A SCIENTIFIC INVENTORY MODEL FOR A RESEARCH CENTER CENTRAL STOREHOUSE

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PREFACE

This report pertains to the development of a scientific inventory model for the central storehouse of the research center of a large petrochemical company. The purpose of the study was to derive a replacement for the present inventory control system which attempts to achieve proper inventory balance largely on the basis of intuition. The proposed model consists of quantitative decision rules based on mathematical derivations and will provide consistency in the day-to-day multitude of individual inventory decisions.

The study of such a central storehouse was carried on at the Esso Research Center, Linden, New Jersey. An initial study, undertaken by the author during the period June through August, 1965, was concerned with the analysis of storehouse manpower requirements, operating procedures, and layout. The data and background information from this study, along with extensive research on the subject of inventory control, comprise the sources of data for the report. It might be well to preview briefly the organization of the report to see the approach which was taken in deriving the model. Chapter I presents a brief discussion of the purpose and theory of scientific inventory control. Chapter II describes the nature, operating procedures, and present inventory control methods used in the central storehouse. Chapter III contains a description of the proposed inventory model. Decision rules for reorder quantities, reorder points, buffer stocks, and the various other parts of the model are presented. Chapter IV discusses implementation and suggests a simulation technique for comparing the results which might be expected from using the proposed model with the actual results of the present system.

The principal limitations to the study were primarily those which resulted from being physically removed from the research center. A more readily accessible operating system would have made the empirical testing of the proposed model feasible. Also, more exacting data for estimates and classification of inventory items would have been available.

A great deal of thanks is owed to Dr. William W. Thompson, Associate Professor of Management, who served as adviser for this report. Without Dr. Thompson's guidance and able assistance, it would not have been possible to write the paper. Indebtedness is also acknowledged to those members of the faculty of the College of Business who have made it possible for the author to complete the requirements for the Master of Business Administration Degree. In addition to Dr. Thompson, special recognition is given to Mr. Richard R. Weeks, Director, MBA program and Assistant Professor of Marketing, Dr. Wayne A. Meinhart, Associate Professor of Management, Dr. James U. McNeal, Assistant Professor of Marketing, and Dr. James F. Jackson, Assistant Professor of Finance, for their assistance and encouragement in attaining this academic milestone.

TABLE OF CONTENTS

LIST OF EXHIBITS

CHAPTER I

SCIENTIFIC INVENTORY MANAGEMENT

This chapter contains a fairly general and condensed discussion of the theory and purpose of scientific inventory management and of the basic models utilized for inventory problems.

Theory and Purpose

Buchan and Koenigsberg describe the inventory management problem broadly as one of maintaining, for a given financial investment, an adequate supply of something in order to meet an expected pattern of demand.[1] This definition applies equally as well to a large research center storehouse stocking 8,000 different items as to a small business stocking only one or two items. In either case, the proper control of inventory represents efficient operation and dollar savings.

Maintaining the correct level of inventory is not a natural tendency and therefore should not be left solely to the intuition and experience of clerical or even managerial personnel. When this is the case, some of the inventory decisions are made carefully while others are made hurriedly or overlooked entirely. It is the aggregate of all these decisions on individual inventory items which determines the return on inventory investment and the customer service level.

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[1] Joseph Buchan and Ernest Koenigsberg, Scientific Inventory Management (Englewood Cliffs, New Jersey, 1963), p. v.

Scientific inventory control techniques eliminate, or at least greatly reduce, the inconsistencies inherent in an informal system such as the one described above. By applying mathematics to inventory control, it is possible to derive a set of decision rules which will minimize total system costs subject to providing the desired level of service. The effectiveness of these scientific inventory control techniques has been demonstrated in numerous cases in which reductions in inventory levels and/or improvements in service levels have been attained.

Although numerous books and articles have been written on the subject of inventory control, several works are especially noteworthy.[2]

Basic Inventory Models

Buffa defines a model as an abstraction of the actual system for which we wish to predict performance.[3] If the model is an adequate representation of the actual business system, it is possible to find ways to improve the operation by experimenting with the model.

Scientific inventory control makes extensive use of a wide range of models in the various inventory decision systems which have been developed. The three basic and simplest models used for inventory control are as follows:

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[2]See, for example: Thomson M. Whitin, The Theory of Inventory Management (Princeton, N. J., 1957). Martin K. Starr and David W. Miller, Inventory Control: Theory and Practice (Englewood Cliffs, N. J., 1962). G. Hadley and T. M. Whitin, Analysis of Inventory Systems (Englewood Cliffs, N. J., 1963).

[3]Elwood S. Buffa, Models for Production and Operations Management (New York, 1963), p. 9.

(1) "Classical" or fixed order quantity model

(2) Replenishment model

(3) Optional replenishment model

The "classical" or fixed order quantity model has been used widely and is extremely valuable for demonstrating the nature of an inventory control system. In this system, the reorder quantity is fixed, and the reorder point is reached when the inventory on hand drops to some particular level.

The fixed order quantity is defined as that quantity which will minimize total variable costs of managing the inventory. Ordering costs and carrying costs are combined to form a total cost function. The total cost function, in turn, is mathematically minimized with respect to order quantity, (Q), resulting in the following equation for the economic order quantity:[4]

$$Q = \sqrt{\frac{2 C_o S}{C_u i}}$$

where S = Annual usage (units)

C_o = Cost of placing an order

C_u = Unit cost of an item

i = Cost of carrying inventory in percent per year

Exhibit 1 illustrates an "idealized" inventory cycle. The inventory level is reduced by a constant rate (annual average usage) until it reaches zero just as an amount Q is received.

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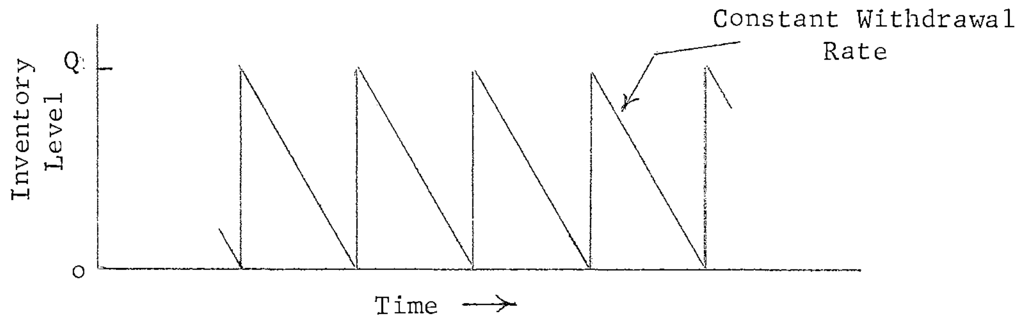
[4]This derivation is carried out in Buffa, p. 595.

Exhibit 1

IDEALIZED INVENTORY CYCLE



However, this idealized case omits two important considerations. First, it does not consider the time lag between placing and receiving an order. To allow for this, the average demand during lead time must be added to zero in calculating the reorder point. Secondly, a buffer stock must be added to expected demand during lead time to provide protection for the times (50%) when the actual demand during lead time exceeds average demand. Exhibit 2 shows an inventory cycle which includes these two considerations. The reorder point (P) is given as:

$$P = B + \overline{S}_d L$$

where P = Reorder point (units)

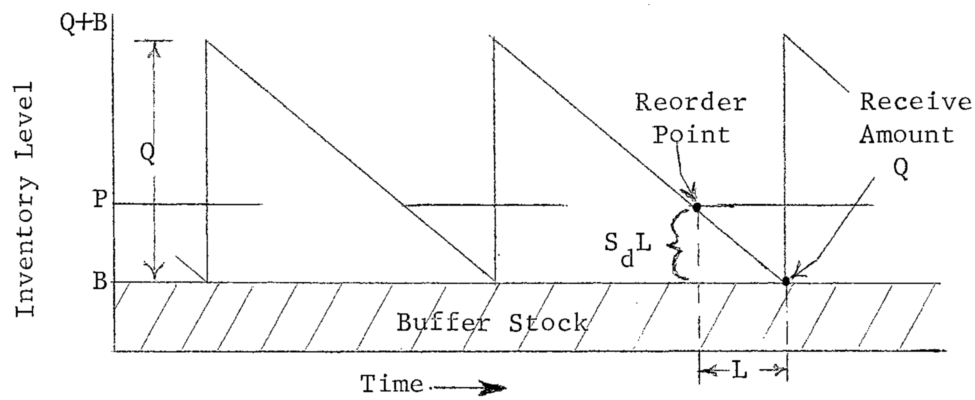
B = Buffer stock (units)

$\overline{S}_d$ = Average daily use (units)

L = Lead time (days)

Exhibit 2

INVENTORY CYCLE WITH $S_d L$ AND BUFFER STOCK



The second major inventory system is in the replenishment model. This system has a fixed order period and, therefore, no fixed reorder quantity. Review intervals are determined by analysis of demand. The amount of each item in inventory is then reviewed at these intervals. The order quantity equals the amount by which the replenishment level (M) exceeds the actual level. The replenishment level is determined as follows:

$$M = B + \bar{S}_d \ (L + R)$$

where B = Buffer stock (units)

$\bar{S}_d$ = Average daily usage (units)

L = Lead time (days)

R = Review interval (days)

The third common inventory system, a modification of the replenishment model, is called the optional replenishment system. In this system a lower limit is placed on the size of the variable reorder quantity. This system makes use of both the replenishment level idea and a minimum reorder quantity.

