock with the projected cost of needing the item after not having stocked it.

Alan Kaplan of the U.S. Army's Inventory Research Office was the first to introduce the COSDIF formula. This formula resulted from a simple decision model as illustrated in Figure 4.

Here the demand development period (DDP) is assumed to be two years. The DDP is the initial two years in a new system's use. During this time Demand Data, in the form of replacement and resupply requisitions for each part of the system, is recorded and reviewed to develop demand projections based on real world use of the new system. After that time, it is expected that the observed demand will provide good forecasts.

When all the costs and probability values are known for the states of nature, the expected cost for each decision can be evaluated. The optimal decision is that which creates the least expected expense. In order to decide whether to stock an item or not, it is convenient to use the difference between the projected expenses associated with each decision. For the rest of this section, this difference in expenses will be called the COSDIF. The differences in cost between the decision to stock or not to stock are analytically expressed in the following equation:

Decision	States of Nature	
	No demand during DDP	**Demand during DDP**
Make a provisioning buy	Cost of procurement plus two years' holding cost	Two years of average annual variable costs
Do not make a provisioning buy	No costs	Costs of spot buys during first year and average annual variable cost for second year

Figure 4

A Provisioning Decision Matrix

$$COSDIF = (Do/Dss) \times [A+2IC(ROP+Q)] + (1-Do/Dss) \times [4A\ D/Q + ICQ/2 + Dss \times CI] - (1-Do/Dss) \times [Dss \times (CSP+K \times PLT/4) + Dss \times C \times P]$$

where:

Dss= Steady state annual demand

Do/Dss= Probability of no demand in two years, given an annual steady state demand forecast (total) of Dss

A= Cost of procurement

I= Carrying cost rate

C= Unit price

ROP= Reorder point quantity

Q= Optimal order size

C1= Cost of issuing stock

CSP= Cost of spot procurement

PLT= Production lead time in quarters

K= Shortage cost per unit per year

P= Spot purchase premium rate.

When the resulting COSDIF value is negative, the costs of not purchasing and stocking the item are greater than those faced if the purchase is made. In other words, it would be preferable to make the purchase. However, if the COSDIF value is positive, it would be less cost-effective to make the purchase. When the result is zero, either decision would be equally acceptable from an economic standpoint, but it is less work for the provisioner to not buy, so the purchase is usually not made.

In the development of the provisioning budget, the COSDIF formula is used as the range model, and is therefore highly important to managers when they determine their initial stockage priorities.

M. DETERMINING THE PURCHASE QUANTITY AND BUDGET

If, by the use of the COSDIF formula, it is determined that an item should be stocked, the quantity of the purchase must be decided. The U.S. Department of Defense stipulates that the quantity should be equivalent to the expected demand over the course of time that includes the forecasted replenishment procurement lead time plus one quarter. The provision of the extra quarter is to provide a cushion of safety stock. In order to compute this quantity, the following formula is used:

$$D(L+1)=Di \times (L+1)/4$$

where L represents the procurement lead time.

For those items which do not meet the COSDIF requirements, there is a re-examination in order to see if they should be classified as insurance or Numeric Stockage Objective (NSO) items. If they can be so classified, the quantity of purchase of these items is considered to be one Minimum Replacement Unit (MRU).

The cost of purchasing an item depends on whether the item is demand based or is an insurance or NSO item. In the format case the cost of C x D(L+1) and in the latter, just C. By summing the procurement costs of all the items, the total value of the provisioning package is determined, which amount is the proposed provisioning budget.

In the U.S.A., the total value of the provisioning package is set as the "budget constraint," the monetary value which serves as the firm upper limit on the amount that may be spent to purchase the materials for the stock. While the actual range and purchase quantities of the materials for the stock may vary from the values used in the processing of the budget, the procedures used must be approved.

1. Example

Suppose that the program installation schedule for a new weapons system MK-98 is as follows:

Months:	O	N	D	J	F	M	A	M	J	J	A	S
Year: 1986			1	1	2	2	2	2	3	4	4	4
Year: 1987	6	7	7	7	8	8	9					

and PTB=12 months.

First we must determine the initial TWAMP and the steady state TWAMP.

Cumulative Program Buildup

Year, 1986												
Months	O	N	D	J	F	M	A	M	J	J	A	S
Mo. #			1	2	3	4	5	6	7	8	9	10
Ik 1/			1	1	2	2	2	3	4	4	4	4
Dm 2/			.5	1.5	3	5	7	9	11.5	15	19	23

Year, 1987												
Months	O	N	D	J	F	M	A	M	J	J	A	S
Mo. #	11	12	13	14	15	16	17	18	19	20	21	22
Ik 1/	6	7	7	7	8	8	9	0	0	0	0	0
Dm 2/	28	34.5	41.5	48.5	56	64	72.5	77	77	77	77	77

Therefore, steady state TWAMPss=77 since it represents the total installation to be made.

The initial TWAMP for PTB=12 will be:

$$TWAMPi = \frac{\sum_m Dm}{PTB} = \frac{0.5+1.5+3+5+7+9+11.5+15+19+23+28+34.5}{12}$$

$$= \frac{157}{12} = 13.08$$

Assume there are four demand based consumable repair parts for the Mark-98 which are being provisioned. Suppose that the data for each and the sign of the COSDIF value are as follows:

Item No.	COSDIF	N	BRF	COST	MRU
1	(-)	3	0.35	150	1
2	(-)	10	0.15	10	2
3	(-)	1	0.05	30	1
4	(+)	2	0.10	5	1

The L value is 5.4 quarters for all items.

The following steps are involved in determining provisioning budget:

1. Ignore items with positive (+) COSDIF
2. Decide whether item is insurance or demand based item
3. If it is an insurance based item, then buy one MRU
4. The cost for the insurance items is computed by the following equation:

   COST= C x MRU

5. If the item is a demand based item, then compute the initial annual demand by using the following formula:

   Di= TWAMPi x N x BRF

6. Compute the initial demand during the procurement lead time (L) plus one quarter by using the following formula:

   D(L+1) = Di x (L+1)/4

7. Finally, the cost of each item is computed by using the following equation:

   COST = C x D(L+1)

According to these for the example given, the data we have is:

Item #1: a. Di= 13.08x3x0.35=13.73
b. D(L+1)=13.73x(5.4+1)/4=22
c. Cost=150x22=$3,300

Item #2: a. Di=13.08x10x0.15=19.62
b. D(L+1)= 19.62x1.6=31
c. Cost= 31x10=310

Item #3 a. Di=13.08x1x0.05=0.654
b. D(L+1)-0.654x1.6=1
c. Cost= 1x30=3-

The Provisioning Budget will be:

For item 1:	22x150=	$3300
item 2:	31x 10=	$ 310
item 3:	1x 30=	$ 30
Total budget		$3,640

IV. INVENTORY CONTROL MODELS

A. GENERAL INFORMATION

The significant costs of inventory control techniques were introduced in the first chapter. Evolving from the considerations of costs, management control, and accounting procedures are two operating doctrines known as the continuous review and periodic review systems.

The assumptions that are made have a direct bearing on the complexity and accuracy of the models. In general, a model becomes easier to work with and understand as more factors are assumed away in it. On the other hand, the results from such a simple model are more likely to be inaccurate. Thus, it becomes necessary to analyze the tradeoffs between the accuracy and the simplicity of the model. The user or the developer of inventory models tries to strike a balance between these two factors, creating models that are simple to understand and implement but also do not assume away reality to such a degree as to endanger their accuracy. [Ref. 4:pp. 1-9]

B. PERPETUAL OR CONTINUOUS REVIEW MODELS

It is possible to mathematically derive the answers to the questions of when and how much to order by use of the variable operating cost equations. The resulting solution, basic and simplified, is the class of inventory models known as perpetual or continuous review systems. In these models, a transaction reporting system keeps the running totals of material on hand for each item in order to accurately determine the precise time for placing an order. Fluctuations in usage cause variations in the time between orders. The amounts of the purchase or order, however, are predetermined using the Economic Order Quantity (EOQ) formula. When the inventory drops to a predetermined re-order point, that critical level of stock that signals need for replenishment, an order for a fixed number of units is placed. The lead time for an order which is affected by such variables as transit time and cost, plays a large role in the determination of that re-order point. It is important to understand the assumptions, which are invariably made, of the inventory control models. To illustrate this, we shall list and discuss the assumptions of the Simple EOQ Model. This model incorporates the following simplifying assumptions:

1. Demand is constant and continuous over time.
2. Lead time for replenishment is known and constant.
3. Backorders are not permitted.
4. Price or cost is constant and independent of the order.
5. No inventory is in transit.

6. Single item of inventory or no interaction between items.

7. Infinite planning horizon.

8. No limit on availability of capital.

There is a very close relationship between the first three assumptions. We know precisely the amount that will be in demand for each relevant time span. Thus, in respect to the rate of usage over the course of time, demand is linear while the time span between placing the order and its receipt, the lead time, is constant. These factors preclude the possibility of stockouts and therefore end the concern over stockout costs.

For some businesses, such as those where the variation in the demand is very slight, the extra accuracy achieved by a more complex model would be so small as to not be worth the added expense. The Simple EOQ Model is also a convenient beginning point for the available data in firms that are only beginning to implement inventory models. Some firms implement very sophisticated models in cases where the data is quite simple, thus getting virtually no greater accuracy than if they had used a simpler, less costly model.

