APPLICATION OF INVENTORY CONTROL PROCEDURES TO AN ELECTRONIC PARTS WAREHOUSE

by

Lowell E. Solien

A thesis submitted to the Faculty and Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Mathematics).

Golden, Colorado

Date 26 MARCH 1990

Signed: [signature]

Lowell E. Solien

Approved: [signature]

Dr. R. E. D. Woolsey
Thesis Advisor

Golden, Colorado

Date 26 March 1990

[signature]

Dr. Ardel J. Boes, Head
Department of Mathematics

ABSTRACT

Inventory control in an industrial organization must answer some fundamental questions in order to perform its assigned task. These questions are

1) what to stock?
2) how much to stock?
3) when to order ?
4) how much to order?

The purpose of this thesis is to analyze these choices and show how one company is applying the concepts of inventory control to lower costs while providing an acceptable level of customer service. The subject company is a producer of television satellite receiver systems in the Denver area. The company's initial inventory control system was largely intuitive. The goal is to suggest solutions which would not have unacceptable drawbacks within the company. The final product was politically feasible and shows significant improvement over the previous system as measured by present worth.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

ACKNOWLEDGEMENTS

I would like to express my appreciation to the members of my thesis committee who guided me in the completion of this endeavor. A special thanks to Dr. R.E.D. Woolsey who constantly challenged his students with the applied aspect of education. He has been the finest academic advisor a student could hope for.

Many thanks to Prof. William R. Astle and Dr. Paul L. Anderson who were instrumental in helping me deal with the statistical aspects of this project and in my completion of the CSM curriculum. I would also like to thank Dr. Ruth Maurer for her help and advice in researching this problem.

My sincerest gratitude goes to the management and employees of Houston Tracker Systems who tolerated my persistent questions and presence for nearly a year. Their cooperation was paramount in the completion of this document and was indicative of that company's competitive spirit.

I especially want to thank my wife, Birgit, for her help and understanding throughout the completion of my thesis. Her constant encouragement and assistance contributed more than all of my work combined.

Chapter 1
INTRODUCTION

Inventory is the stock of any item or items used in an organization (Chase and Aquilano 1989, 579). Inventories are one of many expenditures that companies make in order to carry out the process of production and marketing. Although frequently treated as an unimportant aspect of the production process, its value may constitute a large portion of the sales revenue of the average manufacturer. For example, during the month of April, 1989 total sales from U.S. manufacturers of electronic machinery were $17.9 billion. On hand inventory for the month, however, was estimated to be $37.4 billion (Survey of Current Business 1989, 93). This is over 200% of gross sales for the month. The carrying or holding cost associated with the value of this inventory is tremendous and will be discussed later in this document. Nevertheless, controlling the level of inventory can result in significant cost savings to the company from the standpoint of both purchase and carrying costs.

Since companies usually want to minimize costs to aid in maximizing profits, the ability of a corporation to lower costs associated with inventory is beneficial. Given this, it is ironic that the management in many inventory holding entities (e.g. corporations, small businesses, and even the U.S. Army) never feel that a problem exists unless they are unable to provide the part or necessary material upon demand. Therefore, customer satisfaction becomes the alarm. The point is that the costs associated with ordering and holding inventory (the variable costs) are largely hidden and may be overlooked by management. For example, units responsible for the stockage and issue of repair parts in the U.S. Army are driven strictly by the level of service they can provide their customers. The leadership is totally unconcerned about the indirect costs of holding and ordering stock. However, these costs are just as real and necessary as capital investment dollars (Stermole 1974, 144).

Within a company, different personnel will have different opinions on inventory control. The accountant wants to minimize the dollar value at any given time and, therefore, wants inventory levels kept low. The purchasing department wants to make as few purchases as possible so would like to order large lot sizes infrequently. On the other hand, the inventory manager is literally abused when he can't provide a part and lives by the adage that more (on hand) is better than less. The problem, then, is to balance the cost of the inventory and customer service level. In a nutshell, this is the purpose of inventory control. An inventory system can then be defined as the controls and policies for determining:

1) the level of inventory to maintain;

2) when to reorder stock;

3) how large orders should be (Chase and Aquilano 1989, 579).

Much work has been done in the area of inventory control, resulting in a number of lot-sizing algorithms. The ability to use many of these methods can be hindered by two problems.

1. The algorithm may require a relatively accurate method of forecasting demands by time period. Random or stochastic demand can make this very difficult.

2. The system must be comprehended and accepted by the people

who use it. An extremely complicated algorithm that results in lower costs can fail simply because it is not understood. The users have to believe in it: simplicity is a decision criteria.

A number of models were considered while formulating the final recommendation for the company involved in this study. These models are discussed in detail in the next chapter. The final recommendation was not based on a given algorithm's ability to produce the minimum cost of operating the inventory. While this was a consideration, more realistic criteria were:

1) will the algorithm significantly lower variable costs over the present system;

2) the type of system required to forecast demands;

3) acceptability by management and the users of the system;

4) what can be economically and logically instituted.

The bottom line is not what system is optimal, but what can be realistically implemented and still show improvement over the present system.

The following chapters document how applying basic inventory control procedures can improve operating conditions within a company. The specific aspects considered are the variable costs of operating the inventory and the customer service level afforded by the new system. While the final product is not an optimal solution based on annual cost, its implementation is and will result in significant cost savings for the company involved, Houston Tracker Systems (HTS).

Chapter 2
INVENTORY MODEL OPTIONS

Inventory control theory, as we know it, is primarily an invention of the 20th century. The concept of lot-sizing was first published in 1915 and a method of computing reorder points was published in 1934 by R. H. Wilson (Plossl and Wight 1967, 4). Application of the theory was slow to come and probably resulted from the widespread use of operations research techniques after World War II. With the advent of the computer age, the ability to apply relatively complicated algorithms to large inventories has developed. A few of these methods are discussed in this chapter.

2.1 Algorithms

Several algorithm options were considered while formulating the final recommendation for the management of HTS. Although optimality may be measured by lower total annual cost, the ability to implement a given system becomes the real bottom line. In this case, additional constraints were: to formulate a system that management could easily grasp in a briefing without attending a graduate level college course and to acknowledge that demands could not be accurately forecast.

The Wagner-Whitin algorithm is probably the most common of all models that are classified as dynamic programming approaches. It uses a repetitive process to examine all alternatives for ordering to satisfy known demand. It will then pick the alternative which results in the lowest total controllable cost (Tersine 1982, 341). While Wagner-Whitin does result in an optimal solution from the cost standpoint, it has some serious drawbacks. Since it examines all alternatives for cost comparison, Wagner-Whitin rapidly becomes computationally expensive as the total number of items stocked increases. Additionally the algorithm requires a relatively accurate demand forecast for several periods into the future. In this case, the ability to forecast demands by period was questionable at best and would probably have resulted in frequent recalculation of ordering schemes for this algorithm.

Two popular heuristic methods were developed by Edward Silver and Harlan Meal. These methods are very similar except that one allows reorders at any time while the other requires that replenishments be made at the beginning of discrete time periods (Tersine 1982, 341-342). The Silver and Meal heuristics attempt to minimize the average cost per period as measured by holding and carrying costs. While not optimal, these methods yielded total costs within 1% of those obtained with Wagner-Whitin in tests cited by Winston (Winston 1987, 819-821). The Silver and Meal algorithms also require less computational effort than Wagner-Whitin. The primary drawback is still the requirement for a relatively good forecast of demands for multiple periods in the future.

Part-period balancing equates order cost and holding cost derived part-periods to generated part-periods. A part-period is the quantity of a given item held in inventory multiplied by the number of periods the parts are held (Tersine 1982, 346). The method equates order and holding costs in terms of part-periods by adjusting the order horizon. The order horizon is the number of time periods of forecasted demand for which an order will be placed. While this method will not perform as well as Silver and Meal or Wagner-Whitin, the results are generally better than economic order quantity, which will be discussed later. The problem is that part-period balancing is also dependent on a forecast of demand by period, multiple periods into the future.

An interesting alternative to complicated algorithms is lot-for-lot ordering. This method simply orders based on the forecasted demands in upcoming periods by the exact quantity required for each period. Therefore, one order is launched for the quantity forecasted for each period (Tersine 1982, 341). While this method effectively minimizes holding costs, it totally ignores the cost to order and any available price break discounts.

The economic order quantity (EOQ) model is probably the most commonly used throughout industry today. It is also one of two models currently used by the U.S. Army (D.A. 1984). While it is frequently referred to as the Wilson EOQ model, the classic model was actually developed in 1915 by F. W. Harris of Westinghouse Corporation (Winston 1987, 682). The EOQ algorithm essentially attempts to minimize the cost of carrying or holding inventory and the cost to place orders. By picking the point at which these cost curves intersect, variable costs have theoretically been minimized.