The choice among the various systems depends on the demands of the specific application. Chapter II presents background information on the central storehouse studied, and describes the characteristics which must be considered in developing the model required for this application.

CHAPTER II

CENTRAL STOREHOUSE OPERATION

This chapter contains background information on the nature and operation of the research center storehouse under study and a discussion of the present inventory control and order filling systems. The information provided is necessary for an understanding of the requirements placed on the proposed inventory model. In addition, a brief resume is given of an initial study of the storehouse which covered various other aspects of its operation.

Background Information

The central storehouse (Esso Research Center Building #19) is the shipping and receiving center for the Esso Research and Engineering Company and stocks approximately 8,000 items for distribution to the company's 15 stock locations and 2,000 employees. The value of the stock turnover of the central storehouse is in the vicinity of one and one-quarter million dollars per year. Approximately 13,000 receipts of stock items are recorded annually. These figures give an idea of the magnitude and value of the storehouse operation. The present storehouse layout is shown in Appendix A and the organization chart for the 11 storehouse personnel is depicted in Appendix B.

Generally speaking, the storehouse stock can be divided into three broad categories. These are:

(1) Stationery

(2) Mechanical

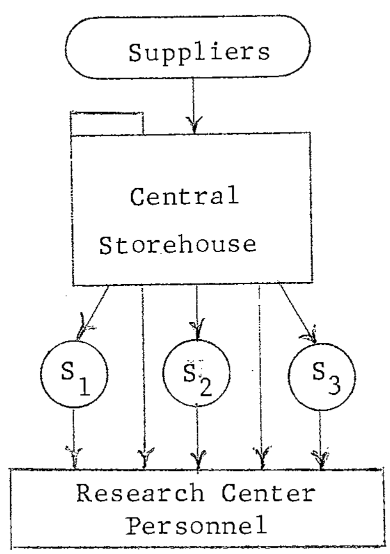
(3) Chemical

From these areas, the highly diversified nature of the items stocked by the storehouse can be seen. The items vary in value from pumps costing several hundred dollars to bolts costing less than a cent. A sampling of the inventory would include such items as pencils, charts, pads, screws, batteries, expensive pipe fittings, wrenches, test tubes, and chemicals. These items exemplify the extremely diverse nature of the requirements of the research center.

The overall supply system for the research center is shown in Exhibit 3. All items are received from the various suppliers by the central storehouse. The items are then drawn for use by research center personnel from one of the 15 stock locations or from the central storehouse.

Exhibit 3

RESEARCH CENTER SUPPLY SYSTEM



The proposed inventory model is designed only for use in the central storehouse and does not apply to the stock rooms. However, the use of average demand in determining the parameters of the system for the storehouse will compensate for any changes which may be made in the inventory control systems in the stock rooms. The present system of the stock rooms ordering from the storehouse at regular intervals lends itself to a replenishment type of inventory control system. Such a system could be based on the same data that is utilized by the storehouse model presented in Chapter III.

Present Inventory System

Orders for stock items are received by the storehouse in the form of Material and Supplies Requisitions (MSRs). An MSR is shown in Appendix C. A stock picker in the central storehouse selects the items off the shelves needed to fill the order. The orders are then delivered to the requester by regularly scheduled company delivery trucks.

A reorder level is posted at the stock location of each item. After filling each order for an item, the stock picker checks to see if the inventory remaining on hand is less than the minimum quantity specified by the reorder point. If reorder is necessary, the stock picker puts a check in the back order column of the MSR. If the stock picker is unable to supply the full quantity ordered, he sends the amount available and checks the back order column on the MSR. If the item requested is completely out of stock, the stock picker enters the number ordered in the back order column. In this case, the reorder clerk fills out a new MSR for the backordered quantity of the item.

Inventory records for each item are kept on individual cards in a large bin file. The reorder clerk receives a copy of the MSRs after the orders have been filled and pulls the inventory cards for those items which have the back order column checked on the MSR. If an order has already been made for the item, the clerk determines if another order is necessary by examining the quantity of back orders. The clerk then passes to the storehouse supervisor the processed inventory cards for the items to be reordered.

The storehouse supervisor, in turn, determines the quantity of each item to be ordered. This quantity is determined from the reorder quantity on the inventory card and the judgment and intuition of the supervisor. The cards, including reorder quantities, are then forwarded to the purchasing department where the actual purchase orders are prepared.

To complete the cycle, the inventory cards are returned to the reorder clerk. When the clerk receives notification of the arrival of the goods, the quantity received is recorded on the inventory card.

Basically then the present system operates as a fixed order quantity system. A reorder point signals the need for an order to be made. The order quantity is semi-fixed and subject to the intuition and experience of the storehouse supervisor.

Investigation of the present decision rules for the reorder points and order quantities revealed that these quantities originally had been set by the supervisor solely on the basis of past demand and his judgment. They initially had been set seven years earlier and had never been revised. Not only was the supervisor employing his judgment in altering the order quantity called for on the inventory card, but he had originally set the order quantities utilizing the same technique. The supervisor was actually determining the overall parameters of the entire inventory system by his day-to-day ordering decisions. No explicit consideration was given to cost factors, inventory level, or service level. In addition, the supervisor was spending an excessive amount of time processing the reorder cards.

These circumstances set the stage perfectly for the application of the scientific inventory model developed in Chapter III. Signs of poor inventory management were evident throughout the storehouse. Observation revealed that numerous items had remained on the shelves for unwarrented lengths of time. In the cases of many items, there was an obvious surplus of inventory on hand, yet the number of stock outs appeared to be generally excessive. All in all, the present system was suffering from lack of scientific inventory control methods and displayed inconsistency in the treatment of the various inventory items.

Results of Initial Study

Although the initial storehouse study mentioned in Chapter I is only indirectly related to the problem of inventory control, a brief discussion of the objectives of the study will contribute to the overall understanding of the nature of the storehouse operation and of the requirements of the proposed inventory system. The overall objective of the study was to improve the efficiency of operation wherever possible. The study was broken down into the following areas and their related objectives:

1. Manpower requirements: To review manpower assignments and revise as necessary.

2. Office layout and telephone system: To determine the optimum office locations for storehouse personnel and to examine the storehouse telephone system for possible improvements.

3. Space utilization and storehouse layout: To survey the present utilization of storehouse space and to investigate alternative layouts for the storehouse storage and work areas.

4. Shipping, receiving, and stock picking areas: To examine the procedures and paper work systems in these areas for possible improvements.

The modifications in manpower assignments, operating procedures, and layout recommended in this initial study combine well with the proposed inventory model. The improvements expected from the incorporation of the inventory model will contribute significantly to the overall goal of improving the efficiency of operation of the storehouse.

CHAPTER III

PROPOSED STOREHOUSE INVENTORY MODEL

The previous chapter dealt with the present operation and inventory control system of the research center storehouse. Chapter III presents the various aspects of the actual scientific inventory control system designed for the storehouse. The chapter first introduces the idea of inventory classification as a means of having selectivity in the degree of control for various classes of items. Next, economic order quantities and reorder points are discussed and decision rules defined for the new system. Consideration of special situations such as quantity discounts and extremely low usage is also included.

