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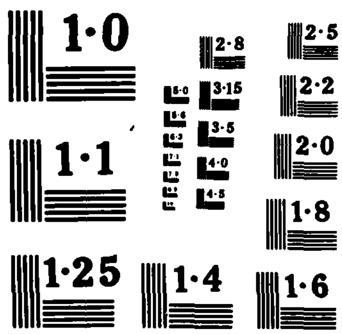
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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A MODEL FOR EVALUATING VENDOR BIDS
FOR STOCK REPLENISHMENT OF AN ITEM

by

Richard D. Gray

December 1984

Thesis Advisor: A. W. McMasters

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bids include both a unit price and an estimate of production lead time. The thesis examines the impact of differences between the forecasted and actual values for lead time and price on the optimum total annual cost of stocking the item as computed by the UICP model. A modification of the model for comparison of the total annual cost associated with the lead time and price combination of each vendor bid is developed. Some expected effects of implementing the model are discussed and areas requiring further research are identified.

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A Model for Evaluating Vendor Bids for Stock Replenishment of an Item

by

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Submitted in partial fulfillment of the
requirements for the degree of

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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 an estimate of production lead time. The thesis examines the impact of differences between the forecasted and actual values for lead time and price on the optimum total annual cost of stocking the item as computed by the UICP model. A modification of the model for comparison of the total annual cost associated with the lead time and price combination of each vendor bid is developed. Some expected effects of implementing the model are discussed and areas requiring further research are identified.

Keywords include: see 14

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I. INTRODUCTION

A. BACKGROUND AND PURPOSE

The Navy's Uniform Inventory Control Program (UICP) sets optimum inventory levels for SPCC managed 1H cognizance symbol items based on minimization of the average annual variable cost of stocking those items. The UICP model was developed from traditional continuous review lot size - reorder point models for stochastic demands and no quantity price discounts, and thus does not include the average annual cost of purchasing the items in its inventory cost equation. Because the purchase costs of the items make up a significant portion of the total annual cost of stocking them, reductions in the "optimal" cost may in fact be posible. In particular, total cost savings may be realized from a reduction in the purchase cost of an item, even though that reduced price is associated with some increase in variable inventory costs.

That method of reducing total costs is addressed by classic price break models, such as those found in Chapter 2 of Hadley and Whitin [Ref. 1], which do include the purchase costs. Project EOQ [Ref. 2] resulted in the implementation of such a model within the Air Force wholesale supply system. All of those price break models consider unit cost as a function only of the order quantity and do not consider any relationship between unit price and procurement lead time.

Hadley and Whitin [Ref. 3] have developed a model for negotiated procurement lead times in which the item's price is assumed to be a function of both the purchase quantity and procurement lead time. It is assumed that the unit price offered by the vendor increases as lead time decreases, and a given price is applicable over a lead time interval. The solution algorithm is to select the maximum lead time associated with each unit price - the vendor is assumed to always deliver at the end of a lead time interval - then solve for the optimum order quantity and reorder quantity and associated total cost.[1] The unit cost, and hence the lead time interval, with the lowest associated total cost is then selected.

Negotiation of lead time based on total inventory costs is not part of the current procurement process, however. The current practice at the Navy's Inventory Control Points is to treat the inventory management and procurement functions as unrelated activities even though they are, in fact,

[1]The model uses a number of simplifications in its solution algorithm which are not acceptable in the UICP model, including deleting backorders from the holding cost term when taking partial derivatives of total cost with respect to the decision variables, and not assigning a time weighting to backorder costs.

key parts of a single supply system, sharing the goal of maximum fleet support within annual budget constraints.

Reorder levels and order quantities are set on the basis of minimizing variable costs. Then vendor bids are requested and evaluated principally on unit price (subject to a required delivery date constraint). The UICP model uses the prices and lead times resulting from the procurement actions to update its data base for calculating inventory levels. It seems likely that integration of the two system functions can produce savings in the inventory costs currently incurred.

This thesis will attempt to modify the UICP model to provide more information to integrate the inventory management and procurement activities and to minimize the total expenditure of Navy dollars required to stock consumable items. In particular, it will examine the impact of varying combinations of unit price and procurement lead time on total costs predicted by the UICP model to determine what savings are possible and how to achieve them.

B. THESIS OBJECTIVES

To develop a management tool for use by procurement personnel which will permit evaluation of vendor bids on the basis of their impact on variable inventory costs in addition to the current procedure of ranking them on the basis of lowest unit price and ability to meet a required delivery date. The management tool will emphasize speed and ease of use with minimal requirement for computer or calculator equipment.

C. APPROACH

The relationships between variables and their effect on predicted inventory costs in the UICP consumables procurement model will be examined through 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. Unit price and procurement lead time will be the variables of principal concern. However, the sensitivity of the cost predictions to errors or variations in other variables will also be examined.

D. SCOPE AND LIMITATIONS

The stock procurement process will be examined at the point where the buy quantity and required delivery date have been determined and vendor bids have been solicited but no contract awarded. The examination will evaluate a model for reducing total inventory costs for a stocked item which provides inventory cost information to purchasing personnel for comparison of the total costs associated with each vendor's bid.

The UICP inventory model for SPCC managed 1H cognizance symbol (consumable) material will be utilized as the basis for developing the thesis model. The repairable item and ASO consumable item models contain additional constraints and/or cost equation variables that will not be addressed in the thesis. 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 distribution 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. Since current procurement procedures do not solicit competitive lead times, the variations in lead time (and unit price) between bids for sample items in the thesis are not based on historical data.

E. THESIS FORMAT

Chapter II will present a brief overview of the current UICP consumables procurement model to establish the basis for the modification of the model presented in Chapter III. Model assumptions, limitations, and the total expected annual variable cost (TVC) equation and its optimization methodology will be discussed.

Chapter III will present the bidding modification of the UICP optimization method. The modification will add the expected annual purchase cost of an item to the UICP's TVC equation to produce a total expected annual cost (TC) caused by the non-optimality of the given Q and R for those C and L pairs.

For example, suppose that the unit price is the same in the UICP model forecast and the vendor's bid. A bid lead time which is shorter than the L used to calculate $\hat{Q}$ and $\hat{R}$ will produce higher holding costs because the $\hat{R}$ is now too high, and thus the expected on-hand quantity does not drop as low as expected by the UICP model before the new order arrives. However, the stockout costs will be lower because of this higher average on-hand quantity. A bid lead time which is longer than forecasted lead time will have the opposite effect on holding and stockout costs.

The effect of lead time on the total cost terms when unit price is held constant for a typical item[1] is shown graphically in Figure 1.[2] The first of two major effects on total cost from holding $\hat{Q}$ and $\hat{R}$ constant while permitting L to vary is seen on the figure. The minimum TC does not occur at the forecasted lead time (100% on the horizontal

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[1]The same item will be used for all figures in the thesis. Its characteristics are given in Section F of Chapter III.