The assumption that there is no inventory in transit basically means that the transportation for delivery (FOB) is included in the purchase price of the item. This also means that there is no responsibility on the orderer's part for the goods during transport because the title for them is not transferred until delivery.

The constant cost assumption essentially implies that there are no volume discounts on prices and that the prices are relatively stable.

These assumptions in the Simple EOQ Model leave only two types of costs to be considered: inventory carrying cost and ordering or setup cost. In the simple model, the resulting decision analyzes the tradeoffs between these two costs. Consideration of the inventory carrying cost alone would lead to a decision of ordering as little as possible at a time because this cost rises in direct proportion to increases in lot size (Figure 5). On the other hand, a decision based solely on the order or setup cost, which is fixed per order, would be to place fewer and larger orders in order to decrease the total order costs (Figure 6). A compromise decision must be reached balancing these two costs in determining the lot size with the aim of reducing the overall costs (Figure 7).

A mathematical formulation of the total annual cost with the above assumptions is expressed as follows:

$$K(Q) = \tfrac{1}{2}QIC + \frac{\lambda}{Q}A = C$$

where:

λ = The annuual rate of demand or requirement for the period.

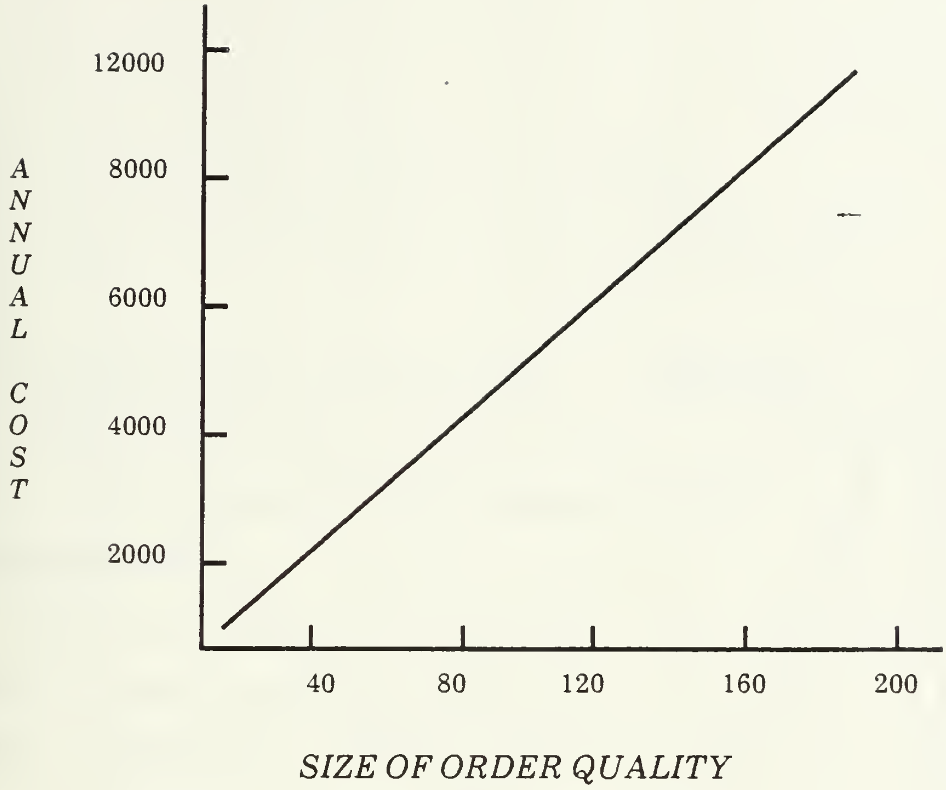


Figure 5. Carrying Cost

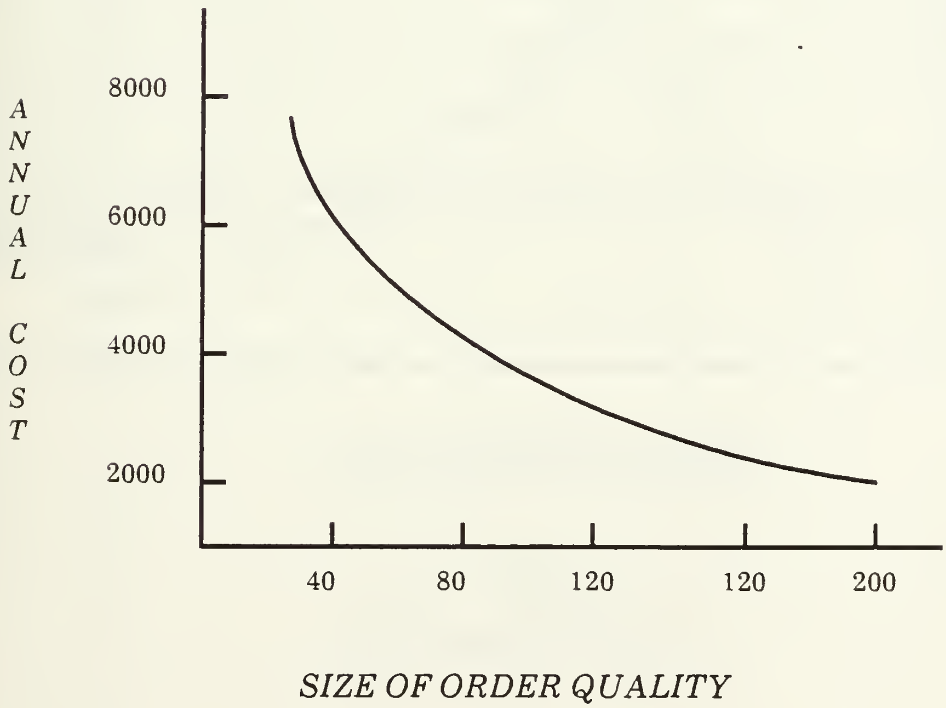


Figure 6. Order or Setup Cost

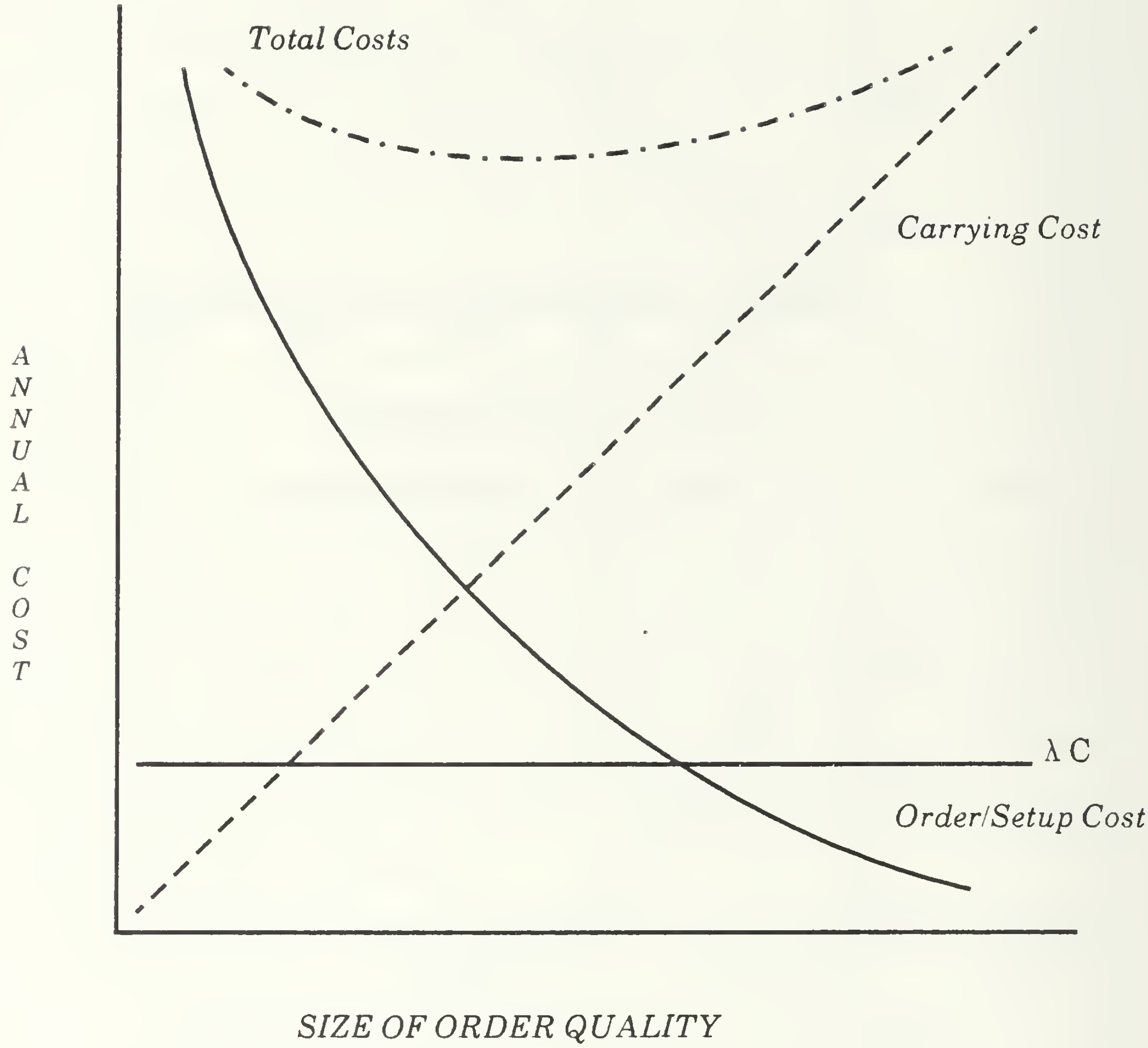


Figure 7

Total Annual Cost

Q= The quantity ordered or lot size.