The nature of the storehouse operation and of the present operating system suggest continued use of a fixed order quantity system designed for use by storehouse operating personnel. Such a system is consistent with the present operation of the storehouse and will contribute greatly to improved efficiency of operation.

Inventory Classification

The first part of the proposed system is the introduction of an inventory classification scheme for the various storehouse items. The concept of inventory classification is quite useful for introducing selectiveness in the control effort expended on the various items. This approach involves identifying items by their dollar usage and therefore allows the allocation of available time and effort proportionately.

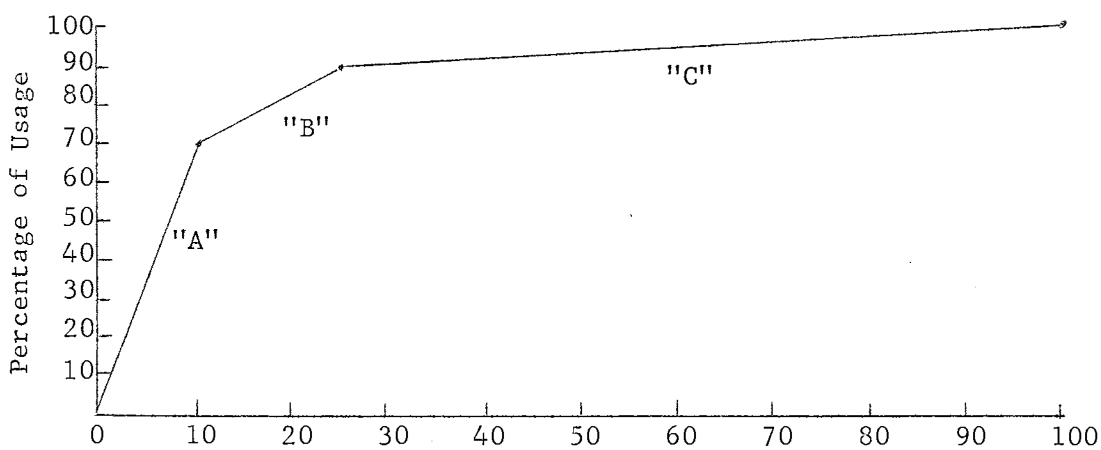
It results in management concentrating the control effort on the high usage inventory items and spending less time on the ones with relatively low usage.

The ABC system, developed by the General Electric Company, is probably the most commonly used system of classification.[5] This analysis consists of first arranging the gamut of inventory items in descending order by annual dollar usage. Then, by accumulating the usage and number of items, a classification breakdown can be made. Exhibit 4 represents a typical inventory so classified.

Exhibit 4

"ABC ANALYSIS" OF PROPORTIONAL USAGE OF INVENTORY ITEMS

Inventory Class	Usage	% of Inv. Items	% of Annual Usage
A	Critical	10%	70%
B	Intermediate	15%	20%
C	Minor	75%	10%



[5] H. F. Dickie, "Six Steps to Better Inventory Management," <u>Factory Management and Maintenance</u>, Vol. 111, (August, 1953), p. 96.

As shown by Exhibit 4, class A items account for 70 percent of the inventory usage but only 10 percent of the items. These items would generally be ordered in smaller quantities and buffer stocks kept to a minimum. A greater proportion of time and effort would be spent controlling this group of items. On the other hand, a minimum of time would be spent controlling class C items. A greater protective stock of these items would not significantly increase total inventory value and would reduce the time and effort spent in frequently reordering these relatively low usage items.

The relationships shown in Exhibit 4 are not unusual, but common to the majority of inventory situations. Exhibit 5 illustrates a six-group inventory usage classification and a speculation of how the proportions among these groupings might fall for the storehouse inventory.

Exhibit 5

SIX-GROUP INVENTORY USAGE CLASSIFICATION

Inventory Class	Usage	% of items	% of annual usage
1	Critical	3	50
2	Major	6	25
3	Intermediate	10	13
4	Low	16	7
5	Minor	25	3
6	Nil	40	2
		100	100

The implications of such a classification scheme are obvious. For a replenishment inventory system, reorder intervals would vary according to the importance of the usage classification of the items. In an ABC system, for example, class A items might be inventoried weekly, class B items biweekly, and class C items monthly.

The breakdown by usage is significant for the fixed order quantity system being developed for the storehouse. Although not as directly applicable to order quantities and reorder points, it is a valuable guide to the proper expenditure of time and effort for control and cost reduction purposes. Frequency and effort in evaluating buffer stocks and usage should be proportioned according to the usage analysis. Items with high usage should be given prime stock locations and special attention in ordering and processing. Also, the results of this analysis could be applied almost directly to the replenishment systems previously mentioned as possible for the individual stock rooms.

Economic Order Quantity

As discussed in Chapter I, the fixed order quantity system is based on selecting the order quantity which will minimize the total variable costs of holding and controlling inventory. Total cost is generally broken down into ordering cost and inventory carrying cost.

Ordering cost is the cost associated with placing an order from a vendor or supplier. The following individual costs contribute to the total cost of placing an order:

(1) Salary of stock reorder clerk.

(2) Salaries of personnel in purchasing organization.

(3) Salaries of receiving and stock shelving personnel.

(4) Paper and postage costs.

Prichard and Eagle point out that one way to compute the single order cost is to sum all of the applicable costs and divide by the number of orders placed per year.[6] However, they go on to point out that in choosing the economic order quantity all that need be considered is the part of the ordering cost that can be varied by selection of the economic order quantity. In other words, the cost to be considered is not the cost of placing one order, but rather the difference in the cost between obtaining a given amount of an item in one order or in two orders.

The cost per order is generally found to be relatively small, usually ranging from $1 to $5. It tends to be constant for all items in the inventory and is usually independent of order size. Considering all of these factors, the variable cost per order for the storehouse inventory model was set at $3. This is a reasonable approximation of the variable cost involved and is used in determining the economic order quantity.

The carrying cost is defined as the cost of physical storage of inventory plus the opportunity cost of the money tied up in inventory.[7] The former cost includes insurance, taxes, warehouse rental, etc. The later cost represents the rate of return which the firm could obtain from alternative investments rather than having the funds invested in inventory. The rationale of setting this figure is that money should not be invested in inventory unless it offsets costs at least to the extent of its average alternative earning power.

Inventory carrying costs are generally expressed as a percent of the total value of the inventory and, as could be expected, are somewhat

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[6] James W. Prichard and Robert H. Eagle, Modern Inventory Management (New York, 1965), p. 52.

[7] Buchan and Koenigsberg, p. 3.

difficult to measure. A typical breakdown of these costs is shown in Exhibit 6.[8]

Whitin found that 6 percent per year is the answer frequently given by businesses to the question concerning the costs of carrying inventory.[9] He also states that in the hundreds of businesses that he has studied, he has yet to find one in which 6 percent is the actual cost. Instead, the total carrying cost is seldom actually less than 10 percent nor greater than 20 percent. Economists' estimates of inventory carrying cost substantiate Whitin's findings.[10]

Exhibit 6

A TYPICAL BREAKDOWN OF INVENTORY CARRYING COSTS

Return on investment	6.00%
Handling	2.00%
Depreciation	4.00%
Obsolescence	4.00%
Warehouse space cost	3.00%
Taxes and insurance	1.00%
	20.00%

Considering all of these factors, the cost of carrying inventory for the central storehouse was estimated to be 15 percent per year. This

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[8]Walter K. Krowicki, "Three Useful Inventory Control Techniques," N. A. A. Bulletin. Vol. 43, (May, 1962), p. 71.

[9]Whitin, p. 219.

[10]Two of these are: John M. Keynes, The General Theory of Employment, Interest, and Money (New York, 1935), p. 318. L. P. Alford and J. R. Bangs, Production Handbook (New York, 1944), p. 397.

figure is a reasonable approximation of the cost involved and therefore is used in determining the economic order quantity.

The effort expended in determining these costs need only be proportional to the sensitivity of the final results to the estimated costs. Reorder quantities rise and fall only as the square root of ordering costs and carrying costs rise and fall. In addition, it is highly significant that even if the cost estimates are not precisely correct and perfect economic order quantities are not obtained, the result will still be a consistent ordering policy for all inventory items. These ideas, along with the reasonable accuracy of the cost estimates, indicate the proposed system will result in a great deal of improvement over the present ordering system.