[2]The shape of the backorder cost and total cost curves may vary considerably from the examples in Figure 1. See Chapter IV for cost component/curve sensitivity to item characteristics in the cost equation. Also, all curves are not as smooth as depicted in the thesis figures, because procurements are made for discrete integer vice "continuous" quantities. The lack of smoothness is consistent for each item and does not effect the curve comparisons that will be made.

used in developing the variable cost terms of the UICP's TVC equation (the calculation of B in particular) remain valid even though the expected number of backorders and the portion of cycle length during which they occur will both increase substantially because of stock drawdown for bidder procurement lead times which are longer than that used to determine $\hat{Q}$ and $\hat{R}$.

C. THE TOTAL ANNUAL COST EQUATION

Addition of the average annual purchase cost term $(C \cdot 4 \cdot D)$ to the UICP's TVC equation produces a total annual cost equation which will permit consideration of both item manager and purchasing agent concerns and emphasize reducing the total expenditure of Navy dollars. These expected annual total costs to be minimized are given by:

$$TC = C \cdot 4 \cdot D + \frac{A \cdot 4 \cdot D}{\hat{Q}} + I \cdot C(\hat{R} + \frac{\hat{Q}}{2} - L \cdot D + B) + \frac{E \cdot \lambda \cdot \bar{B}}{S}$$

The proposed solution technique which will be detailed later in this chapter begins by solving for the $\hat{Q}$, $\hat{R}$, and optimum TC associated with the forecasted C and L values by utilizing current UICP procedures. The model then determines other combinations of C and L which will produce that same TC (or one which is a given increment larger or smaller than that value) given those $\hat{Q}$ and $\hat{R}$ values. Numerous C and L pairs can produce that same TC because of the compensating impacts on the individual cost terms of the TC equation

equation. At this later point in time during the stock replenishment cycle, R must have been reached, or the procurement process would not have been initiated. Additionally, the procurement personnel would not have changed the value of Q that had been previously determined. Unit price and procurement lead time, however, are dependent on the vendor bids which are received as a result of the solicitation. Furthermore, the procurement personnel can select the winning bid based on the lowest total annual cost associated with its price and lead time values (given all other contractual specifications are satisfied) rather than just lowest unit price.

B. ASSUMPTIONS

The following are assumed in addition to the assumptions listed in Chapter II for the current UICP model:

(1) MAD_L is independent of the expected value of lead time, permitting the same value to be used in computing PPV for different lead times. That is, deviations in lead time from the expected value are assumed to be the same for all bid lead times.

(2) Variations in unit price between bids will not change the total purchase cost ($C \cdot \hat{Q}$) so drastically that the administrative cost breakpoint will be crossed; ie, the administrative order cost (A) will not change.

(3) The simplification and approximation techniques

III. THE PROPOSED MODIFICATION OF THE UICP MODEL

A. DEVELOPMENT OF THE MODIFICATION

The modified model concentrates on the stock procurement process after inventory levels have been set by the current UICP model. It assumes that a buy has been triggered by the fact that inventory position has dropped below the reorder point, and as a result, the item manager has passed the requirement for the buy quantity of the item as well as its required delivery date to the procurement section. At this point the purchase order has not yet been awarded to the item's manufacturer or wholesaler.

It is important to emphasize that the current UICP model considers the role of the procurement section only indirectly, using the unit price and lead time obtained from the previous buy to update its forecasts for the next review and level revision. The model needed for making procurement decisions makes use of the UICP total variable cost model; only now it also includes the item's purchase cost. Since the unit price is a prime consideration for procurement personnel in awarding the purchase order, the purchase cost term is critical to cost minimization at this stage in the process.

In addition, Q and R are now assumed fixed, while C and L are the decision variables in minimizing the total cost result in a non-optimum solution if unit cost and procurement lead time are decision variables in selecting the best vendor bid. Procurement lead time is currently only a constraint on the lowest unit price bid in that the RDD must be met. 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 purchase cost which outweigh increases in other variable cost elements.

E. LIMITATIONS OF THE TVC COST MINIMIZATION METHOD

Because the average annual variable costs are based on historical unit price and procurement lead time data, the UICP model 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 a random variable in a competetive bidding environment where the result is a contract which specifies the values of these two variables.

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 section proceeds to solicit bids on the purchase order, Q is fixed and R has already been reached, while C and L are unknown until the manufacturers' 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. 6] which generally means obtaining the material at the lowest bid price among the vendors who can meet the required delivery date along with the other contractual requirements.

It will be shown in the development of the model modification in the next chapter that the lack of an average annual purchase cost term in the UICP's TVC equation may

$$EBO \leq \tilde{Q} \cdot \tilde{P}_{out}$$

where

$$EBO = \sqrt{PPV}\left(\Phi\left(\frac{R - Z}{\sqrt{PPV}}\right) - \Phi\left(\frac{R + Q - Z}{\sqrt{PPV}}\right) + \left(\frac{R + Q - Z}{\sqrt{PPV}}\right)\Phi\left(\frac{R + Q - Z}{\sqrt{PPV}}\right) - \left(\frac{R - Z}{\sqrt{PPV}}\right)\Phi\left(\frac{R - Z}{\sqrt{PPV}}\right)\right)^{1}$$

$P_{out} \geq .01$ for all items

$P_{out} \leq .99$ for category C items (further constrained to .50 in setting Q)

$\leq .40$ for category B items

$\leq .30$ for category A items

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

$$\hat{R} = \max \begin{cases} 0 \\ \text{Numerical Stocking Objective (NSO)} \\ \text{Mean lead time demand } (Z) \\ \min \begin{cases} Z + D \\ \max\ (R,\ \text{number of policy receivers}) \\ 4 \cdot D \cdot H + Z - D \end{cases} \end{cases}$$

$$\hat{Q} = \min \begin{cases} \tilde{Q} \\ 4 \cdot D \cdot H - \max\ (0;\ \hat{R} - Z) \end{cases}$$

---

[1] This algorithm obviously assumes that demand during procurement lead time is normally distributed.

$\phi(x)$ = density function for the standard normal distribution.

$\Phi(x)$ = complementary cumulative density function for the standard normal distribution, or the probability that a random variable having that distribution will have a value greater than x.

P_{out} = the fraction of the average cycle length that the system is expected to be out of stock at any random point in time.

PPV = procurement problem variance - the expected variance in lead time demand, derived from the mean values and variances of quarterly demand and procurement lead time.

Z = "procurement problem variable" or mean lead time demand.

2. <u>Relationships Used in Optimization</u>

$$P_{out} = \frac{S \cdot I \cdot C}{S \cdot I \cdot C + \lambda \cdot E}$$

$$Q = \frac{8 \cdot A \cdot D}{I \cdot C(1 - P_{out})}$$

$$B = \left(P_{out}\right)^2 \left(\frac{Q}{2}\right)$$

$$EBO = Q \cdot P_{out}$$

$$PPV = L(1.57\ MAD_D{}^2) + D^2(1.57\ MAD_L{}^2)$$ [1]

R is determined using an iterative algorithm which seeks the smallest R such that the expected number of back-orders is less than or equal to $\tilde{Q} \cdot \tilde{P}_{out}$ (where the ~ is used to denote constrained values), or mathematically:

---

[1] For Mark code 4 items ($D \cdot C$ > \$75, D > 5 units).