A= The cost of placing an order or setup cost.

C= The value or cost of one unit of inventory.

I= Carrying cost per dollar value of inventory per year expressed as a percentage.

The first term of the equation refers to inventory carrying cost, that is equal to the average number of units in the economic order cycle (½Q) multiplied by the value per unit (C) and by the carrying cost (I). We can understand the logic of the equation looking at the so-called sawtooth model (Figure 8). The vertical line (Q) represents the amount ordered or produced for the economic order size. We start each period with this amount. During the order cycle (t), we use up or sell this amount at the rate represented by the sloping line. The average number of items on hand during the period directly affects the cost of carrying the inventory through this period. Simply, the average number of items on hand, given a constant demand rate, is equivalent to one half of the starting amount (Q). The dashed horizontal line represents average inventory. The logic is proven quite simply. Assuming that Q equals 100 items and the demand is 10 items daily, the 100 items would last 10 days (t). Halfway through the time period, after the fifth day, 50 items would be remaining, or one half of Q (½ x 100).

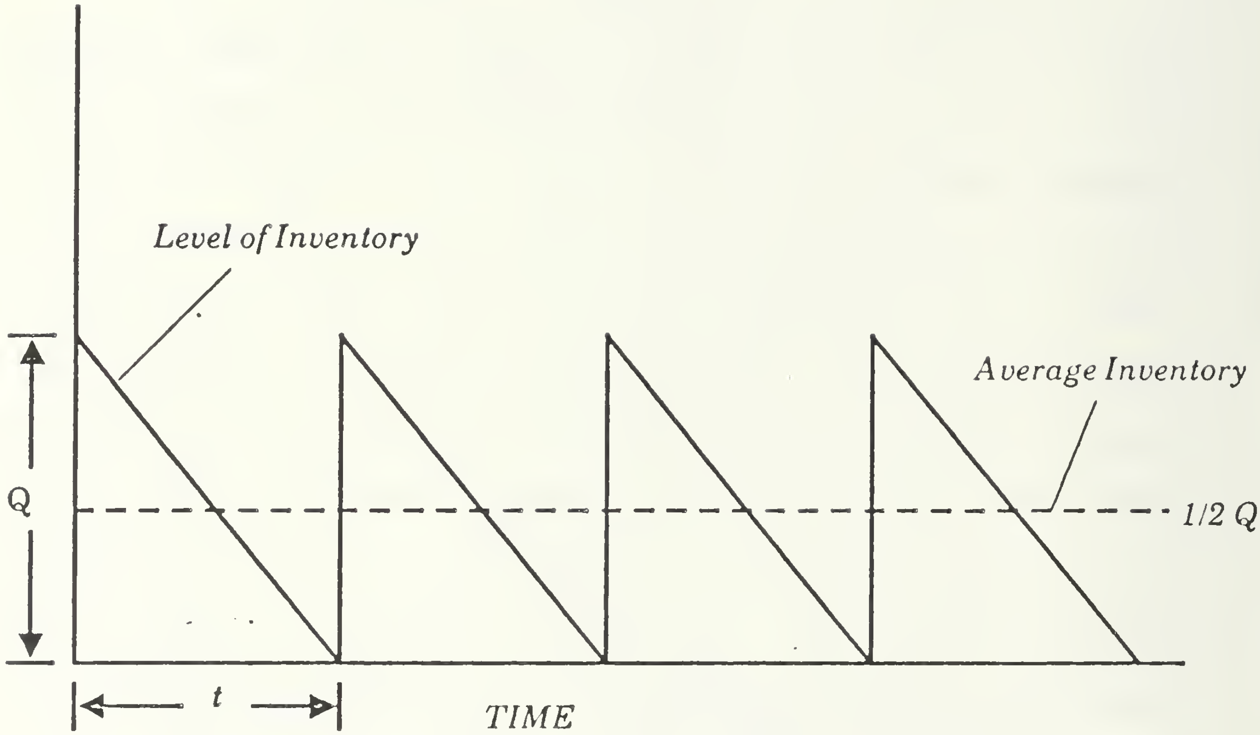


Figure 8. Sawtooth Model

The equation's second term refers to the setup or order cost. An increase in the size of Q would result in few orders annually because the demand remains constant. Therefore, annual order costs would decrease with increased order quantities.

The equation's third term represents the yearly purchase or manufacturing cost, which quite simply is equivalent to the annual demand multiplied by the per-unit purchase or manufacturing cost.

The next step is the determination of the Q, the economic order quantity (EOQ). The EOQ equals that value of Q which minimizes the total annual cost (K(Q)). This can be done mathematically by differentiating the K(Q) function with respect to Q as follows:

$$K(Q)=\tfrac{1}{2}QIC+\frac{\lambda}{Q}A+\lambda C$$

$$\frac{dK(Q)}{dQ}=\frac{IC}{2}-\frac{A\lambda}{Q^2}$$

Setting dK(Q)/dQ equal to zero and solving for Q gives:

$$Q^2=\frac{2\lambda A}{IC} \quad \text{or} \quad Q=\sqrt{\frac{2\lambda A}{IC}}$$

This is the Harris and H. Wilson formula. For the U.S. Navy, λ represents the average quarterly demand. So the optimal order quantity is:

$$Q=\sqrt{\frac{8\lambda A}{IC}}$$

For example, let us assume the following to show how the formula would work:

C= \$100 per unit

I= 25%

A= \$200

λ= 3,600 units per year

If we solve for Q, we will have:

$$Q = \frac{2\lambda A}{IC} = \frac{2 \times 3600 \times 200}{925 \times 100} = 240 \text{ units.}$$

Reference to Table 3 and Figure 9 probably best demonstrates the nature of the tradeoffs and the logic of the above solution. These show the development of a range of different Q's from 100 to 500 with their accompanying inventory carrying cost and order cost in addition to the total cost.

As the table illustrates, order costs are higher for lower values of Q, as predicted above, but the carrying costs are low. As the value of Q increases, up to 240, the ordering costs become lower because the number of orders per year decreases. On the other hand, the higher average inventories increase the carrying costs. For values of Q over 240, the decreases in the ordering costs become lower than the increases in the carrying cost, resulting in higher total costs.

TABLE 3

TOTAL COSTS FOR VARIOUS EOQ AMOUNTS

Q	Order Cost λ/Q	Carrying Cost 1/2 QIC	Total Cost
100	$7200	$1250	$8450
140	5140	1750	6890
180	4000	2250	6250
220	3270	2750	6020
240	3000	3000	6000
260	2770	3250	6020
300	2400	3750	6150
340	2120	4250	6370
400	1800	5000	6800
500	1440	6250	7690