The reorder quantity calculations are based on the classical inventory model as discussed in Chapter I. The reorder quantity formula which minimizes the total variable reorder cost plus inventory carrying cost is expressed for the proposed system as follows:

For yearly usage: $$Q = \sqrt{\frac{2\ (\$3)\ S}{C_u\ (.15)}} = 6.32\sqrt{\frac{S}{C_u}}$$

For monthly usage: $$Q = \sqrt{\frac{24\ (\$3)\ \bar{S}}{C_u\ (.15)}} = 21.91\sqrt{\frac{\bar{S}}{C_u}}$$

Where S = Annual usage (units)

$\bar{S}$ = Monthly usage (units)

C_u = Unit cost of an item (dollars)

A unit is defined for these purposes the same way that it is within the present storehouse-stock room system. It may be one pound, one dozen, one gallon, one package, etc. This value is clearly designated for each item in the store's catalog and therefore the proposed system will cause no problem with defining units. Also favorable for the proposed system is that monthly and yearly usage data is readily obtainable from the present inventory cards discussed in Chapter II.

All the components needed for calculating reorder quantity have now been presented. In order to facilitate implementation of the system, a nomograph for calculating reorder quantity has been prepared, and is presented in Chapter IV on implementation.

The question of quantity discounts or price advantage obtainable through larger purchases will now be considered. Although it is possible to make a rigorous mathematical analysis of this situation, its value does not justify its use in the proposed system. Buchan and Koenigsberg discuss a case study in which a simplified quantity discount rule is used.[11] The rule can be applied to the proposed storehouse system by the following procedure:

1. Express the price discount per unit as a percentage of the original undiscounted unit price.

2. Express the excess quantity (which must be added to the economic order quantity to obtain the price discount) in number of months' average usage.

3. If (1) $\geq$ 5/8 (2), order the larger quantity. If (1) $<$ 5/8 (2), order the economic order quantity.

The rule is simple, easy to understand, and easy to apply as shown by the following example:

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[11] Buchan and Koenigsberg, p. 147.

An item with average monthly usage of 10 units is priced at \$4.50 per unit. Economic order quantity is 20. If 50 or more units are ordered, the price per unit is \$4.00.

$$(1)\quad A = \frac{.50}{4.50} \times 100 = 11.11$$

$$(2)\quad e_m = \frac{50 - 20}{10} = 3$$

$$(3)\quad A > 5/8\ e_m \quad \therefore \quad \text{order 50 units}$$

A 12 month supply is the maximum order quantity in any case and overrides the purchase of an even larger quantity. The quantity discount rule will be applied by the purchasing department after they receive the inventory card with the economic order quantity already calculated and written in by storehouse personnel.

Reorder Point

The reorder quantity or how much to order has been defined. The question of when to reorder will now be considered. Recall from the discussion of the classical inventory system in Chapter I that the reorder point is based on two important considerations. These are the average demand during lead time and the buffer stock which is added to provide protection when actual demand during lead time is greater than normal or average demand.

A stock-out is defined for the proposed inventory control system as the case where any item on an order is completely out of stock. A partially filled order for an item does not constitute a stock-out. This definition is consistent with the present operating system.

It is extremely difficult in almost all inventory systems to determine the cost to be assigned to each shortage or stock-out. The nature of the storehouse makes determining this cost virtually impossible. All storehouse stock-outs are back ordered and finally delivered to the "customers." The cost of a stock-out in a situation such as this results almost entirely from the delay or inconvenience caused by the stock-out. Naturally, some items tend to be more critical in this respect than others. The seriousness of a stock-out is high on some items, such as certain chemical supplies and mechanical apparatus, but low on others, such as pencils, nails, etc.

These ideas lead to the use of an alternative procedures for setting service levels. Instead of specifying the stock-out cost, the service level is defined by specifying an upper limit to the average percentage of the time for which the system is out of stock. For example, a limit of 90 percent could be specified, and the buffer stock formulated so that the probability is .90 that no stock-out will occur. Even more desirable though, is to divide the inventory into priority groups based on the consequences of a stock-out. The desired levels of protection can then be assigned accordingly.

From the storehouse inventory model, the priority classifications are defined as follows:

PRIORITY CLASSIFICATIONS

I. Critical: Items for which there are no available substitutes, and the shortage of which is quite costly.

II. Important: Items for which substitutes are sometimes available, and the shortage of which is costly.

III. Intermediate: Items for which substitutes can almost always be made at intermediate cost.

IV. General: Items for which substitutes are readily available or the cost of the absence of which is insignificant.

Exhibit 7 shows the desired level of protection against stock-outs for each of the priority classifications. Also shown is an estimate of the number of items which will fall in each group.

Exhibit 7

PRIORITY CLASSIFICATION PROTECTION LEVELS

Priority Classification	Desired Level of Protection	Estimated Number of Items
I	.99	50
II	.95	850
III	.90	3100
IV	.80	4000
		8000

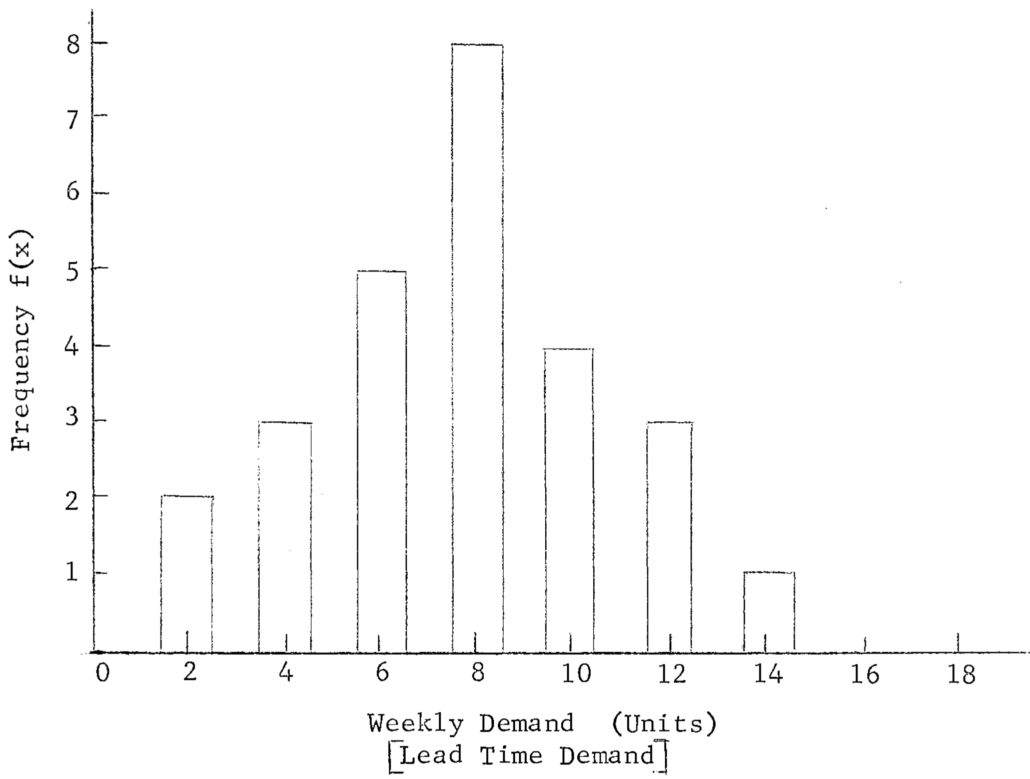
In order to demonstrate how stock-out levels are incorporated in the system for setting reorder points, it is first assumed that lead time for each item is known and is fairly constant. If both lead time and demand during lead time display significant variation, it is necessary to simulate the interaction of the fluctuations with Monte Carlo techniques. However, the simpler case is satisfactory for the needs of the storehouse system. Lead time data for each item can be obtained from the past histories on the inventory stock cards.

If lead time is assumed to be constant, it is only necessary to know the distribution of actual demand about the average demand in order to determine a level of buffer stock which will provide a specific level of protection against stock-outs.

Exhibit 8 shows a possible demand distribution for a hypothetical inventory item. The distribution, f(x), represents the frequency or number of weeks at the various levels of demand.