$\left(\frac{4 \cdot D}{Q}\right)$ = average number of procurement actions or inventory cycles per year.

$\left(R + \frac{Q}{2} - L \cdot D + B\right)$ = expected number of units in stock at any random point in time (average on-hand inventory level).

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

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. Appendixes B, C, and D of Reference 5 treat in detail the Navy's development of the computational methods used in solving these two equations. The additional variables and parameters needed to solve the equations and some key relationships developed in that reference are provided below.

1. Definitions

EBO = expected number of backorders at the end of the inventory cycle (just before the new order arrives).

H = item shelf life.

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.

1. Notation[1]

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 advertized contracts (over $8,000).

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

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

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

I = inventory holding cost rate, composed of storage, obsolescence, and opportunity costs as percentages of unit cost for storage for one year (equal to .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 1H01 and 1H02 cog) items, $1,000 for category B (formerly 1H03 cog) items, and $500 for category C (formerly 1Hbb cog) items.

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

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[1]The same notation will be used in the modified model developed in Chapter III.

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

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

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.

B. ASSUMPTIONS

The following assumptions apply to the UICP model. These assumptions will also be used in the modification of the model which is developed in Chapter III.

(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 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).

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 cognizance symbol items forms the basis for the model developed in this thesis.[1] The model seeks "to minimize the total of variable order and holding costs subject to a constraint on time-weighted, essentiality-weighted requisitions short" in compliance with Department of Defense policy [Ref. 4]. 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

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[1]The UICP cost equation and solution algorithm is similar to other continuous review stochastic models having decision variables of order quantity and reorder point, called (Q,r) models. Chapter 4 of Hadley and Whitin [Ref. 1] should be reviewed if a more detailed description of inventory models of this type is desired.

equation. This equation will then be examined by adjustment of unit price and lead time to reflect the role of the competitive bidding process in controlling inventory costs. The modified model's development will be illustrated graphically, the solution algorithm will be detailed, and a management tool for determining lowest cost vendor bids presented.

Chapter IV will discuss the impact of the timing of reorder level and order quantity recomputations on the optimum bid lead time for lowest total annual cost, the applicability of the bid evaluation tool to items with differing characteristics (such as demand or unit price), and the impact of using longer lead times to reduce total costs on SMA.

Chapter V will provide a summary of the chapters and present conclusions regarding the value of the management tool, applicability of the bidding model, and further research required on the model.

Impact of L on Inventory Costs
(Q, R, and C Constant)

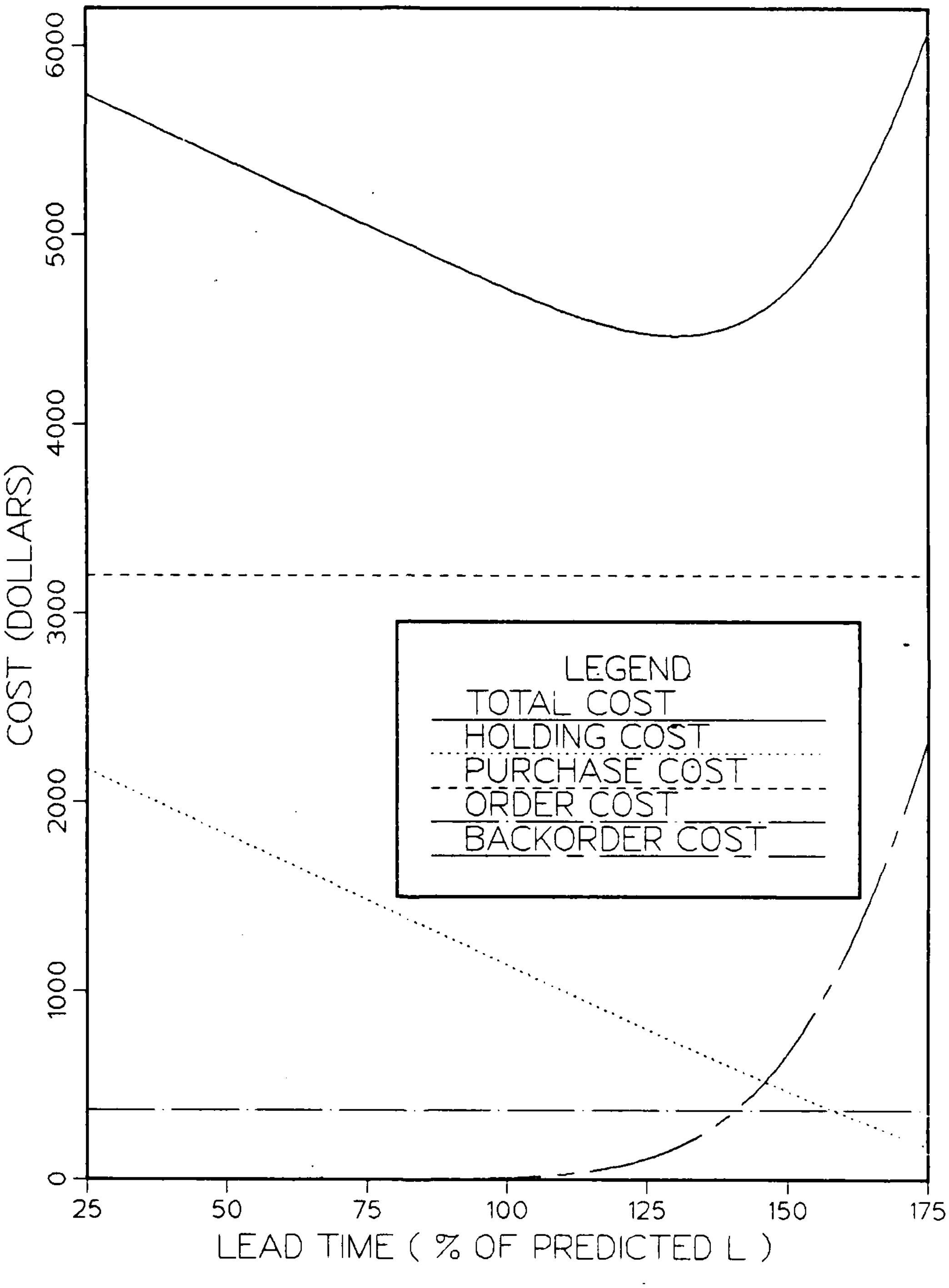

Figure 1

axis) but rather at a lead time between 25 and 50 percent longer.

The effect of unit price on the total cost terms when lead time is held constant at the forecasted value is shown graphically in Figure 2 for the same example item used in Figure 1. For any given lead time, a higher unit price will produce a higher purchase cost, a higher holding cost and thus higher TC. The impact of unit price is linear unlike the more complex impact of lead time.

