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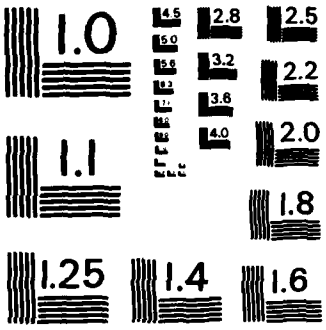

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A TECHNIQUE FOR EVALUATING VENDOR BIDS FOR STOCK REPLENISHMENT OF A CONSUMABLE ITEM

by

Joshua Steinberg

June 1985

Thesis Advisor: Alan W. McMasters

Approved for public release; distribution unlimited

Prepared for: Commanding Officer
Naval Ships Parts Control Center
Mechanicsburg, PA 17055

NAVAL POSTGRADUATE SCHOOL
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The work reported herein was prepared at the request of the Navy Ships Parts Control Center, Mechanicsburg, Pennsylvania, but was unfunded.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS 54-85-003	2. GOVT ACCESSION NO. AD-A159 257	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Technique for Evaluating Vendor Bids for Stock Replenishment of a Consumable Item		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 1985
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Joshua Steinberg in conjunction with Alan W. McMasters		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943-5100		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943-5100		12. REPORT DATE June 1985
		13. NUMBER OF PAGES 76
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Inventory Model; Uniform Inventory Control Program (UICP);

Procurement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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S N 0102-LF-014-6601

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#20 - ABSTRACT - (CONTINUED)

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A Technique for Evaluating Vendor Bids for Stock Replenishment of a Consumable Item

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 1985

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ABSTRACT

The Ships Parts Control Center (SPCC) Uniform Inventory Control Program (UICP) wholesale replenishment model for 1H cognizance symbol (consumable) material is an order quantity-reorder level or (Q,r) model. A stocked item's order quantity and reorder level are established in large part by the unit price and procurement lead time forecasted for it. When a replenishment is needed, the order quantity is specified and the procurement officer requests bids from vendors. These bids include both a unit price and production lead time. This thesis analyzes the influence of different bids with different unit price and different lead time on the future optimum total annual cost of stocking the item as computed by the UICP model. Based on this analysis, a simple technique to evaluate those bids is developed and steps to implement this technique are suggested.

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I. INTRODUCTION

A. THE PROBLEM

The current practice at the Navy's Inventory Control Points (ICPs) is to treat the wholesale level inventory management of an item and the procurement of replenishment stock as separate functions even though they are, in fact, key elements of the same single supply system and share the goal of maximum fleet support within annual budget constraints. The Uniform inventory Control Point (UICP) inventory models are used to determine the reorder level and order quantity based on data from recent past procurements. When the inventory position of an item drops below the computed reorder point, an order is sent to the procurement department to buy the computed order quantity. The procurement department then solicits bids from potential vendors who are interested in filling the order. The vendor selected is usually the one who has bid the lowest unit price and can deliver within an ICP established desired delivery date. Some time later the UICP inventory models receive the new price and production lead time values of the vendor winning the contract. A new reorder point and order quantity are then computed and form the basis for the next procurement replenishment stock.

If the information from the vendors' bids could be incorporated in the inventory models at the time that the bids are

being evaluated rather than after a bid has been accepted, a better evaluation of the bids should result. The bid to be accepted should be the one which provides the lowest future average annual inventory costs.

B. BACKGROUND

For each item managed, the Navy's UICP models compute the values of the reorder point and order quantity which minimize the average annual variable costs of ordering, holding, and time-weighted backorders. These models are based on the traditional steady-state continuous review lot size-reorder point models for stochastic demands which assume a constant price and procurement lead time for each item. Under the assumption of a constant price, the average annual total procurement cost is a constant value which is independent of the decision variables, order quantity and reorder point. As a consequence, this cost term can be ignored.

If, however, the procurement cost is known to be variable between vendors then the average annual procurement costs should be added to the average annual costs of managing the inventory of an item when a reprocurement is being considered since its magnitude is usually much larger than the average annual variable costs. The UICP models would then take on the form of stochastic price-break models. Solution techniques for solving such models are well known. Hadley and Whitin present these techniques in Chapters 2 and 4 of Reference 1. The UICP models were

originally programmed to consider such price-breaks. In recent years, however, that option has not been used because of limited computer capacity.

Another dimension of the bidding process is that vendors will typically submit different estimates of production lead time. Fortunately, inclusion of variable production and therefore procurement lead times in the UICP model does not require any additional average annual cost terms. The impact of lead time on the optimization is concentrated in the determination of the reorder point. However, the determination of the reorder point also includes an item's price because the reorder point influences not only the expected number of shortages but also the expected inventory holding costs.

Hadley and Whitin [Ref. 1] have developed a price-break model for considering the influence of both unit price and lead time. In this model they assume that the unit price is both a function of the order quantity and the lead time. They assume, in particular, that the unit price offered by a vendor will increase as lead time decreases in a stepwise fashion; i.e., the same unit cost applies over a range of lead time values as well as order quantity values. An algorithm is also presented for solving this problem. Unfortunately, the model differs significantly from that of the UICP; there is no back-order term in the holding costs and the shortage costs are based on the expected number of backorders rather than time-weighted backorders. In addition, while their assumed

relationship between price and lead time might be true for negotiations with a single vendor, it is not obvious that it would be valid for all potential vendors.

Rather than attempt to identify if some such relationship exists for all vendors or to assume it even if it doesn't, it seems more efficient to conduct a study of the impact on the UICP model of varying combinations of unit price and procurement lead time and then to develop a simple methodology for comparing two or more bids. The result would provide a procurement manager with a simple technique which would enable him to integrate the inventory management and procurement activities in order to minimize the total expenditure of Navy dollars required to stock consumable items.

C. THESIS OBJECTIVE

The objective is to develop a management technique for use by procurement personnel which will permit evaluation of vendor bids for consumable items on the basis of their impact on total average annual inventory costs. This technique should be both simple and quick to use with minimal requirement for computer or calculator equipment.

D. APPROACH

The approach will be to examine the impact of varying combinations of unit price and procurement lead time values on total average annual costs predicted by the UICP consumable model to determine what savings are possible and how to achieve them. The effect of changing either the unit price or the lead time

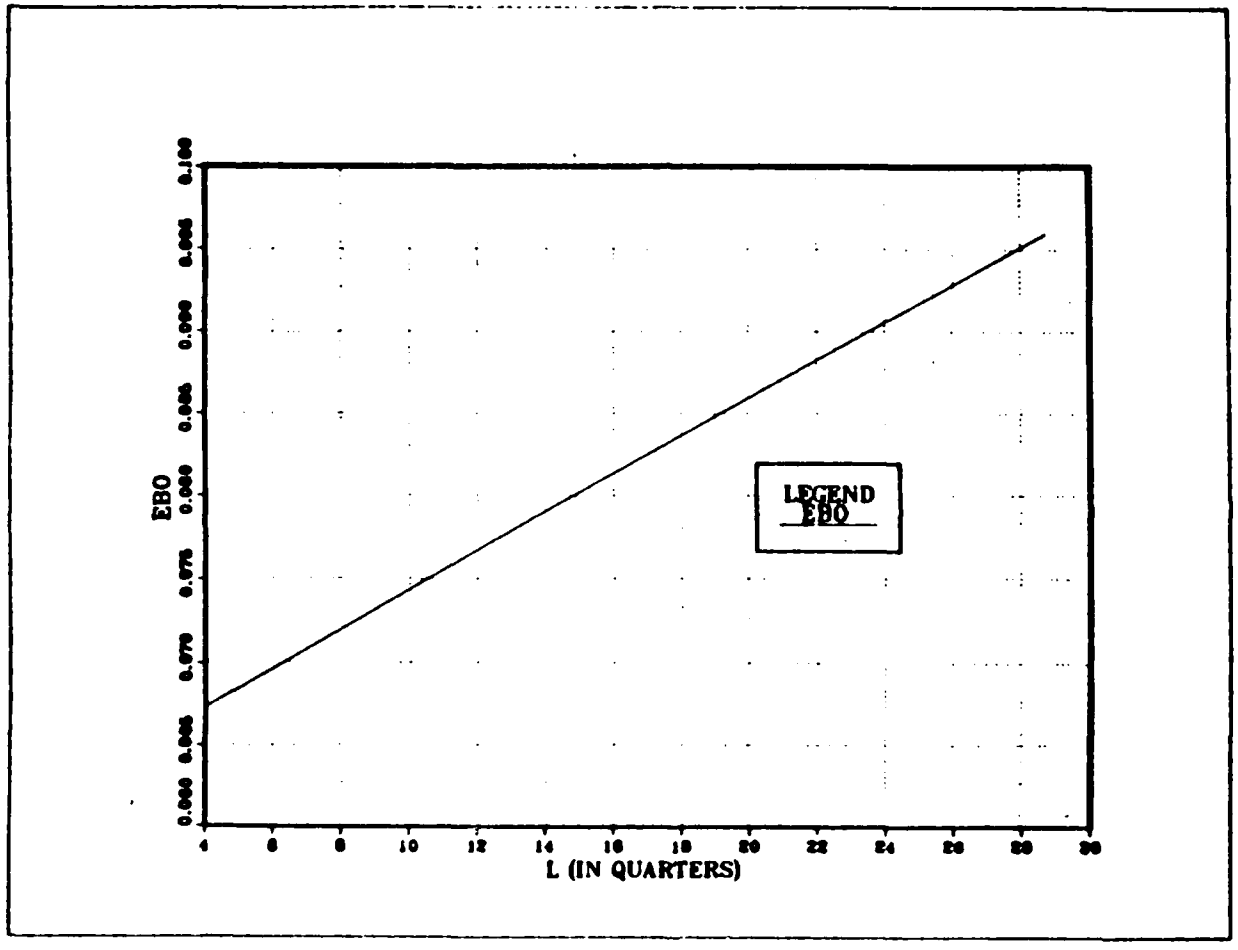

Figure 2. The Expected Value of B(Q,R) as a Function of L

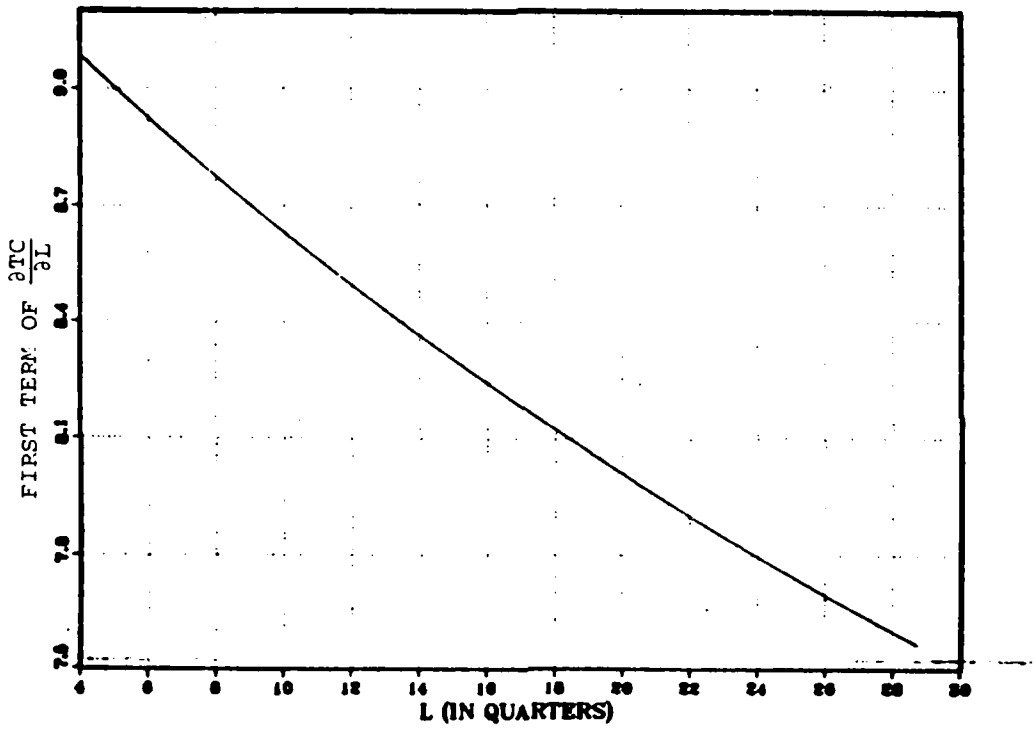

Figure 1. Behavior of the First Term of the Equation for $\frac{\partial TC}{\partial L}$ As A Function of L.

Turning next to the BOC term, we get

$$\frac{\partial(BOC)}{\partial L} = \frac{\lambda E}{S}\frac{\partial[B(Q,R)]}{\partial L} .$$

Substitution of these partials in the ∂TC equation gives

$$\frac{\partial TC}{\partial L} = \frac{IC(1.57\ z\,MAD_D^2)}{2\sigma} + \frac{\partial B(Q,R)}{\partial L}(IC + \frac{\lambda E}{S}) .$$

The first term of $\frac{\partial TC}{\partial L}$ is dependent on L in the denominator because of σ and, since this is true, the term gets smaller as L increases. The behavior of this term is shown in Figure 1 for the following set of parameter values.

$$\begin{aligned} D &= 8 \text{ units/quarter;} \\ MAD_D &= 2.50 \text{ units/quarter;} \\ MAD_L &= 2.25 \text{ quarters;} \\ A &= \$380; \\ E &= 0.50; \\ I &= 0.23; \\ S &= 1.00. \end{aligned}$$

Its behavior appears almost linear in L and the rate of decrease is quite small, being 0.07 on the average.

The behavior of the second term of $\frac{\partial TC}{\partial L}$ can be deduced from the behavior of B(Q,R) as a function of L in Figure 2. This figure shows that the relationship is virtually linear with a slope of 0.0012.

and, since OC and PC are not functions of L,

$$\frac{\partial(OC)}{\partial L} = \frac{\partial(PC)}{\partial L} = 0$$

The remaining terms include B(Q,R), a complex function of L.

The holding cost formula is a linear function of the safety stock $z\sigma$ and σ is a function of L. The normal deviate z is not a function of L since it is determined from the RISK formula. Therefore

$$\frac{\partial H}{\partial L} = IC[z\,\frac{\partial\sigma}{\partial L} + \frac{\partial B(Q,R)}{\partial L}] \ .$$

If we assume that we are considering Mark IV items and that MAD_L is independent of L, then

$$\frac{\partial\sigma}{\partial L} = \frac{1}{2}(1.57\ MAD_D^2 \cdot L + 1.57\ MAD_L^2 \cdot D)^{-1/2}(1.57\ MAD_D^2)$$

$$= \frac{1.57\ MAD_D^2}{2\sigma} \ .$$

Substitution of this formula into $\frac{\partial H}{\partial L}$ gives

$$\frac{\partial H}{\partial L} = IC[\frac{1.57\ z\,MAD_D^2}{2\sigma} + \frac{\partial B(Q,R)}{\partial L}] \ .$$

Because B(Q,R) is a very complex function of both C and L we will not attempt to obtain its partial derivative with respect to L analytically. Instead we will examine B(Q,R)'s behavior with respect to L empirically below.

Reduction in the expected average annual total cost of stocking an item from that predicted by the "optimum" UICP solution is possible because negotiated variations in unit price and lead time can result in savings in some variable cost elements and/or the average annual purchase cost. A reduction in the latter usually outweighs increases in other variable cost elements.

F. PARTIAL DERIVATIVES FROM THE TC EQUATION

In order to understand their influence on the total cost equation, we will first take partial derivatives with respect to the lead time L and unit price C. The total cost equation is the sum of TVC and the average annual procurement costs; that is,

$$TC = OC + HC + BOC + PC$$

where

$$OC = \text{ordering cost} = \frac{4AD}{Q} ;$$

$$HC = \text{holding cost} = IC[\frac{Q}{2} + z\sigma + B(Q,R)] ;$$

$$BOC = \text{backorder cost} = \frac{\lambda E}{S} B(Q,R) ;$$

$$PC = \text{procurement cost} = 4DC .$$

First,

$$\frac{\partial(TC)}{\partial L} = \frac{\partial(OC)}{\partial L} + \frac{\partial(HC)}{\partial L} + \frac{\partial(BOC)}{\partial L} + \frac{\partial(PC)}{\partial L}$$

$$0.01 \leq \text{RISK} \leq \begin{cases} 0.99 & \text{for category C items;} \\ 0.40 & \text{for category B items;} \\ 0.30 & \text{for category A items.} \end{cases}$$

and

category C corresponds to $3 > W \geq 1$;

category B corresponds to $5 > W \geq 3$;

category A corresponds to $W \geq 5$.

E. LIMITATIONS OF THE TVC COST MINIMIZATION METHOD

The UICP model assumes that the average annual variable costs are based on historical unit price and procurement lead time data and does not take into account that control over those two variables is possible during the procurement process. Price is, in fact, not a constant nor is lead time in a competitive bidding environment. In other words, the UICP model treats C and L as known values, and proceeds to solve for Q and R. However, when the procurement personnel solicit bids for reprocurement, Q is fixed and R has already been reached, while C and L are unknown until the vendors' bids are received.