Exhibit 8

DEMAND DISTRIBUTION FUNCTION



The next step is to convert the weekly demand distribution to a lead time demand distribution. Lead time demand (S_dL) is defined as follows:

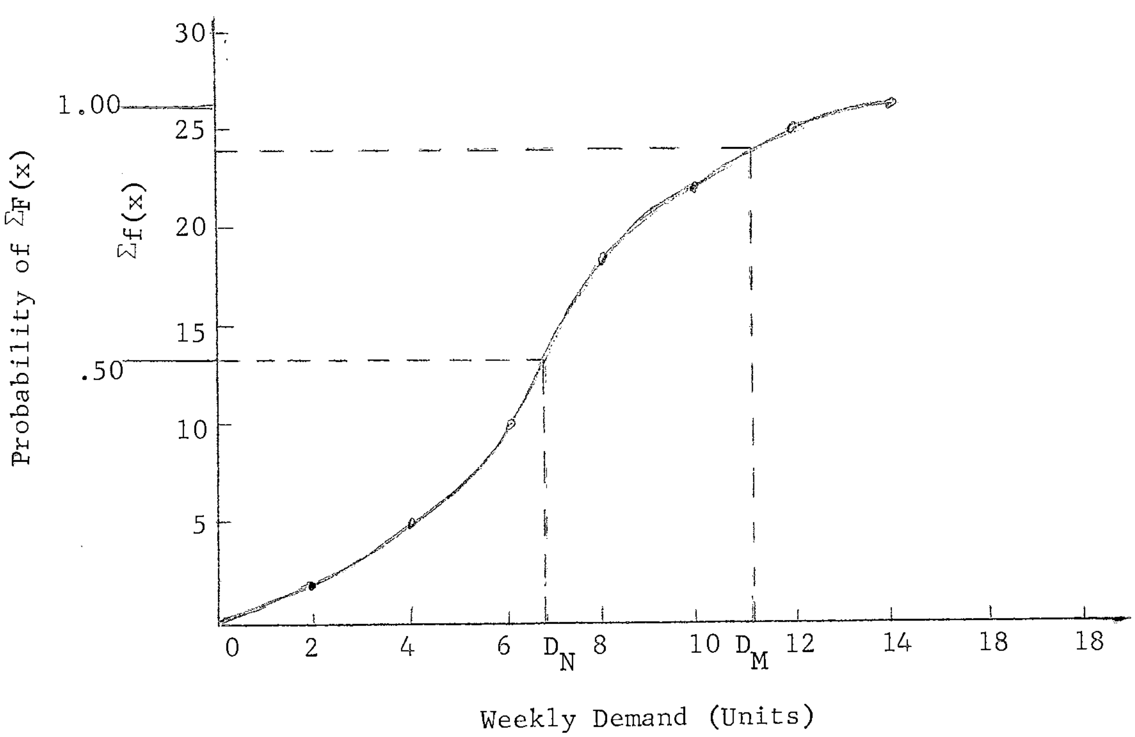
$$S_dL = \frac{\text{weekly demand}}{5} \times \text{Lead time (days)}$$

Obviously, if lead time is exactly 5 days, the lead time demand frequency distribution will be identical to the weekly demand frequency distribution. This is the case assumed for the purpose of demonstration and therefore Exhibit 8 also represents the lead time demand frequency distribution.

From this data a cumulative f(x) distribution is determined. In essence, the cumulative f(x) shows the number of weeks that lead time demand is less than a given level of demand. Also, a percentage scale is applied to the cumulative f(x) column and represents a derived probability scale. Exhibit 9 shows the cumulative probability function for the hypothetical item.

Exhibit 9

CUMULATIVE PROBABILITY FUNCTION



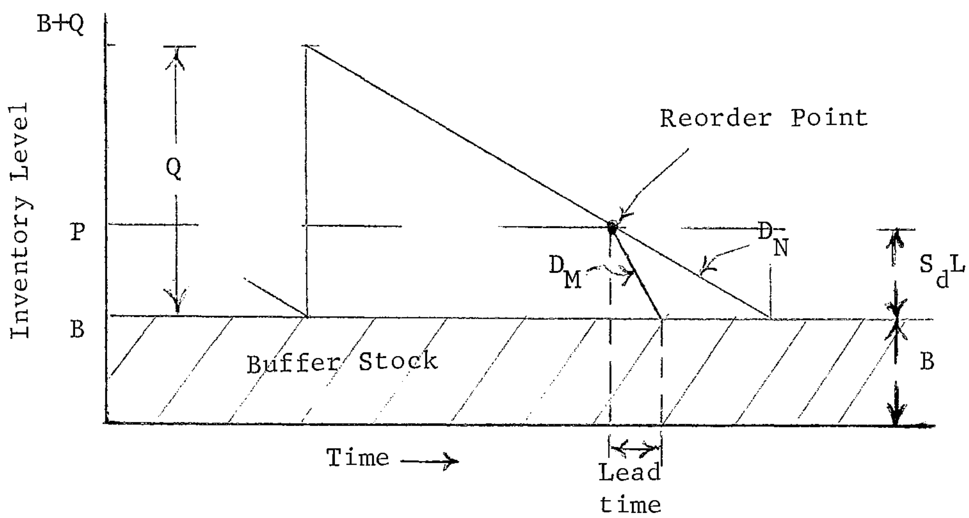
The lead time demand with a probability of occurrence of .50 is designated as the normal or average level of usage during lead time. However, recall that the objective of adding a buffer stock is to provide protection for the times when the normal lead time demand is exceeded. The cumulative probability distribution provides this information, along with the level of protection provided. For example, suppose the hypothetical item is a priority classification III item and therefore a stock-out protection level of 90 percent is desired. The lead time demand (D_m) associated with a .90 probability is taken from Exhibit 9. It can then be said that if the reorder point is set at the quantity D_m, the probability of no stock-out occurring is .90. The buffer stock, equal to $D_m - D_n$, has been determined rationally from the knowledge of the probability distribution of demand and from the level of service desired.

Exhibit 10 illustrates the same idea expressed in another way. It shows that the buffer stock level is set so the inventory level approaches zero during lead time if the maximum expected demand (D_m) occurs. Average lead time demand (D_n) and maximum expected lead time demand (D_m) can be thought of as the slopes of the usage curves. These are the same values as were obtained from Exhibit 9.

In many cases, it may be possible to avoid having to accumulate the demand distribution for each item. Demand may follow the pattern of a well-known statistical distribution, such as the poisson, normal, or exponential. If this relationship can be found, certain short cuts can be taken due to the special characteristics of these distributions.

Exhibit 10

INVENTORY LEVELS REQUIRED FOR AVERAGE AND MAXIMUM DEMAND



The preceding procedure for determining reorder points should be used for all items except those with an extremely low usage. The reorder point for these items can be set by a simplified rule. For priority classifications III and IV items with a monthly usage of only a few dollars, the reorder point should be set at a point approximately equivalent to two months' average usage. This rule provides a rapid guide for determining reorder points for relatively unimportant, low usage items.

For the situation where lead time demand exceeds the economic order quantity, a minor modification of the system is necessary. It is obvious that when $S_dL > Q$, the inventory will always be less than the reorder point. In order for the system to be effective, a new reorder point is defined as the normal reorder point minus the reorder quantity (P - EOQ). By doing this, the order point is moved so that a new order is placed before the previous order arrives.

In this chapter, the actual storehouse inventory model has been developed. Reorder quantity and reorder point decision rules have been formulated and provisions made for certain special situations such as quantity discounts and extremely low usage items. In the next chapter the implementation and some implications of the proposed system are considered.

CHAPTER IV

IMPLEMENTATION, IMPLICATIONS, AND CONCLUSIONS

The preceding chapters have described the nature and operation of the research center storehouse and have developed the various aspects of the scientific inventory model for the storehouse. The caliber and volume of work involved and the lack of the availability of data processing equipment call for a simplified manual system.