Figure 3 shows the combined impact of unit price and lead time as curves of total cost versus lead time for successive increments of unit price are plotted. Each curve retains the shape from Figure 1, and the increasing unit price shifts each successive curve upward. Cutting the curves horizontally with an isocost line (equal to the TC value calculated when $\hat{Q}$ and $\hat{R}$ were determined) shows a second major effect of shifting from Q and R to C and L as decision variables. Unlike the unique Q and R solution for a given C and L, a wide variety of C and L combinations will produce the same total cost. Unfortunately, using Figure 3 to accurately determine the total cost associated with a bid's unit price and lead time is difficult, because the vertical axis represents total cost (which is to be determined) rather than unit price (which is known). Additionally, if a bid's unit price is not equal to one of the graphed increments

Impact of C on Inventory Costs
(Q, R, and L Constant)

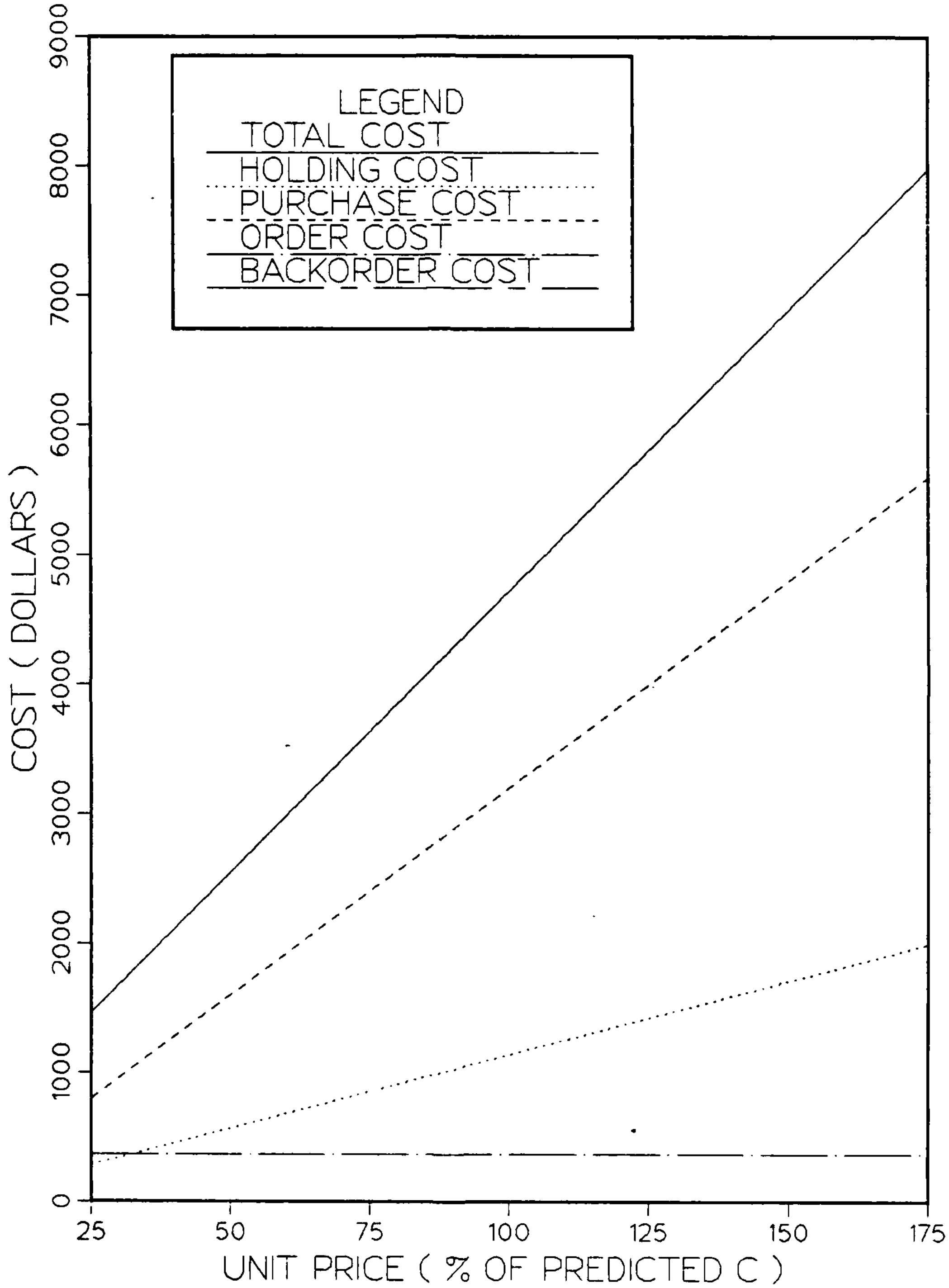

Figure 2

Combined Impact of C and L on TC
(Q and R Constant)