The total cost of stocking an item then becomes

$$TC = RP + \frac{CR}{Q} + \frac{QH}{2} \tag{2.1}$$

where

TC = total annual cost of stocking an item or line of inventory,

R = annual demand in units,

P = purchase cost of a unit,

C = order cost per order,

H = PF = holding cost per unit per year,

Q = lot size or order quantity in units,

F = annual holding cost as a fraction of unit cost.

The term (RP) is the total annual purchase cost for the inventory line. (CR)/Q is the fixed cost of ordering on an annual basis for the line. This term is dependent on the order cost per order (C). The cost constant (C) is independent of order size and consists of such expenses as bookkeeping, handling costs, and generic costs of generating and receiving an order. (QH)/2 represents the holding or carrying cost for the inventory line based on the theoretical average inventory level of Q/2. This term is dependent on the holding cost (F) which is the cost of capital to the company, taxes, insurance, the cost of storage, breakage, obsolescence, and theft expressed as a fraction. It amounts to a charge for putting a dollar in inventory instead of other investment opportunities.

Notice that while equation (2.1) encompasses the cost to purchase, hold, and order items for inventory, no mention is made of the cost for not having an item when it is needed. This term is commonly called the stockout or penalty cost. While this is a very real cost to most corporations, it is also usually very difficult to quantify and frequently left out of the total cost equation. The EOQ algorithm does not take into account the penalty cost so it has been omitted from equation (2.1).

The economic lot size to order (Q) is found by taking the derivative of equation (2.1) and setting it equal to 0.

$$\frac{dTC}{dQ} = 0 - \frac{CR}{Q^2} + \frac{H}{2}$$

Solving for Q yields

$$Q = \sqrt{\frac{2CR}{H}} \tag{2.2}$$

By taking the second derivative of the total cost equation, we have

$$\frac{d^2(TC)}{dQ^2} = +2CRQ^{-3}$$

This confirms that we have found a minimum.

Since the total purchase cost over a year should be constant regardless of the lot-sizing scheme used, this term would logically not be used in the lot-size calculation. Consistent with this, the purchase cost

(R P) goes to 0 when the derivative is taken and does not appear in the computation of Q. From this

$$n = \frac{R}{Q} = \sqrt{\frac{HR}{2C}}$$

where

n = expected number of orders during the year and

$$T = \frac{1}{n} = \frac{Q}{R} = \sqrt{\frac{2C}{RH}}$$

where

T = the average order interval or cycle time.

2.2 Reorder Points

In the most simplistic sense of EOQ, replenishment is assumed to be instantaneous at the time the requirement is known. With this in mind, the on-hand balance could always be allowed to go to 0 before a replenishment is initiated. The obvious reality is that there is a lead time associated with ordering and receiving most items stocked for an inventory. Generally, there is also a penalty or stock-out cost associated with not having a part on-hand upon demand. The solution then becomes to calculate the expected usage during lead time and set the reorder point equal to this value. The equation then becomes

$$ROP = \frac{RL}{12} \qquad (2.3)$$

where

ROP = reorder point,

L = lead time in months,

R = annual demand,

or

$$ROP = \frac{RL}{52} \qquad (2.4)$$

where

L = lead time expressed in weeks.

The previous calculation will work well as long as the cycle time does not exceed the lead time for replenishment. When lead time is greater than cycle time, the reorder point will exceed the maximum quantity on-hand. This is because the calculated order quantity (Q) will not last the lead time required for replenishment. Hence, the on-hand quantity will always be below the reorder point. An alternate reorder point calculation presented by Nahmias (Nahmias 1989, 150) can be used in this situation.

1. Form the ratio L/T. Units must be consistent in the fraction.

2. Multiply the fractional remainder of this ratio by the cycle time to convert back to the base unit.

3. Multiply the result from step 2 by the demand rate to obtain the reorder point. Again consistent units must be used throughout this

calculation.

As an example, consider an item that has a calculated Q of 25, an annual demand of 500 units, and a lead time (L) of 6 weeks. The cycle time (T) is 25/500 = .05. Applying the above algorithm:

1. L/T = (6/52)/.05 = 2.31. Notice that lead time had to be converted to an annual basis to be consistent with the cycle time. The 2.31 indicates that every order has to be initiated 2.31 cycles in advance.

2. (.31)(.05) = .0155

3. ROP = (.0155)(500) = 7.75 or 8

2.3 Safety Levels

One of the assumptions in the basic EOQ model as well as the other models discussed is that future demands are relatively continuous and known with certainty. This condition is usually referred to as deterministic demand. Actual demand, as in the case of HTS, is frequently unknown or more random in nature. The problem is to protect against a stockout during unknown demand. One solution is to do nothing and attempt to satisfy abnormally large demands by expediting orders as required. This not only forces the company to bear the cost of a stockout but also to incur the added cost of expediting delivery when necessary.

Another approach is to maintain safety stock in anticipation of fluctuations in demand. If the safety level is well chosen, the result can be greatly improved service to the customer. The downside is that as the safety level increases to offer greater protection against a stockout, the carrying cost also increases. This carrying cost can become significant quickly. Referring to equation 2.1, the carrying or holding cost associated with Q is

$$\frac{QH}{2} \tag{2.5}$$

The carrying cost for safety stock, however, is calculated at full value. This assumes that the safety stock is never used and theoretically it is not. The cost of stocking the safety stock then becomes

$$(s)(H)\text{or}(s)(P)(F) \tag{2.6}$$

where

s = the number of items held as safety stock.

Several methods of calculating an appropriate safety level are available. One method is to select a level based on days of supply (DA 1984, 271). This is the method currently used by the U.S. Army for repair parts stockage. The safety level using this method then becomes

$$s = (SLD)(\overline{D}) \tag{2.7}$$

where

SLD = safety level days,

$\overline{D}$ = average daily demand.

While the days of supply method is extremely simple and easy to compute, it's ability to protect against a stockout condition is questionable. This follows since the selection of the SLD is not related statistically to fluctuations in demand.

A more commonly accepted safety level computation involves selection of the customer service level and standard deviation of demand (Tersine 1982, 140). This method assumes that demand is normally distributed; however it can also be adapted to a poisson distribution. The computation of safety level now becomes

$$s = Z\sigma = Z\sigma_D\sqrt{L} \tag{2.8}$$

where

Z = standard normal deviate,

σ = estimated standard deviation of lead time demand,

L = lead time,

σ_D = estimated standard deviation of demand.

Throughout this thesis, the standard deviation is estimated from the most recent 52 weeks of demand history.

One of the many advantages to this method is that it can be adapted to a desired customer service level. In this case, customer service is defined as the probability of not incurring a stockout during lead time (Nahmias 1989, 201). By choosing a desired service level, we effectively define the percent of the area under the standard normal curve to trap. The appropriate Z value is then taken from a standard normal table to trap this area. As an example, for a customer service level of 97.5%, the corresponding Z value would be 1.96 (Scheaffer and McClave 1986, 610). As a word of caution, the standard deviation must be calculated from data in the same units as the lead time.

2.4 Quantity Discounts

Companies can frequently purchase at a discount by buying in quantity. Two methods of doing this are through incremental quantity discounts and all-unit discounts. Incremental quantity discounts would offer, for example, the first 100 units at one price, the next 1,000 units at a lower price , and perhaps the next 5,000 units purchased at still a lower price. In this manner, the discount is incremented over the quantity purchased. All-unit discounts apply to all the units purchased under one requisition. If a discount is offered for buying over 500 units of an item, all the units purchased are discounted and not just those over 500. We will concern ourselves with the all-unit discount; as it appears to be the most common and is the type offered by the vendors of HTS.

The concept of all-unit discounts is best presented by Tersine through the following verbal algorithm (Tersine 1982, 88).

1. Calculate the total cost for each price-break quantity. This is done using equation (2.1). A price-break is defined as the lowest quantity that the discount is available for.

2. Calculate the EOQ for each unit price using equation (2.2).

3. Calculate the total cost for each valid EOQ using equation (2.1). A valid EOQ is one greater than the price-break quantity. The price-break quantity is 0 for units with no quantity discount.

4. The lowest cost is incurred by picking the quantity with the lowest total cost found in 1 or 3 above.

The following example is presented by Tersine:

where

R = 8,000

C = $30.00/ order

F = 30% per unit cost per year

P = $10.00 for Q < 500

= $9.00 for Q >= 500

Step 1.

$$TC = 8000(9) + \frac{(8000)30}{500} + \frac{500(.30)9}{2} = \$73,155.00$$

Step 2.

$$Q_{10} = \sqrt{\frac{2(30)8000}{10(.30)}} = 400 units$$

$$Q_{9} = \sqrt{\frac{2(30)8000}{10(.30)}} = 422 units$$

The EOQ with $9.00 is invalid since it is unavailable for order quantities less than 500. The EOQ with $10.00 is valid. The total cost for the valid EOQ follows in step 3.