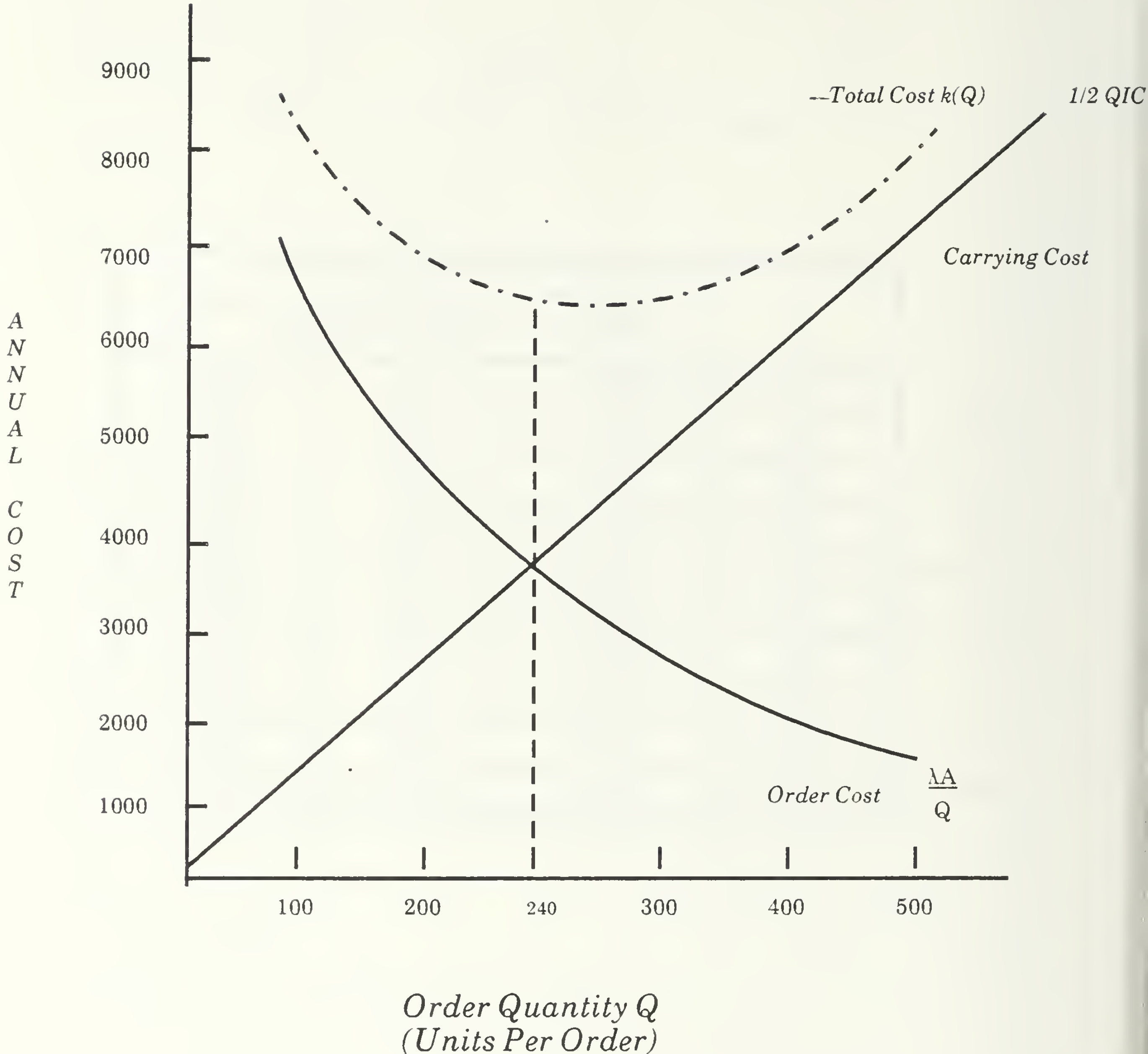


Figure 9.

Total Annual Cost of EOQ Example

By defining the optimum Q based on total costs, we are quickly able to determine from the table that the optimum Q is 240, according to the definition that has been established. The same result can be derived from Figure 9. Based on this EOQ system, expensive items and those for which the carrying cost (I) is high are ordered in small quantities at frequent intervals. But inexpensive and cheaply stored items will be ordered less frequently and in large quantities.

C. RE-ORDER POINT

In the above text it was pointed out that not only must one know the quantity to order, but also at which time to order. This point in time is generally called the re-order point, which is determined on the basis of a level of inventory or a number of units in stock. In accordance with the predetermined assumptions, there must be in inventory just enough stock to carry through the replenishment or lead time. Thus, when the lead time is known and constant, the amount of stock needed can be determined merely by multiplying the number of days of lead time by the daily demand. Then, when the level of inventory drops to this re-order point, an order is placed for the predetermined quantity. Under conditions of any uncertainty the re-order point must be redetermined to create an additional margin called safety stock. Thus, the re-order point effectively amounts to the average demand during the lead time plus safety stock to allow for minor changes in demand. This principle is depicted graphically in Figure 10.

So, based on the above example, if the lead time is 10 days, the daily demand will be 10 units (3,600/360) and 100 units will be the re-order point (10 days x 10 units).

For the purposes of the U.S. Navy, the re-order level (RL) is a function of lead time demand, the variability of demand, and economic considerations.

RL = D x L x SL

where:

D= Quarterly demand average

L= The procurement lead time in quarters

SL= Safety level, a function of demand and lead time variability and the desired level of service.

D. PERIODIC REVIEW MODELS

A policy of reviewing inventory and ordering at fixed regular intervals up to an optimal Requisition Objective (RO), is the basis of the periodic review model. Each order is intended to return the inventory level to a predetermined state. However, the size of the order may vary from interval to interval. At set intervals, the orders are placed without checking the stock level between orders. Thus, the inventory must provide for the expected demand

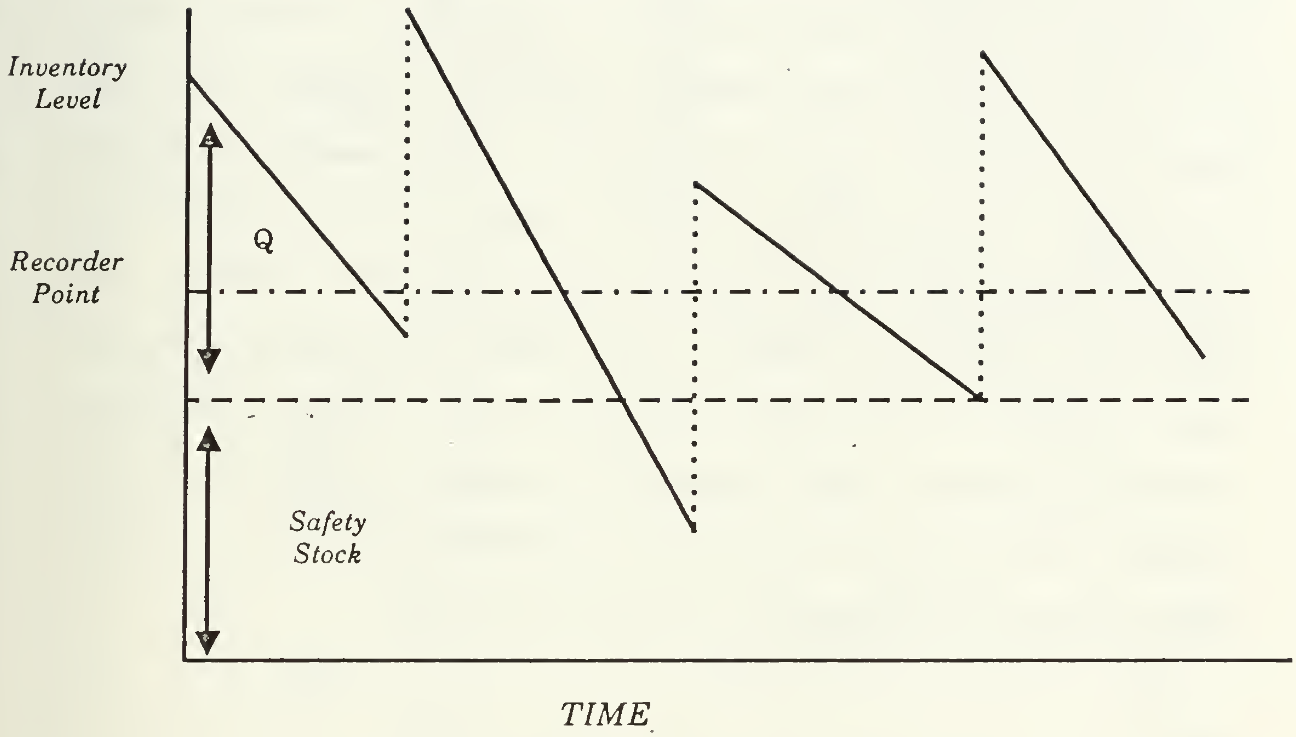


Figure 10.

Inventory Model Under Conditions of Uncertainty between these intervals as well as allowing for some variations in the demand. Under this system, larger inventory levels must be maintained than in a continuous review system with similar demand and lead time.

The target Requisition Objective must at least include sufficient quantities to cover the expected demand during the lead time plus the demand during one review time plus the Safety Stock, if any (Figure 11). The quantity ordered is determined by finding the difference between the RO and the inventory on hand at the time of the review. The additional costs generated by the higher investment level of this system are partially offset by lower clerical and data processing costs. For inexpensive items, a periodic review system may possibly be the most economical system. The U.S. Navy defines the RO as:

$$RO = D \times L + D \times R + SL$$

where:

R= The length of the review period in quarters.

For deterministic demand with no stockouts, the optimal review period R' is:

$$R' = \frac{Q}{4D}$$

E. MATERIAL REQUIREMENTSS PLANNING (MRP)

Production scheduling and inventory control are the concerns of material requirements planning (MRP). MRP