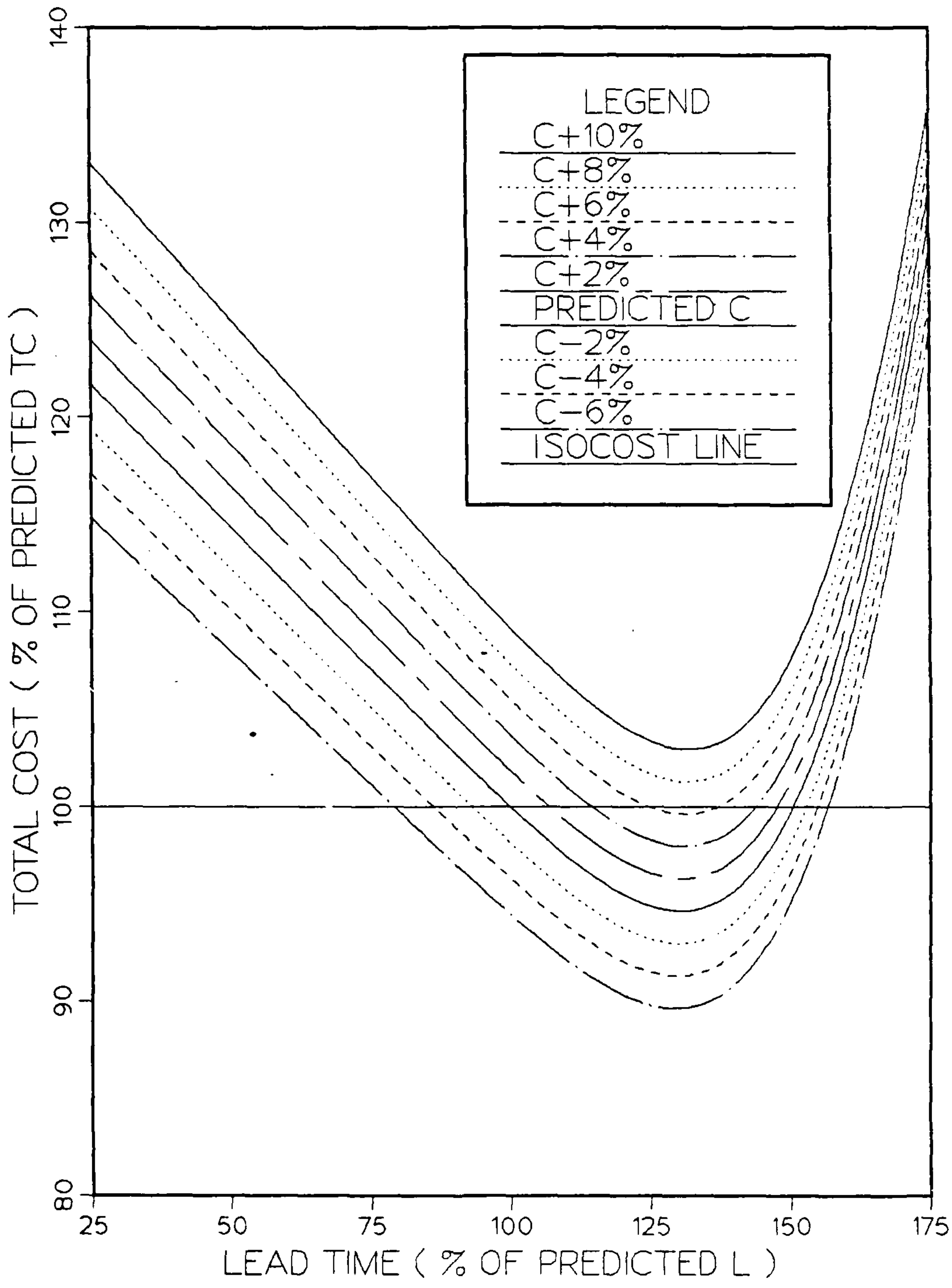

Figure 3

of C, the varying distance between the cost curves as lead time varies makes interpolation of the associated total cost difficult.

D. COMPARISON OF THE TOTAL COSTS ASSOCIATED WITH BIDS' (C,L) POINTS

To more easily compare the total costs associated with the prices and lead times in vendor bids, a graph of a constant total cost curve as a function of unit price and lead time can be used. Figure 4 shows the isocost curve consisting of (C,L) pairs which produce the same total cost as that predicted by the UICP model when $\hat{Q}$ and $\hat{R}$ were determined. The rise in the isocost curve as lead time increases, and the location of its maximum point, parallel the decline and minimum point of the total cost curves in Figure 3.

This curve permits a quick comparison of bids since each bid's (C,L) point can be compared with the others. For example, a point lying above the curve represents a higher total cost than that predicted when the inventory levels were set and a point lying below the curve represents a lower total cost than that predicted.

Plotting isocost curves in Figure 5 for values of TC that are 10% larger or smaller than the predicted value shows that the curve shape does not vary with TC, but that the vertical distance between curves over lead time does. This is shown more clearly in Figure 6 which plots the vertical distance, or unit price difference, over lead time

C/L Pairs Producing the Optimum TC
Associated with Forecasted C and L
(Q and R Constant)

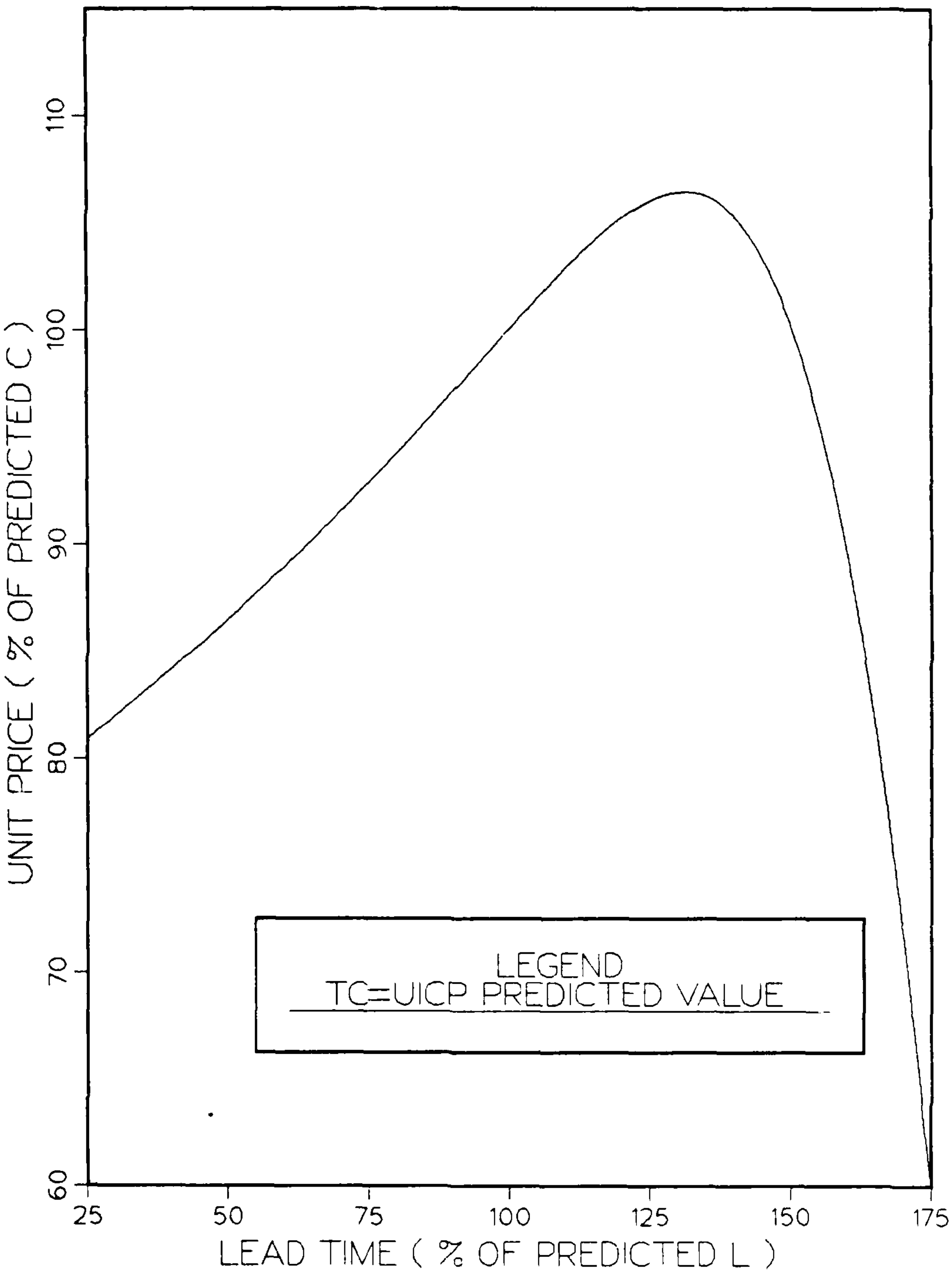

Figure 4

C/L Pairs Producing a TC Equal to, 10% Greater Than,
and 10% Less Than the Optimum TC
Associated with the Forecasted C and L (Q and R Constant)