Step 3.

$$TC = 8000(10) + \frac{8000(30)}{400} + \frac{400(10)(.3)}{2} = \$81,200.00$$

Step 4.

The cost order quantity is 500. This is found by comparing the total costs for the valid EOQ and the price break quantity.

This chapter serves as a brief presentation of the concepts applied in this thesis. It is not intended to be a comprehensive discussion of the theories of inventory control. The next chapter will serve to acquaint the reader with the original inventory system in use at Houston Tracker Systems.

Chapter 3
HOUSTON TRACKER SYSTEMS

3.1 Background

Houston Tracker Systems (HTS) is a wholly owned subsidiary company of Echosphere Corporation; both are located in Denver, Colorado. HTS officially markets a variety of television satellite receiver systems under the names of HTS and Echosphere for distribution in North America and Europe. The company's product is the decoder box. All other components of the system are purchased off the shelf and packed with the decoder to make a receiver system. Echosphere and HTS offer 12 different models of decoder boxes under the two company names. These models are available in a multitude of configurations/sets to distributors or the individual decoder box may be purchased.

HTS does not produce their product but contracts for it's production from one or more companies in the Orient. They do, however, design the product in their engineering department. The ability of these overseas facilities to produce a quality product ready for sale has come under question and this, combined with limitations on technology that can be shipped overseas (such as video ciphers), has forced HTS into opening post-production facilities in Denver and Holland. These facilities serve as final boxing and test centers, and as facilities to perform intricate modifications, assembly completion, and any repairs necessary. Consequently, every receiver sold is processed through one of these two facilities. The Denver production facility employs approximately 100 personnel who are involved with this process (not including the corporate headquarters). Over half of these people are hired through temporary agencies.

The company is organized under Subchapter "S" of the Internal Revenue Code. This means the corporate income can be distributed directly to the company shareholders at their individual tax rate, thereby avoiding the corporate tax (Downs and Goodman 1987, 408). The owners of the company are assumed to be in the 33% effective tax bracket. One can theorize that their motive for organizing under chapter S is related to the tax treatment afforded such a company. HTS is profitable. The mark-up on it's product is approximately 77%. An estimate from one informed individual is that the company will realize a 22%-30% after tax return on invested capital for tax year 1989. The same individual classified 1989 as a rather flat year.

HTS maintains a repair parts stockage that serves a variety of purposes. The stockage initially consisted of over 1,700 separate items (as of December 1989) and was valued at roughly $2.84 million. This stockage feeds the production facility in Denver and serves as the supply source for all HTS and Echosphere repair centers in North America. It also supplies the internal Research and Development (R and D) department and individual customers. This means that demands are determined by the production schedule, R and D efforts, and the failure of units in the field. The company does not have a good system of forecasting production requirements so combined demand tends to be highly random and unknown.

The inventory control section consists of four personnel: an inventory manager, two warehousemen, and a temporary data entry clerk who also performs the function of a warehouseman. This staff appears able to handle work requirements for any given day.

3.2 Initial Observations

The author first became involved with the HTS inventory in August of 1989. Research revealed a wide range of problems to include an inventory control system that was managed largely by intuition. That is to say, stockage levels were set by the inventory manager based on intuitive guess and not by a standard algorithm. There were indications that the company's cost to maintain the inventory was too high. In an industry where obsolescence can render an inventory line useless quite rapidly, holding costs can be considerable due to the inability to liquidate stock. The company can have dollars locked up in obsolete inventory lines that have no salvage value. In this situation, the holding cost continues to accrue. A review of the HTS Bill of Materials list dated 09/15/89 revealed that of 1,726 lines listed, 620 had no demand history in the last 18 months. Of the 620 lines, 271 showed quantities on hand. Many of the remaining 1,106 lines showed extremely high on-hand quantities as demonstrated by multiple years of stock on-hand.

In August 1989 there were initially 2 parts stockages housed in adjacent rooms; one for HTS to serve the production line and HTS service centers and a second to serve Echosphere service centers. An early recommendation was to combine the two stockages since they supported similar product lines. This has been completed. The amount of duplication between these warehouses was tremendous although the Echosphere warehouse was miniscule compared to the HTS stockage.

The company has 4 computers that are operated and managed by the MIS group; 1 - Vax 8600, 1 - Vax 8700, and 2 - Altos 2086 supermicrocomputers. The Accounting Department uses a Vax for many of it's needs, which include maintaining one of it's versions of the Bill of Materials. A second Bill of Materials is kept on the Altos and produced by the Accounting Department for invoicing procedures. The Inventory Control section also maintained it's transactions on the Altos. However, Inventory Control maintained and accessed a different data base and therefore, produced a third version of the Bill of Materials. This so called Bill of Materials was actually a stockage list collated in part number sequence. The programs in use served to update the on hand balances of each stocked line and tracked demand history for each line by week. There was no computational algorithm in use for lot-sizing or reorder point calculation. By February of 1990, the various data bases had been consolidated to produce one stockage list.

This system of parallel hardware and software appears to be a product of company development. The Vax computers are used primarily by the parent company, Echosphere. The Altos supermicrocomputers are utilized by HTS. The Management Information Systems (MIS) Group is in the process of consolidating programs to eliminate some of this parallelism. The inventory programs and demand history data base are part of this consolidation effort.

As previously stated, inventory management was performed on an intuitive basis. A reorder level was set, and when the on hand balance went below this level a "quantity to order" was printed in a separate column to initiate bringing the balance back up to the reorder level. No maximum quantity to stock was established. Therefore, the computer interpreted the reorder level also as the quantity to stock. The result was that when one item was used from a line at the reorder level, the next run of the Bill of Materials would reflect that a quantity of one should be ordered. Following this would have initiated replenishment orders after each issue. Consequently replenishment orders were really being placed when a glance in the storage location indicated that the on hand balance was low.

On hand balances on the Inventory Control Bill of Materials were also found to be unreliable. The Bill of Materials update program was designed for daily updates and could be considered a perpetually updated system. Although the current employees in Inventory Control were extremely conscientious about doing daily updates, it was apparent that past personnel had not always performed this ritual accurately. On hand balances were frequently wrong by large factors. Additionally, security within the warehouse area was initially rather lax. These problems were adequately corrected by the end of year inventory performed in December 1989.

When the company moved to Denver from Houston in December 1987, it brought most of it's existing inventory. Most of these items were stocked "carte blanch" instead of being periodically reviewed. Many of these lines had a low or no demand history over the previous 18 months (the approximate length of the current data base), possibly due to obsolescence and lack of periodic review. The bottom line was that no periodic review system or criteria for stockage were in place.

3.3 Inventory Procedures

As previously stated, the original inventory control system at HTS was largely based on intuition and therefore very personality dependent. Orders were initiated when an alert stock clerk determined the storage bin was low. Additionally, many orders were not promptly launched due to shortcomings within the Purchasing Department. This effectively increased lead time by some unknown factor. In late 1989, a purchasing agent was hired whose sole responsibility was purchasing for inventory control. This experienced individual has effectively cut the internal time to initiate a purchase order to one day or less. Since then, the tracking of all open purchase orders has been formalized. In short, the present purchasing system appears extremely efficient.

Parts requirements (demands) were identified either by an unprocessed invoice or verbally to the warehouse clerk, depending on the source of the request. Although parts were issued during the day as needed, the attempt was to process all invoiced parts that had to be shipped in the morning. This allowed deprocessing of receipts in the afternoon. Parts requirements based on invoice were packed for shipment and a copy of the invoice was retained for data input in the afternoon. Those items issued based on verbal demand were issued and signed for by the receiver on a local form. Issues on this form were then input in the afternoon to update the data base. By September 1989, it was my observation that the Inventory Control personnel were extremely conscientious about parts issue procedures and the daily update.

When a part was unavailable for issue (either the line was 0 balance or not stocked), a back order was initiated. If the item could be obtained from a stateside vendor, it was ordered by the purchasing department and shipped by an express freight company, such as "Federal Express" or "United Parcel Service". The priority of shipment was dependent on the customer (i.e. a field service requirement would warrant an expedient shipment). Many items were bought from a sole source supplier in the Hong Kong; the manufacturer of the decoder boxes. The expedited shipment of such an item could become very expensive, as HTS was paying $1.39/lb for priority air shipments. This was the case for many items which added to the cost of stockouts. The new purchasing agent is now attempting to find alternative vendors for these items.