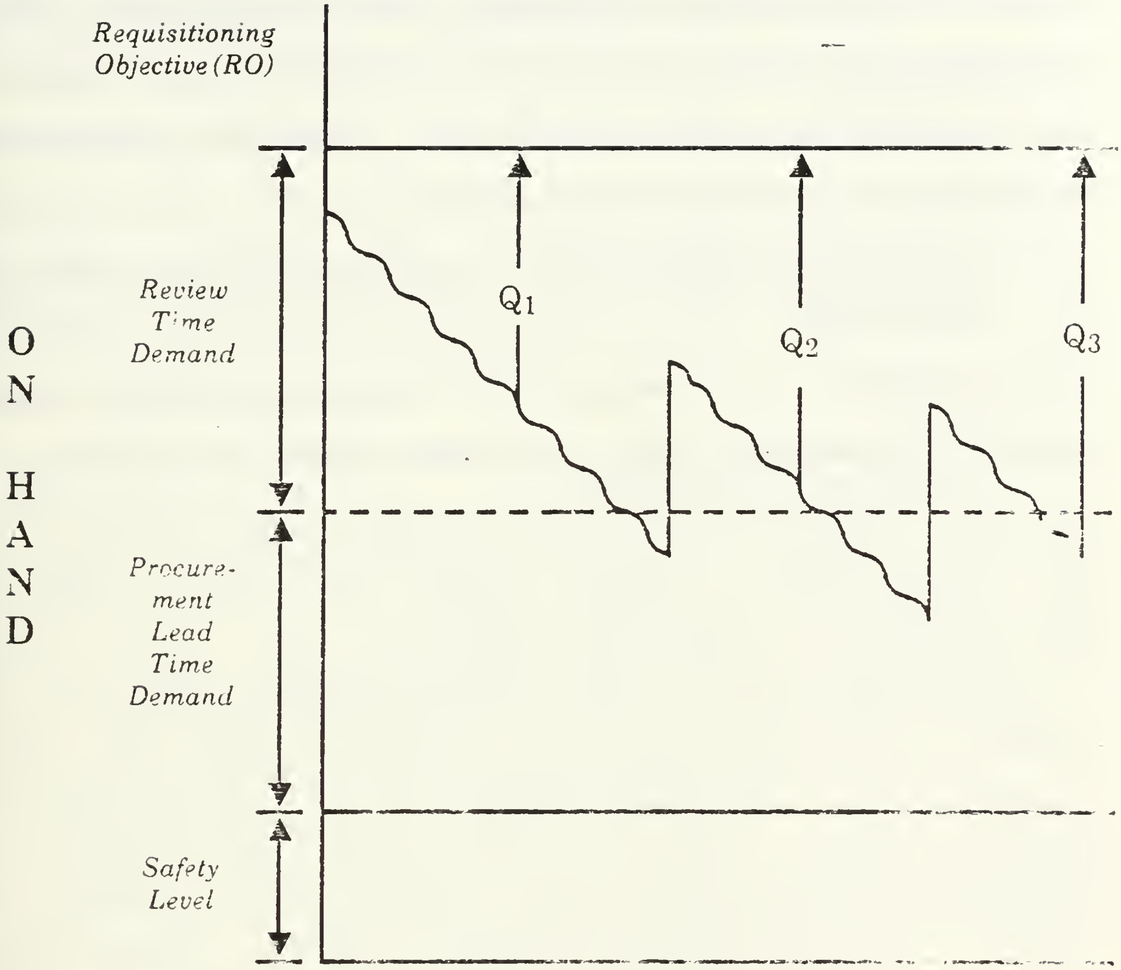


Figure 11
A Periodic Inventory System

provides a precise scheduling system, an efficient material control system, and, in order to revise plans should changes occur, a rescheduling mechanism, while maintaining minimum levels of inventory and ensuring that necessary materials are available as they are required. The MRP system's major objectives are to simsultaneously:

1. Ensure that materials, components, and products are available for planning production and for customer delivery.
2. Maintain the inventory at the lowest possible level.
3. Plan manufacturing activities, delivery schedules, and purchasing activities.

The meaning of dependent and independent demand items was introduced in the third chapter.

The demand pattern for dependent demand items is a lump pattern incompatible with the constant demand rate that is assumed in the basic EOQ Model. It was to better cope with these dependent demand items that MRP was developed. MRP begins with the scheduled completion dates, working backward to determine at which points dependent demand items will be ordered and the quantities to be ordered.

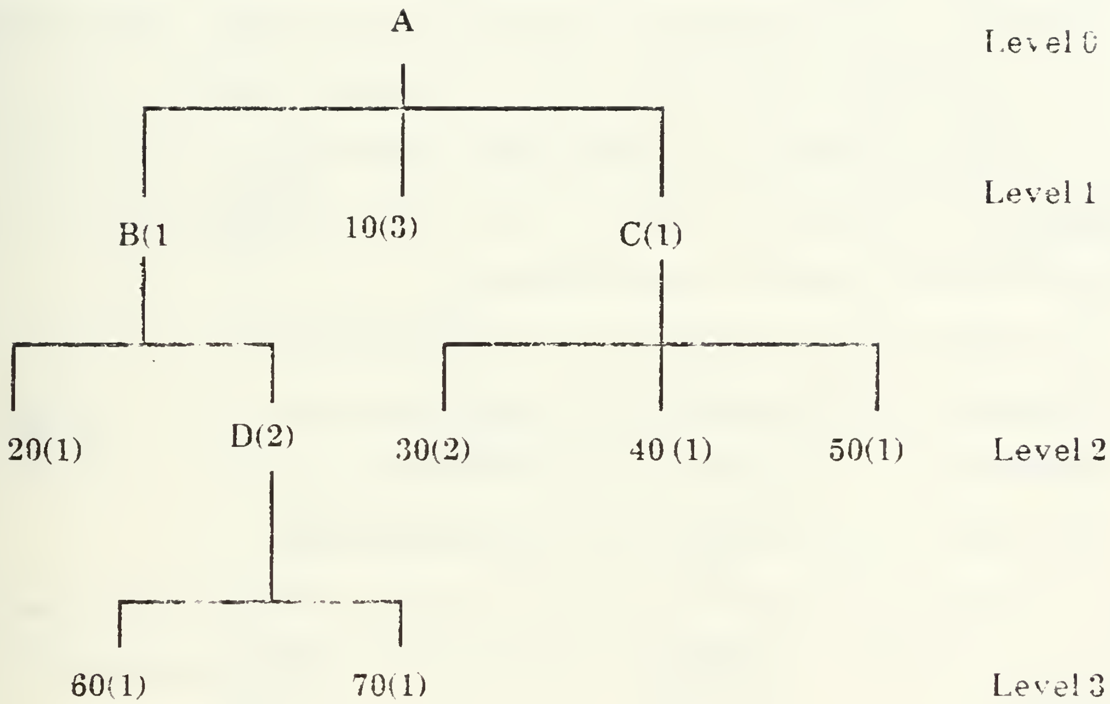
The MRP system does not require forecasting of dependent demand items, but calculates the quantities from the master schedule. Except for lot sizing economies, it is important that these items are available at the precise time they are needed, not before and not after. Most inventory items in manufacturing organizations are dependent and therefore should be managed by use of an MRP system.

The MRP system's key features are the time phasing of requirements, generation of lower level requirements, planned order releases, and re-scheduling capability. The function of the time phasing of requirements is to determine the time period in which the material should be made available in order to meet the delivery date of the end product as denoted on the master schedule. Beginning with the end product, MRP controls all the necessary scheduling for the lower-level requirements. Planned order releases show the timing for placing orders by purchasing and manufacturing. When it becomes impossible to complete the work as scheduled, the MRP re-schedules planned orders to maintain realistic and meaningful priorities.

The MRP system requires three major items of input. These items are the master production schedule, inventory status records, and the product structure records.

This system takes the master production schedule for the end products and uses the product structure records to determine the gross quantities of components required. In order to obtain these gross quantities, the system uses a process of "exploding" the product structure record, breaking it down into its lower level requirements. This process simply multiplies the required amount of each component for a single end product. Also identified by the explosion process are necessary components and the quantity of each needed to produce a certain number of the product. The term explosion is appropriate because the analysis of each level in the product schedule uncovers more requirements than in the previous one. The gross quantities are adjusted by referring to the inventory status records and subtracting from the gross quantities the number of items available in inventory. The "when," which is as important as "what" and "how many," is determined by setting back in time the lead times for each component. In this manner, each component's material requirements are phased over time in a pattern determined by lead times and parent requirements.

A schematic representation of a product structure is shown in Figure 12. The structure of product A defines the relationship between the various items that make up the product in terms of levels as well as parent/component relationships. Th product has four levels of manufacture. The end product is designated by convention, as being at level 0, its immediate components at level 1, and so forth. The parent/component relationship indicates that A is the parent of the components B, C, and 10; B is the parent of components D and 20; C is the parent of components 30, 40, and 50; and D is the parent of components 60 and 70. The



The letters represent assemblies/subassemblies, and the numerals represent parts. The numbers in parentheses are the quantities required for assembly.

Figure 12. Typical Product Structure

only item that is not a component is the independent demand item, A. The dependent demand items B,C, D, 10, 30, 40, 50, 60, and 70, are components. Items B, C, and D are parents as well as components.

For example, suppose we are to produce 100 units of product A in period 8 with the product structure shown in Figure 13. If no stock is on hand or on order, determine when to release orders for each component and the size of each order. Product A is made from components B and C; C is made from components D and E. By simple computation we can calculate our quantity requirements:

Component B: (1)(number of A's)=1(100)=100

Component C: (2)(number of A's)=2(100)=200

Component D: (1)(number of C's)=1(200)=200

Component E: (2)(number of C's)=2(200)=400

Now we must consider the time element for all the items. Table 3 creates a material requirements plan based on the demand for A.

A material requirements plan has been developed for product A based on the product structure of A and the lead time needed to obtain each component. Planned order releases of a parent item are used to determine gross requirements for its component items. Planned order releases a requirement in the same time period for its lower level components. In order to complete 100 units of product

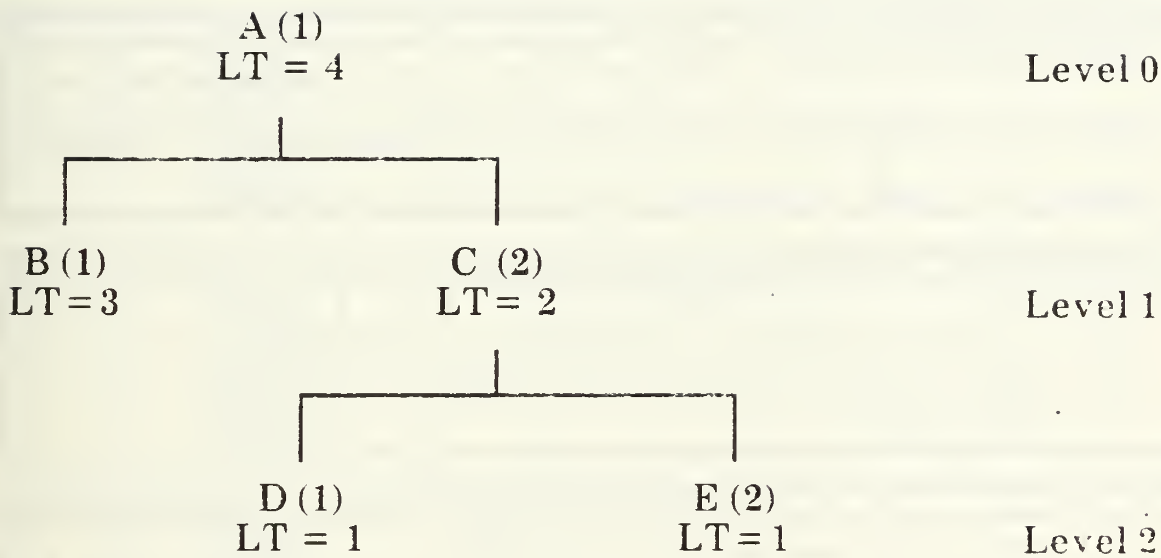


Figure 13. Typical Product Structure

A in period 8 it is necessary to release orders for 100 units of B in period 1, 200 units of C in period 2, 200 units of D in period 1, and 400 units of E in period 1. Planned order release dates are obtained by setting back in the lead times. A component's gross requirements time period is the planned order release period of its parent.