Additionally, the item manager is looking at only variable inventory costs, while the purchasing agent is primarily concerned with the purchase cost. The purchase contract is awarded to a "responsible contractor" who offers the item at a "fair and reasonable price" [Ref. 3] which generally means obtaining the material at the lowest bid price from among the vendors who can meet some required delivery date.

item. Mark II and Mark IV items are both characterized by having quarterly demand of more than 5. The difference between these "marks" is a function of the product of the quarterly demand and the unit cost; Mark IV items correspond to items for which this product is greater than 75, Mark II items have product values not exceeding 75.

For Mark IV items the formula for σ is

$$\sigma = \sqrt{1.57\ MAD_D^2 \cdot L + 1.57\ MAD_L^2 \cdot D^2} \quad .$$

where

MAD_D = Mean absolute deviation of quarterly demand for item; forecasted from historical demand data.

MAD_L = Mean absolute deviation of procurement lead time; forecasted from prior procurement actions.

For Mark II items the formula is

$$\sigma = \sqrt{1.57\ MAD_D^2 \cdot L + D^2 \cdot L} \quad .$$

The optimal values of Q and R are then subjected to the following constraints:

$$Q = \min \begin{cases} 12D; \\ \max(D;1;Q^*); \end{cases}$$

and

$$\beta(R+Q) = \frac{1}{2}[\sigma^2 + (R+Q-DL)^2]\,\Phi\left(\frac{R+Q-DL}{\sigma}\right) - \frac{\sigma}{2}(R+Q-DL)\,\phi\left(\frac{R+Q-DL}{\sigma}\right) .$$

The notation ϕ corresponds to the density function for the normal distribution and Φ corresponds to its complementary cumulative distribution function.

D. OPTIMIZATION AND KEY VARIABLE RELATIONSHIPS

As with other inventory models, the UICP cost equation is minimized by taking the partial derivatives of TVC with respect to the decision variables, Q and R, and setting them equal to zero. Unfortunately, the results are two complex equations in Q and R. The solutions derived by the Operations Research group at the Navy Fleet Material Support Office, the constraints on these values, and parameters needed to solve the formulas are provided below:

$$Q^* = \sqrt{8AD/IC} = \text{the usual EOQ}$$

$$\text{RISK} = 1 - F(R^*) = \frac{DIC}{DIC + \lambda WE}$$

and, from the table of the cumulative density function for the standard normal distribution, we can find the value of the normal deviate, z. R is then computed from

$$R = DL + z\sigma ,$$

where σ is the standard deviation of demand during procurement lead time. The formula for σ depends on the Mark Code of the

E = military essentiality of the item, currently set at 0.5.

$[\frac{4D}{Q}]$ = average number of procurement actions or inventory cycles per year.

$[R + \frac{Q}{2} - LD + B(Q,R)]$ = expected number of units in stock at any random point in time (average on-hand inventory level).

$\frac{B(Q,R)}{S}$ = expected number of requisitions on backorder at any random point in time.

The formula for $B(Q,R)$ is, from Hadley and Whitin [Ref. 4],

$$B(Q,R) = \frac{1}{Q} \int_R^{\infty} (x - R)[F(x + Q;L) - F(x:L)]dx$$

where

$F(x;L)$ = the distribution function of demand x over lead time L.

Hadley and Whitin reduce this formula to the general form of

$$B(Q,R) = \frac{1}{Q}[\beta(R) - \beta(R+Q)].$$

When demand over procurement lead time is assumed to be normal with a mean of DL and a standard deviation of σ,

$$\beta(R) = \frac{1}{2}[\sigma^2 + (R-DL)^2]\Phi(\frac{R-DL}{\sigma}) - \frac{\sigma}{2}(R-DL)\phi(\frac{R-DL}{\sigma})$$

cost, the middle term the holding cost, and the last term the backorder cost.

$$TVC = [\frac{4 \cdot D}{Q}]A + I \cdot C[R + \frac{Q}{2} - L \cdot D + B(Q,R)] + \frac{\lambda E}{S}[B(Q,R)]$$

where:

TVC = total variable costs of one stocked item per year.

D = expected or average number of units demanded per quarter; forecasted from historic demand quantities and trends.

Q = order quantity.

A = administrative cost of a procurement action; equal to $380 for purchases under $8,000, $1,050 for negotiated contracts (over $8,000), and $1,080 for advertised contracts (over $8,000).

R = reorder level (based on inventory position, not just stock on hand).

L = procurement lead time (mean value forecasted from past procurement actions).

B(Q,R) = expected number of units backordered at any random point in time (a function of Q and R).

I = annual inventory holding cost rate, composed of storage, obsolescence, and opportunity costs as percentages of unit cost (equal to 0.23 for consumable items).

C = unit cost of the item.

S = expected number of units demanded per customer requisition.

λ = shortage cost of one requisition backordered for one year. Currently set at $1,500 for category A (formerly 1HO1 and 1HO2 cog) items, $1,000 for category B (formerly 1HO3 cog) items, and $500 for category C (formerly 1Hbb cog) items.

B. ASSUMPTIONS

The following assumptions apply to the UICP model. These assumptions will also be used in developing the technique which will be presented in Chapter IV.

(1) Steady state environment--The mean and standard deviation of the random variables, quarterly demand and procurement lead time, are assumed constant over all future time.

(2) No quantity price discount--The unit price is the same regardless of the number of units in an order. A price-break subroutine is contained in the UICP implementation but it is not used at present.

(3) Instantaneous reorder--Replenishment orders are placed immediately after the inventory position drops below the reorder level. Although this assumption is a practical impossibility, the actual time delay is compensated for by including the associated administrative lead time as part of the procurement lead time.

(4) The cost to hold one unit of stock is proportional to the unit price of the item (currently set at 23% of the unit price per year).

(5) The time-weighted cost of a backorder for an item can be accurately quantified for determining stockout costs. Although this value (lambda) is actually determined from budget and supply material availability (SMA) constraints, for computational and analysis purposes, lambda will be assumed to accurately represent actual stockout costs.

(6) The military worth (essentiality) of an item can be accurately quantified, as required for the determination of stockout costs. Essentiality is currently fixed at 0.5 for all items by SPCC.

(7) No interaction exists between items. Each item's order quantity and reorder point can be determined independently of other items. Similarly, total inventory costs for a group of items can be determined by adding the independently computed costs for each item.

C. TOTAL VARIABLE COST EQUATION

The UICP total average annual variable cost equation is presented below, with the first term representing the order

II. THE CURRENT UICP MODEL

A. GENERAL DESCRIPTION OF THE MODEL

The Navy's Uniform Inventory Control Program (UICP) wholesale consumables model, used to set inventory levels for SPCC managed 1H cog items, forms the basis for the model developed in this thesis. The model seeks "to minimize the total of variable order and holding costs subject to a constraint on time weighted, essentiality-weighted requisitions short" [Ref. 3]. The average annual total variable cost (TVC) equation used contains three main terms: an ordering cost term, or average number of orders per year times the administrative cost to place an order; a holding cost term, or the average number of units on hand at any random point in time multiplied by the cost to hold a unit in stock for a year; and a shortage cost term, consisting of the average number of requisitions backordered at any random point in time multiplied by the cost incurred by not filling a requisition for a year times the military essentiality or worth of the item. The average annual cost of the items procured (unit price multiplied by average annual demand) is considered a fixed cost independent of the decision variables and is not considered in the model.

procurement which is done by the Navy is for the normally distributed items even though they represent only 4% of the items managed by SPCC and 13% managed by ASO [Ref. 2].

F. PREVIEW

Chapter II will present a brief overview of the current UICP consumables procurement model to establish the basis for analyzing it in both Chapters II and III. Model assumptions, constraints, and the total expected annual variable costs (TVC) equation and its optimization methodology will be discussed. Mathematical analysis of the TVC equation by taking partial derivatives and examining its behavior graphically will also be presented.

Chapter III will describe the computerized incremental analysis of TVC when it is subjected to changes in the unit price and procurement lead time. The results will be then analyzed by using the isocost technique. The results will be illustrated graphically and limitations on the values of the bid variables will be suggested.

Chapter IV will present a technique for evaluating bids based on the analyses of Chapter III.

Chapter V will provide a summary of the chapters, present conclusions regarding the value of the bid evaluation technique, and recommend steps for implementation. Recommendations for further research on the technique will also be provided.

will be examined by taking partial derivatives of the total cost equation. In addition, the relationship between these variables and their effect on predicted inventory costs in the UICP consumables model will be examined through the use of a computer program which will first duplicate the UICP(Q,r) solution process, then incrementally change the variables of interest and compute the resulting inventory costs.

E. SCOPE AND LIMITATIONS

The stock procurement process will be examined at the point where the buy quantity has been determined and vendor bids have been solicited but no contract awarded. No required delivery date will be assumed. Since current procurement procedures do not retain bid data, the variations in lead time and unit price between bids are not known, and therefore the thesis model will allow for a large range of possible values of each.

The UICP inventory model for SPCC managed 1H cognizance consumable material will be utilized as the basis for the thesis model. For simplicity in programming and to keep the scope to manageable size, only items having sufficient average demand quantities such that their lead time demand quantities can be assumed to be normally distributed are considered. Slower moving items with Poisson or negative binomial distributions of lead time demand can be similarly analyzed with appropriate changes in the sections of the computer program which calculate the reorder level and the expected number of backorders. As a matter of fact, most of the replenishment

Thus, the second term is essentially a constant. The term $(IC + \frac{\lambda E}{S})$ which multiplies the term $\frac{\partial B(Q,R)}{\partial L}$ is partially from the holding cost term (IC) and partially from the backorder cost $(\frac{\lambda E}{S})$.

Figure 3 suggests that the backorder term in the holding cost dominates the safety stock term for the values of L shown so that TC is essentially linear in L. In that figure the TC is called TVC since it does not include the fixed cost of annual procurement.

The minimum value of L; namely, four quarters, shown in the figures corresponds to the current average administrative lead time value at SPCC. Since the procurement lead time includes both administrative and production lead time, realistic values of L can be expected to exceed this four quarters minimum value.

Next we take the partial derivative of the TC formula with respect to the unit price C. The variables that change with C are Q, R, B(Q,R) and RISK. We can reasonably assume that λ and σ are not changing with C.

$$\frac{\partial(TC)}{\partial C} = \frac{\partial(OC)}{\partial C} + \frac{\partial(HC)}{\partial C} + \frac{\partial(BOC)}{\partial C} + \frac{\partial(PC)}{\partial C} .$$

First we get

$$\frac{\partial(PC)}{\partial C} = 4D .$$

Next, the OC term contains Q which is a function of C at its optimal value.

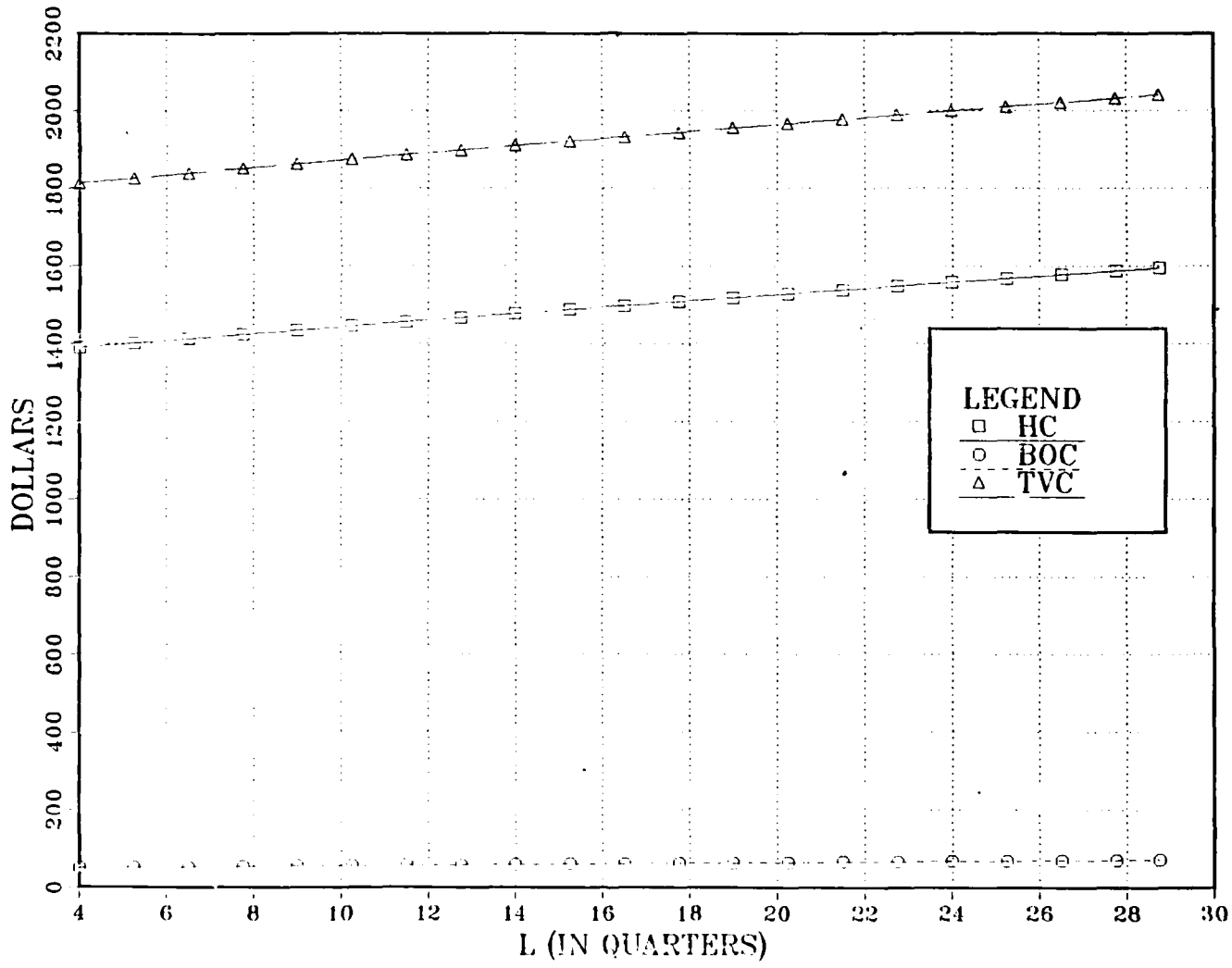

Figure 3. Components of the Inventory Cost as a Function of L

$$\frac{\partial(OC)}{\partial C} = \frac{\partial}{\partial C}\left(\frac{4AD}{Q}\right) = 4AD\cdot\frac{\partial}{\partial C}\sqrt{\frac{IC}{8AD}}$$

$$= 4AD\cdot\frac{1}{2}\left(\frac{IC}{8AD}\right)^{-1/2}\cdot\frac{I}{8AD} = \sqrt{\frac{ADI}{2C}}\ .$$

The holding cost term is a very complicated function of C since it depends on safety stock and B(Q,R). The safety stock is a function of z which is a function of RISK and hence a complex function of C. A plot of z as a function of C is shown in Figure 4 (the horizontal line up to a unit cost of 33 is a result from the UICP constraint that RISK $\geq$ 0.01). The term B(Q,R) (which also appears in the backorder cost term of TC) is also a complex function of C and has been plotted in Figure 5.

From these figures we might conclude that there is little to be obtained from considering $\frac{\partial TC}{\partial C}$. Fortunately, the plots of OC, HC, and BOC as a function of C in Figure 6 indicate an almost linear relationship and we know that the PC term is indeed linear. Combining this information into a plot of TC as a function of C, also shown in Figure 6, indicates that TC is virtually linear in C and is dominated by the PC term.

In summary, we have considered the partial derivatives of TC with respect to L and C. We found that simple analytical formulas describing these derivatives could not be obtained, mainly because of the backorder term B(Q,R). However, empirical analysis has shown that TC is virtually linear in both L and C. This fact will be important for the development of the technique to be presented in Chapter IV.