Receipts for stockage or to fill back orders could be received any time during the day, but were generally received in the late morning. These items were then deprocessed (either placed in the appropriate stockage bin or shipped out against an existing back order). The receipt documents were then held and input in the daily computer update to change the on hand quantities. Deprocessing receipts was a particular problem because each HTS supplier invariably shipped parts under its own part number, with no cross-reference list enclosed. Therefore if the warehouseman did not recognize the part by sight, he had to access a cross-reference program to perform this before the receipts could be posted in the daily update and warehoused. This could be very time consuming for an inexperienced warehouseman. The HTS warehouse personnel were very competent at this and their other duties and must be appropriately credited here.

As previously mentioned, daily data input of receipts and issues was performed. This essentially gave a perpetually updated inventory system although the on hand quantities were frequently in error. The update program only amended on hand quantities and determined if the on hand balance had penetrated the reorder level. The maximum or authorized quantity was treated as the reorder level, so when the on hand balance reached one below the reorder level, the program recommended ordering one unit to get back up to the reorder level. If the on-hand quantity exceeded the reorder level, a negative quantity to order was printed. Again, a lot-size was not computed.

3.4 Operating Conditions

In most inventories, probably the two most important operating conditions are the cost of stocking the inventory, and the customer service level it provides. HTS had no method of tracking either of these values. Additionally, records had not been kept to allow for their direct computation.

Interviews with the Inventory Manager, the Director of Production, and the Service Center Manager showed that customers generally felt the service level was between 75% and 80%. These were, of course, best guesses. Furthermore, the consensus was that the goal for the service level needed to be at least 95% or better. The justification for this level of service was in the potential cost of a stockout. In many cases, the cost of a stockout was very difficult to measure such as an unfilled demand from a field service center. However, the stockout cost was easy to estimate when a stockout stopped production. The production problem always centered around the decoder box in the system. The company's investment per box was approximately $373.00 (as charged from the vendor). It was sold to the distributor for $660.00. Therefore, the inability to produce cost the company approximately $287.00 per box in delayed profit, where there had already been an initial investment of $373.00. The inventory of decoder boxes turned over in excess of 14 times per year, so carrying costs were negligible unless production stopped. This situation was complicated because about 66% of the company's production was sold before it was shipped. In short, the cost of not being able to complete the production goal was high. Generally, the target was to produce 500 to 600 units per day in order to satisfy demand.

The current cost of stocking the inventory was also not known by the inventory manager or upper level management. However, it was generally felt that the cost was too high. Through conversations with various individuals, to include the Accounting Controller, an ordering cost (C) of $75.00 per order and an annual holding cost of 25% were agreed upon.

Logically, one would be interested in the total cost of stocking a given line of inventory as defined in equation (2.1). However, over a period of time the purchase cost for an item will be a constant based on demand for the item. This would indicate the costs that can be affected by any lot-sizing technique are the fixed cost to order (CR/Q), and the variable cost to carry an item in inventory (QH/2). The revised total cost equation based on these terms is

$$TC = \frac{CR}{Q} + \frac{QH}{2} \qquad 3.1$$

At this point, a means had to be devised to estimate the total cost as defined by equation (3.1) under the present system. The entire cost analysis was conducted with data taken as of 2 November 1989. Since neither the on-hand quantity nor the unit price from the inventory control stockage list could be relied upon, it was decided to use a random sampling technique to estimate the present total cost of operating the inventory. In doing so, the unit price, quantity on-hand, and actual demand history could be verified and corrected for the lines in the sample.

As stated earlier, a high number of lines stocked showed a low or no demand history. Many publications on inventory control did not address when to stock or drop an item. One method discussed by Fenske (Fenske 1968, 705) and later modified by Silver (Silver 1969, 359) required knowing the percent of sales lost if the item is not stocked. The inability to estimate this parameter is the same reason the stockout cost term was omitted from the total cost calculation, equation (2.1). It was mutually decided with the inventory manager to use the convention of 3 demands in the most recent 52 weeks to stock or retain an item (D.A. 1984, 16). This is one criterion currently used by the U.S. Army. Seemingly unscientific, the criterion was intended as a guideline to cause items to be reviewed, and not as a hard and fast rule. A manual review was deemed the best way to make this decision.

Lines appearing on the stockage list could be thought of as parts or components, and the completed product lines. This thesis is only concerned with the stockage of parts. There were 1,724 parts lines listed on the 2 November list. These lines could be generally classified as lines to retain for stockage, lines that were candidates for deletion based on the above criteria, and lines not stocked. There were also 10 distinct part categories which are listed in Appendix C.

It was desirable to analyze costs based on lines that would stay in the stockage, and lines that were candidates to delete. This is because there were so many candidates for deletion. An initial sample was taken to estimate the carrying cost of lines that were candidates to drop from the stockage. This sample consisted of 22 lines randomly selected from a stockage list run on 2 November 1989. Lines were selected utilizing a random number table (CRC 1978, 544). The results of this sample are contained in Table 3.1.

Table 3.1

Sample of Candidate Lines to Delete

LINE NUMBER	UNIT COST	ON-HAND QUANTITY	DEMANDS LAST 52 WEEKS	$ VALUE OF ON-HAND QTY
T183250	$.20	2,525	158	$505.00
T150100	$6.00	253	102	$1,518.00
T115230	N/A	0	0	$0.00
T154232	$.36	638	110	$229.68
T202120	$.004	16,803	200	$67.21
*T150730	$1.75	201	2	$351.75
*T131010	$6.43	63	1	$405.09
T219120	N/A	0	0	$0.00
*T213101	$30.00	73	2	$2,190.00
T150240	$1.80	448	69	$806.40
T201898	N/A	0	0	$0.00
T240030	$2.50	0	0	$0.00
T219150	$8.50	338	3,800	$2,873.00
T180396	$1.10	15,268	51,000	$16,794.80
T110030	$12.00	179	12	$2,148.00
T150090	$6.00	0	80	$0.00
T202040	$.004	15,153	18,000	$60.61
T110920	$1.75	0	0	$0.00
T130060	$1.75	1,435	150	$2,511.25
T212960	$20.00	87	22	$1,740.00
T112010	N/A	0	0	$0.00
*T122327	$3.00	46	0	$138.00

N/A denotes the unit price was not applicable since the line was not stocked.

* denotes lines which qualify for deletion.

The 22 line sample contained 4 lines that met the criterion for deletion. Assuming this random sample was a true representation of the population, one can estimate that approximately 313 lines are candidates for deletion. Furthermore, the 4 lines in the sample that qualified for deletion had a dollar value of $3,084.84 or $771.21 per line. The estimated total dollar value of lines qualifying for deletion becomes

$$(\$771.21)(313 lines) = \$241,388.73 \tag{3.2}$$

In fact, estimates resulting from the add/delete criteria in January 1990 indicate that substantially more than 313 lines will be deleted. This means the ultimate cost savings computed in the next chapter is probably understated by some unknown amount.

None of the lines qualifying for deletion had been ordered in the last year so the only costs involved were carrying costs. Based on an annual carrying cost of 25%, the total cost to stock this segment of the inventory was

$$\$241,388.73(.25) = \$60,347.18 \tag{3.3}$$

The result of equation (3.3) represents the carrying cost of the final on-hand balances and does not account for the few items issued during the previous 52 weeks. The carrying cost of items issued during the year as computed by equation (2.5) is negligible.

The next step was to estimate the current cost of those items stocked which could be expected to remain in the inventory. This was also accomplished using a random sample. This time the ten parts categories in Appendix C were considered. Again, lines were selected using a table of random numbers (CRC 1978, 544) with a quota of lines for each category preselected. This was a 23 line sample, with each category represented at least once. The larger categories received larger representation, although not proportionally to size. The results of this sample are listed in table 3.2.

Table 3.2

Sample of Lines to Remain in Stockage

LINE NUMBER	PARTS CATEGORY	UNIT COST	ON-HAND QUANTITY	$ VALUE ON-HAND QTY	# DEMANDS LAST 52 WEEKS	# ORDERS LAST 52 WEEKS
T110210	JAC	$0.25	4,589	$1,147.25	146	1
*T115140	JAC	$2.80	228	$638.40	72/30 wks	2
*T221111	CON	$0.23	389	$89.47	277/38 wks	1
T221070	CON	$0.25	397	$99.25	76	0
T120740	CHA	$0.80	11	$8.80	22	0
T122360	CHA	$3.00	125	$375.00	89	2
T120720	CHA	$2.50	1,134	$2,835.00	1,626	10
*T230240	MISC PAR	$0.54	592	$319.68	522/25 wks	1
T132020	MISC PAR	$0.54	1,983	$1,070.82	113	1
T124490	MISC PAR	$2.50	1,042	$2,605.00	1,759	3
*T217000	BDS	$2.80	800	$2,240.00	700/25 wks	2
T210690	BDS	$38.79	0	$0.00	165	3
T210730	BDS	$15.89	0	$0.00	45	0
T280040	REM	$11.50	0	$0.00	8	0
T153140	IC	$0.32	499	$159.68	242	1
*T150105	IC	$6.00	2,292	$13,752.00	146/11 wks	0
*T150135	IC	$6.00	1	$6.00	15/10 wks	0
T183020	CAP	$0.24	46	$11.04	60	0
T180170	CAP	$0.10	2,175	$217.5	820	1
T184030	CAP	$0.93	1,339	$1,245.27	443	0
T200392	RES	$0.774	195	$150.93	5	0
*T201642	RES	$0.025	1,325	$33.125	2675/13 wks	2
T300080	LNB	$55.00	262	$14,410.00	743	5

* Denotes lines which did not have a full year of demand history. Annual demand was approximated by multiplying average weekly demand by 52.