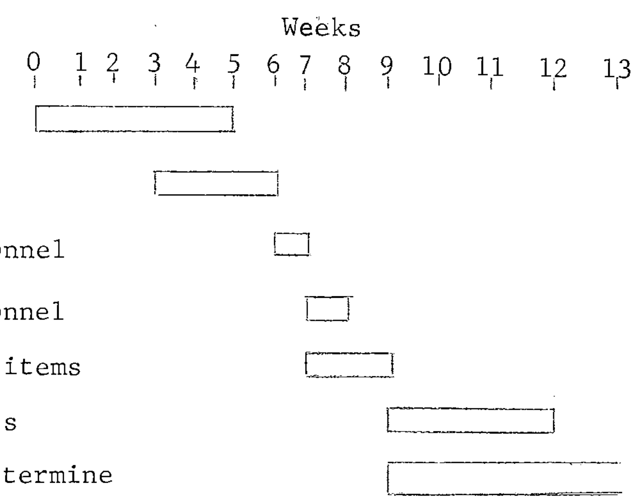
The implementation of the proposed system must be made on a well-planned basis in order to insure an orderly and successful transition. The Gantt chart shown in Exhibit 11 is an estimate of the extent and relative timing of the events connected with the installation of such a system.

Exhibit 11

GANTT CHART FOR IMPLEMENTING PROPOSED SYSTEM

<u>Activity</u>

1. Data collection
2. Data processing
3. Training of storehouse personnel
4. Training of purchasing personnel
5. Classification of inventory items
6. Calculation of reorder points
7. Begin using nomographs to determine economic order quantities



Use of Nomographs

As discussed in Chapter III, the proposed system is designed so that the economic order quantity is derived from the nomograph included as Appendix D. The nomograph is essentially a calculating device with simple operating rules. It puts the economic order quantity rules into visual form to simplify day-to-day usage. The construction of the nomograph will not be considered in detail. However, a brief description of how to use the nomographs for deriving economic order quantities is included.

To use the nomographs, a straightedge is positioned to connect monthly usage on the left hand scale to unit cost on the right scale. The economic order quantity is read from the center scale at the point where it crosses the straightedge. The following example, plotted on the monthly usage nomograph in Appendix D, illustrates this technique.

Connect:	Monthly Usage	=	100 on Scale A
To :	Unit Cost	=	$1.00 on Scale C
Read :	Economic order quantity	=	219 on Scale B

In the case of items which can be purchased only in package quantities, the nearest package quantity should be ordered. Also, the maximum order quantity for all items should be a 12 month supply, regardless of the economic order quantity calculation.

Management Acceptance

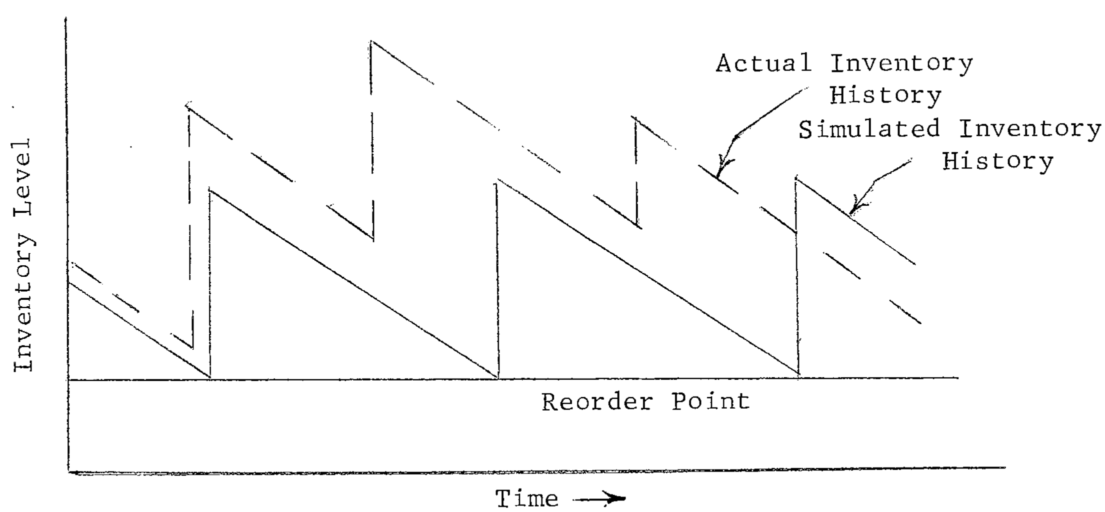
Management is naturally skeptical about changing procedures which have been used satisfactorily over an extended period of time. The proposed inventory system therefore must be sold to management just as management acceptance had to be gained for the proposals resulting from the initial storehouse study.

The first step in gaining management acceptance of the proposed system is to predict by simulation the results expected from its use and compare them with the results of the existing system. To do this, a sample of approximately 300 items should be selected at random from the 8,000 items. Any new items or items with incomplete data on past demand and orders should be eliminated from the sample. Data on past demand for each item in the sample should be used to plot the item's actual inventory history for a representative test period covering several inventory cycles for that item.

A simulated history should then be determined for each of the test items for the same period. This can be done by using the actual demand data along with the reorder rules of the proposed inventory model. Exhibit 12 shows an example of the simulated evaluation for a hypothetical item.

Exhibit 12

SIMULATED EVALUATION FOR AN INVENTORY ITEM



Average inventory investment, stock-out level, and number of orders placed should be recorded for each item under both actual and simulated conditions. Exhibit 13 shows the comparison of expected and actual results for a hypothetical item.

Exhibit 13

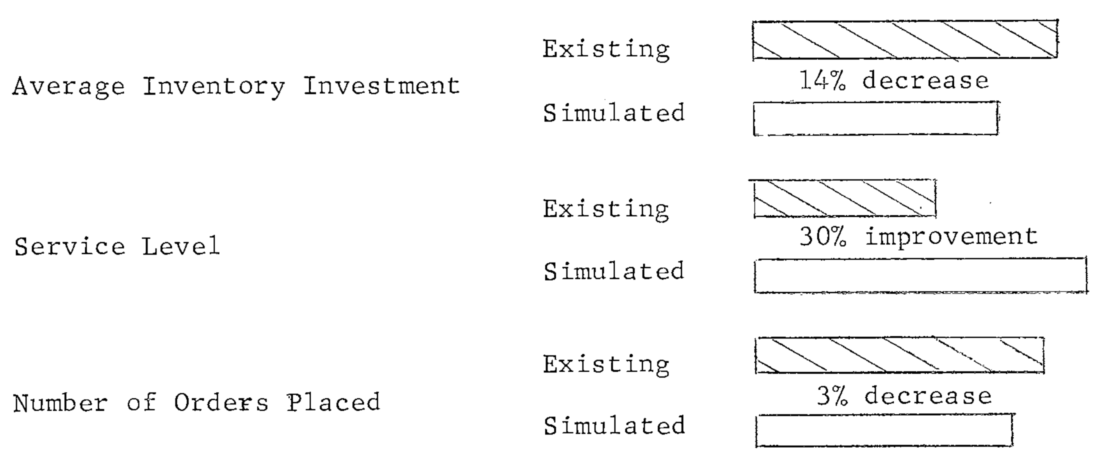
COMPARISON OF EXPECTED AND ACTUAL RESULTS FOR ONE ITEM

	Average Inventory	Service Level	# of Orders Placed
Actual results	$2000	.70	20
Simulated results	$1800	.90	19
Percentage improvement	10%	30%	5%

By projecting the differences in the totals for the sample items to all 8,000 items, the expected results of the proposed system are obtained. Exhibit 14 summarizes a comparison of simulated results with existing conditions as projected for an entire inventory.

Exhibit 14

COMPARISON OF EXPECTED AND ACTUAL RESULTS
PROJECTED FOR ENTIRE INVENTORY



Expected Results

The implementation of the proposed system should result in minimal disturbance to the present storehouse operating procedure and will not alter noticeably the work load of storehouse personnel.

Based on analysis of the proposed and existing systems, a significant improvement in over-all service level should result from incorporating the new system. The use of priority classifications in setting desired service levels provides protection in relation to the consequences of the occurrence of a stock-out. It results in a decrease in inventory level and an improvement in service level. No increase in number of orders is expected, and hopefully, a small decrease will occur due to the consistency of ordering for all items.

It is estimated that the average inventory of the storehouse will decline after the proposed system is installed. Again based on analysis of the proposed and present systems, this reduction in inventory could easily be as high as 20 percent. The use of inventory classification allows flexibility within the system. This, along with consistency in order quantity and reorder point, results in the reduction.