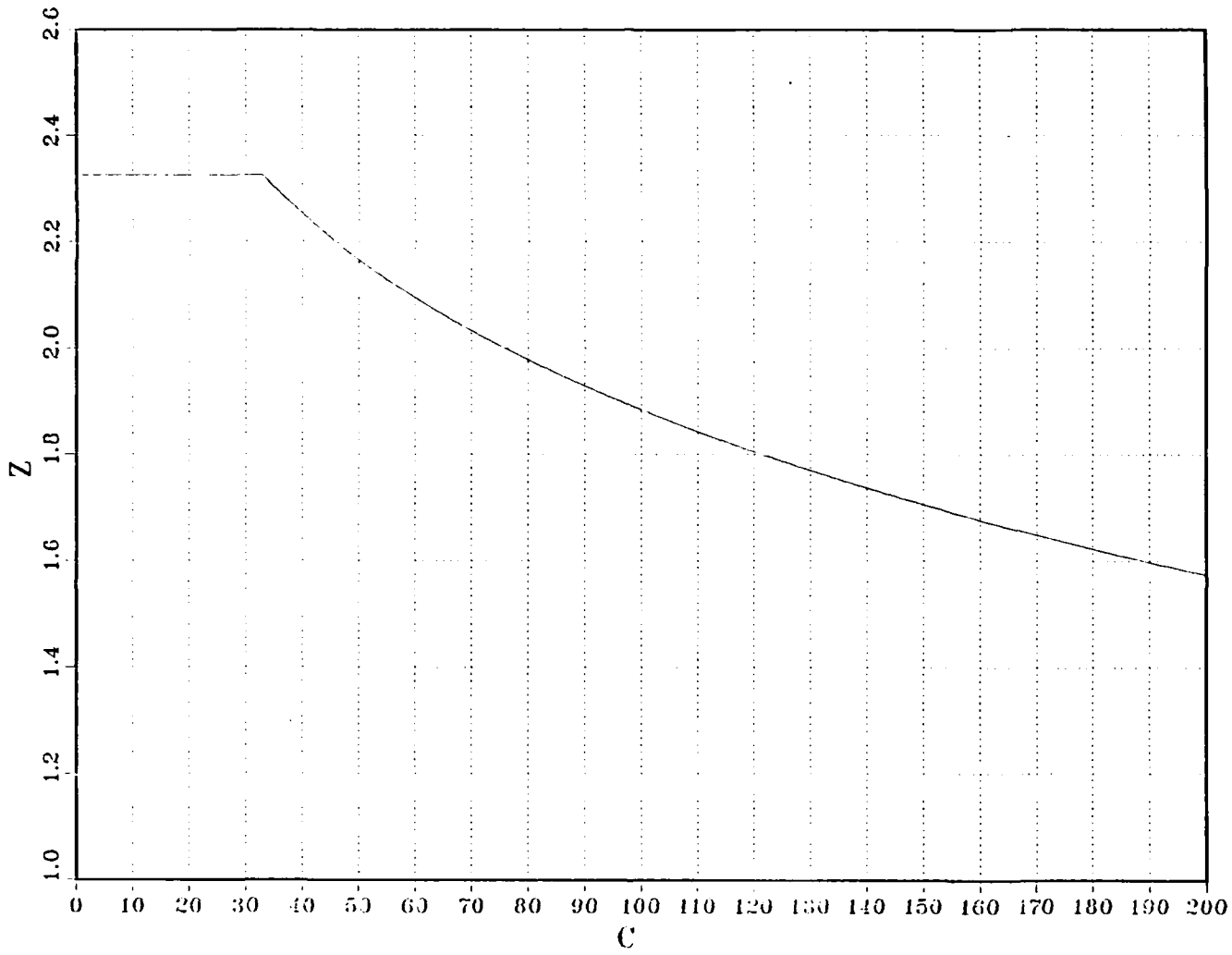

Figure 4. Safety Stock Parameter Z, as a Function of C

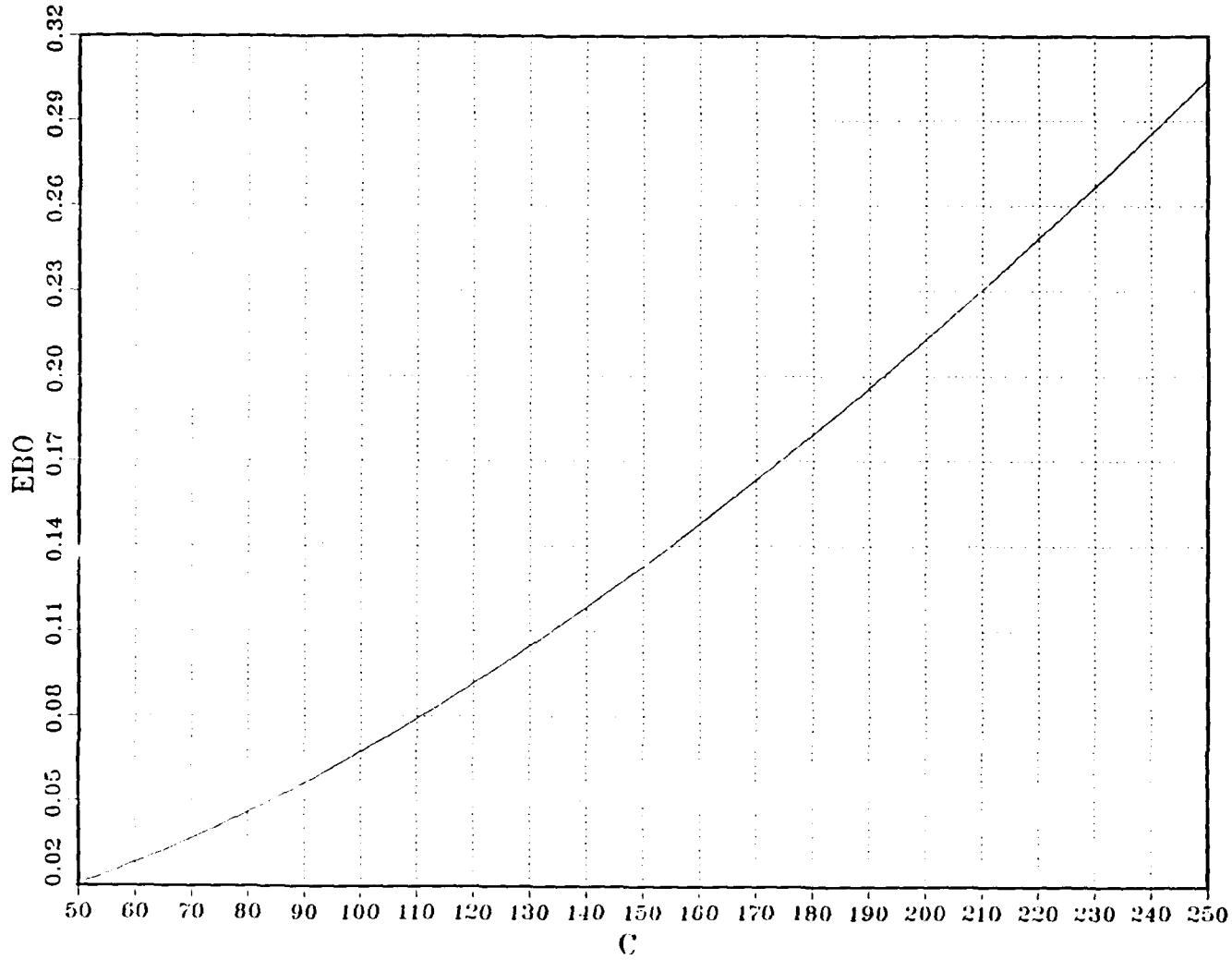

Figure 5. B(0,R) as a Function of C

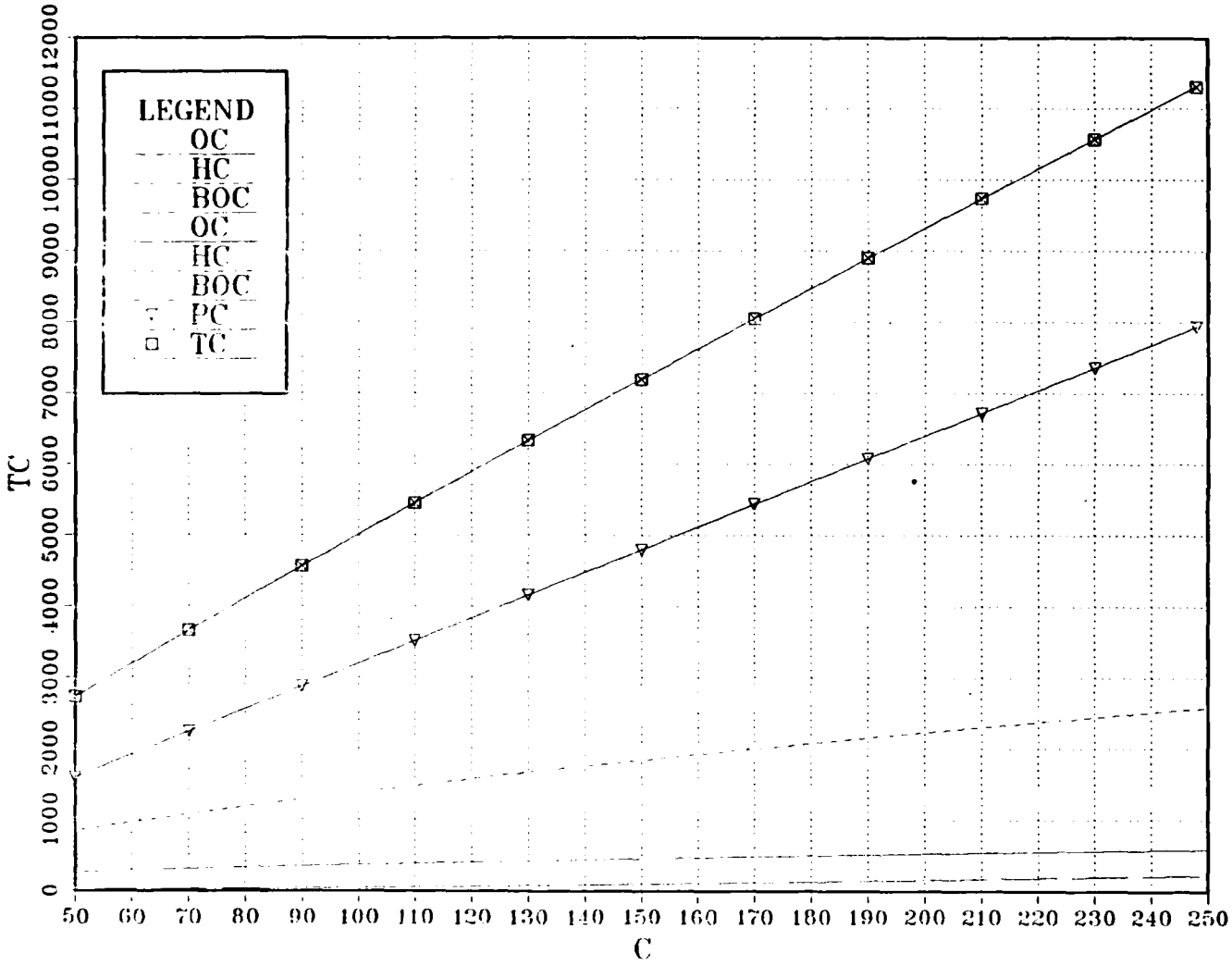

Figure 6. Components of the Inventory Cost as a Function of C

III. ISOCOST ANALYSIS

A. ANALYSIS METHODOLOGY

In Chapter II we analyzed the behavior of the expected total annual costs (TC) as a function of C and L by taking the partial derivatives with respect to each and studying their behavior. This provided an indication of the independent influences of C and L on TC. That analysis and the analyses to be presented in this chapter are based on the important assumption that TC represents a steady state situation in which the bid C and L values being evaluated will be the same for all future reprocurements. In this chapter we will analyze the behavior of TC when C and L are both allowed to vary. In particular, we will attempt to determine those C and L combinations which give the same value of TC.

Changes in both C and L from those currently in the ICP computer files are expected from a reprocurement buy. In fact, we expect each vendor who bids on the procurement contract will submit a bid having C and L values which are different from those of the other vendors.

In Chapter II we realized that the partial derivatives were complex functions of C and L and that we had to resort to computer-aided analysis of a simple numerical example. It is clear that allowing both C and L to vary will make the analysis problem even more complex and therefore we will also use computer-aided analysis of that same example in this chapter.

The computer program for this analysis is contained in Appendix A. It is designed to calculate, for each combination of C and L, the order quantity (Q), the reorder level (R), the expected number of backorders and then the values of the components of TC. All of the formulas and constraints from Chapter II are included. As in Chapter II, MAD_L is assumed to be independent of the bid value of lead time, permitting the same values to be used in computing σ for different bids.

B. VALUES OF C AND L

Both the ranges of C and L and the increment within each range need to be selected before the analysis can be conducted.

The range of lead time values we will use is from four to 16 quarters. The four quarters lower bound corresponds to the current average value of the time between when the reorder point triggers a buy and the contract is signed with the vendor. The maximum lead time values we have observed have been about 4 years or 16 quarters. The lead time increment used in the computer program was selected to be 0.25 quarters as a compromise (daily increments were considered to be much detail and quarterly increments were considered to provide insufficient detail).

The selection of a range for C is complicated by its role with the expected quarterly demand, D, in defining when certain other UICP model parameters change. They are used in defining the borders between Mark II and Mark IV and in defining the border between different values of the administrative

order cost A. Crossing the border between Mark II and Mark IV requires changing the equation for σ. That border is defined by CD = 75. For our example, we assumed the quarterly demand to be 8 so the border between the marks will be at $C = \frac{75}{8} = \$9.375$.

When the total purchase cost of a buy (CQ) exceeds a certain volume the value of A changes. At the time of the initial work done on this vendor bid problem [Ref. 5] the value of A changed from \$380 to \$1050 when CQ exceeded \$8000. These values have also been used in our example. The 1985 values have increased to \$390, 1080, and 10,000, respectively.

In our example we don't want A to change from the assumed value of \$380, therefore we need to find the range of C which ensures this for D = 8.

Now

$$CQ = C \cdot \sqrt{\frac{8AD}{IC}} = \sqrt{\frac{8ADC}{I}} = \sqrt{\frac{8.380 \cdot 8 \cdot C}{0.23}} = 325\sqrt{C}$$

Therefore, if $CQ \leq 8000$, then

$$325\sqrt{C} \leq 8000$$

resulting in

$$C \leq 605 .$$

Based on these "boundary" values for C, we selected a range for C, from \$1 up to \$600, and we will use increments of \$1.

C. TOTAL COST CURVES

The computer program was designed to run the ranges of unit costs from $1 to $600. For each unit cost the program computes a TC value for each lead time value from 4 quarters to 16 quarters in steps of 1/4 quarter. A sample printout is shown in Appendix B. However it is easier to visualize and study these results if they are presented graphically.

Ideally the results should be shown in three dimensional graphs. Unfortunately it is very difficult to present and understand the results from that kind of graph. Instead we have chosen to show the results on two dimensional graphs. Figures 7 and 8 show the results. Every 48 points on the x axis correspond to one unit cost value and all of the 48 lead time values ranging from 4 quarters to 15.75 quarters. This axis is called 'C and L' to reflect the sequencing. For example the first graph (Figure 7) shows a series of sloping steps; the first at the origin has a unit cost of $1 and the x axis values from 0 to 47 correspond to all the L values. The TC values of this first step begins $181 for L = 4 quarters and gradually increase as L increases to a value of $197 for L = 15.75 quarters. The second step corresponds to C = $2 and its TC values range from $233 to $258.

Figure 7 shows how TC behaves for very small values of C. From $1 to $9 the item is a Mark II item. Above $9 it is a Mark IV. The change from Mark II to Mark IV occurs at the "C and L" values of 432. Figure 7 has a maximum C value of $30. Figure 8 shows C values from $21 to $40.