The total cost of maintaining the sample lines in the inventory had to be calculated. Since the original inventory system had no lot-sizing algorithm in place, orders were placed erratically and for varying amounts. This meant that carrying costs could not be calculated with the term (QH)/2 from equation (2.5) since there was no Q designated. Known factors which could be used to determine carrying and order costs were

1. Quantity on-hand as of 2 November 1989
2. The week in which orders were received and the quantity received
3. The quantity issued by week for the last 52 weeks
4. The correct unit price could be determined

A Lotus 1-2-3 spreadsheet was designed to aid in determining the annual carrying and ordering costs by line. A description of this spreadsheet is contained in Appendix D. In cases where a full year of history was not available, an average per week was calculated from available history and multiplied by 52. This meant that annual results would always be compared which is consistent with equation (3.1). The results of this sample are listed in Table 3.3.

Table 3.3

Costs For Sample of Retained Lines

LINE #	PARTS CATEGORY	ANNUAL CARRY COST	ANNUAL ORDER COST	TOTAL ANNUAL COST
T110210	JAC	$291.08	$75.00	$366.08
T115140	JAC	$87.69	$260.00	$347.69
T221111	CON	$30.50	$102.63	$133.13
T221070	CON	$26.30	$0.00	$26.30
T120740	CHA	$3.28	$0.00	$3.28
T122360	CHA	$101.68	$150.00	$251.68
T120720	CHA	$844.01	$750.00	$1,594.01
T230240	MISC PAR	$83.71	$156.00	$239.71
T132020	MISC PAR	$193.99	$75.00	$268.99
T124490	MISC PAR	$430.44	$225.00	$655.44
T217000	BDS	$216.18	$229.41	$445.59
T210690	BDS	$260.06	$225.00	$485.06
T210730	BDS	$79.26	$0.00	$79.26
T280040	REM	$4.53	$0.00	$4.53
T153140	IC	$20.02	$75.00	$95.02
T150105	IC	$3,541.23	$0.00	$3,541.23
T150135	IC	$13.58	$0.00	$13.58
T183020	CAP	$4.85	$0.00	$4.85
T180170	CAP	$30.08	$75.00	$105.08
T184030	CAP	$350.66	$0.00	$350.66
T200392	RES	$35.25	$0.00	$35.25
T201642	RES	$8.60	$557.14	$565.74
T300080	LNB	$3,769.62	$375.00	$4,144.62
	TOTAL:	$10,426.60	$3,330.18	$13,756.78

A number of the lines sampled had not been ordered in the most recent 52 weeks. Although there logically should have been some average order cost assigned to these lines, the benefit of the doubt was given to the present system to compute a conservative estimate of the original costs. Therefore, a number of lines have order costs of $0.00.

The average order and carrying cost for each parts category was then computed by

$$\overline{C}_{i\cdot} = \frac{\sum_{j=1}^{n_i} C_{ij}}{n_i} \tag{3.4}$$

where

$\overline{C}_{i\cdot}$ = average order or carrying cost for parts in category i

C_{ij} = order or carrying cost for line j in category i

n_i = total lines from the sample in category i

The average order and carrying costs now had to be distributed over the entire inventory. This was first done within each parts category with the formula

$$TCC = K_i\overline{C}_{i\cdot} \tag{3.5}$$

where

TCC = Total category carrying or holding cost

K_i = Total number of lines in category i

The total carrying or holding cost could then be found by summing all the TCC's. The results of this are contained in Table 3.4.

Table 3.4

Cost by Category for Retained Lines

PARTS CAT'Y	TOTAL LINES	AVG CARRY COST	AVG ORDER COST	TOTAL CARRY COST	TOTAL ORDER COST	TOTAL COST
JAC	96	$189.39	$167.50	$18,181.44	$16,080.00	$34,261.44
CON	89	$28.40	$51.32	$2,527.60	$4,567.48	$7,095.08
CHA	127	$316.32	$300.00	$40,172.64	$38,100.00	$78,272.64
MISC PAR	205	$236.05	$152.00	$48,390.25	$31,160.00	$79,550.25
BDS	109	$185.17	$151.47	$20,183.53	$16,510.23	$36,693.76
REM	29	$4.53	$0.00	$131.37	$0.00	$131.37
IC	151	$1,191.61	$25.00	$179,933.11	$3,775.00	$183,708.11
CAP	115	$128.53	$25.00	$14,780.95	$2,875.00	$17,655.95
RES	148	$21.93	$278.57	$3,245.64	$41,228.36	$44,474.00
LNB	9	$3,769.62	$375.00	$33,926.58	$3,375.00	$37,301.58
			TOTAL:	$361,473.11	$157,671.07	$519,144.18

Based on these results, the total cost of stocking the inventory under the original system was the summed total for those lines which could be expected to be deleted from table 3.3 and those lines which would remain as depicted in table 3.4. The total cost estimate for maintaining the inventory under the old system was

$$\$519,144.18 + \$60,347.18 = \$579,491.36 \quad (3.6)$$

At this point, the sampling techniques used in this thesis should be discussed. There is probably a correlation between the parts category an item falls in and the unit price. That is to say, the average price of circuit boards is certainly higher than the average cost of resistors. It would have been desirable to sample by parts category. The 22 line sample described in this chapter was taken with no consideration given to parts categories. This decision was made because of the time required to sample from each category and the research required to determine true demand history. It should be kept in mind that all estimates based on the deletion candidates were made under this condition. The 23 line sample used to analyze items to remain in the stockage was made with parts categories in mind. Each category was sampled to select a predetermined number of lines for the analysis. Cost estimates were then made using equations (3.4) and (3.5).

This chapter has served to present the costs of stocking inventory under the original system at HTS. While the final dollar figure may seem high, one must remember these costs are somewhat hidden. No payment is made by the company each month or year. However, they are a real cost and financial burden to the company. In the following chapter, the cost of maintaining the inventory under the revised system will be presented.

Chapter 4
THE REVISED SYSTEM FOR HTS

4.1 Overview

The revised inventory control system for HTS was a variation of economic order quantity. The inventory manager was very concerned about the perception that the customer service level was too low. This made the use of an effective safety level paramount. The most effective safety level computation discussed is contained in equation (2.8), which is based on the service level desired and standard deviation of demand. The inventory manager indicated that he felt a 97.5% customer service level was a must. While this may seem high, the cost savings compared to the original system is still significant. The final presentation to management in November 1989 revealed that this level of service and the associated cost were acceptable. The MIS programmer has been provided a range of z-statistics in order to adjust this value. Obviously, lowering the customer service level means a lower carrying cost for safety stock, while the reverse is true for raising the service level. This concept is explored later in the chapter.

Reorder points also had to be determined, as no system was in place to make this computation. Using the 23 line sample from chapter 3 for items remaining in the inventory, it was found that there were lines that would require the alternate method of reorder point calculation as described at the end of section 2.2. Therefore, both this method and equation (2.4) had to be applied.

In the case of HTS, demands frequently were for multiples of a given item. It would be possible under these conditions for the on-hand quantity to fall well below the established reorder point with the arrival of one demand. Therefore, an (s,S) policy of reordering was adopted (Nahmias 1989, 209). Under this policy, s is defined as the calculated reorder point plus the safety level. S equals the safety level plus Q from equation (2.2). The method requires that when the on-hand balance is less than or equal to s, a replenishment order is placed for the difference between S and the on-hand balance. While the (s,S) policy is usually associated with a periodic review system, its use allows the on-hand balance to reach the maximal quantity, or S, even in a perpetually updated system. It is incorporated in the EOQ system currently used by the U.S. Army (D.A. 1984, 17), which is a perpetually updated system.

4.2 Revised Costs

At this point, the cost of operating under the new system had to be estimated. Since it makes sense to only estimate costs for lines expected to remain in the inventory, the previous 23 line sample was used for this purpose. Estimated costs for the sample were computed using the software programs STORM II and QSOM in conjunction. A discussion of this method and a sample calculation appear in Appendix E. Estimated costs for the sample under the revised system are shown in Table 4.1.