F. AN EOQ-MRP COMPARISON

There are many advantages to the MRP system as opposed to the fixed order size system in terms of controlling production of items. A comparison of the characteristics of these two inventory management techniques can be found in Table 4. The following are some of the disadvantages inherent in fixed order size systems:

1. A large inventory investment is necessary.
2. With a highly varying demand rate it becomes unreliable.
3. There is a large safety stock investment required.
4. All items must be forecasted.
5. It is based on past demand data.
6. There is a greater chance of material obsolescence.

When demand is dependent, the EOQ system can cause serious problems in the operation as well as an excessive inventory investment. A bill of materials explosion should be used to calculate demand for the dependent demand items. When demand can be calculated, there is no reason to use

TABLE 4

MRP PLAN FOR 100 UNITS OF PRODUCT A IN PERIOD 8

Lead Time			1	2	3	4	5	6	7	8
4	A	Gross requirements								100
		Planned order releases				100				
3	B	Gross requirements				100				
		Planned order releases	100							
2	C	Gross requirements				200				
		Planned order releases		200						
1	D	Gross requirements		200						
		Planned order releases	200							
1	E	Gross requirements		400						
		Planned order releases	400							

forecasting. While independent demand items must be forecasted, this is not the case for dependent demand items. Therefore, the latter should be calculated. Efficiency is greatly enhanced when components are ordered based on product requirements and the component inventory is driven to zero between requirements. The result of implementing MRP will be to reduce inventory investment substantially for dependent demand items while at the same time removing the EOQ's built-in risk of shortages, thus greatly improving operational efficiency. The use of independent demand inventory models for dependent demand items generates excessive inventory at times when it is not needed and the risk of shortages and stockout when it is needed.

TABLE 5. COMPARISON OF FIXED ORDER SIZE AND MRP SYSTEMS

Fixed Order Size System EOQ	MRP System
Part oriented (every item)	Product/component oriented
Independent demand	Dependent demand
Continuous item demand	Discrete/lumpy item demand
Continuous lead time demand	No lead time demand
Reorder point demand signal	Time-phased ordering signal
Historical demand base	Future production base
Forecast all items	Forecast end items only
Quantity-based system	Quantity and time-based system
Safety stock for all items	Safety stock for end items only

V. FORECASTING

A. THE IMPORTANCE OF THE FORECAST

Inventory control is concerned with the future because the past is beyond control. It is important to begin with the present position and to work from there to prepare for the future. In order to achieve this goal, one must assume, guess, or otherwise estimate what will occur in the future. With all other factors being equal, an organization is only able to survive if it can prepare itself to meet the needs of its customers. [Ref. 9:p. 13]

In decision making, the avoidance of forecasting is impossible. An estimation of future demand is a prerequisite for every decision in production planning and inventory management. Forecasts are necessary to:

1. Set up performance standards for customer service.
2. Determine the allocation of the total inventory investment.
3. Order replenishment stock.
4. Identify the necessities for additional production capacity.
5. Be able to choose among alternative operating techniques.

After the decisions are made, there is only one thing that is certain--the forecasts will not be correct. The result is the need to determine the precise magnitude of the errors and to ensure that past decisions are reviewed for any necessary alterations in response to those errors.

B. FORECASTING PRINCIPLES

It is important to establish the general principles of forecasting before discussing the techniques which are based upon them. Briefly, the most important of these principles are as follows:

1. The accuracy of forecasts improves with larger groups of items.

2. Shorter periods of time are more accurately forecasted.

3. An estimate of error should be incorporated in each forecast.

4. The forecasting methods should be tested before they are applied to any forecasting system. [Ref. 9:p. 18]

C. MAKING A FORECAST

There are three essential steps for forecasting:

1. Preparation of the data.

2. The actual making of the forecast and its accompanying error estimate.

3. Tracking the forecast.

D. WHAT TO EXPECT FROM A GOOD FORECASTING SYSTEM

M.J. Netzorg, a management consultant who has nearly thirty years of experience, described the environment and situation in which forecasts of the demand for individual items are made:

> . . . we seldom have the time to make genuinely new forecasts . . .. For most items we get no market research support . . .. The only new information we get routinely is a month's net sales figures, by item, by region, to compare to the forecasts made earlier for that month . . . therefore one must not promise or even aim for accurate forecasts from month to month, but only forecasts that wouldn't crucify production and customer service.

Netzorg suggests a simple 12-month moving average for forecasting very low volume or C items. The length of time for the moving decreases gradually to six months for the highest volume of B and A items among the slow movers. In agreement with this standpoint, it is preferable that the more sophisticated forecasting models be applied only to the most important items, those in categories A and B.

Therefore, an ideal forecast, from the viewpoint of effective inventory management and production planning, should:

1. Estimate the demand to be expected in physical units.
2. Estimate the actual demand's probably range in reference to the expected value point (i.e., forecast error).
3. Be timely by completing the forecast in time to allow for necessary decisions to be made.
4. Update the forecast regularly so that prompt revisions can be made.
5. Balance the costs of errors in the forecast against the costs of forecasting.
6. Allow for overriding of the mechanical forecasts, whose main advantage is the ability to assimilate large amounts of information and historical data, by human judgement.

It is important to keep the number of items of information needed for forecasting at an absolute minimum. The forecasting technique's logic should be clear and easy to follow so that it is understood and usable by those who will supply the value judgements, thereby transforming the forecasts into predictions.

There exist a great many techniques and systems for projecting past patterns onto the future for purposes of forecasting. These techniques are classified in many ways, one of which is based upon the time period involved:

1. Aggregate Longer-Term Forecast.
2. Individual Item Short-Term Forecast.

One other classification scheme is illustrated in Figure 14. This scheme distinguishes between formally recognized forecasting techniques (formal) and approaches such as intuition and other similar "informal" techniques.

E. AGGREGATE LONGER TERM FORECASTS

An aggregate time series, which deals with the patterns of a group of products, is generally more stable than an individual item's sales pattern. However, in cases where the time series is not stable, or where the forecast deals with individual items, the use of the Individual Item Short Term Forecast is preferable.