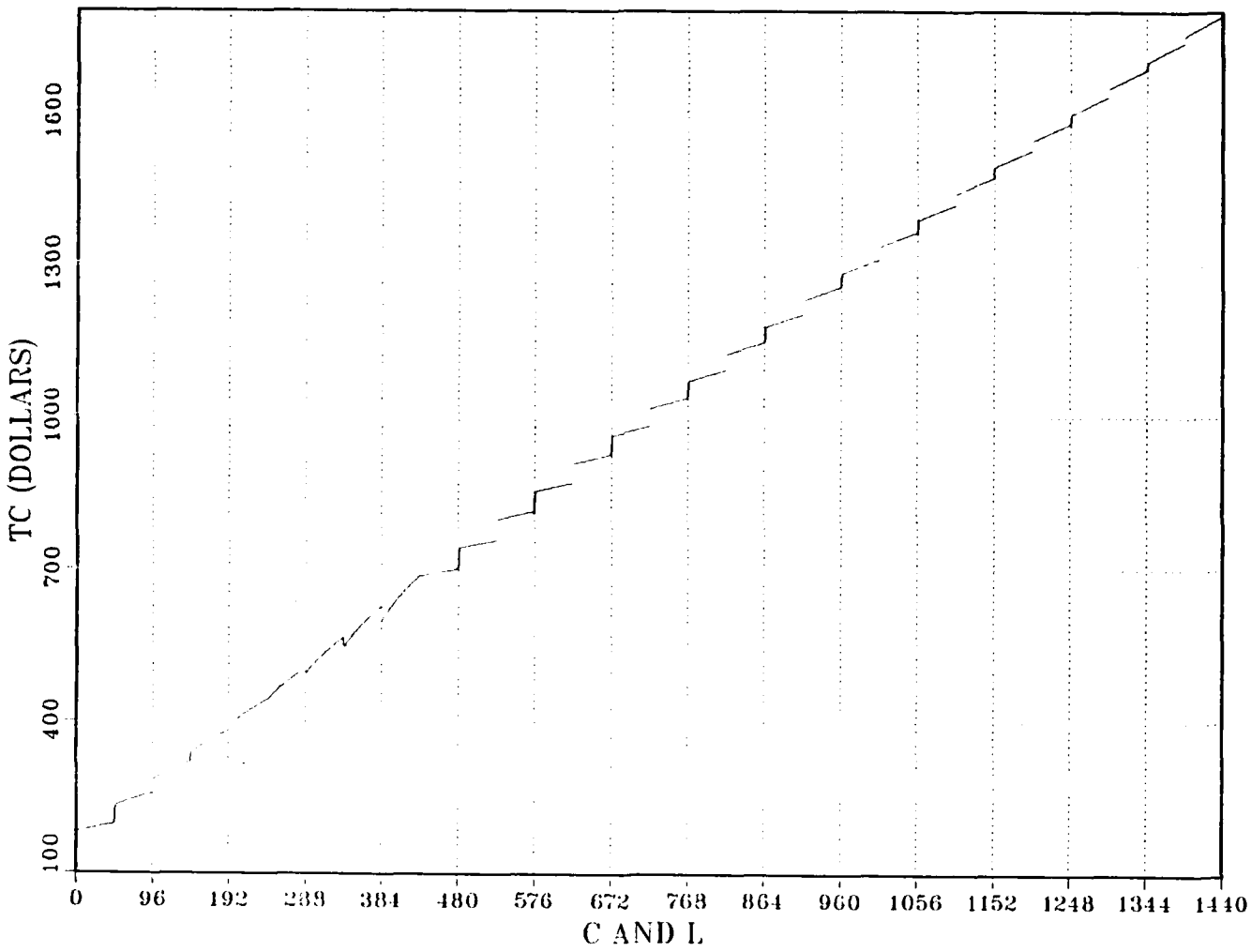

Figure 7. Total Cost as a Function of C and L

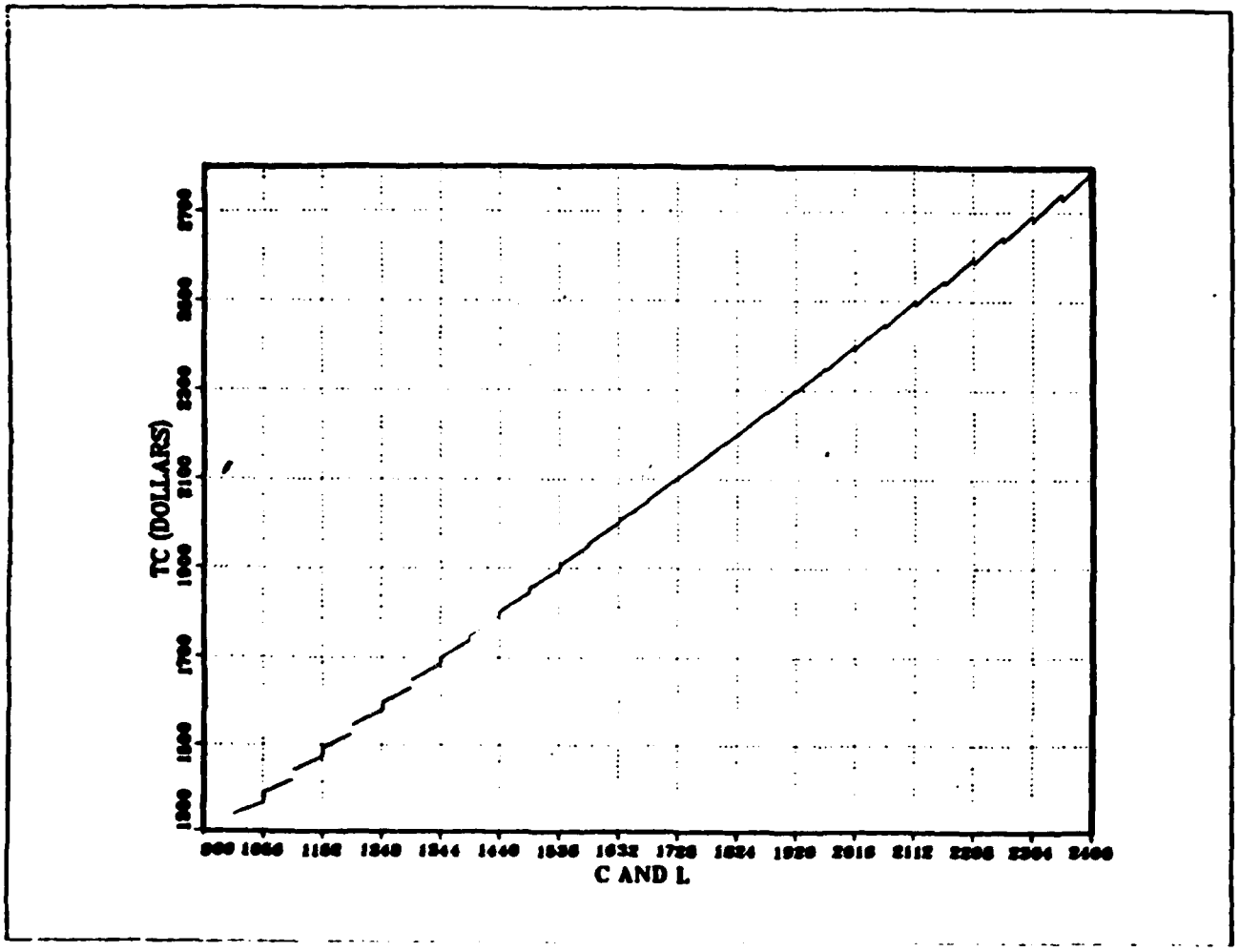

Figure 8. Total Cost as a Function of C and L

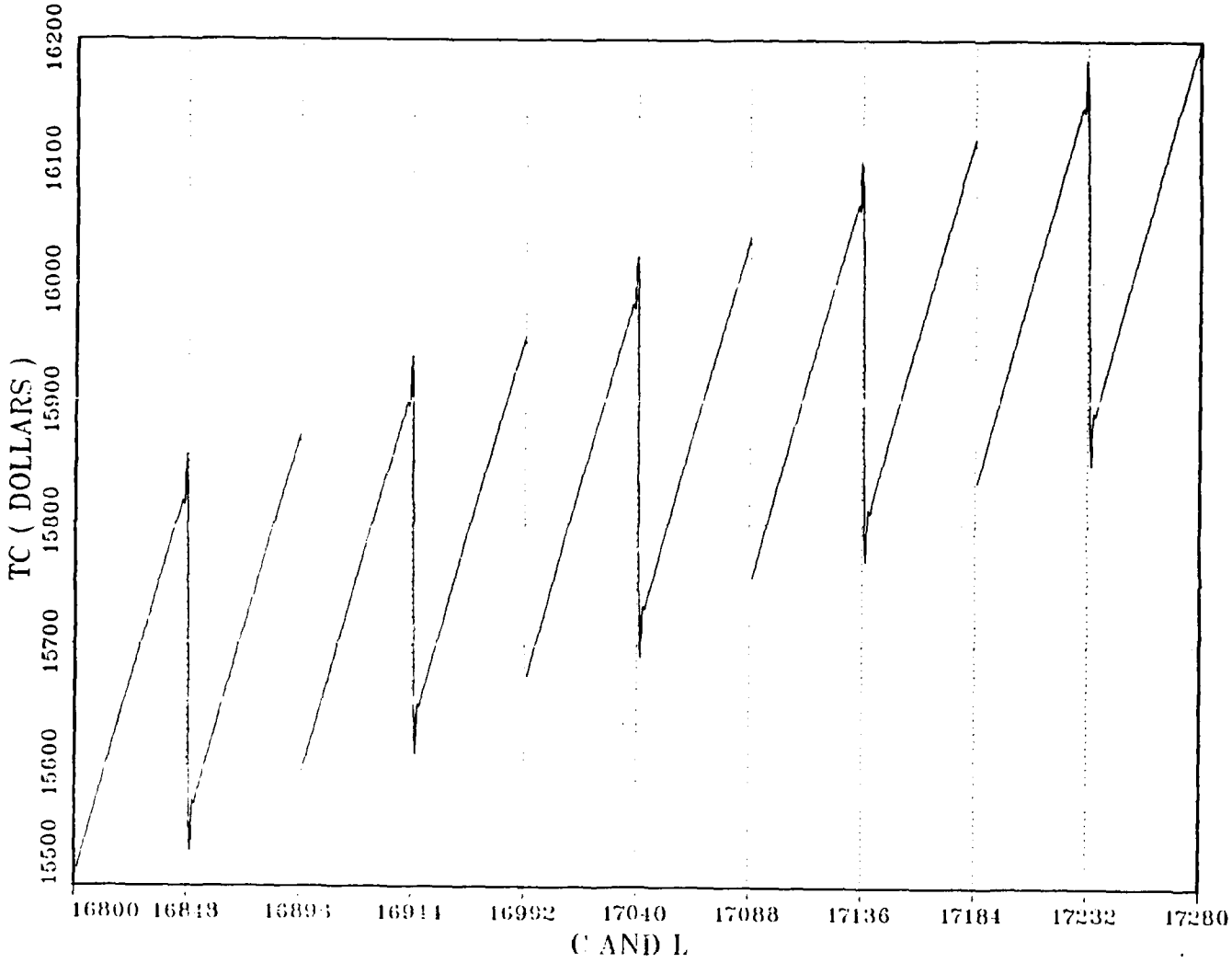

Figure 9. Total Cost as a Function of C and L

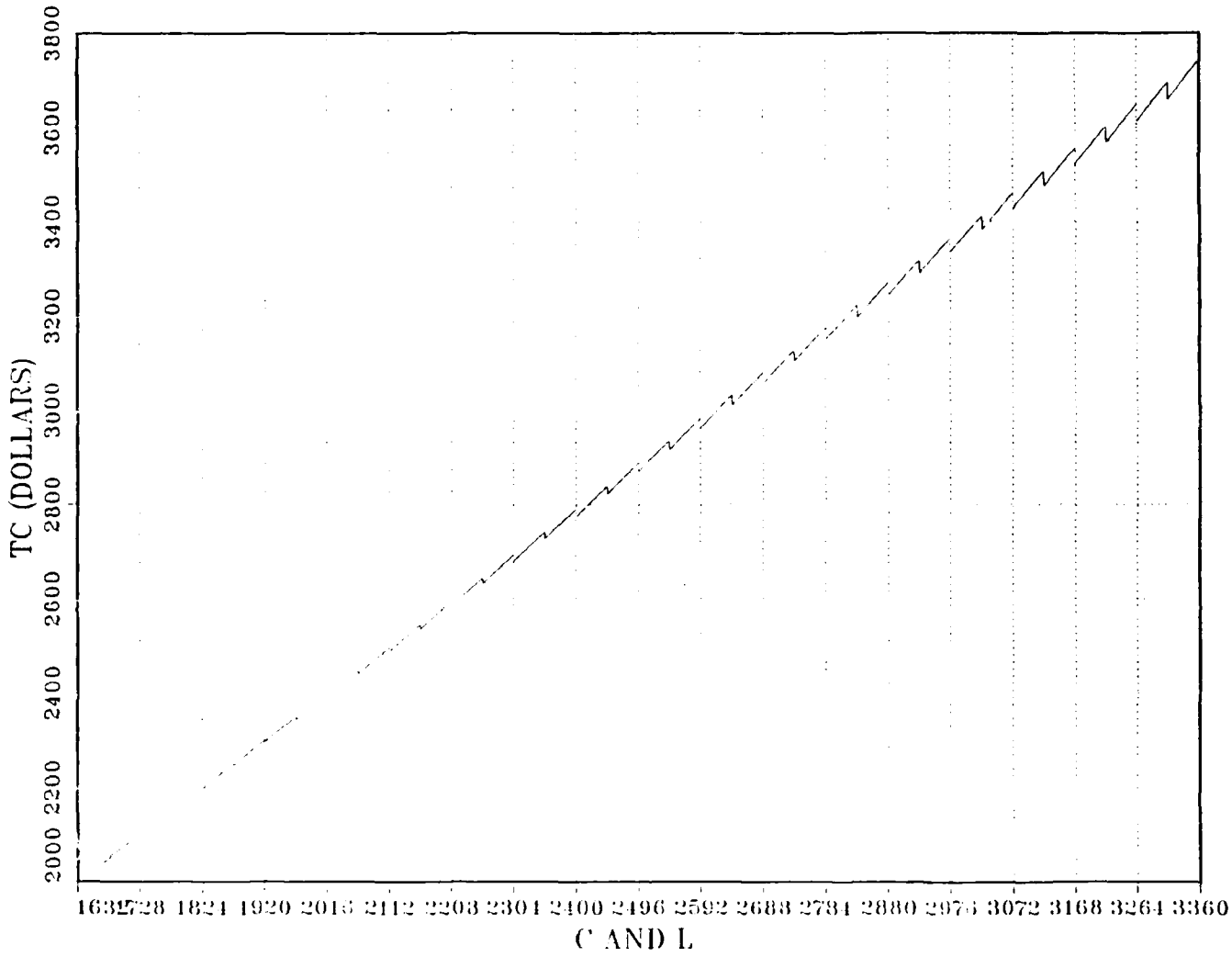

Figure 10. Total Cost as a Function of C and L

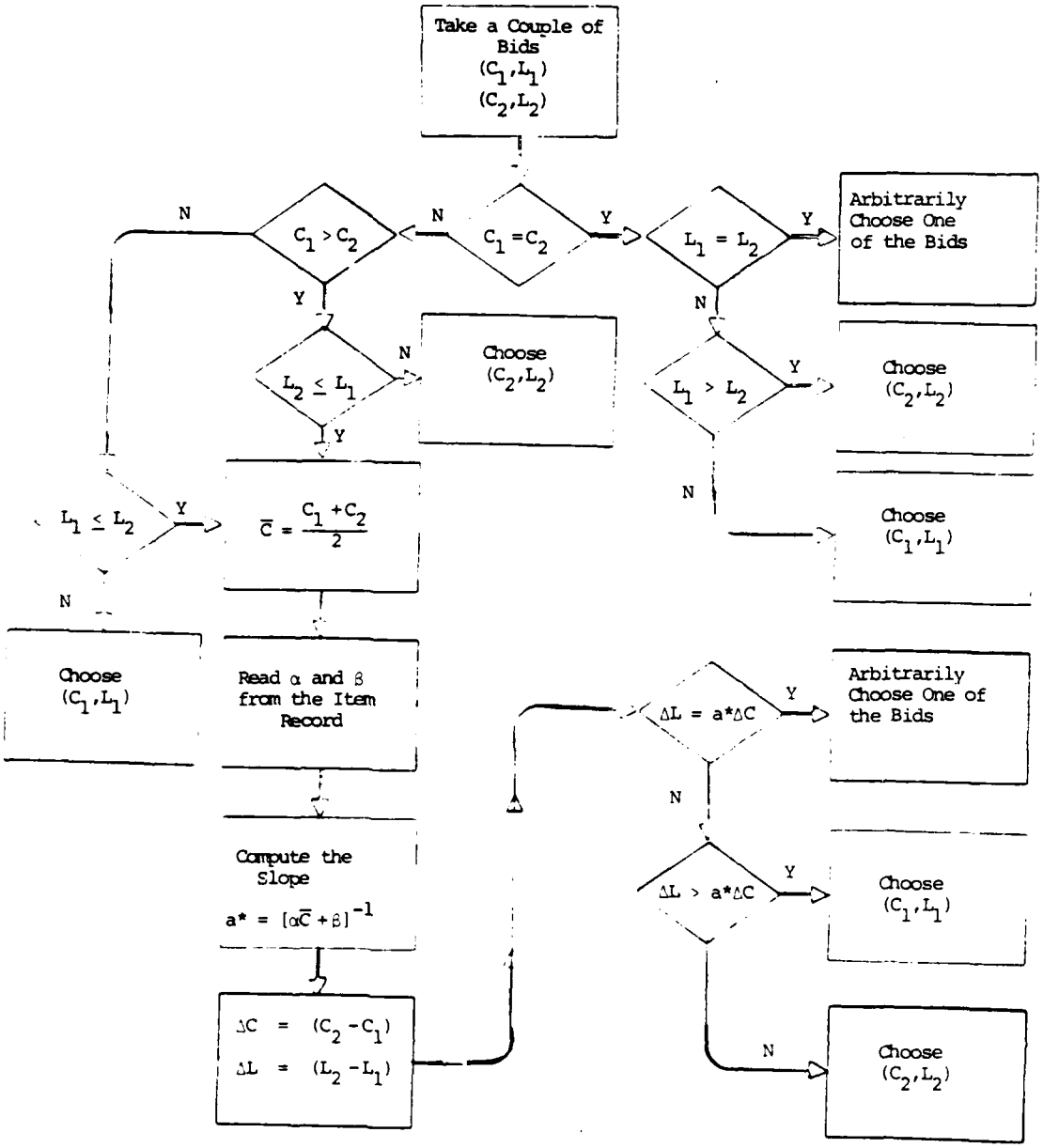

Figure 17. Bid Evaluation Flow Diagram

IV. A BID EVALUATION TECHNIQUE

A. INTRODUCTION

It is obvious that anyone could use a computer program similar to that used in Chapter III to compute the TC for each bid. However, this would require that a procurement officer have access to the ICP mainframe computer so that he could make several computer runs. This could take considerable time and money even if computer capacity was available. Because this is not usually possible at an ICP due to saturated computer capacity, some simpler approach is needed for bid evaluation. The purpose of this chapter is to present such an approach for consumable items. This approach would require, at the most, access to a micro computer. In most cases, it would require only a hand-held calculator.