Table 4.1

Revised Costs For 23 (Retained) Line Sample

LINE #	PARTS CATEGORY	ANNUAL CARRY COST	ANNUAL ORDER COST	SAFETY LEVEL CARRY COST	TOTAL ANNUAL COST
T110210	JAC	$18.50	$18.50	$3.58	$40.58
T115140	JAC	$57.40	$57.07	$11.88	$126.35
T221111	CON	$28.75	$28.50	$3.76	$61.01
T221070	CON	$15.63	$11.40	$1.22	$28.25
T120740	CHA	$12.80	$12.89	$3.41	$29.10
T122360	CHA	$49.88	$50.19	$41.97	$142.04
T120720	CHA	$195.31	$195.00	$168.44	$558.75
T230240	MISC PAR	$74.12	$74.16	$9.16	$157.44
T132020	MISC PAR	$33.75	$16.95	$1.50	$52.20
T124490	MISC PAR	$203.13	$202.96	$316.09	$722.18
T217000	BDS	$195.65	$195.35	$172.82	$563.82
T210690	BDS	$247.29	$242.65	$629.66	$1,119.60
T210730	BDS	$81.44	$82.32	$68.99	$232.75
T280040	REM	$28.75	$29.99	$19.87	$78.61
T153140	IC	$26.96	$26.93	$3.36	$57.25
T150105	IC	$197.25	$196.82	$75.60	$469.67
T150135	IC	$66.00	$66.48	$5.28	$137.76
T183020	CAP	$15.00	$9.00	$0.579	$24.58
T180170	CAP	$27.73	$27.73	$2.20	$57.66
T184030	CAP	$62.19	$62.10	$15.84	$140.13
T200392	RES	$6.00	$6.05	$0.263	$12.31
T201642	RES	$50.08	$50.08	$3.83	$103.99
T300080	LNB	$618.75	$619.17	$2,364.54	$3,602.46
	TOTAL:	$2,312.36	$2,282.29	$3,923.84	$8,518.49

A comparison of Table 4.1 with Table 3.4 shows the difference in costs between the old and revised systems for the sample. The old system had a total cost of $13,756.78, compared to $8,518.49 for the revised system. These are present worth, before tax dollars, not corrected for inflation. In light of the first paragraph of this chapter, one could ask how high the service level could be pushed, while preserving a cost advantage. The difference between the revised order plus carrying costs and the original cost of stockage is

$$\$13,756.78 - \$4,594.65 = \$9,162.13 \tag{4.1}$$

This figure represents the breakeven point for the safety stock carrying cost. A sensitivity analysis of this carrying cost using STORM II follows:

Table 4.2

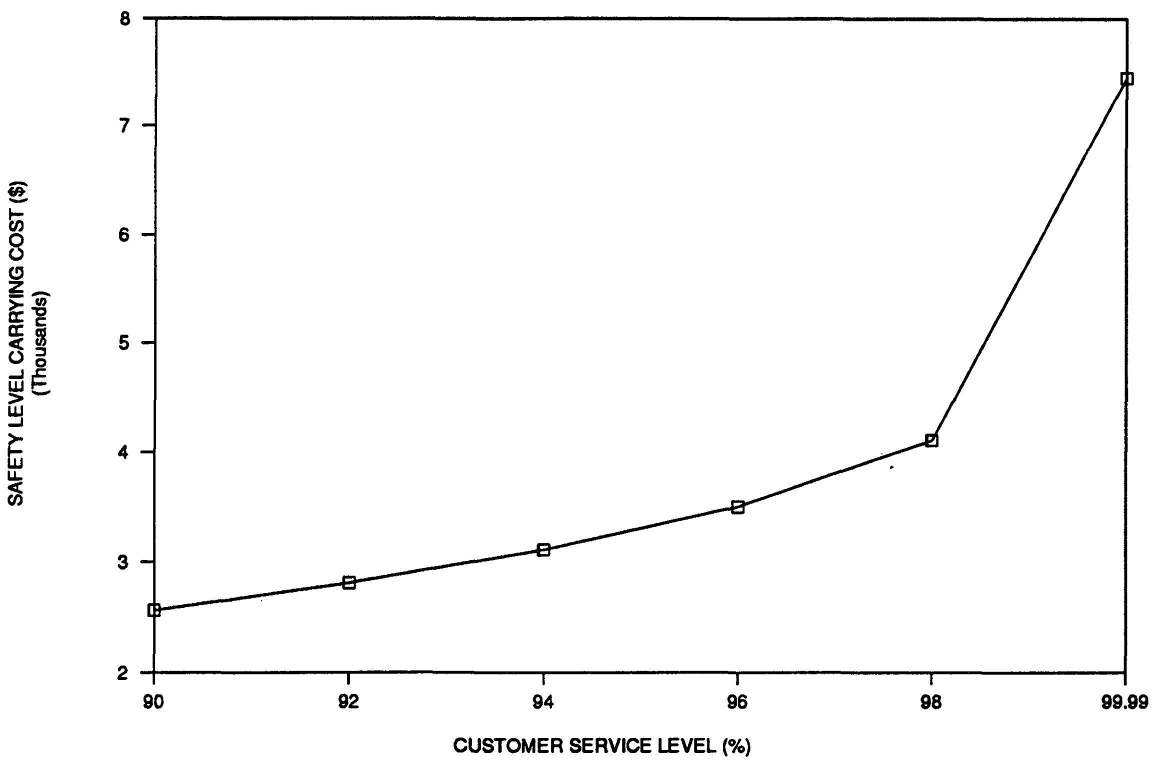
Safety Stock Carrying Cost and Service Level

CUSTOMER SERVICE LEVEL	SAFETY STOCK CARRYING COST
90.00%	$2,565.66
92.00%	$2,812.93
94.00%	$3,112.64
96.00%	$3,504.84
97.50%	$3,923.84
98.00%	$4,111.59
99.00%	$4,657.30
99.99%	$7,445.33

A better representation of this relationship is portrayed graphically in figure 4.1.

Figure 4.1

Safety Stock Carrying Cost Vs. Service Level



The graph suggests that as the service level is pushed higher, the carrying cost increases exponentially. There is, in fact, a diminishing return for every additional dollar invested in the safety level. From the cost standpoint, it is desirable to hold the service level to a reasonable number. Because costs were so high under the old system, the service level could be pushed to 99.99% and still make the new system economically feasible. It is doubtful that shelf space is available to support this kind of service level, and it would seriously cut the cost savings. Therefore, 97.5% is probably a good starting point given the realities involved.

The final test is to compare projected costs for the entire inventory and formulate the final cost savings. Using equations (3.4) and (3.5), costs were projected for the revised system by part category and appear in table 4.3.

Table 4.3

<u>Cost Projections - Revised System</u>

PARTS CAT'Y	TOTAL LINES	TOTAL CARRY COST	TOTAL ORDER COST	SAFETY LEVEL CARRY COST	TOTAL COST
JAC	96	$3,643.20	$3,627.84	$742.08	$8,013.12
CON	89	$1,974.91	$1,775.55	$221.61	$3,972.07
CHA	127	$10,922.00	$10,925.81	$9,051.29	$30,899.10
MISC PAR	205	$21,252.35	$20,094.10	$22,328.60	$63,675.05
BDS	109	$19,052.11	$18,904.96	$31,663.41	$69,620.48
REM	29	$833.75	$869.71	$576.23	$2279.69
IC	151	$14,607.74	$14,607.74	$4,240.08	$33,455.56
CAP	115	$4,021.55	$3,788.10	$714.15	$8,523.80
RES	148	$4,149.92	$4,154.36	$303.40	$8,607.68
LNB	9	$5,568.75	$5,572.53	$21,280.86	$32,422.14
	TOTAL:	$86,026.28	$84,320.70	$91,121.71	$261,468.69

A comparison of Table 4.3 with Table 3.4 shows that the costs for lines remaining in the inventory under the revised system are projected to be $257,675.49 lower. This is a before tax, present worth figure, not adjusted for inflation.

A further savings will be experienced in the first year by the liquidation of lines being dropped from the inventory. The total estimated dollar value of these items is $241,388.73, from equation (3.2). A review of some of these candidates with the inventory manager revealed that over 95% of this segment of the inventory would probably be dropped. As a conservative estimate, the author chose to assume that 75% of this inventory would be dropped and 25% would remain. Therefore, the total cost under the revised system had to be incremented by the holding rate multiplied by 25% of this inventory. Using the result from equation (3.2)

$$\$241,388.73(.25)(.25) = \$15,086.80 \tag{4.2}$$

In the worst case, assuming that none of the lines can be liquidated, 75% of the total dollar value must be written off for tax purposes. The one time tax write-off becomes

$$\$241,388.73(.75)(.33) = \$59,743.71 \tag{4.3}$$

By adding the carrying cost of the unliquidated lines, the adjusted annual cost to operate under the new system is

$$\$261,468.69 + \$15,086.80 = \$276,555.49 \tag{4.4}$$

In summation, cost estimates indicate the revised system will generate a one time tax write-off of $59,743.71 in the current year. More importantly, by comparing equation (4.4) to the results of equation (3.6), the revised system lowers annual operating expenses by over 52%, from $579,491.36 to $276,555.49 in year 1.