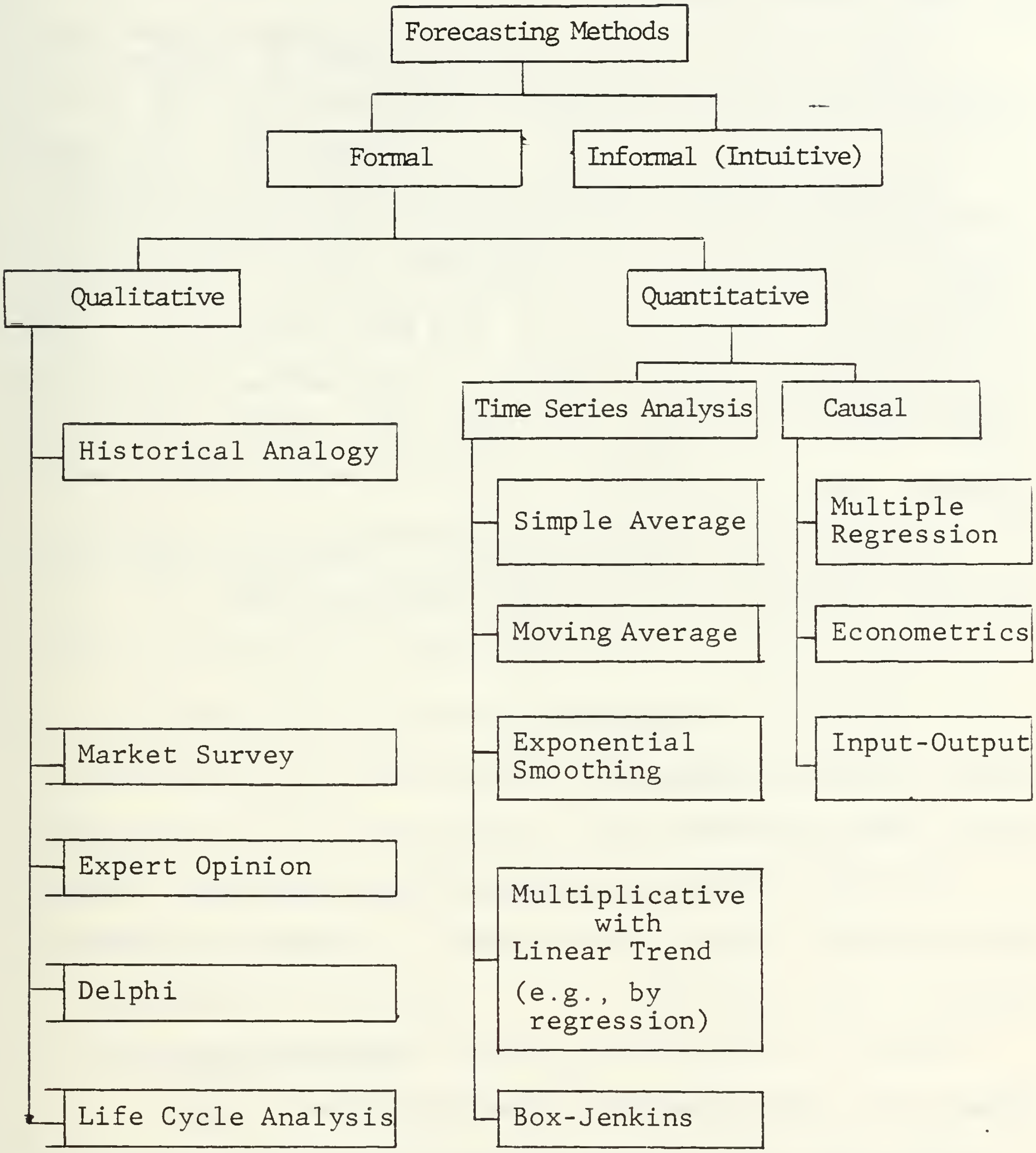


Figure 14

Classification Scheme of Forecasting Methods

F. TIME SERIES ANALYSIS

A time series is "an ordered group of values of a variable measured at successive positions in time or for successive intervals of time." In this process we determine the number of items in the inventory at specific points in a range of time and also calculate the number of items sold over specific time intervals. The conclusion of the time series consists of developing a time series forecasting model which can become the basis for predicting future trends. [Ref. 10:p. 683]

The Time Series Analysis makes the assumption that there are four component parts to the historical data:

1. The trend, T.
2. A seasonal variation, S.
3. A cyclical variation, C.
4. Random variation, R.

The trend component consists of the long-term general developmental trends in the series, to include any constant amounts within the data.

Seasonal variations are those variations due mainly to nature, but also affected by human behavior.

It is only over a span of several years that a cycle or cyclical variation can be discerned.

Those variations without specific determinable cause and without any pattern fall into the random variations component. After the fact, however, these fluctuations may sometimes be explained.

By use of the concepts one may develop a multiplicative model of a time series:

Sales=(Trend)x(Seasonal)x(Cyclical)x(Random)=TxSxCxR

Each of the four components can be isolated from any time series by application of related statistical procedures. Once the T, S, and C have been identified for a specific future time span, it is possible to generate a forecast with the multiplicative formula.

There is an alternative forecasting technique. The Least Squares Regression Analysis may be substituted in order to forecast the aggregate sales.

G. INDIVIDUAL ITEM SHORT-TERM FORECASTS

There are two techniques for forecasting the quarterly demand when we are forecasting on an individual item basis or in a situation where the time series is unstable:

- Moving average
- Exponential smoothing.

1. Moving Average

This technique forecasts for the subsequent period by averaging the actual demand for the last n time periods, where n is usually between 4 and 7. Thus, any data from before n previous time periods is ignored. The usual basis for determining the value of n is the expected seasonality of the data, such as 4 quarters or 12 months in a year. By making such a choice, one effectively eliminates the impact of seasonality in the data. At times n must be chosen arbitrarily, in which case it should be based upon the value which best describes the historical data when used in the model.

The moving average is computed mathematically as:

$$F_{t+1}=\frac{1}{n}\sum_{i=(t-n+1)}^{t} Di$$

where:

t= Period number for the current period

F_{t+1} = Forecast of demand for the next period

Di= Actual demand for period i

n= Number of periods of demand to be included, also called the "order" of the moving average.

As an example, in order to forecast demand for the next quarter of this year (i.e., quarter 3 1985 or period 15 from data of Table 6) using a moving average of order 4 (that is n=4), we would compute:

$$F_{14+1}=\frac{1}{4}\sum_{i=14-4+1}^{14} Di$$

or

$$F_{15}=\frac{1}{4}\sum_{i=11}^{14} Di$$

$$F_{15}=(D_{11}+D_{12}+D_{13}+D_{14})/4$$

$$F_{15}=(7,500+15,000+13,500+17,500)/4$$

$$F_{15}=13,375$$

TABLE 6

HISTORICAL DATA (MOVING AVERAGE)

Year	Quarter	Period Number	# of Items
1982	1	1	3,500
	2	2	8,000
	3	3	5,500
	4	4	10,000
1983	1	5	4,500
	2	6	6,000
	3	7	3,000
	4	8	5,500
1984	1	9	5,500
	2	10	9,500
	3	11	7,500
	4	12	15,000
1985	1	13	13,500
	2	14	17,500

Thus, the next quarter's forecast would be 13,375 items.

There is a problem when an item is first introduced into the inventory system in that there is no available historical data to use. The data is still missing after the first three quarters. However, the use of an "initialized moving average" can easily overcome this shortcoming. This figure is determined by finding the sum of the available data and dividing it by the number of quarters from which that data is drawn, up until data has been accumulated for four quarters, at which time, use of the moving average formula is possible.

2. <u>Exponential Smoothing of Exponentially Weighted Average</u>

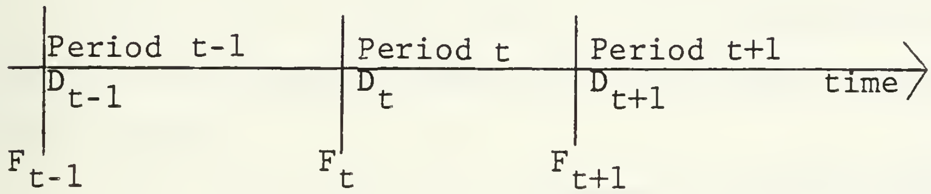
When forecasting, it is usually preferable to make use of the most current available data, while also incorporating sufficient observations over time in the series in order to smooth out as much as possible the random fluctuations. The technique of exponential smoothing seems perfectly suited for achieving these goals.

The formula below uses exponential smoothing to generate the forecast. If, for example, we consider demand data:

New demand forecast=(a)current demand+(1-a)previous demand forecast, or:

$$F_{t+1} = aDt+(1-a)F_t$$

where a is a smoothing constant which has to be greater than or equal to zero and also less than or equal to one. The other symbols are illustrated in the following diagram.



The act of changing the value of a allows one to alter, at any time, the sensitivity of the exponentially weighted average. In order to place greater emphasis on the recent data, thereby increasing the sensitivity of the average, the value of a is increased. The reverse holds true for decreasing values of a, less emphasis is placed on the recent data. The sensitivity of the moving average is only able to be changed by the use of a different number of quarters as the basis on which the moving average is calculated.

In the U.S. Navy, the value of a is set at 0.2 unless they suspect a change in the mean of the distribution of the actual demand of the present period. In that situation, they set the value of a at 0.4.

The U.S. Navy has found it practical when beginning a forecasting system with the exponentially weighted average method, to use, as in the moving average technique, an initial estimate using the same moving average approach of 1,2, 3, and 4 periods. The first forecasting demand value of the exponentially weighted model is then the first full four quarter average.

Change a based on a trend test, compute:

$$T = \frac{2(Dt + Dt-1)}{Dt + Dt-1 + Dt-2 + Dt-3}$$

The U.S. Navy changes the value of a from a=0.2 to a=0.4 if:

$T \leq 0.9$ and $Dt \leq Ft$

$T \geq 1.1$ and $Dt \geq Ft$

and returns to a=0.2 when the value of T returns to:

$0.9 < T < 1.1$

H. FORECAST ERRORS

When measuring forecast error, there are two common systems, the mean absolute deviation or MAD and the bias.

$$MAD = \frac{1}{n} \sum_{i=1}^{n} |Fi-Di| \qquad BIAS = \frac{1}{n} \sum_{i=1}^{n} (Fi-Di)$$

where:

Fi= forecast of demand in period i.

Di= Actual demand in period i.

n= number of periods of data analyzed.

The MAD determines the average size of the error by summing the absolute values of the errors, adding both positive and negative errors to the sum. Thus, the manager receives a sense of the general accuracy of the forecasting, but is unable to determine if the error is above or below the forecast.

On the other hand, the bias shows the typical trend of the forecast to be either too high or too low and by how much. By using the MAD, one determines the average size of the error while the bias determines the direction of the error. The best forecasting techniques are those which result in the least error measurements.

I. FORECASTING LEAD TIME

The lead time is that span of time beginning with the discovery by the inventory manager that the inventory has dropped below the re-order point and ending when the ordered material is received into the inventory.

The lead time can usually be divided into two sections. The first is the time taken by the inventory manager and procurement personnel to prepare the order and negotiate with the manufacturer. The second block of time is that during which the manufacturer produces and delivers the order. The former period of time is generally labelled the administrative lead time (ALT), while the latter is called the production lead time (PLT). The sum of both time periods is the total procurement lead time (L).