B. BID EVALUATION

The bid evaluation procedure is shown as a flow diagram in Figure 17 and will be discussed in this section. It can be used for any number of bids but can consider only two at a time. In the following discussion we will therefore consider only two bids, denoted by (C_1,L_1) and (C_2,L_2).

The first step is to determine which bid has the lower unit cost C since this is the dominant bid parameter. Three cases can occur: $C_1 = C_2$, $C_1 < C_2$, or $C_1 > C_2$.

If we have $C_1 = C_2$ then we must examine the values of L_1 and L_2. If $L_1 = L_2$ then the two bids are identical in the

The formula for the curve will therefore be:

$$a = \frac{1}{-0.0017638C - 0.0536825} .$$

This curve has been plotted on Figure 16 and we see that it provides a very good fit to the points on the graph. While more precise methods can be applied to find the curve, we suspect that in most cases the function we have selected reflects the general shape of the curve.

From this curve we see that for small values of the unit cost the slope a is very negative which means that a large reduction in L is needed to compensate for a small increase in C in order to maintain the same total cost value. For large values of C the slope a approaches -1 which means the isocost line has an angle of -45°. Thus, the unit cost and the lead time have almost the same influence. A small increase in the unit cost can be compensated for by a small reduction in the lead time in order to remain at the same total cost value.

We can now attempt to fit a mathematical curve through the points on this graph. Although we could try a variety of formulas, our intuition suggests that the curve behaves as:

$$a = \frac{1}{\alpha C + \beta} .$$

We see that the denominator is a linear function of C. The parameters α and β can be found by using two extreme points of the curve. For this example, when C = \$178 the slope a is -2.72, and when C = \$302, the slope a is -1.7. Substituting these values to the above formula, we get

$$-2.72 = \frac{1}{178\alpha + \beta}$$

$$-1.7 = \frac{1}{302\alpha + \beta}$$

which can be rewritten in the following form

$$484.16\alpha + 2.72\beta = -1 ;$$

$$513.4\alpha + 1.7\beta = -1 .$$

Solving these two equations for the two variables gives:

$$\alpha = -0.0536825 ;$$

$$\beta = -0.0017638 .$$

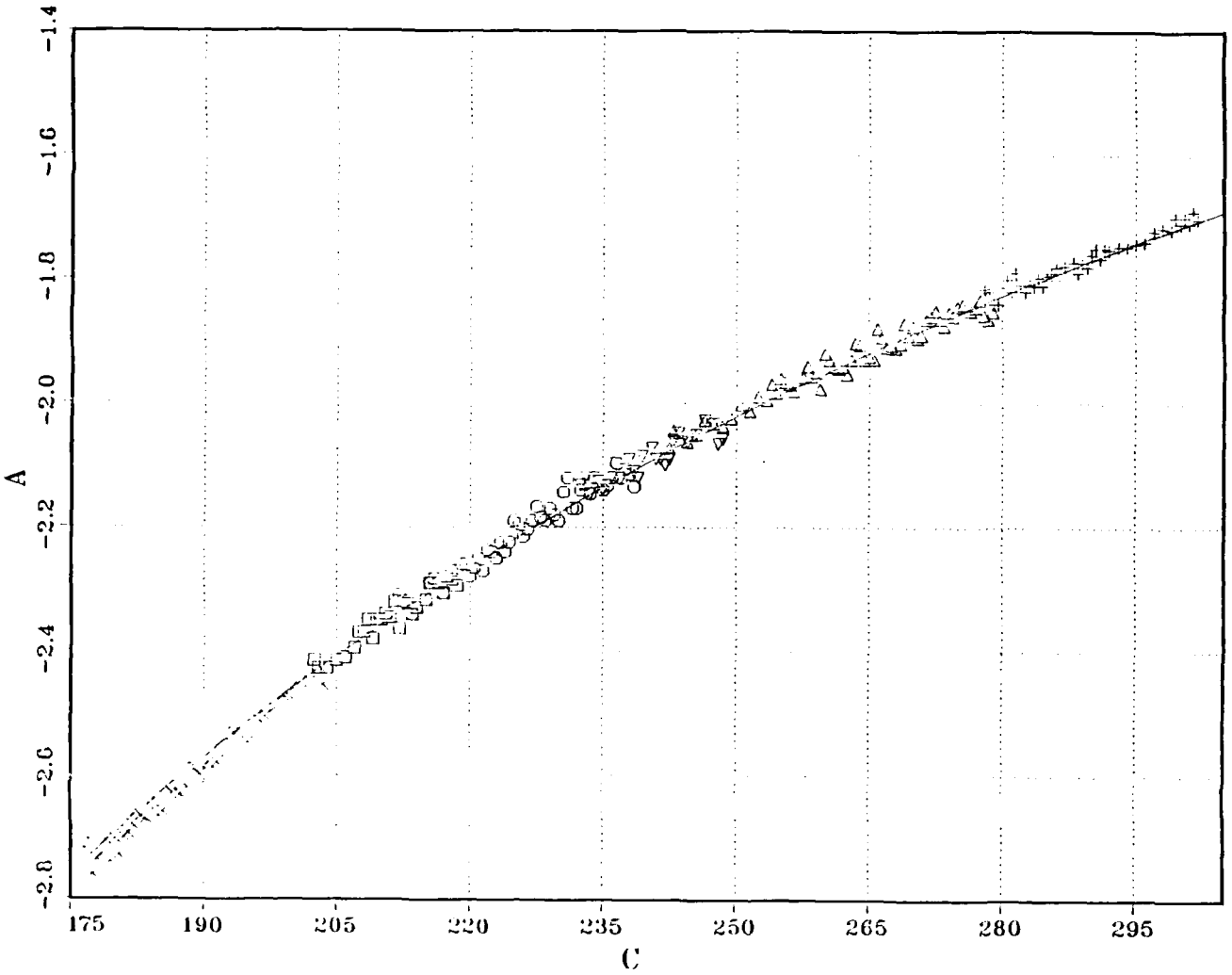

Figure 16. Isocost Slopes as a Function of C

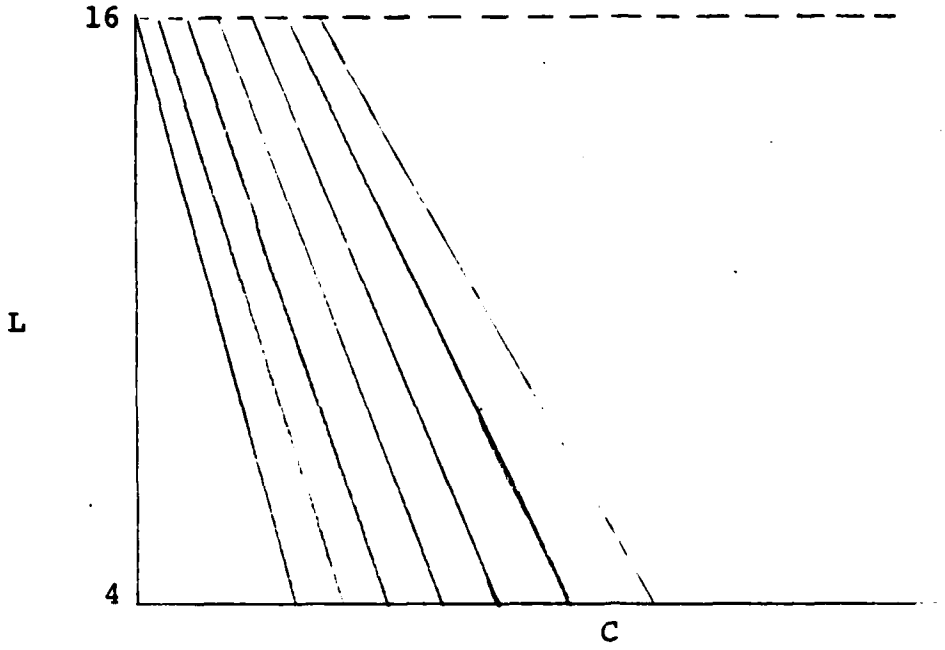

Figure 15. Theoretical Shape of Isocost Lines

We could fit a curve to the data of Figure 14 to obtain the function a = f(TC). However, we are more interested in providing a tool for procurement personnel and therefore we prefer to discuss a curve of the slope a as a function of C. Each TC value has a certain corresponding value of the slope a as shown in Figure 14. On the other hand, each TC has a range of C which creates this TC as shown in our example in Table 1 and theoretically in Figure 15. We can compute the average of these C values from the range of values used in the computer program to generate Figure 14 and relate this average to the corresponding slope values via the corresponding TC value. The graph of the slope a versus C which results is shown in Figure 16. As should be expected, this curve also has oscillations.

TABLE 1

Data for the Isocost Lines

TC = 10,060			TC = 10,070			TC = 10,080		
C	L	Actual TC	C	L	Actual TC	C	L	Actual TC
213	14.5	10,056	213	15.0	10,065	213	15.75	10,078
213	14.75	10,061	213	15.25	10,069	214	13.25	10,077
214	12.0	10,055	213	15.5	10,074	214	13.5	10,081
214	12.25	10,059	214	12.75	10,068	215	10.75	10,075
214	12.5	10,064	214	13.0	10,073	215	11.0	10,079
215	9.75	10,056	215	10.25	10,066	215	11.25	10,084
215	10.0	10,061	215	10.5	10,070	216	8.5	10,076
216	7.5	10,057	216	8.0	10,066	216	8.75	10,080
216	7.75	10,062	216	8.25	10,071	217	6.25	10,076
217	5.25	10,057	217	5.75	10,066	217	6.5	10,080
217	5.5	10,062	217	6.0	10,071	218	4.0	10,075
						218	4.25	10,080
						218	4.5	10,084
a = -2.31			a = -2.35			a = -2.29		

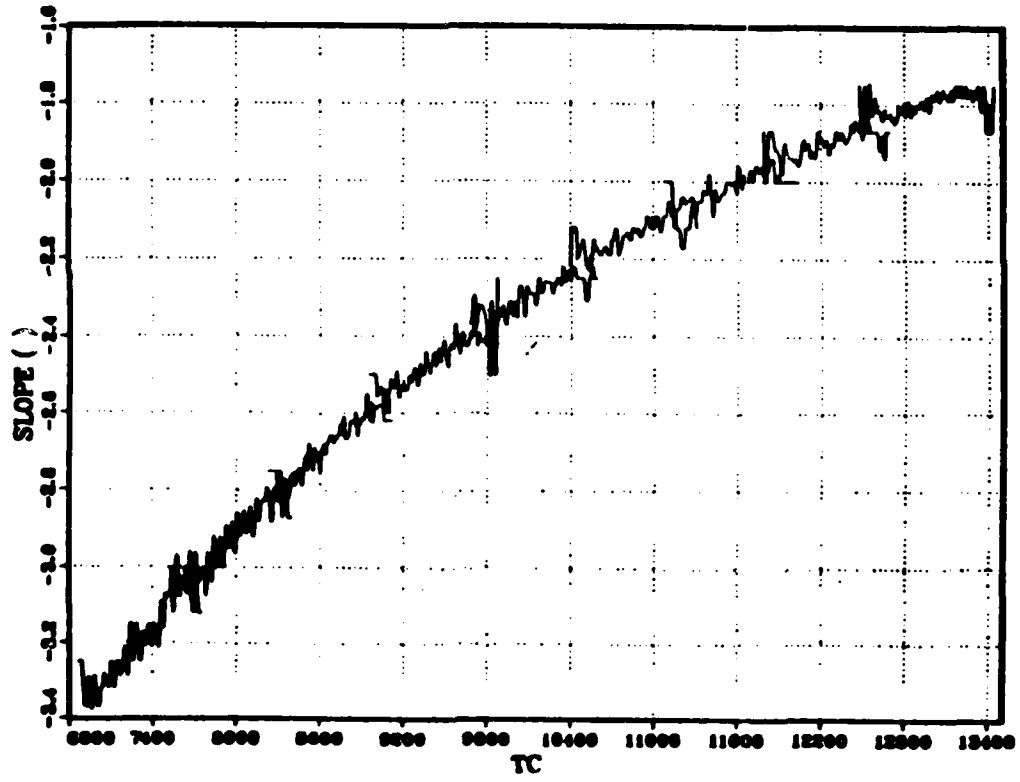

Figure 14. Isocosts' Slopes as a Function of the Total Cost

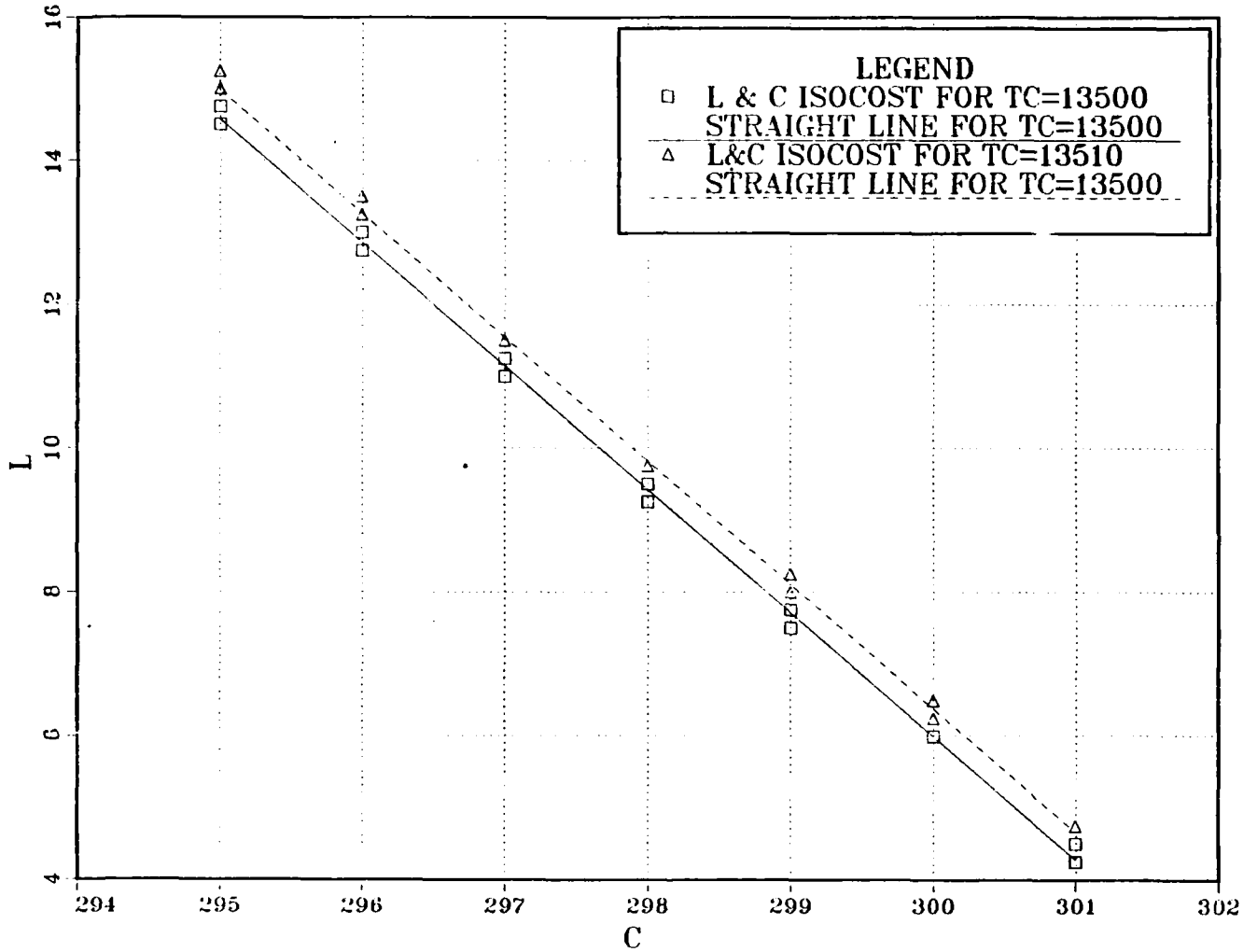

Figure 13. Isocost Lines

coefficient of 0.999 and therefore the shape of the isocost line can be considered as linear. The equation for the isocost line is

$$L = -1.71C + 520.29$$

Figure 13 shows the resulting line. This figure also shows the line for TC = $13,510 and indicates that as TC increases, the isocost line would move to the right.