In many cases, a number of the new reorder points should be close to the old ones. Others will be raised or lowered significantly. The reorder points which are close to the old ones will do much to instill confidence in the new system.

In addition to these advantages, several less tangible benefits will be derived from the new system. The improved service level will result in a better relationship between storehouse and other research center personnel. "Customers" will receive better service and will be more cooperative with storehouse personnel and procedures.

Another intangible benefit is the saving of people's time. The use of nomographs for decision rules makes much of the reorder work routine for clerical personnel. Stock pickers will spend less time attempting to fill orders for items which are out of stock. The time required for processing paper work for back orders will be reduced.

The improvements resulting from installing the proposed inventory control system fit well into the objectives of the initial study of the storehouse discussed in Chapter II. The initial study objective of improving the overall storehouse efficiency is certainly bolstered. The recommended revision of manpower assignments and improved utilization of storehouse space coincide nicely with the new inventory control system.

Conclusions

The objective of the study has been fulfilled by the development of the proposed scientific inventory model for the research center storehouse. Mathematical techniques have been applied in deriving a set of decision rules which will minimize system costs while providing the desired level of inventory service. Classification schemes have been used to introduce flexibility in the system by varying the amount of time and effort spent controlling items depending on their relative importance. Special situations have been considered and simplified rules postulated for these cases. A simulation procedure for demonstrating to management the effects of the new techniques has been proposed and speculation of the results set forth.

The benefits obtainable from the new system are numerous. Service levels will be significantly improved while, at the same time, inventory levels will be reduced. The overall system will be based on a rational, scientific basis and will provide consistent treatment for all inventory items.

Certain estimates and assumptions have been necessary in formulating the model. Although in some cases they have not been precise, the inaccuracy does not affect the usefulness and effectiveness of the system at hand. For example, ordering and inventory carrying cost estimates cannot be precisely accurate, yet they are reasonable approximations and, as such, are adequate for the purposes of the proposed system. Regardless of slight inaccuracies in these cost estimates, the result is still a consistent ordering policy for all items. The assumption of constant lead time, although not precisely the case, provides a simplified, adequate basis for determining buffer stocks.

Finally, the study lacks test data which would have been obtained if an empirical testing had been feasible of the proposed system in the actual storehouse installation. Due to the limiting factors of the study as discussed in the preface, such a testing was not possible. Therefore, every effort has been made throughout the study to tailor the proposed system to fit the needs of the storehouse and to show estimates of the type of results which can be expected after implementation. These estimates were based on results obtained from other studies along with a knowledge of the existing conditions in the storehouse. Although crude at best, they do demonstrate quite well the results which can be anticipated.

In conclusion, it can be said that the incorporation of the proposed scientific inventory model for the storehouse will improve the efficiency of operation. The use of the decision rules formulated will provide consistency in the day-to-day inventory decisions and will result in decisions based on a rational rather than an intuitive basis.

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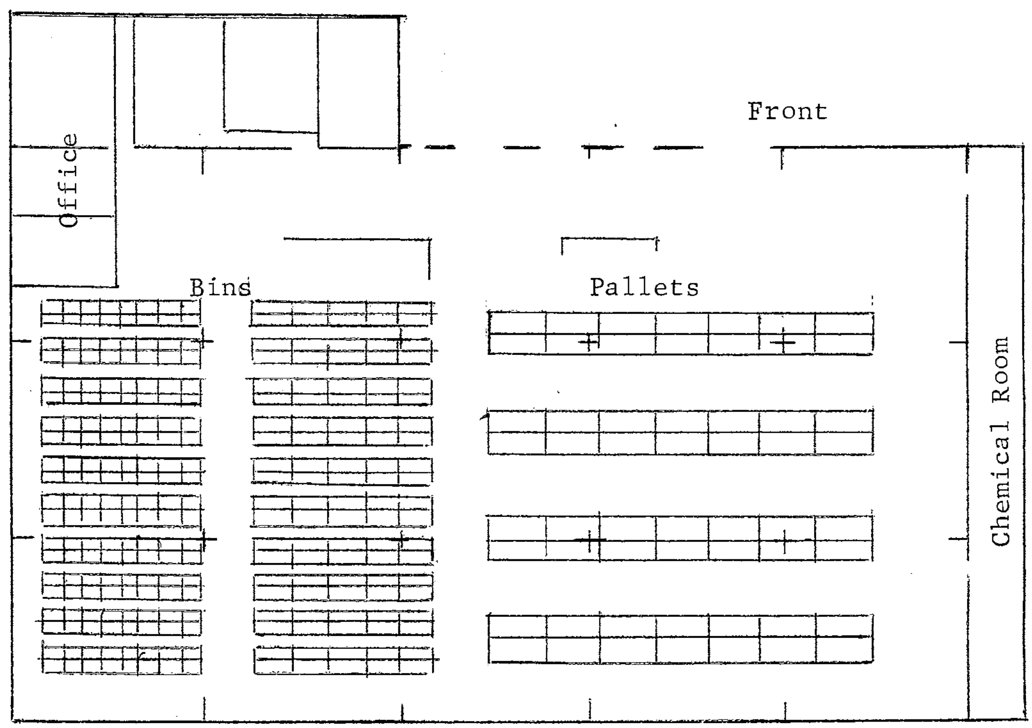
APPENDIX A

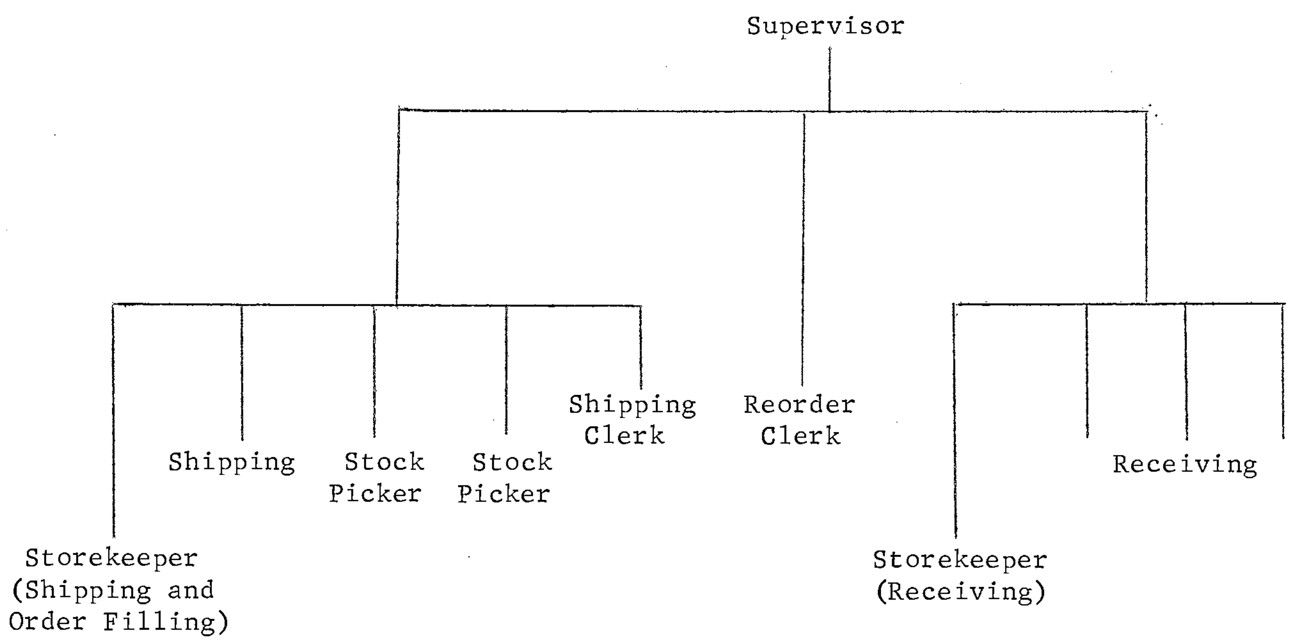
CENTRAL STOREHOUSE LAYOUT



1" = 30'

APPENDIX B

CENTRAL STOREHOUSE ORGANIZATION CHART



1 - Supervisor
2 - Storekeepers
6 - Special Utility
2 - Clerks
11

APPENDIX C

MATERIAL AND SUPPLIES REQUISITION

UNUSED LINES MUST BE BLANKED OUT.
USE UNIT OF ISSUE SHOWN IN CATALOG.