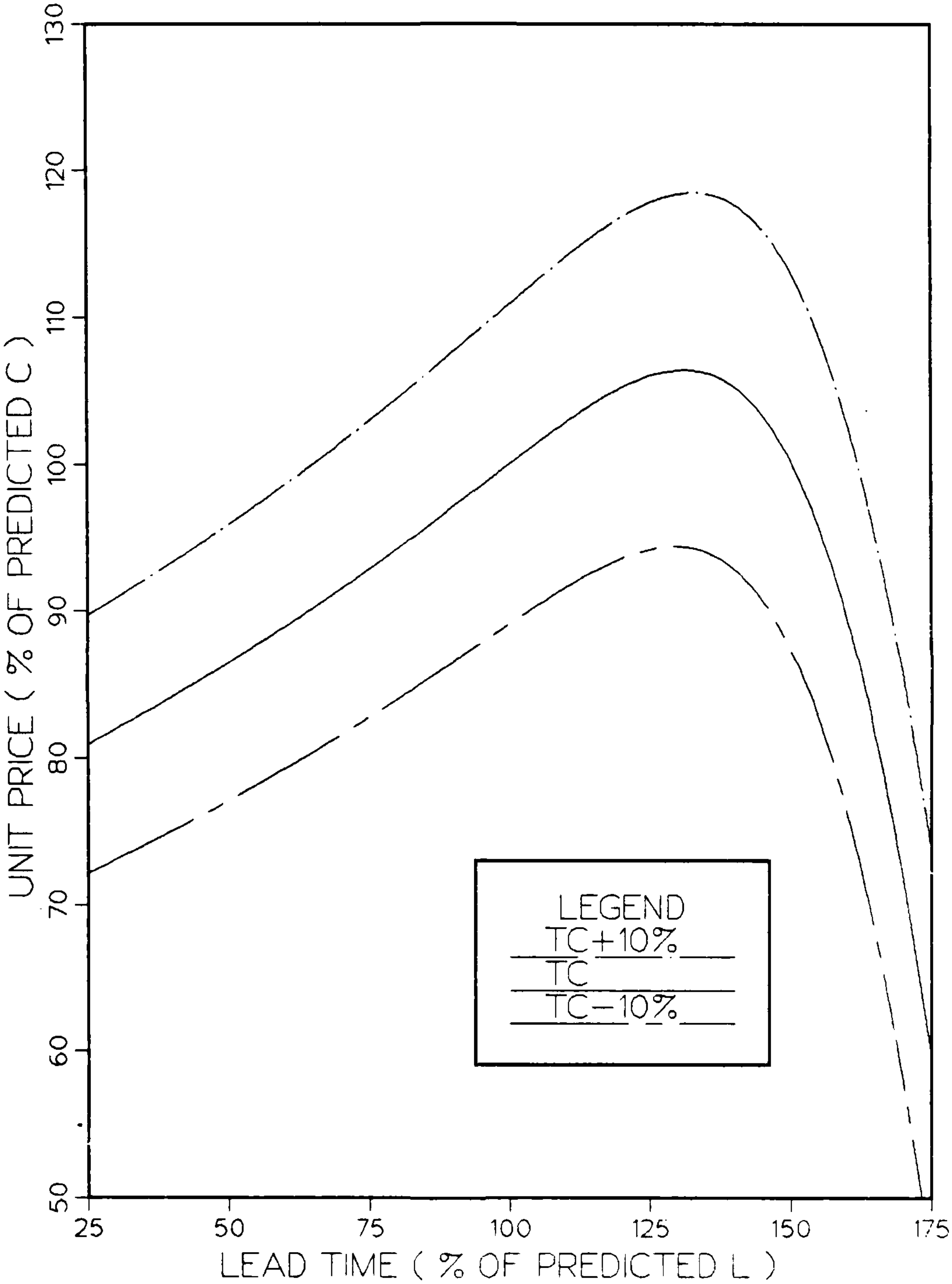

Figure 5

Change in C Required to Produce a 10% Change in TC
(Q and R Constant)

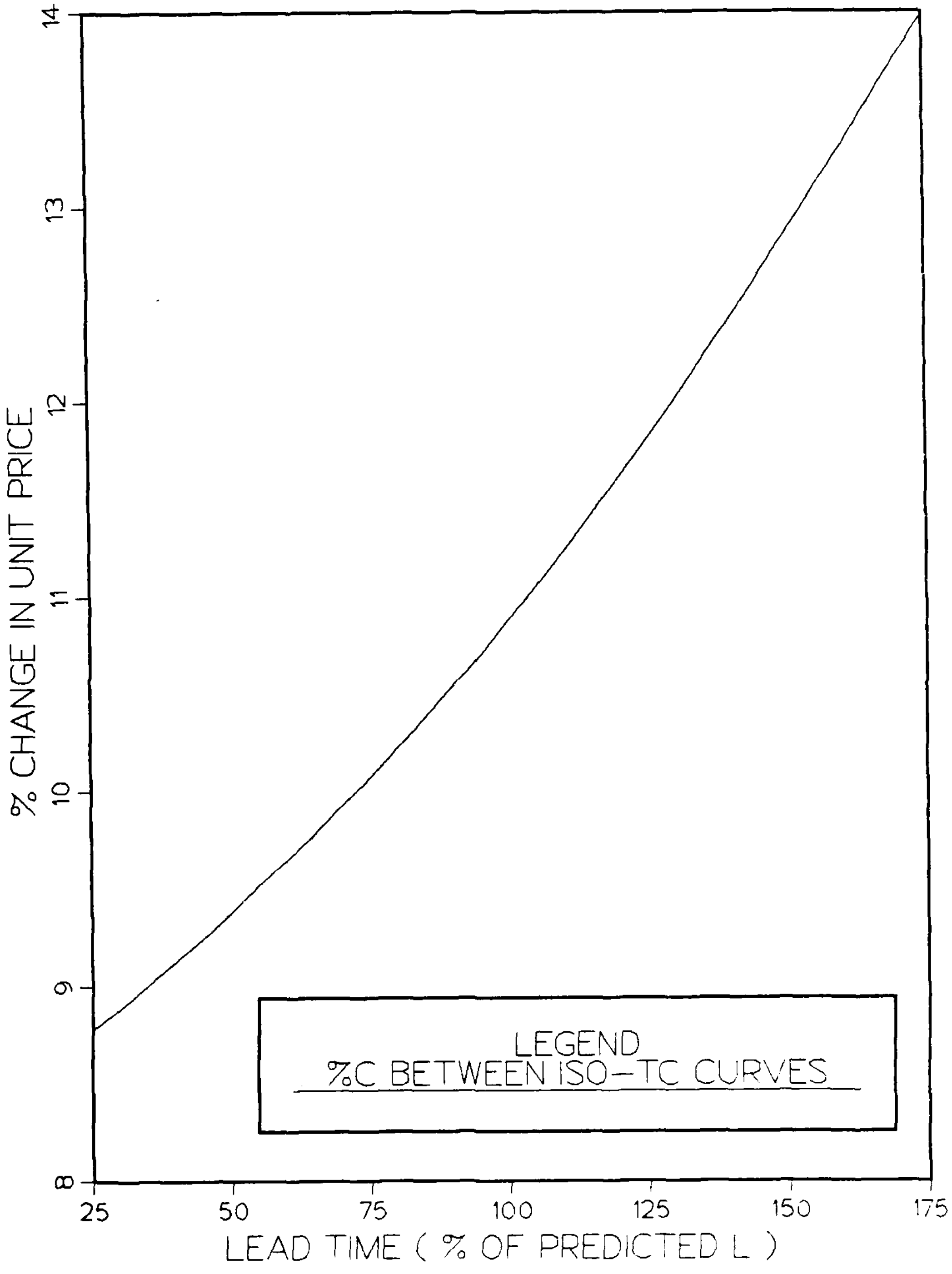

Figure 6

between two adjacent isocost curves in Figure 5. It can be seen that at a lead time which is 25% of the predicted length less than a 9% change in unit price will generate a 10% change in predicted total cost, while at a lead time 175% of the predicted length a change in unit price of approximately 14% is required for the same total cost change.