A computer program (Appendix C) was written to compute the parameters of the isocost lines for TC values from $6800 to $13,400. For each TC value C,L pairs were used if they resulted in a value which was within $5 of the desired TC value. Typical results from the program are presented in Appendix D. From these results a curve of the slope a was plotted as shown in Figure 14. If the oscillations are ignored, it is clear that the slope becomes less negative as TC increases and that theoretically a family of isocost lines should appear as shown in Figure 15.

The oscillations are a consequence of the use of C,L combinations which are not exactly the value of TC. In other words, the inaccuracies induced by "rounding" to the nominal value of TC create least square fits with slopes which oscillate. Table 1 illustrates the situation. As the rounding range is reduced, the oscillations are also reduced and, in the limit, would provide a smooth curve of a as a function of TC.

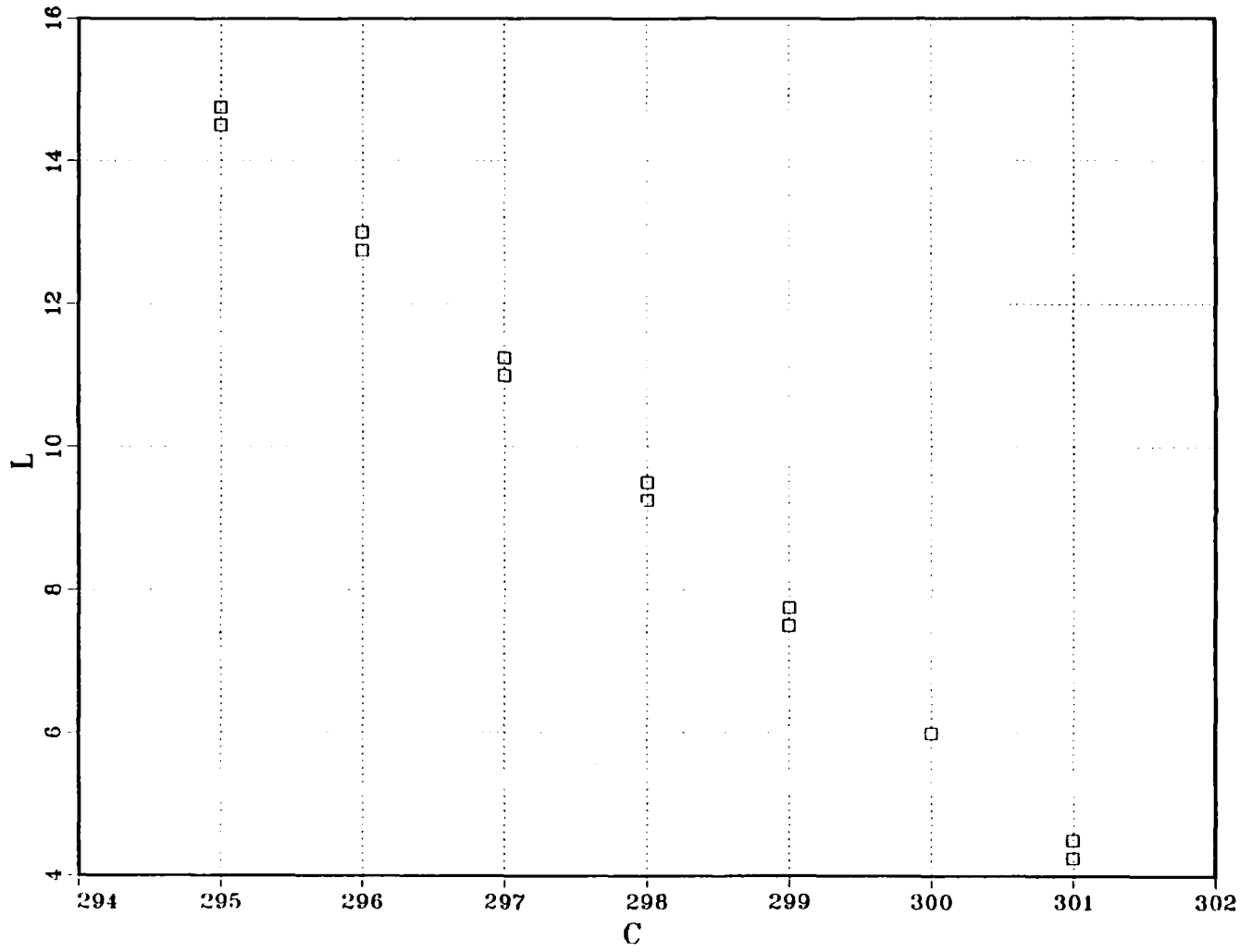

Figure 12. C and L Combinations Which Produce the Same Total Cost ($13,500)

D. ISOCOST LINES

Isocost is a term from microeconomics which means that we have numerous combinations of two resources which can be used to produce the same quantity of product. As Heinz Kohler observed [Ref. 4], "We can draw a family of straight isocost lines, each of which shows all the alternative combinations of two inputs that the firm is able to buy in a given period at current market prices, while incurring the same total cost." As we can see from Figures 7, 8, 9, and 10, the variables of interest, C and L, do have several combinations which produce the same TC value. The questions which remain to be answered are:

1. Can isocost curves be constructed for all L and C values in the ranges we are considering?
2. What is the shape (linear or non-linear) of those isocost curves that can be constructed?

The answer to the first question is that isocost curves can only be constructed for those C values above the thresholds observed in the last section (C = $5 for Mark II and C = $38 for Mark IV). The answer to the second question requires us to examine some C and L pairs.

Figure 12 presents thirteen combinations of C and L in the Mark IV category. These combinations correspond to a nominal value of TC of $13,500. In reality, searching for C, L pairs which give TC = $13,500 precisely is extremely time-consuming. What is shown are C,L pairs which gave TC values within the range of $13,500 ± $5. A least squares fit of a straight line through these points resulted in a correlation

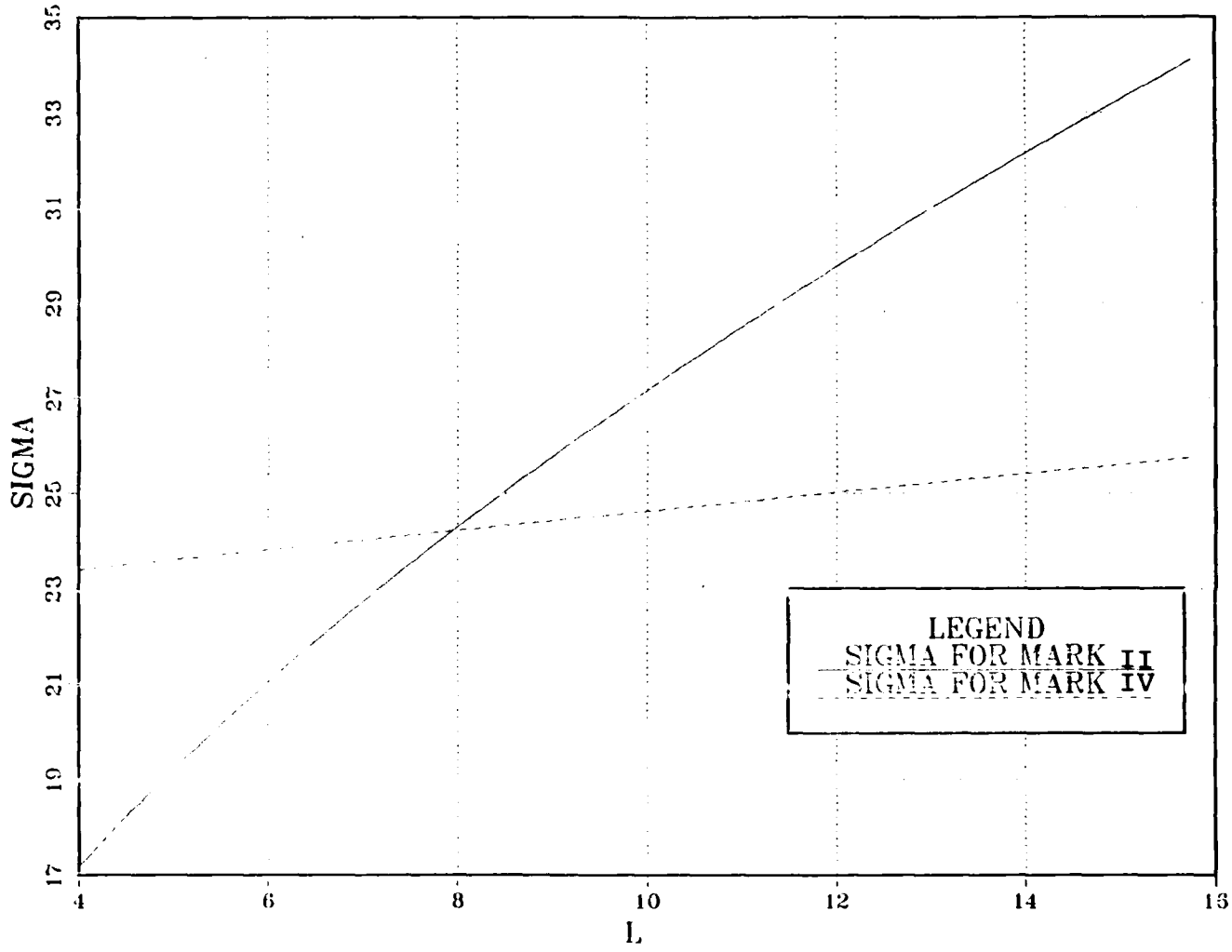

Figure 11. Behavior of σ in the Mark II Region and Mark IV Region

The behavior of the TC curves in Figures 7 and 8 for the Mark II and Mark IV ranges of C are similar. For the low C values in each range, each TC step is higher than that for the preceding C values for all of its range of L values. Thus, if we had two bidders whose C values are in this range, the bidder with the lowest C value would be the winner regardless of his L value.

On the other hand, after C passes a certain threshold for each Mark, we see the same TC values can occur for two adjacent values of C. In fact, Figure 9 shows this can occur for more than two C values. In such a situation, we would not want to automatically select a bidder with the lower C value until we had compared his L value with that of the higher cost bidder. The threshold C value for Mark II appears to be $5 and, for Mark IV, it appears to be $38.

The reason for the change in slopes between the C = 9 curve (Mark II) and the C = 10 curve (Mark IV) is due to the difference in the formula for the standard deviation of lead time demand between the two Mark codes. Figure 11 shows that the Mark II standard deviation increases with L much more rapidly than for the Mark IV. Since R and hence B(Q,R) are increasing functions of L because of their relation to the standard deviation, the shortage costs and safety stock holding costs terms of TC increase more rapidly with L for Mark II than for Mark IV for any given C value.

sense of the bid parameters and vendor selection is left to the discretion of the procurement personnel. If $L_1 < L_2$, then (C_1,L_1) is the better bid since it provides the lower TC value (as Figure 7 showed). If $L_2 < L_1$, then (C_2,L_2) is the winner for the same reason. The upper right side of Figure 17 describes these steps.

If $C_1 < C_2$ and if $L_1 \leq L_2$ then the bid (C_1,L_1) is the better. Similarly, if $C_1 > C_2$ and $L_2 \leq L_1$ then (C_2,L_2) is the better. Again, the reasoning can be confirmed by referring to Figure 7. The steps for these comparisons are shown in the top part of the left side of Figure 17.

If $C_1 < C_2$ and if $L_1 > L_2$ or $C_2 < C_1$ and $L_2 > L_1$ then we must determine which bid has the lower TC value by using α and β. We first compute the average of C_1 and C_2; that is

$$\overline{C} = \frac{C_1 + C_2}{2} .$$

We then compute the slope associated with $\overline{C}$ using the following formula:

$$a^* = [\alpha\overline{C} + \beta]^{-1} .$$

Next we compute the differences in the C and L values using the following formulas:

$$\Delta C = (C_2 - C_1) ;$$

$$\Delta L = (L_2 - L_1) .$$

Finally, we compare ΔL with the value of the product $a^*\Delta C$. If $\Delta L > a^*\Delta C$ then (C_1,L_1) is the better bid; if $\Delta L < a^*\Delta C$ then (C_2,L_2) is the better bid, and if $\Delta L = a^*\Delta C$ both bids are equally good. The steps of this comparison are shown in the bottom part of Figure 19.

The reasoning behind these comparison steps can be deduced by considering Figures 18 and 19.

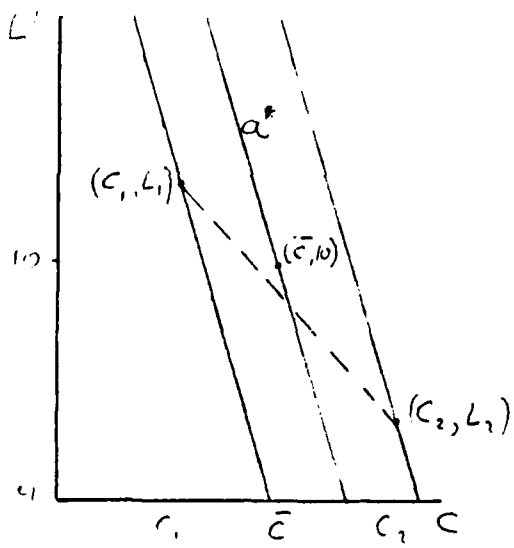

Figure 18. (C_1,L_1) with Lower TC Value

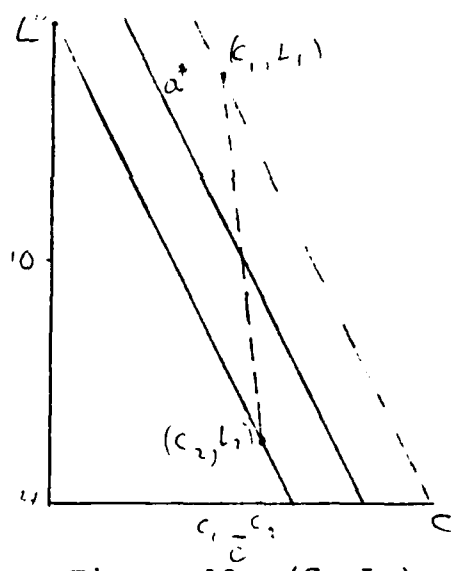

Figure 19 (C_1,L_1) with Higher TC Value

In Figures 18 and 19, we see the isocost line for $\bar{C}$ passing through the point $(\bar{C},10)$ where $L = 10$ is the average value of L. The value of a^* is, in fact, the slope of the isocost line passing through this "average point" as a consequence of the analysis from the last section of Chapter III.

In Figure 18 we see that (C_1,L_1) has a lower TC value than (C_2,L_2). If we connect these two points with the dotted line, the slope of that line is:

$$a = \frac{\Delta L}{\Delta C}$$

and we see that $a > a^*$ since it is less negative. Now we can rewrite that inequality as

$$\frac{\Delta L}{\Delta C} = a > a^*$$

and, after multiplying both sides by ΔC, we obtain the first result that

$$\Delta L > a^* \Delta C .$$

In Figure 19 the (C_2,L_2) bid has the lower TC value. In this case the slope of the line is

$$a = \frac{L_1 - L_2}{C_1 - C_2} = \frac{L_2 - L_1}{C_2 - C_1} = \frac{\Delta L}{\Delta C}$$

In this case, however, $a < a^*$ since it is more negative. Thus

$$\frac{\Delta L}{\Delta C} = a < a^*$$

and therefore

$$\Delta L < a^* \Delta C .$$

C. AN EXAMPLE

The example in this section illustrates the technique described above. Let us suppose that the current price and lead time are \$230 and 10 quarters, respectively, $\alpha = -0.00176$ and $\beta = -0.0537$, and the rest of the parameters are those of the example in Chapter II. Now suppose we have received four new bids:

a) \$228 and 15 quarters;

b) \$232 and 5 quarters;

c) \$232 and 6 quarters;

d) \$233 and 4 quarters.

As we explained in Section B, we will consider two bids at a time. Let us take b and c. In this case we denote them as 1 and 2, respectively.

$$C_1 = \$232 \qquad L_1 = 5 \ ;$$

$$C_2 = \$232 \qquad L_2 = 6 \ .$$

Figure 17 tells us that when we have $C_1 = C_2$, we have to check L_1 and L_2. In this case L_2 is greater than L_1 so bid 1 is better. Now let us compare bid d with the winner bid (b). As above, we now denote these as 1 and 2, respectively.

$$C_1 = \$233 \qquad L_1 = 4 \ ;$$

$$C_2 = \$232 \qquad L_2 = 5 \ .$$

Now we must use the left side of Figure 18 because we have C_1 is greater than C_2 and L_2 is greater than L_1. We have to compute the slope a*. The first step is to compute $\overline{C}$.

$$\overline{C} = \frac{233 + 232}{2} = 232.5 .$$

Substituting α, β, and $\overline{C}$ values into the a* formula, we obtain

$$a^* = [-0.00176 \cdot 232.5 + (-0.053)]^{-1} = -2.16 .$$

Next we need the value of ΔC and ΔL.

$$\Delta C = C_2 - C_1 = 232 - 233 = -1$$

$$\Delta L = L_2 - L_1 = 5 - 4 = 1$$

The ΔL test needs $a^*\Delta C$.

$$a^*\Delta C = (-2.16)(-1) = 2.16$$

comparing ΔL with $a^*\Delta C$, we see that

$$\Delta L < a^*\Delta C,$$

and therefore (C_2, L_2) is the better bid. This corresponds to bid b.