There are two parts to be forecast. They are the L and the mean absolution deviation for L (MADL).

If we use L(n) to denote the computed forecast of L, the following equation can be used to determine its value, assuming the exponential weighting model:

$$L(n+1) = a\ L(\text{observed}) + (1-a)\ L(n)$$

where:

L(observed)= the sum of the procurement lead times in days for purchases received during the observed period divided by the number of purchases received during the observed period multiplied by 91.

The denominator is multiplied by 91 because a quarter consists of 91 days.

For example, assume that two purchases arrived this quarter. One of these purchases took 265 days from the time it was initiated until the time it was received; the other took 310 days. We compute L(observed) as follows:

$$L(\text{observed}) = \frac{265 + 310}{2 \times 91} = 3.16 \text{ quarters}$$

The U.S. Navy bases the value of a on what they perceive as the validity of L(n), for S.P.C.C.:

a=0.2 if previous purchase arrived in quarter N-1.

a=0.5 if previous purchase arrived in quarters N-2 to N-4.

a=1.0 if previous purchase arrived before N-4.

Although these values may not be directly applicable to the Hellenic Navy, they provide a general idea of the probable, preferable range of values for a.

J. PROBABILITY DISTRIBUTION

In the U.S. Navy, the fast moving or high demand items get normal distribution while the Poisson distribution is applied for the slow moving items. Based on experience, 75% to 80% of the entire spares requirement is shown to be slow moving while fast moving items account for only 15% to 20%. It is typical for 80% of the demands to be for the fast movers.

K. NORMAL DISTRIBUTION

By far the most important of the special probability densities used in statistics is the normal probability density, which is usually called the normal distribution for purposes of simplicity. In the eighteenth century, this normal probability was first studied when scientists discovered that the errors of measurement had an astonishingly high degree of regularity. They found that a continuous distribution, referred to as the "normal curve of errors" and attributed to the laws of chance, was what their observed patterns and distributionsn approximated most closely.

The equation for the normal distribution is called the density function and is represented by this formula:

$$f(x;m,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^2} \qquad -\infty<x<\infty$$

with the parameters that:

m= the mean,

σ= the standard deviation.

The graph generated by the normal distribution is a bell-shaped curve that extends in both directions to infinity. Rarely will it be necessary for the tails of a normal distribution to be extended for any great distance because the area under the tails which lies farther away from the mean 4 or 5 standard deviations is for all intents and purposes negligible. In practice, a standard normal table can be used to determine the areas under normal curves. This table gives the areas beneath different portions of the normal curve for the normal distribution where the mean is zero and the standard deviation is one.

In order to convert this information to that which can be associated with a random variable x, normally distributed with a general mean of m and the standard deviation σ, the following equation is used:

$$Z=\frac{(x-m)}{\sigma}$$

In order to find the areas under those normal curves where the mean is not 0 and the standard deviation is not 1, the value of any x of interest is converted into z and then the standard normal distribution table may be used. This table's entries are the areas beneath the standard normal distribution curve between a and non-negative values of z. For determining the probability of z lying between two values, take the difference between the area values for both the smaller and larger values of z.

In the field of inventory management, when we apply this principle, we have the mean during the procurement lead time represented as:

$m-DxL$

The variances of the demand and the lead time which are the standard squared are represented:

$\sigma D^2=1.57(MADD)^2$

$\sigma L^2=1.57(MADL)^2$

The variation of demand during lead time can then be represented by:

$\sigma^2=Lx\sigma D^2+D^2x\sigma L^2$

and the standard deviation is then the square root of this equation.

If we are interested in the probability that demand during lead time is less than or equal to some value, say x, we first compute:

a. z using equation $z=\frac{(x-m)}{\sigma}$

b. m using equation $m=DxL$

c. σ using equation $\sigma^2=Lx\sigma D^2+D^2x\sigma L^2$

Then we look up the area associated with z in the table of the standard normal. This area is the desired probability value.

L. POISSON DISTRIBUTION

The Poisson distribution is a discrete distribution represented by the following formula:

$$f(x,\lambda) = \frac{\lambda^x e^{-\lambda}}{x!} \quad \text{for } x = 0, 1, 2, \ldots$$

with λ equal to the product np and in the inventory field $\lambda = DL$.

When we use Poisson distribution we need only the mean of the mean demand (DL) during lead time.

To compute f(x) for x=1, 2, 3, . . ., we use the following steps:

$$\text{for } x=0,\ f(0)=e^{-DL}$$

$$\text{for } x=1,\ f(1)=DL\cdot e^{-DL}=f(0)DL$$

$$\text{for } x=2,\ f(2)=\frac{(DL)^2 e^{-DL}}{2!} = \frac{DL}{2}(DLe^{-DL}) = \frac{DL}{2}f(1)$$

$$\text{for } x=3,\ f(3)=\frac{(DL)^3 e^{-DL}}{3!} = \frac{DL}{3}f(2)$$

In general, $f(x)=\frac{DL}{x}f(x-1)$

Example:

Suppose that: D=0.5 units per quarter

L= 6 quarters

Then: DL=(0.5)(6)=3.

x	f(x)	$\sum_{x=0}^{x} f(x)$
0	$e^{-3} = 0.0498$	0.0498
1	3/1(0.0498) = 0.1494	0.1992
2	3/2(0.1494) = 0.2240	0.4232
3	3/3(0.2240) = 0.2240	0.6472
4	3/4(0.2240) = 0.1680	0.8152
5	3/4(0.1680) = 0.1008	0.9160

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

In the first chapter we described the difficulties that the Hellenic Navy faces in its efforts to supply the necessary materials wherever and whenever they are needed. We also discussed the procedure and the technique used in order to accomplish this.

We then introduced the concept of inventory techniques and the costs that are subject to control by our inventory technique, such as, holding cost, stockout cost, ordering and procurement cost.

We have had a glance at the history of inventory models' development and the efforts made by the United States Navy in order to develop models that fulfill specific demands.

In the second chapter, we developed the meaning of ABC Analysis and the manner in which this analysis can be used so that we can accomplish a more effective control of the surplus with less cost.

In chapter three we discussed provisioning of depot stock to provide initial backup supply support to a newly inducted equipment or weapon system. In this chapter, we began with the definition of provisioning and provisioning methods and then we introduced the key dates that are considered important for provisioning. This was followed by a discussion of demand and how to determine initial demand forecasts and then the meaning of demand and non-demand items was introduced. A model called the Cost Difference Formula was then described, determining the range of items to buy. Finally, a model for computing the purchase quantity for those items to be bought was presented and steps for computing the procurement budget were shown. An example which illustrated the steps for developing a provisioning budget was also presented.

In chapter four we formalized the concepts of costs that were introduced in chapter one, into mathematical inventory control models. We discussed the development of the simple Economic Order Quantity Model (EOQ) in which we assumed a constant and known rate of demand and a constant lead time without stockouts. The formula for total annual cost, the optimal order quantity Q and the reorder point were derived and their use was illustrated by an example. Here, we discussed the meaning of continuous and periodic review models and when they are applied. Then we introduced the Material Requirement Planning (MRP) technique and an example was given. Finally, a comparison betwen EOQ and MRP was also given.

In the fifth chapter, we dealt with forecasting lead time demand and probability distribution for this demand. Two forecasting models, the Moving Average and the

Exponentially Weighted Average were presented. The moving average is a simple model for estimating the mean value of demand based on four observed demands. The exponentially weighted average is a model that overcomes the disadvantage of storing four times of demand information. It forecasts based on one time demands and its forecast. The weight can be changed if trends are detected. Another model, based on the mean absolute deviation (MAD) of forecasting errors was suggested for estimating the standard deviation of demand.

B. CONCLUSIONS

Total inventory costs can be reduced through the implementation of various models for cost optimization. We can establish a conscious policy to increase inventory as long as the additional expenditure for inventory leads to compensating cost reductions in other areas. For example, a high inventory level significantly decreases the risk of backorder and stockout costs.

The cost of storage varies depending upon the type of inventory. Raw materials invariably require minimal storage facilities compared to finished goods which need rather sophisticated facilities and may even require temperature and humidity control. In the case of the Naval Stores Depot, most of the inventory consists of finished items requiring careful handling, and, at times, regulated temperatures.

The fixed quantity model for cost minimization has been discussed. Customarily, this type of model is used when dealing with the more important inventory items. A continuous review must be used for these items. Close surveillance is expensive and should only be done for the more important items. A periodic review model would be to review inventories at fixed intervals and order variable quantities. That model does not require the close monitoring of inventory levels. Such a periodic review model is often used for less expensive items.

C. RECOMMENDATIONS

The sophisticated inventory control models must start to be used and tested in the Hellenic Navy for the inventory control. In order to accomplish the above, the following procedure is recommended:

1. There must be specially trained personnel to control the supplies. The training of the personnel must be oriented to the requirements needed to perform the job in order to comprehend and successfully implement the sophisticated inventory control models.

2. An up-to-date, detailed historic data file of all materials in inventory must be kept.

3. Every inventory control model must be tested, improvised and implemented in accordance with the realistic and pragmatic needs of the Hellenic Navy.

As long as the model is tested and is proven to be acceptable, then, and only then, can it be approved, become official, and go into the applications phase.

In this thesis the models used are not highly sophisticated but they constitute a starting point from which to develop more elaborate ones in the future. They are the ones that meet the present needs of the Hellenic Navy and can be most realistically applied.

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