Chapter 5
CONCLUSION

Although the use of economic order quantity is not being hailed as the answer to the world's inventory problems, it is showing very favorable results for Houston Tracker Systems. If nothing else, it has forced a badly needed review of the original inventory. More importantly, the final projected cost savings for HTS are significant.

As this document was being written, the revised inventory system at HTS was also being implemented. Final results were, therefore, not available. The lack of substantial records to study, coupled with the fact that the company previously had no computational system, made analysis of the original inventory system very difficult. Consequently, only projected costs and savings could be presented. Every effort was made to give the original method of operation the benefit of the doubt, in order to develop conservative cost-savings estimates.

In November 1989, an estimate of the cost to implement the revised system was made. As it turned out, the company had all the necessary hardware and personnel. The requirements were to

1. Engineer the software. This became the responsibility of the company MIS department.

2. Perform a 100% wall-to-wall inventory and appropriately update records.

3. Update item costs.

The total cost was bracketed between $4,062 and $5,440. This cost was entirely for labor, the majority of which was for writing the computer program. It appears the implementation will be accomplished well within this estimate.

Although the final cost comparison heavily favored changing to the revised system, it is not always successful in lowering costs. Of the 23 items in the sample of retention lines, 8 actually performed better under the old system. Foregoing an in-depth analysis of the reasons, these lines appear to fall into one or more of the following categories:

1. The item is a high cost, high demand item. This would indicate the line may be an "A" line under "ABC" analysis (Hesse and Woolsey 1980, 44). A run on STORM II of the sample using "ABC" analysis revealed that 2 of the 8 lines were "A" lines. This is similar to the findings of Glass (Glass 1985, 73).

2. The line's demand history had a high standard deviation which, in turn, drove the safety level up.

3. Available records indicated the line had not been ordered in the last 52 weeks. In this case, the order cost was assumed to be $0.00 for the analysis presented. The part was obviously ordered by the company at some point in time. An argument could be made to charge a portion of those order costs to the current year.

One area in which limited research appears to have been done is the formulation of criteria for items to be added and deleted from the inventory. The system used was found in a U.S. Army publication (D.A. 1984, 16) and is currently in use by that institution. Its applicability to the corporate world remains to be judged.

Within HTS, it would be most helpful to have an effective forecasting system for the production of their product lines. The ability to forecast that portion of the parts demands in inventory control could go a long way toward lowering the variance of demand in some items stocked. One such possibility would be to blend a just-in-time system with the economic order quantity formula as described by Hoffman (Hoffman 1985, 243) The effect would be to lower safety levels and incur a lower total cost to stock the inventory.

The results of this study at the present time are:

1. A new inventory system has been proposed, accepted, and implemented at Houston Tracker Systems.

2. Estimated savings in ordering and carrying costs are $302,935.87 in the first year. This is a 52.3% reduction from the original system.

3. A one time projected tax write-off of $59,743.71 can be taken by the company if unneeded inventory cannot be otherwise liquidated.

REFERENCES CITED

Chase, Richard B. And Nicholas J. Aquilano. Production and Operations Management. 5th ed. Homewood: Richard D. Irwin, Inc.

CRC. 1978. CRC Standard Mathematical Tables. 25th ed. Ed. William H. Beyer. Boca Raton: CRC Press, Inc.

Department of the Army (D.A.). 1984. "Supply Support Activity Supply System: Manual Procedures." Department of the Army Pamphlet 721-2-2. Washington D.C.

Downs, John and Jordan Elliot Goodman. 1987. Barron's Dictionary of Finance and Investment Terms. New York: Barron's Educational Series, Inc.

Fenske, R. W. 1968. " Non-Stocking Criterion." Management Science. Vol 14, No. 12: 705-714.

Glass, Carl T. 1985. " A Study in Applying Inventory Analysis at an Existing Warehouse." Masters thesis, Colorado School of Mines, Golden, Colo.

Hesse, Rick and Gene Woolsey. 1980. Applied Management Science. Chicago: Science Research Associates, Inc.

Hoffman, William H. 1985. "Lot Size." American Production and Inventory Control Society 28th Annual International Proceedings. October 21-25, 1985: 243-244.

Lotus 1-2-3. Release 2.01. Lotus Development Corporation, Cambridge, Ma.

Nahmias, Steven. 1989. Production and Operations Analysis. Homewood: Richard D. Irwin, Inc.

Plossl, G. W. and O. W. Wight. 1965. Production and Inventory Control. Englewood Cliffs: Prentice-Hall, Inc.

Quantative Systems for Operations Management (QSOM). Version 1.0. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Scheaffer, Richard L. and McClave. 1986. Probability and Statistics for Engineers. 2d ed. Boston: Duxbury Press.

Silver, Edward A. 1969. " A Note on 'Non-Stocking Criterion'." Management Science. Vol 15, No. 8: 359-360.

Stermole, Franklin J. 1974. Economic Evaluation and Investment Decision Methods. 2nd ed. Golden: Investment Evaluations Corporation.

Storm. Personalized Version 1.1. Storm Software, Inc., Cleveland, Oh.

Tersine, Richard J. 1982. Principles of Inventory and Materials Management. 2d ed. New York: Elsevier Science Publishing Co., Inc.

U.S. Department of Commerce/ Bureau of Economic Analysis. June 1989. Survey of Current Business. Vol. 69, No. 6: 93.

Winston, Wayne L. 1987. Operations Research: Applications and Algorithms. Boston: Duxbury Press.

APPENDIX A

Glossary

Glossary

Algorithm - A step by step procedure for solving a given problem or type of problem. It is usually more involved than solving a single mathematical equation.

Carrying cost - The total interest charge for holding items in inventory. It includes the cost for storage facilities, insurance, pilferage, obsolescence, taxes and insurance, and the opportunity cost of capital for the company. For an individual item, it is calculated by the annual holding cost as a fraction of unit cost multiplied by the unit purchase cost.

Customer service level - The percent of demand that is met on time.

Cycle time - The time interval between the arrival of orders. In a theoretical model where shortages are not permitted, it becomes the time period that the economic order quantity (Q) will last. Also called the order interval.

Demand rate - The average demand during a given time period.

Deterministic demand - Demand that is known in advance.

Dynamic programming - The solving of a problem in stages. In the case of inventory models, all possible combinations of ordering are tried to determine the order policy which results in the lowest cost.

Heuristic - Technique to solve a problem which is logical but does not necessarily give an optimal answer. It also may not be mathematically proven.

Holding cost - See carrying cost.

Lead time - The elapsed time between the time of order placement and receipt. Lead time can be measured in days, weeks, months, etc.

Line or line number - In the context of this document, a part number or stock number appearing on the stock status or Bill of Materials. It may also be referred to as an item.

Ordering cost - The cost of generating and receiving an order. It is a fixed cost independent of order size or purchase cost. It would include such expenses as the bookkeeping cost associated with an order.

Penalty cost - See stock-out cost.

Quantity discount - Discount on the purchase cost of an item when bought in larger batches.

Reorder point - The inventory level at which a replenishment order should be placed.

Safety level or safety stock - stock kept on-hand in addition to the expected demand for a designated time period. Safety stock affords protection against a stock-out. The amount of safety stock is based on the desired customer service level.

Safety level days - Safety level based on days of supply. A day of supply is the average demand for one day. Therefore, selecting 15 safety level days means holding 15 days of average daily demand as safety stock.

"S" corporation - A corporation whose taxable income and net losses are passed through to the corporations shareholders. Taxation at the corporate level is thereby avoided. Subchapter "S" of the Internal Revenue Code gives corporations with 35 or fewer shareholders that meet certain other requirements the option of organizing under this provision.

Service level - See customer service level.

Shortage cost - See stock-out cost.

Stochastic demand - Random or unknown demand.

Stock-out cost - The inability to supply demand when it occurs.

APPENDIX B

Variable Listing

Variable Listing

TC - Total annual cost of stocking an item

R - Annual demand for an item in units

P - Purchase cost of an item

C - order cost per order. The fixed cost to make an order.

F - Annual holding cost as a fraction of unit cost. Other references may refer to this as i.