Now we must compare bid a to bid b. We denote them as 1 and 2, respectively.

$$C_1 = \$228 \qquad L_1 = 15 \;;$$

$$C_2 = \$232 \qquad L_2 = 5 \;.$$

In this case again we must use the left side of Figure 17 since C_2 is greater than C_1 and L_1 is greater than L_2.

$$\bar{C} = \frac{228 + 232}{2} = 230$$

$$a^* = [-0.00176 \cdot 230 + (-0.053)]^{-1} = -2.18$$

$$\Delta C = C_2 - C_1 = 232 - 228 = 4$$

$$\Delta L = L_2 - L_1 = 5 - 15 = -10$$

$$a^* \Delta C = (-2.18)4 = -8.72$$

Comparing ΔL with $a^* \Delta C$ we again have

$$\Delta L < a^* \Delta C$$

and therefore (C_2, L_2) is better which means that bid b is a better bid than a. We also know now that it is the best of the four bids.

We can now compare this result to the real total costs from the computer program as shown in Table 2. Table 2 shows the TC values for each bid determined by the computer program and confirms our conclusion.

TABLE 2

Computed Values of TC

Bid	Unit Price C	Lead Time L	Total Cost
a	228	15	10,700
b	232	5	10,680 * (the best)
c	232	6	10,700
d	233	4	10,700
current terms	230	10	10,690

D. MODIFICATION TO THE UICP PROGRAM

To facilitate this approach two additional item parameters need to be computed and stored in the Master Data File (MDF). These should logically be computed each quarter by the cyclic levels and forecasting application (D 1). The additional parameters are the values of α and β from the curve fit to the plot of a as a function of C (see Figure 16). The subroutines needed to make these calculations can be developed from the programs in Appendices A and C. Then, when the request to make a buy of an item is sent to the procurement personnel by the inventory manager, the former can use these parameters in evaluating bids from vendors.

V. SUMMARY AND CONCLUSIONS

A. SUMMARY

Chapter II presented a brief overview of the purpose and underlying assumptions of SPCC's UICP wholesale consumable procurement model. The model's total variable cost equation and optimization results were presented, and it was shown that the model determines the optimum order quantity and reorder level for an item based on that item's forecasted quarterly demand rate, procurement lead time and unit price. Later in the chapter we analyzed the behavior of the total inventory cost as independent functions of the unit price and the procurement lead time. The total cost was found to be a linear function of each of these two variables.

Chapter III examined the behavior of the total costs as a combined function of these two variables. The results showed that equal values of the total inventory costs existed for different pairs of C and L. This fact suggested that we could find an isocost curve describing all the combinations of C and L. Subsequent analysis showed this curve to be a straight line. The slope of this line was also found to be a nonlinear function of unit costs and a formula was found which described that change.

Chapter IV then used this information to develop a simple technique for evaluating different bids.

B. CONCLUSIONS AND RECOMMENDATIONS

Total inventory costs can be reduced through modifications of the procurement process to include procurement lead time as well as unit price in selecting the winning bid for stock replenishment contracts. The simple technique developed in Chapter IV can be used to efficiently evaluate bids containing lead time as well as unit price.

Implementation of the technique can be done in three major steps.

The first step would be to add a subroutine to the UICP "levels" application (D 1) which would calculate for each item the parameters needed for using the technique. After calculating these parameters (which should be done quarterly), they should be included in the Master Data File for each item so that they can be given to procurement personnel when a replenishment buy is needed.

The second step would be to develop a procedure for providing the procurement personnel with the additional information and computing equipment needed to use the technique.

The third step would be to train procurement personnel in the use of the technique. It may also be appropriate to explain the evaluation technique to potential vendors who are going to compete for supplying the item to the Navy. Some initial monitoring of the use of the technique should also be considered.

C. AREAS FOR FURTHER RESEARCH

The fit of a mathematical expression to the curve of the slope of isocost lines as a function of unit price needs further investigation. Statistical validation of the proposed mathematical expression from Chapter III is needed and possible other functions should be investigated also.

In the implementation of the additions to the UICP levels application D 1, discussed in Chapter IV, several modifications of the programs from Appendices A and C should be investigated which have the potential for reducing the computational steps. One modification would be to limit the range of unit price values used to determine the parameters needed for the bidding technique to those values which would be expected to be bid. Perhaps, for example, a range of unit price values from ninety to two hundred percent of the current value stored in the Master Data File is reasonable.

Another related improvement would be a procedure for automatically selecting the incremental value of unit price to be used to develop the curve of isocost slopes as a function of unit price. The size of the increments influences the computer program's ability to compute isocost slope values and the time required to determine them. Manifestations of the problem are the "threshold values" observed in Figures 7 and 8 of Chapter III. Below such values it appeared that no slopes could be or needed to be computed. In reality, these threshold values go to zero as the increments of the unit price go to zero

and slopes can indeed be determined for all positive unit prices. However, as a unit price approaches zero, the isocost slope approaches negative infinity. A tradeoff analysis is therefore needed between the size of the increment and the need for isocost slope values for small unit price values. The results of such an analysis should provide a formula or a "rule of thumb" for determining the unit cost increment size to use for developing the isocost slope curve.

A P P E N D I X A

```
$JOB
C*********************************************************************
C THIS IS A NONINTERACTIVE PROGRAM UTILIZING THE WATFIV COMPILER WHICH *
C INPUTS AN INVENTORY ITEM'S CHARACTERISTICS FROM A DATA FILE AND THEN *
C DETERMINES THE OPTIMAL ORDER QUANTITY AND REORDER LEVEL AND THE      *
C AVERAGE ANNUAL COST OF STOCKING THE ITEM . THE PROGRAM GOES OVER     *
C NUMEROUS VALUES OF UNIT PRICE (C) AND LEAD TIME (L),AND FOR EACH     *
C COMBINATION CLCULATES THE ABOVE PARAMETERS.THE PROGRAM IS ACTIVATED  *
C BY AN EXEC FILE WHICH DEFINES THE OUTPUT FILES AND LOADS THE IMSL    *
C SUBROUTINES.                                                         *
C*********************************************************************
C
C ********** VARIABLE DEFINITIONS **********
C  A = ADMINISTRATIVE COST OF PLACING AN ORDER
C  BOC = AVERAGE ANNUAL COST OF BACKORDERS
C  C = UNIT PRICE
C  CCC = INITIAL UNIT PRICE
C  CQ = PURCHASE COST
C  D = AVERAGE QUARTERLY DEMAND RATE
C  E = ITEM ESSENTIALITY (MILITARY WORTH)
C  EBO = EXPECTED NUMBER OF BACKORDERS JUST BEFORE AN ORDER ARRIVES
C  ERR = ERROR NUMBER
C  F = REQUISITION FREQUENCY (D/S)
C  G = MAXIMUM BOUND ON Q
C  HC = AVERAGE ANNUAL HOLDING COST
C  I = INVENTORY HOLDING COST RATE (FRACTION OF UNIT PRICE PER YEAR)
C  IG = COUNTER FOR UNIT PRICE
C  II = COUNTER FOR LEAD TIME
C  IN = SOURCE OF INPUT DATA-DETERMINED IN VARIABLE DECLARATION
C  KQ = COUNTER FOR 'C AND L'
C  L = PROCUREMENT LEAD TIME
C  LAMBDA = STOCKOUT COST RATE ($/UNIT/YEAR)
C  MADD = MEAN ABSOLUTE DEVIATION OF DEMAND
C  MADL = MEAN ABSOLUTE DEVIATION OF LEAD TIME
C  OC = AVERAGE ANNUAL ADMINISTRATIVE ORDERING COST
C  OUT = DESTINATION OF OUTPUT.DATA-DETERMINED IN VARIABLE DECLARATION
C  P = UNCONSTRAINED RISK
C  PC = AVERAGE ANNUAL PURCHASE COST OF THE ITEM
C  PMAX = MAXIMUM RISK CONSTRAINT
C  PMIN = MINIMUM RISK CONSTRAINT
C  POUT = CONSTRAINED RISK
C  PPV = PROCUREMENT PROBLEM VARIANCE
C  Q = UNCONSTRAINED ORDER QUANTITY
C  QHAT = FINAL CONSTRAINED ORDER QUANTITY
C  RHAT = CONSTRAINED REORDER LEVEL
C  S = AVERAGE NUMBER OF UNITS PER REQUISITION
C  SIGC = STANDARD DEVIATION OF MEAN LEAD TIME DEMAND
C  TC = AVERAGE ANNUAL TOTAL COST OF STOCKING THE ITEM
C  TVC = AVERAGE ANNUAL TOTAL VARIABLE COST
C  Z = PROCUREMENT PROBLEM VARIABLE  (MEAN LEAD TIME DEMAND QUANTITY)
C *** SENTINEL VALUES FOR GENERATING ERROR/WARNING MESSAGES TO THE USER
C  ERR,WARNCQ,WARNQ,WARNR
C
```

```
C ************ VARIABLE DECLARATIONS ******************
C
      REAL   A,C,D,E,F,H,I,L,LAMBDA,MADD,MADL,OC,P,PC,PMAX,PMIN,POUT,
     *PPV,Q,QHAT,R,RHAT,S,TC,TVC,Z,G
      INTEGER   ERR,IN,J,OUT,WARNCQ,WARNQ,WARNR
      DOUBLE PRECISION   B,BOC,EBO
C
      DATA   IN/4/,OUT/6/
 10   CONTINUE
C *** READ INPUT DATA FROM FILE ***
20    READ (IN,450) A,C,D,E,H,I,L,MADD,MADL,S
C *** CHECK FOR END-OF-FILE SENTINEL VALUE IN FIRST COLUMN OF INPUT***
21      IF (.NOT.A.GE.100.)  GO TO 130
C *** WRITE INPUT DATA TO TERMINAL ***
      CCC=C
      KQ=11040
      SL=L
C *** DO LOOP OVER VALUES OF UNIT COST
      DO 902 IJ=231,250
      C=IJ
C *** CACULATING ORDER QUANTITY WITH CONSRAINTS
      Q=SQRT(8*A*D/(I*C))
      G=AMAX1(Q,D,1.)
      QCON=12*D
      QHAT=AMIN1(G,QCON)
C *** DETERMINING ADMINISTRATIVE COST
      CQ=C*QHAT
       IF(C*QHAT.LE.8000.)GO TO 54
       A=1050.00
  54   CONTINUE
C *** DO LOOP OVER LEAD TIME VALUES
      DO 901 II=1,48
      SL=4+(II-1)/4.
      KQ=KQ+1
C
C *** DETERMINE ITEM COG/ASSOCIATED VALUES,CALCULATE PROCUREMENT PROBLEM
C *** VARIABLE AND PROCUREMENT PROBLEM VARIANCE                      ***
C
30    CALL DATACK (C,D,F,I,SL,LAMBDA,MADD,MADL,PMAX,PMIN,PPV,S,Z,ERR,
     *             OUT)
C *** GENERATE ERROR MESSAGE IF DEMAND DATA DOES NOT MEET REQUIREMENTS
C *** FOR ASSUMPTION OF NORMAL DISTRIBUTION OF LEAD TIME DEMAND QUANTITY
      GO TO (31,32,33,34),ERR
31    WRITE (OUT,600)
      GO TO 111
32    WRITE (OUT,610)
      GO TO 111
33    WRITE (OUT,620)
      GO TO 111
34    CONTINUE
C
C *** CALCULATE/CONSTRAIN RISK ***
C
40    P = (D*I*C) / ((D*I*C)+(LAMBDA*F*E))
         IF (.NOT.P.GT.PMAX) GO TO 41
```

```
            POUT = PMAX
            GO TO 43
41        IF (.NOT.P.LT.PMIN) GO TO 42
            POUT = PMIN
            GO TO 43
42        POUT = P
43     CONTINUE
         SIGC=SQRT(PPV)
         CDFA1=1.-POUT
         CALL MDNRIS(CDFA1,ZNOR,IER)
C
C *** NOTE - MDNRIS IS THE NPS COMPUTER CENTER IMSL ROUTINE FOR THE
C *** INVERSE NORMAL PROBABILITY DISTRIBUTION .
C
         RHAT=ZNOR*SIGC+Z
         CALL EBOCAL(EBO,QHAT,SIGC,RHAT,Z,BRRQ)
         B=EBO
C
C *** COMPUTE THE AVERAGE ANNUAL TOTAL VARIABLE COST, AVERAGE  ***
C *** ANNUAL PURCHASE COST, AND AVERAGE ANNUAL TOTAL COST      ***
90     CALL TVCOST (A,B,C,D,E,I,SL,LAMBDA,QHAT,RHAT,TVC,OC,HC,BOC,S)
C
       PC=C*4*D
       TC=TVC+PC
       TCI=TC/10.+0.5
       ICII=AINT(TCI)*10.
       ICIZ=AINT(TC)
       IC=C
       ISL=SL
       WRITE (OUT,750)IC,SL,ICII,QHAT,RHAT,KQ,A
 750   FORMAT(2X,I4,1X,F5.2,2X,I5,2X,F5.1,2X,F6.1,2X,I5,2X,F5.0)
 901   CONTINUE
 902   CONTINUE
111    CONTINUE
120    GO TO 20
130    CONTINUE
       STOP
450    FORMAT (F7.2,1X,F9.2,1X,F7.2,1X,F4.2,1X,F4.1,1X,F4.2,1X,
     *         F5.2,1X,F6.2,1X,F5.2,1X,F5.2)
C
600    FORMAT ('0','INVALID DATA - D IS LESS THAN 0.25 = LEADTIME
     *DEMAND NOT NORMALLY DISTRIBUTED')
610    FORMAT ('0','INVALID DATA - F < 3 AND Z < 4 = LEADTIME DEMAND
     *NOT NORMALLY DISTRIBUTED')
C
620    FORMAT ('0','INVALID DATA- F < 1 AND Z < 20 = LEADTIME DEMAND
     *NOT NORMALLY DISTRIBUTED')
       END
C
C*** END OF MAIN PROGRAM AND BEGINNING OF SUBROUTINES ***
C
       SUBROUTINE DATACK (C,D,F,I,L,LAMBDA,MADD,MADL,PMAX,PMIN,PPV,S,Z,
     *                    ERR,OUT)
C*********************************************************************
C   THIS SUBROUTINE DETERMINES THE ITEM'S COG, AND RETURNS THE SHORTAGE*
```

```
C   COST FACTOR, MAXIMUM ALLOWABLE RISK OF STOCKOUT, THE PROCUREMENT    *
C   PROBLEM VARIABLE AND THE PROCUREMENT PROBLEM VARIANCE TO THE MAIN   *
C   PROGRAM UICP1.  IT ALSO GENERATES AN ERROR MESSAGE IF THE LEADTIME  *
C   DEMAND DISTRIBUTION IS NOT NORMAL (BASED ON THE INPUT DATA.)        *
C*********************************************************************
C
C *** VARIABLE DECLARATION ***
      INTEGER  ERR,OUT
      REAL  C,D,F,I,L,LAMBDA,MADD,MADL,PMAX,PMIN,PPV,S,VS,Z,SIG2D,SIG2L
C
      Z = D * L
      F = D / S
      ERR=4
C
      IF (.NOT.D.LE.0.25) GO TO 100
C *** ITEM IS MARK CODE 0 ***
         ERR = 1
         GO TO 350
100   IF (.NOT.D.LE.5.) GO TO 200
C *** ITEM IS MARK CODE 1 OR 3 ***
         PPV = (2.028 * (Z**.701)) **2.
         GO TO 220
200   CONTINUE
      IF (.NOT.C*D.LE.75.) GO TO 210
C *** ITEM IS MARK CODE 2 ***
         SIG2D= 1.57 * MADD * MADD
         SIG2L= L
         PPV = L*SIG2D + D*D*SIG2L
         GO TO 220
210   CONTINUE
C *** ITEM IS MARK CODE 4 ***
      SIG2D = 1.57 * MADD * MADD
      SIG2L = 1.57 * MADL * MADL
      PPV = L*SIG2D + D*D*SIG2L
220   CONTINUE
C *** EXCESSIVE VARIANCE SCREEN ***
      VS = PPV / Z
      IF (.NOT.VS.GT.150.) GO TO 230
         PPV = 4.112 * (Z**1.402)
230   CONTINUE
C *** CHECK DISTRIBUTION OF Z, ASSIGN LAMBDA,PMAX,PMIN BY ITEM COG ***
300   IF (.NOT.F.GE.5.) GO TO 310
C *** ITEM IS CATEGORY A ***
         LAMBDA = 1500.00
         PMAX = 0.30
         PMIN = 0.01
         GO TO 340
310   IF (.NOT.F.GE.3.) GO TO 320
C *** ITEM IS CATEGORY A ***
         LAMBDA = 1500.00
         PMAX = 0.30
         PMIN = 0.01
         GO TO 340
320   IF (.NOT.F.GE.1.) GO TO 330
C *** ITEM IS CATEGORY B ***
```

```
         LAMBDA = 1000.00
         PMAX = 0.40
         PMIN = 0.01
         IF (Z.LT.4.) ERR = 2
         GO TO 340
330    CONTINUE
C *** ITEM IS CATEGORY C ***
       LAMBDA = 500.00
       PMAX = 0.50
       PMIN = 0.01
       IF (Z.LT.20.) ERR = 3
340    CONTINUE
350    CONTINUE
       RETURN
       END
$EJECT
C
       SUBROUTINE TVCOST (A,B,C,D,E,I,L,LAMBDA,QHAT,RHAT,TVC,OC,HC,BOC,S)
C*********************************************************************
C  THIS SUBROUTINE CALCULATES THE ANNUAL TOTAL VARIABLE COST OF      *
C  STOCKING THE ITEM PER THE UICP CONSUMABLES INVENTORY MODEL,       *
C  CONSIDERING TIME-WEIGHTED,ESSENTIALITY-WEIGHTED REQUISITIONS      *
C  SHORT IN ACCORDANCE WITH DODINST 4140.42.                         *
C*********************************************************************
C
C *** VARIABLE DECLARATION ***
       DOUBLE PRECISION    BOC,B,EBO
       REAL  A,C,D,E,I,L,LAMBDA,QHAT,RHAT,TVC,OC,S
       OC = A*4*D/QHAT
       HC = I*C*(QHAT*.5+RHAT-D*L+B)
       BOC = B*E*LAMBDA/S
       TVC = OC + HC + BOC
       RETURN
C
       END
$EJECT
       SUBROUTINE EBOCAL (EBO,QHAT,SIGC,X,Z,BRRQ)
C*********************************************************************
C    THIS SUBROUTINE CALCULATES THE EXPECTED NUMBER OF BACKORDERS AT
C  THE END OF THE CYCLE FOR A PROPOSED ORDER LEVEL (X), GIVEN A LEAD
C  TIME DEMAND WITH MEAN OF Z AND STANDARD DEVIATION OF SIGC.
C*********************************************************************
C *** NOTE - MDNORD IS THE NPS COMPUTER CENTER IMSL ROUTINE FOR THE  ***
C *** NORMAL PROBABILITY DISTRIBUTION OF A DOUBLE PRECISION VARIABLE ***
C
C *** VARIABLE DECLARATION ***
       DOUBLE PRECISION  A1,B1,CDFA1,CDFB1,CCDFA1,CCDFB1,PA1,PB1,PI,EBO
       REAL X,SIGC,Z,QHAT
       PI = 3.1415926535
       A1 = (X - Z) / SIGC
       B1 = (X + QHAT - Z) / SIGC
       PA1=1./DSQRT(2.*PI)*(DEXP(-A1*A1/2.))
       PB1 = 1./DSQRT(2.*PI)*(DEXP(-B1*B1/2.))
       CALL MDNORD (A1,CDFA1)
       CCDFA1 = 1. - CDFA1
```

```
      CALL MDNORD (B1,CDFB1)
      CCDFB1 = 1. - CDFB1
      BR=((SIGC*SIGC+(X-Z)*(X-Z))*CCDFA1)/2.-SIGC/2.*(X-Z)*PA1
      BRQ=((SIGC*SIGC+(X+QHAT-Z)*(X+QHAT-Z))*CCDFB1)/2.-SIGC/2.*
     *(X+QHAT-Z)*PB1
      EBO=(BR-BRQ)/QHAT
      RETURN
      END
```