This non-uniform and nonlinear vertical scale means that comparison of bid (C,L) points both lying above or below the line cannot be made by simple measurement of their vertical distance from the reference isocost curve in Figure 4.

Plotting several isocost curves for small incremental changes in the predicted total cost provides the required detail for comparison of the bid points. Figure 7 shows curves at 2% total cost increments above and below the predicted total cost value curve. Points A, B, C, D, E, and F represent the (C,L) values for six hypothetical bids.

Bid A has a unit price only 93% as large as the predicted C, and a lead time only 80% as long as the predicted L but, if chosen, it should give the same total cost as predicted by the UICP model. Bid B will result in the highest total cost among the six bids, as its 1% higher-than-predicted price and 20% shorther-than-predicted lead time are expected to produce a TC that is 8% higher than predicted. Bid C has an expected TC which is only 4% higher than predicted, although its C at 103% is higher than B, because its L of 100% is also longer than B's. Bid D has the lowest expected

Graph for Determining the TC Associated with
Bid C/L Pairs

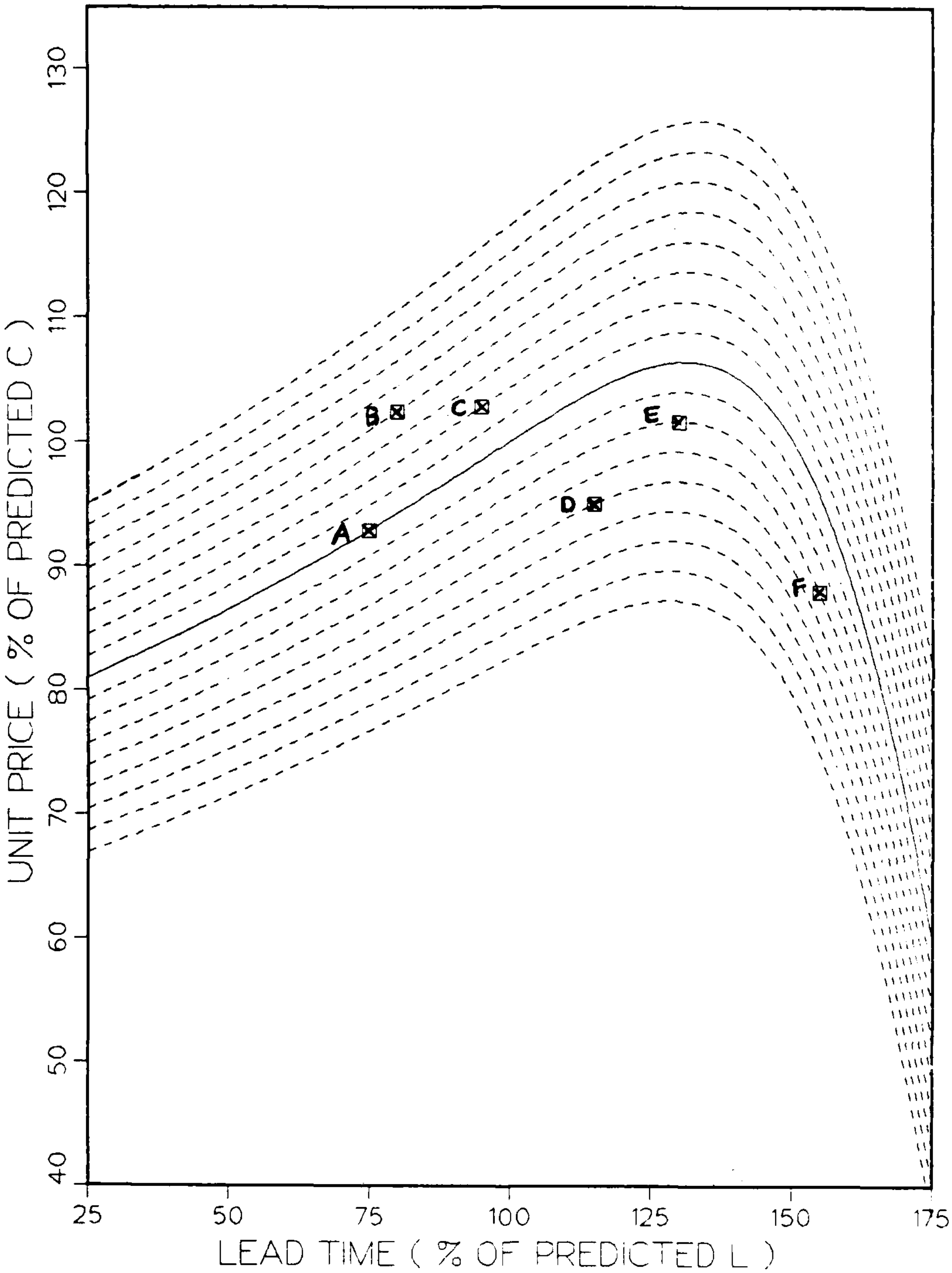

Figure 7

TC among the bids as its 95% C and 115% L should produce a TC that is 8% lower than predicted. Bid E's 102% and 130% L produce a TC that is 4% lower than predicted. Bid F has a slightly higher TC than Bid D despite being the lowest point visually, as its 88% C and 155% L produce a savings of 6% in TC.

The costs associated with these bids tend to defy intuition, particularly for bid E, for which a higher-than-predicted unit price and longer-than-predicted lead time still yield a lower-than-predicted total cost. The reasons for this result will be discussed in Chapter IV.

E. ALGORITHM FOR CALCULATING THE ISOCOST (C,L) REFERENCE CURVE

(1) Compute $\hat{Q}$, $\hat{R}$, and TVC using the UICP model and the historical C and L values.

(2) Add the associated purchase cost value ($C \cdot 4 \cdot D$) to the TVC to obtain TC.

(3) Select a new L.

(4) Calculate the new Z.

(5) Calculate the new PPV.

(6) Calculate the new EBO, which yields P_{out} and B.