62274

MATERIAL AND SUPPLIES REQUISITION ERE-GEN-1-1A

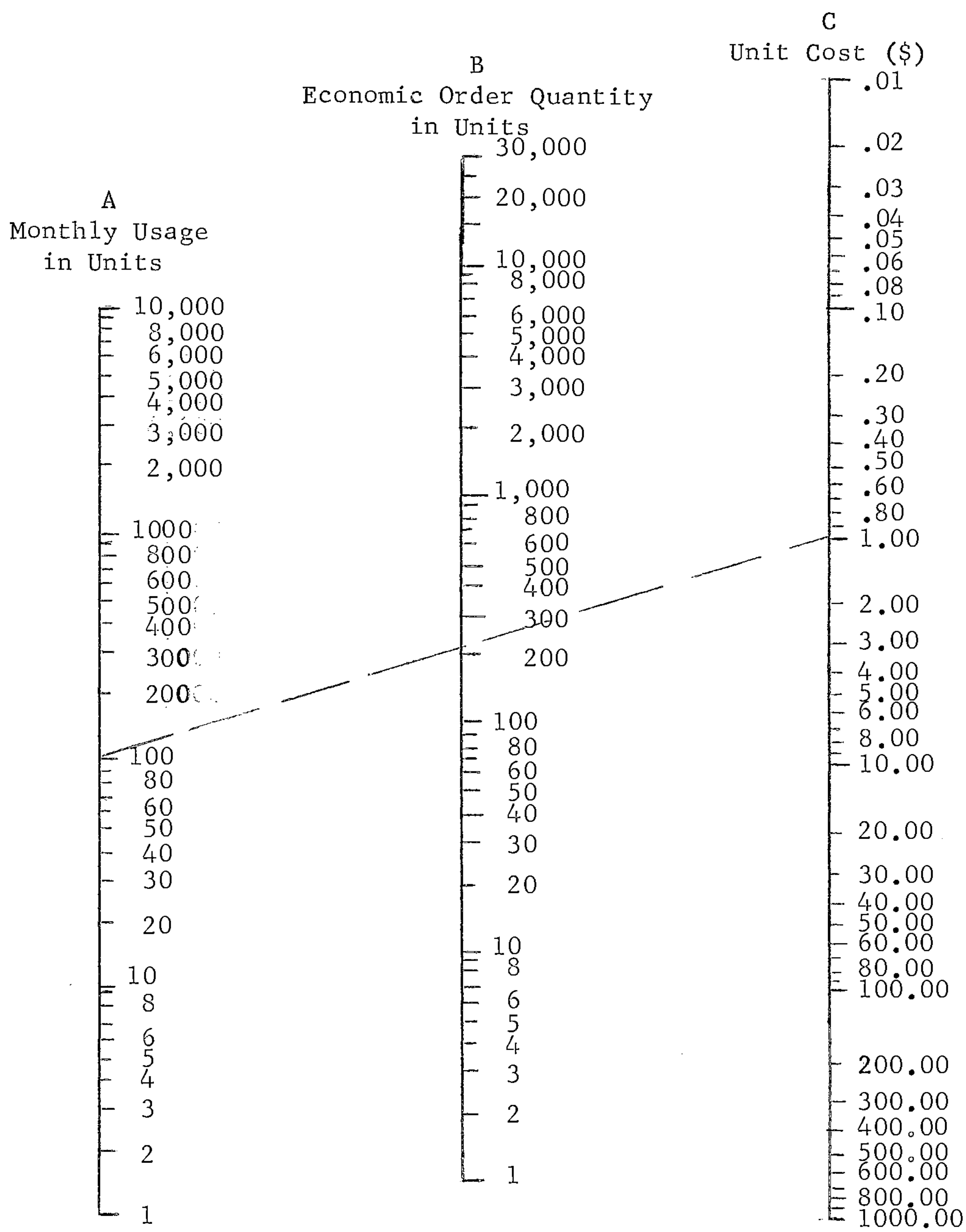
DELIVER TO	LOCATION	DATE

COMPLETE CATALOG NUMBER				QUANTITY ORDERED	QUANTITY		UNIT PRICE	REMARKS
CLASS	SUB.	STOCK NO.	LOCATION		DELIVERED	BACK ORDER		

MECH. CUST. DIV. CODE	MECH. NAME CODE	MECH. WORK REQ. NO.	JOB TYP	JOB ID.	FILLED BY
EMPLOYEE DIV. CODE	DATE	SIGNATURE		STR. RM. CODE	DATE

APPENDIX D

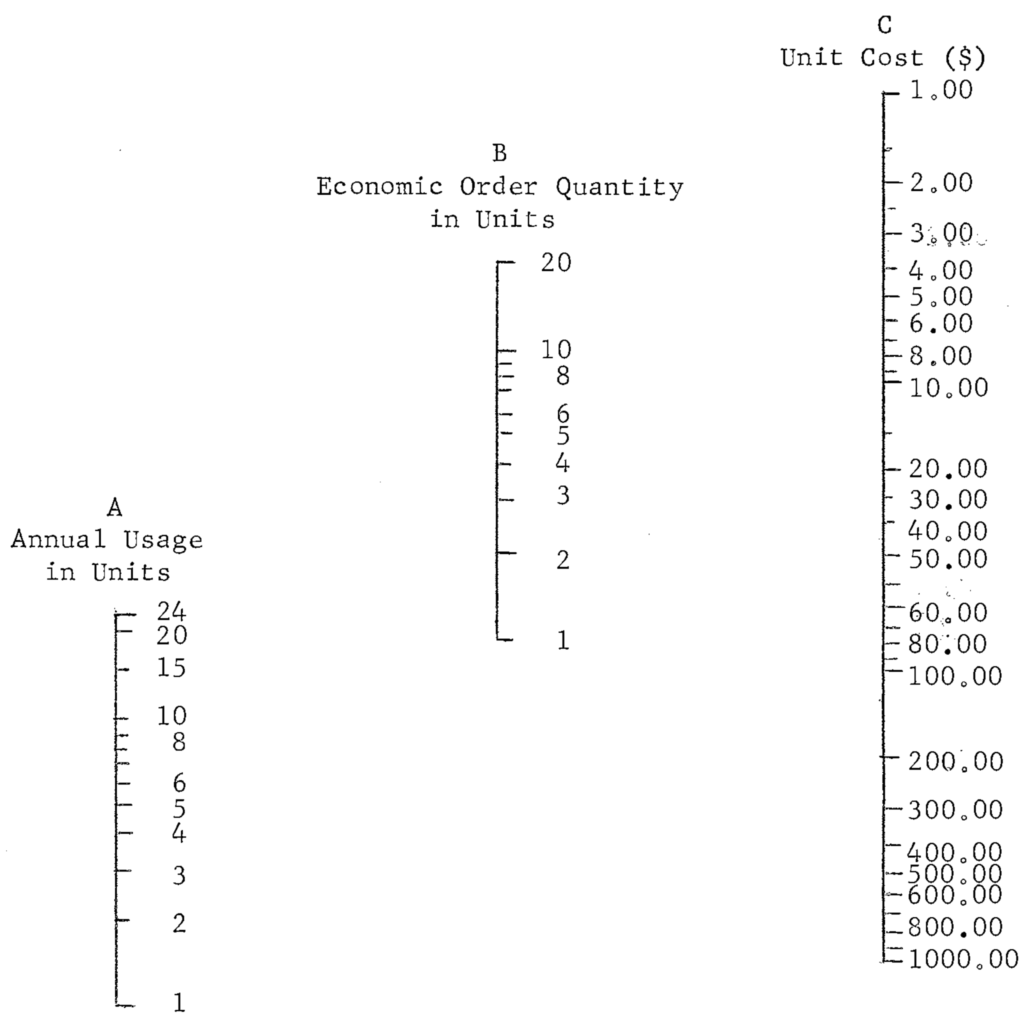
NOMOGRAPH FOR ECONOMIC ORDER QUANTITY DECISIONS
(Monthly Usage Greater Than 2 Units)



For usage less than 2 per month use yearly nomograph

APPENDIX D (con't)

Nomograph for Economic Order Quantity Decision
(Annual Usage Less Than 24 Units)



For usage greater than 24 per year use monthly nomograph

VITA

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