H - Holding cost per unit per year (PF)

Q - Lot size or order quantity in units

n - expected number of orders during the year

T - Average order interval or cycle time

ROP - Reorder point

L - Lead time in days, weeks, months, etc

s - Number of items held as safety stock

SLD - Safety level days

$\overline{D}$ - average daily demand

Z - standard normal deviate or Z - statistic

σ - Standard deviation of leadtime demand

σ_D - Standard deviation of demand

$\overline{C}_{i\cdot}$ - Average order or carrying cost for parts in category i

C_{ij} - order or carrying cost for line j in part category i

n_i - Total number of lines from the sample in category i

TCC - Total part category carrying or holding cost

K_i - Total number of lines in category i that will be retained

APPENDIX C

Explanation of Part Categories

Explanation of Part Categories

An inspection of the Inventory Control stockage list showed 19 categories that stocked items fell in. A further examination revealed that there were only 10 distinct categories of concern. Those categories are listed in Table C-1.

Table C-1

Part Categories

ABBREVIATED CATEGORY NAME	DESCRIPTION OF CATEGORY	# LINES IN CATEGORY THAT MET RETENTION CRITERIA
JAC	ACTUATORS AND COMPONENTS	96
CON	ELECTRICAL CONNECTORS	89
CHA	CHASSIS	127
MISC PAR	MISCELLANEOUS PARTS	205
BDS	CIRCUIT BOARDS	109
REM	REMOTES AND COMPONENTS	29
IC	INTEGRATED CIRCUIT CHIPS	151
CAP	CAPACITORS	115
RES	RESISTORS	148
LNB	LOW NOISE BLOCK DOWN CONVERTERS	9

APPENDIX D

Explanation of LOTUS 1-2-3 Cost Spreadsheet

Explanation of LOTUS 1-2-3 Cost Spreadsheet

It was necessary to estimate costs under the old system with the help of a LOTUS spreadsheet. Since the only inventory balance known was at present with a physical count and no ordering policy was in effect, the holding cost could not be estimated from the quantity Q/2.

The spreadsheet calculated costs by week. Since the ending on-hand balance was known for the most recent week, subtracting receipts and adding issues gave the week's beginning balance. This became the previous weeks ending balance. By knowing when orders were received and issues were made, the year's complete history could be approximated.

An order charge of $75 was made every time an order was received in a week. While this charge should have been made during the week the order was initiated, this date was not always known. The carrying cost for the week was based on the average of the beginning and ending balance. When a full year of history was available, the program summed the carrying and holding costs for the year. In the cases where a full year of history was not available, the average for the weeks available was multiplied by 52 to obtain an annual figure. All cost comparisons could then made on an annual basis. When an item had not been ordered in the past year, no order charge was assessed.

APPENDIX E

Use of STORM II and QSOM

Use of STORM II and QSOM

In order to more easily calculate costs for the 23 line sample under the revised system, the software programs STORM II and QSOM (Quantitative Systems for Operations Management) were used. Although STORM II was capable of dealing with multiple inventory lines, it was unable to handle quantity discounts. It would also compute erroneous reorder points when the lead time exceeded cycle time. Therefore, the lot-size for those items with quantity discounts was computed using QSOM and input into STORM II. The reorder point for lines whose lead time was greater than cycle time was also computed on QSOM. It was found that using the two programs as described in this appendix was consistent with the revised inventory control system described in this thesis.

One drawback to QSOM is that it does not round the lot-size or reorder point to the nearest digit where STORM II does. QSOM is also only capable of dealing with one inventory line of input at a time and will not handle safety levels. All lines were input into QSOM to check the STORM II calculations. Both programs were verified against manual calculations to ensure the output used was consistent with the concepts presented in this thesis.

The following example is presented for line T221070:

QSOM input:

Demand per year (D) = 76
Order or setup cost per order (Co) = 75
Holding cost per unit per year = .0875 (undiscounted price x holding rate: .35 x .25)
Lead time for a new order in year = .01923 (1 week/52 weeks per year)
Unit cost without discount = .35
QSOM then prompts for quantity discount information:
discount breaks to analyze: 1
Discount break # 1:
Break quantity = 500
Discount (%) = 28.57 [(.35-.25)/.35]x100
In this analysis, all discounts were all unit with the holding rate discounted with the price breaks.

QSOM output:

```
Discount Analysis for T221070--All Units Discounts/Holding Cost
Discounted

Without discount:  EOQ =    360.951   Total cost =   58.183

  Discount: 28.6%    Quantity:   500--∞
  EOQ =     427   Total cost =    45.693 ⇒ Out of range
  Break =   500   Total cost =    46.025


  Optimal decision: Discount  28.571 %   Order  500  Total cost =
46.02521


                    Inventory Cost Analysis for T221070
Input Data:
     Demand per year (D) = 76
     Order or setup cost per order (Co) = 75
     Holding cost per unit per year (Ch) = 6.250037E-02
     Shortage cost per unit per year (Cs) = ∞
     Shortage cost per unit, independent of time (π) = 0
     Replenishment or production rate per year (P) = ∞
     Lead time for a new order in year (LT) = .01923
     Unit cost (C) = .2500015
Inventory Cost Analysis:
     Assigned order quantity = 500
     Maximum inventory = 500.000
     Maximum backorder = 0.000
     Order interval = 6.579 year
     Reorder point = 1.461
        Ordering cost = 11.400
        Holding cost = 15.625
        Shortage cost = 0.000
     Subtotal of inventory cost per year = 27.025
     Material cost per year = 19.000
     Total cost per year = 46.025
```

Analysis of QSOM:

1. For this program, notice that the order and holding costs are not equal. This is because the quantity discount made the total cost cheaper to order and hold a large amount of inventory than to order in smaller quantities. This characteristic will carry all the way through this analysis on STORM II.
2. Decimal values are not rounded in this program. One example of this is the reorder point. In this case, the discount quantity of 500 happened to be the optimal EOQ. In other cases, the EOQ value may also be a fraction. This is a drawback to the QSOM program, as one can not have part of a unit.
3. Notice the actual input data do not match the output report labeled "input data". QSOM adjusts the unit cost and holding cost per unit per year to reflect changes in unit price due to quantity discounts. Therefore, the output report may not reflect the actual input data.
4. QSOM will not handle safety levels.

The results of QSOM were then input into STORM II to complete the analysis. The STORM II reports follow.

STORM II input and output

STORM DATA SET LISTING
INVENTORY MANAGEMENT DATA SET

Problem Description Parameters

Title : T221070

Number of items : 1

Default order/setup cost : 75.

Default carrying rate, % : 25.

Time periods per year : 52.

Default service level, % : 97.5

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
T221070

ROW LABEL	ITEM ID	DEMAND/PD	UNIT VALUE	ORDR/SETUP	CARRY RATE
T221070	1	1.4615	0.25	.	.

STORM DATA SET LISTING
DETAILED PROBLEM DATA LISTING FOR
T221070

ROW LABEL	SIGMA(PD)	LEAD TIME	SERV LEVEL	PACKAGING	PRODN/PD
T221070	9.9773	1.	.	500	.

T221070
AGGREGATE INVENTORY VALUES
Inventory carrying charge = 25.00%
Service level = 97.50%

Total number of items	1
Average working stock investment ($)	62.50
Average safety stock investment ($)	4.89
Total inventory investment ($)	67.39
Cost to order EOQ items ($/yr)	11.40
Average working stock carrying cost ($/yr)	15.63
Average safety stock carrying cost ($/yr)	1.22
Total inventory cost ($/yr)	16.85
Total cost ($/yr)	28.25
Number of orders for EOQ items	0
Expected stockouts	0

T221070
ORDERING INFORMATION

Item Name	Item ID	Orders / Setups	Order Size	Reorder Point	Max Orders Outstanding
T221070	1	0.1	500	21	1

T221070
ANNUAL COST INFORMATION

Item Name	Item ID	Order Cost	Working Stock Cost	Safety Stock Cost	Total Cost
T221070	1	11.40	15.63	1.22	28.25

T221070
PROJECTED INVENTORY LEVELS

Item Name	Item ID	Minimal Quantity	Maximal Quantity	Average Quantity
T221070	1	20	520	270

Analysis of STORM II:

1. The order size had to be input as the package size to force STORM II to use the optimal economic order quantity of 500 as calculated by QSOM.

2. STORM II has calculated a safety level and holding cost for the safety stock as described in Chapter 2.

3. Notice the reorder point has been rounded. The reorder point is equal to the calculated reorder point plus the safety level, consistent with the system described in this thesis. The program adds the calculated reorder point and safety level in their decimal forms and then rounds to the nearest digit. The carrying cost of the safety level is calculated based on the decimal form of the safety level, not a rounded number.

4. The maximal quantity is equal to S from Chapter 4 (the safety level plus Q) and the minimal quantity equal to the safety level.

5. Although not depicted in this example, it should be said again that STORM II will not perform the alternate reorder point calculation from Chapter 2. This is required when lead time exceeds cycle time. If the STORM II reorder point is used in this situation, the reorder point becomes greater than the maximal quantity. Therefore, the correct reorder point must be taken from QSOM, as it defaults to the alternate ROP calculation in this situation. This is significant in that HTS has a number of lines that will fall into this category.