APPENDIX B

C	L	TC	Q	R	KQ	A
231	4.00	10620	21.4	67.2	11041	380.
231	4.25	10620	21.4	69.3	11042	380.
231	4.50	10630	21.4	71.4	11043	380.
231	4.75	10630	21.4	73.5	11044	380.
231	5.00	10640	21.4	75.5	11045	380.
231	5.25	10640	21.4	77.6	11046	380.
231	5.50	10650	21.4	79.7	11047	380.
231	5.75	10650	21.4	81.8	11048	380.
231	6.00	10660	21.4	83.9	11049	380.
231	6.25	10660	21.4	85.9	11050	380.
231	6.50	10670	21.4	88.0	11051	380.
231	6.75	10670	21.4	90.1	11052	380.
231	7.00	10680	21.4	92.2	11053	380.
231	7.25	10680	21.4	94.2	11054	380.
231	7.50	10690	21.4	96.3	11055	380.
231	7.75	10690	21.4	98.4	11056	380.
231	8.00	10700	21.4	100.5	11057	380.
231	8.25	10700	21.4	102.5	11058	380.
231	8.50	10710	21.4	104.6	11059	380.
231	8.75	10710	21.4	106.7	11060	380.
231	9.00	10720	21.4	108.8	11061	380.
231	9.25	10720	21.4	110.8	11062	380.
231	9.50	10720	21.4	112.9	11063	380.
231	9.75	10730	21.4	115.0	11064	380.
231	10.00	10730	21.4	117.1	11065	380.
231	10.25	10740	21.4	119.1	11066	380.
231	10.50	10740	21.4	121.2	11067	380.
231	10.75	10750	21.4	123.3	11068	380.
231	11.00	10750	21.4	125.4	11069	380.
231	11.25	10760	21.4	127.4	11070	380.
231	11.50	10760	21.4	129.5	11071	380.
231	11.75	10770	21.4	131.6	11072	380.
231	12.00	10770	21.4	133.7	11073	380.
231	12.25	10780	21.4	135.7	11074	380.
231	12.50	10780	21.4	137.8	11075	380.
231	12.75	10790	21.4	139.9	11076	380.
231	13.00	10790	21.4	142.0	11077	380.
231	13.25	10800	21.4	144.0	11078	380.
231	13.50	10800	21.4	146.1	11079	380.
231	13.75	10810	21.4	148.2	11080	380.
231	14.00	10810	21.4	150.3	11081	380.
231	14.25	10820	21.4	152.3	11082	380.
231	14.50	10820	21.4	154.4	11083	380.
231	14.75	10820	21.4	156.5	11084	380.
231	15.00	10830	21.4	158.5	11085	380.
231	15.25	10830	21.4	160.6	11086	380.
231	15.50	10840	21.4	162.7	11087	380.
231	15.75	10840	21.4	164.8	11088	380.
232	4.00	10660	21.3	67.2	11089	380.
232	4.25	10660	21.3	69.3	11090	380.
232	4.50	10670	21.3	71.3	11091	380.

232	4.75	10670	21.3	73.4	11092	380.
232	5.00	10680	21.3	75.5	11093	380.
232	5.25	10680	21.3	77.6	11094	380.
232	5.50	10690	21.3	79.7	11095	380.
232	5.75	10690	21.3	81.7	11096	380.
232	6.00	10700	21.3	83.8	11097	380.
232	6.25	10700	21.3	85.9	11098	380.
232	6.50	10710	21.3	88.0	11099	380.
232	6.75	10710	21.3	90.0	11100	380.
232	7.00	10720	21.3	92.1	11101	380.
232	7.25	10720	21.3	94.2	11102	380.
232	7.50	10730	21.3	96.3	11103	380.
232	7.75	10730	21.3	98.3	11104	380.
232	8.00	10740	21.3	100.4	11105	380.
232	8.25	10740	21.3	102.5	11106	380.
232	8.50	10750	21.3	104.6	11107	380.
232	8.75	10750	21.3	106.6	11108	380.
232	9.00	10760	21.3	108.7	11109	380.
232	9.25	10760	21.3	110.8	11110	380.
232	9.50	10770	21.3	112.9	11111	380.
232	9.75	10770	21.3	114.9	11112	380.
232	10.00	10780	21.3	117.0	11113	380.
232	10.25	10780	21.3	119.1	11114	380.
232	10.50	10790	21.3	121.2	11115	380.
232	10.75	10790	21.3	123.2	11116	380.
232	11.00	10800	21.3	125.3	11117	380.
232	11.25	10800	21.3	127.4	11118	380.
232	11.50	10810	21.3	129.5	11119	380.
232	11.75	10810	21.3	131.5	11120	380.
232	12.00	10810	21.3	133.6	11121	380.
232	12.25	10820	21.3	135.7	11122	380.
232	12.50	10820	21.3	137.8	11123	380.
232	12.75	10830	21.3	139.8	11124	380.
232	13.00	10830	21.3	141.9	11125	380.
232	13.25	10840	21.3	144.0	11126	380.
232	13.50	10840	21.3	146.1	11127	380.
232	13.75	10850	21.3	148.1	11128	380.
232	14.00	10850	21.3	150.2	11129	380.
232	14.25	10860	21.3	152.3	11130	380.
232	14.50	10860	21.3	154.3	11131	380.
232	14.75	10870	21.3	156.4	11132	380.
232	15.00	10870	21.3	158.5	11133	380.
232	15.25	10880	21.3	160.6	11134	380.
232	15.50	10880	21.3	162.6	11135	380.
232	15.75	10890	21.3	164.7	11136	380.

A P P E N D I X C

```
$JOB
C*********************************************************************
C THIS IS A NONINTERACTIVE PROGRAM UTILIZING THE WATFIV COMPILER.THE *
C PROGRAM READS DATA WHICH WAS PREPARED BY THE INVENTORY PROGRAM     *
C (APPENDIX A),AND THEN CALCULATES ISOCOST PARAMETERS FOR THE VARIOUS*
C COMBINATION OF C AND L WHICH HAVE THE SAME TOTAL COST.THE PROGRAM  *
C IS ACTIVATED BY AN EXEC FILE .                                     *
C*********************************************************************
C
C ********** VARIABLE DEFINITIONS *************
C  A = SLOPE OF THE ISOCOST LINE
C  ANOM = NOMINATOR FOR CALCULATING A
C  B = INTERCEPTION POINT OF THE ISOCOST LINE
C  BNOM = NOMINATOR FOR CALCULATING B
C  C = UNIT PRICE
C  CC = C*C
C  CL = C*L
C  DENO = DENOMINATOR FOR CALCULATING A AND B
C  J = LOOP COUNTER
C  K = NUMBER OF TERMS IN THE REGRESSION
C  KK = CURRENT TOTAL COST
C  L = LEAD TIME
C  LL = L*L
C  LK = NUMBER OF C UNITS IN TC RANGE
C  R = CORELATION COOFICIENT
C  RDEN = DENOMINATOR FOR CALCULATING R
C  RNOM = NOMINATOR FOR CALCULATING R
C  SUMA = ACCUMULATIVE SUM OF A VALUES
C  SUMB = ACCUMULATIVE SUM OF B VALUES
C  SUMC = ACCUMULATIVE SUM OF C VALUES
C  SUMCC = ACCUMULATIVE SUM OF THE PRODUCT C*C
C  SUMCL = ACCUMULATIVE SUM OF THE PRODUCT C*L
C  SUML = ACCUMULATIVE SUM OF L VALUES
C  SUMLL = ACCUMULATIVE SUM OF THE PRODUCT L*L
C  TC = TOTAL COST
C
C *********** VARIABLE DECLARATION ***********
C
      INTEGER SUMC,SUMCC
      INTEGER C(1999),TC(1999),CC(1999)
      REAL A,B,L(1999),LL(1999),CL(1999),SUML,SUMLL,SUMCL
C *** READ INPUT DATA ***
      DO 40 J=1,960
      READ 41,C(J),L(J),TC(J)
 41      FORMAT(T3,I4,T8,F5.2,T15,I5)
 40      CONTINUE
      KK=TC(1)
      CAC=0.
      LK=0
 20      SUML=0
      SUMC=0
      SUMCC=0
      SUMLL=0
```

```
      SUMCL=0
      K=0
C *** LOOP OVER ALL TC VALUES ***
      DO 10 J=1,960
      IF (TC(J).NE.KK) GO TO 11
C *** LINEAR REGRESSION COMPUTATIONS ***
      SUML=SUML+L(J)
      SUMC=SUMC+C(J)
      CC(J)=C(J)*C(J)
      LL(J)=L(J)*L(J)
      CL(J)=C(J)*L(J)
      CF=C(J)
      SUMCL=SUMCL+CL(J)
      SUMCC=SUMCC+CC(J)
      SUMLL=SUMLL+LL(J)
      K=K+1
      IF (K.NE.1) GO TO 11
         C1=C(J)
 11      CONTINUE
 10      CONTINUE
         AVC=(C1+CF)/2.
      IF(K.LE.1)GO TO 21
      DENO=K*SUMCC-SUMC*SUMC
      IF (DENO.EQ.0)GO TO 21
      BNOM=K*SUMCL-SUMC*SUML
      ANOM=SUMCC*SUML-SUMC*SUMCL
      BB=BNOM/DENO
      BBB=BB*100.
      B=AINT(BBB)/100.
      A=ANOM/DENO
      RNOM=K*SUMCL-SUMC*SUML
      RDEN=(K*SUMCC-SUMC*SUMC)*(K*SUMLL-SUML*SUML)
      R=RNOM/SQRT(RDEN)
      PRINT 23,KK,A,B,K,R,AVC
 23      FORMAT (2X,I5,2X,F7.2,2X,F7.2,2X,I2,2X,F7.3,2X,F5.1)
      IF(AVC.NE.CAC) GO TO 101
C *** CALCULATIONS OF A AS FUNCTION OF C ***
      SUMA=SUMA+A
      SUMB=SUMB+B
      LK=LK+1
      GO TO 21
 101  IF (CAC.EQ.0.)GO TO 102
      AA=SUMA/LK
      AB=SUMB/LK
      PRINT,CAC,AA,AB
 102  CAC=AVC
      SUMA=A
      SUMB=B
      LK=1
 21      KK=KK+10
      IF(KK.GT.TC(J-1))GO TO 30
      GO TO 20
 30      CONTINUE
      STOP
      END
```

APPENDIX D

TC	B	A	N	R	AVC
11050	519.00	-2.13	13	-0.999	238.5
11060	517.44	-2.12	10	-0.999	239.0
11070	511.02	-2.09	11	-0.999	239.5
11080	512.46	-2.09	12	-0.999	239.5
11090	512.99	-2.09	12	-0.999	239.5
11100	508.65	-2.07	11	-0.999	239.5
11110	502.19	-2.05	11	-0.999	240.5
11120	509.68	-2.07	13	-0.999	240.5
11130	513.33	-2.09	12	-0.999	240.5
11140	512.85	-2.08	10	-0.999	240.5
11150	516.00	-2.09	10	-0.999	241.0
11160	515.56	-2.09	11	-0.999	241.5
11170	516.95	-2.09	12	-0.999	241.5
11180	517.45	-2.09	12	-0.999	241.5
11190	518.89	-2.10	11	-0.999	242.0
11200	516.80	-2.09	12	-0.999	242.5
11210	517.26	-2.09	12	-0.999	242.5
11220	517.75	-2.09	12	-0.999	242.5
11230	510.75	-2.06	11	-0.998	243.0
11240	510.10	-2.05	12	-0.999	243.5
11250	510.63	-2.05	12	-0.999	243.5
11260	511.12	-2.05	12	-0.999	243.5
11270	508.08	-2.04	11	-0.999	243.5
11280	508.56	-2.04	11	-0.999	244.5
11290	513.17	-2.05	11	-0.999	244.5
11300	522.53	-2.09	11	-0.999	244.5
11310	519.07	-2.07	11	-0.999	244.5
11320	512.41	-2.05	11	-0.999	245.5
11330	514.48	-2.05	12	-0.999	245.5
11340	514.97	-2.05	12	-0.999	245.5
11350	515.47	-2.05	12	-0.999	245.5
11360	508.90	-2.02	11	-0.999	246.5
11370	511.20	-2.03	12	-0.999	246.5
11380	511.73	-2.03	12	-0.999	246.5
11390	512.23	-2.03	12	-0.999	246.5
11400	500.90	-1.98	11	-0.999	247.5
11410	509.68	-2.02	13	-0.999	247.5
11420	516.09	-2.04	10	-0.999	247.5
11430	529.03	-2.09	11	-0.999	247.5
11440	524.32	-2.07	10	-0.999	248.0
11450	524.80	-2.07	10	-0.999	248.0
11460	525.36	-2.07	10	-0.999	248.0
11470	525.84	-2.07	10	-0.999	248.0
11480	521.83	-2.05	9	-0.999	248.0
11490	526.80	-2.07	8	-0.998	248.5
11500	527.40	-2.07	8	-0.998	248.5
11510	527.80	-2.07	8	-0.998	248.5
11520	516.92	-2.02	7	-0.998	248.5
11530	510.00	-2.00	6	-0.997	249.0
11540	510.67	-2.00	6	-0.997	249.0
11550	510.67	-2.00	6	-0.997	249.0

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