(7) Holding TC constant, substitute the new L and B values into the TC equation and solve for C, using:

$$C = \frac{TC - \frac{A \cdot 4 \cdot D}{Q} - \frac{E \cdot \lambda \cdot B}{S}}{4 \cdot D + I\left(R + \frac{\hat{Q}}{2} - L \cdot D + B\right)}$$

(8) Repeat steps 3 through 7.

F. AN EXAMPLE CALCULATION

To illustrate how the isocost unit price and lead time pairs are determined, consider a category A item with the following characteristics where C and L are based on previous procurements:

$C = \$100$	$A = \$380$
$D = 8$ units	$MAD_D = 2.5$ units
$L = 7.5$ qtrs.	$MAD_L = 2.25$ qtrs.
$S = 1$	$E = .5$
$I = .23$	$\lambda = \$1,500$

The UICP model determines the following:

$\hat{Q} = 33$ units	$\hat{R} = 93$ units
$P_{out} = .0298$	$EBO = .9271$ units
$B = .015$ units	$PPV = 582.27$ units

which result in the following expected annual costs:

Order cost = \$368

Holding cost = \$1,139

Backorder cost = \$11

Total variable cost = \$1,518

Purchase cost = \$3,200

Total annual cost = \$4,718

Assuming a new lead time of 10.5 quarters, the cost factors directly affected by lead time must first be recalculated:

$$Z = D \cdot L = 8(10.5) = 84 \text{ units}$$

$$PPV = L(1.57 \cdot MAD_D^{\,2}) + D^2(1.57 \cdot MAD_L^{\,2})$$

$$= 10.5(1.57 \cdot 2.5^2) + 8^2(1.57 \cdot 2.25^2)$$

$$= 611.71 \text{ units}$$

$$EBO = \sqrt{PPV}\left(\Phi\left(\frac{R - 2}{\sqrt{PPV}}\right) - \Phi\left(\frac{R + Q - 2}{\sqrt{PPV}}\right) + \right.$$

$$\left.\left(\frac{R + Q - Z}{\sqrt{PPV}}\right)\phi\left(\frac{R + Q - Z}{\sqrt{PPV}}\right) - \left(\frac{R - Z}{\sqrt{PPV}}\right)\phi\left(\frac{R - Z}{\sqrt{PPV}}\right)\right)$$

$$= \sqrt{611.71}\left(\Phi\left(\frac{112 - 84}{\sqrt{611.71}}\right) - \Phi\left(\frac{112 + 33 - 84}{\sqrt{611.71}}\right) + \right.$$

$$\left(\frac{112 + 33 - 84}{\sqrt{611.71}}\right)\phi\left(\frac{112 + 33 - 84}{\sqrt{611.71}}\right) -$$

$$\left.\left(\frac{112 - 84}{\sqrt{611.71}}\right)\phi\left(\frac{112 - 84}{\sqrt{611.71}}\right)\right)$$

$$= 5.56 \text{ units}$$

$$P_{out} = \frac{EBO}{Q} = \frac{5.56}{33} = .1685$$

$$B = \frac{Q}{2}\left(P_{out}\right)^2 = \frac{33}{2}(.168)^2 = .468 \text{ units}$$

Simple rearrangement and grouping of terms in the TC equation results in the following equation for C:

$$C = \frac{TC - \dfrac{A \cdot 4 \cdot D}{Q} - \dfrac{E \cdot \lambda \cdot B}{S}}{4 \cdot D + I\left(R + \dfrac{Q}{2} - L\ D + B\right)}$$

$$= \frac{4718 - 368 - (.5)(1500)\left(\dfrac{.468}{1}\right)}{32 + .23\left(93 + \dfrac{33}{2} - (10.5)8 + .468\right)}$$

$$= \$105.30$$

The expected total cost terms are now calculated to be:

Order cost = \$368

Holding cost = \$629

Backorder cost = \$351

Total variable cost = \$1,348

Purchase cost = \$3,370

for a total cost of \$4,718 as before.

The longer lead time has decreased the total variable cost by eating down the on-hand inventory and thus reducing expected holding costs to a greater extent than the concurrent increase in the expected number of backorders has increased expected shortage costs. On the other hand, the higher unit price has increased the purchase cost as well as moderating the reduction in expected holding costs resulting from the longer lead time. As intended, the total expected costs remain the same.

G. ALTERNATIVES FOR BID EVALUATION

The total cost resulting from the unit price and lead time of each bid represented by the points in Figure 5 could be calculated and then compared on a direct dollar basis using the same mathematical approach. To do so would require the use of a computer by procurement personnel rather than just a ruler and pencil as would be the case if standard graphs such as Figure 7 were developed for stocked items. Chapter IV will examine the applicability of a given set of used in setting $\hat{R}$ is that of the last procurement action rather than an exponentially smoothed or other averaged value from prior procurement actions.[1] For the example item, the model would set $\hat{R}$ at 112 units (an increase of 19 units) and the resulting expected total cost would become $4,741 (an increase of $23). During the next procurement action the procurement section would attempt to contract for an even longer lead time to again reduce the average on-hand inventory (and thus total cost), and the UICP model will subsequently further increase $\hat{R}$ as this longer lead time enters the forecast. If the item remains stocked in the system long enough and this cycle of increased L and $\hat{R}$ continues, the long term result will probably be higher total costs than would have resulted if the lead time had never been adjusted to lower short term costs. These progressive increases in lead time, reorder level, and expected total cost are illustrated in Figure 14.

2. Fixed $\hat{Q}$, Variable $\hat{R}$

A possible method of breaking this cycle of escalation lies in expanding the current practice of adjusting the forecasted value of L at the time the procurement is signed to include immediately recalculating $\hat{R}$ as well. A vendor bid

[1] This is the current practice used by SPCC to compensate for shortcomings in the model's responsiveness to manufacturer delivery lead times which vary significantly from forecasted values.

D. RECOMPUTATION OF $\hat{Q}$ and $\hat{R}$

1. Fixed $\hat{Q}$ and $\hat{R}$

In the current UICP model $\hat{Q}$ and $\hat{R}$ are fixed for the current procurement action, and to a considerable extent for the next several procurement actions as well. The procurement contract lead time is added to the UICP data base, but an exponential smoothing method is applied in forecasting the lead time value used in determining $\hat{R}$. Thus $\hat{R}$ does not change significantly as the result of the lead time associated with any one procurement action. SPCC's data base containing the unit price value used in computing $\hat{Q}$ is only updated annually and thus $\hat{Q}$ would not be expected to change for at least six months. Manual overrides to this practice are possible of course, but the percentage of stocked items to which overrides can be applied is limited because of the large quantity of line items managed.

This does not mean that the model will not react to the longer lead times and increased stockouts incurred in the effort to reduce total costs. $\hat{R}$ is not fixed in the long run. It will be adjusted by the UICP model to raise safety stock levels to compensate for the longer lead time; that will cause an increase in total costs. For example, suppose that a 30% longer lead time was contracted for and actually met by the vendor, and that unit price was the same as the forecasted value. To permit the effects of this change to be seen more rapidly, it is assumed that the L

Sensitivity of the Isocost Curve to Forecasted MAD_L

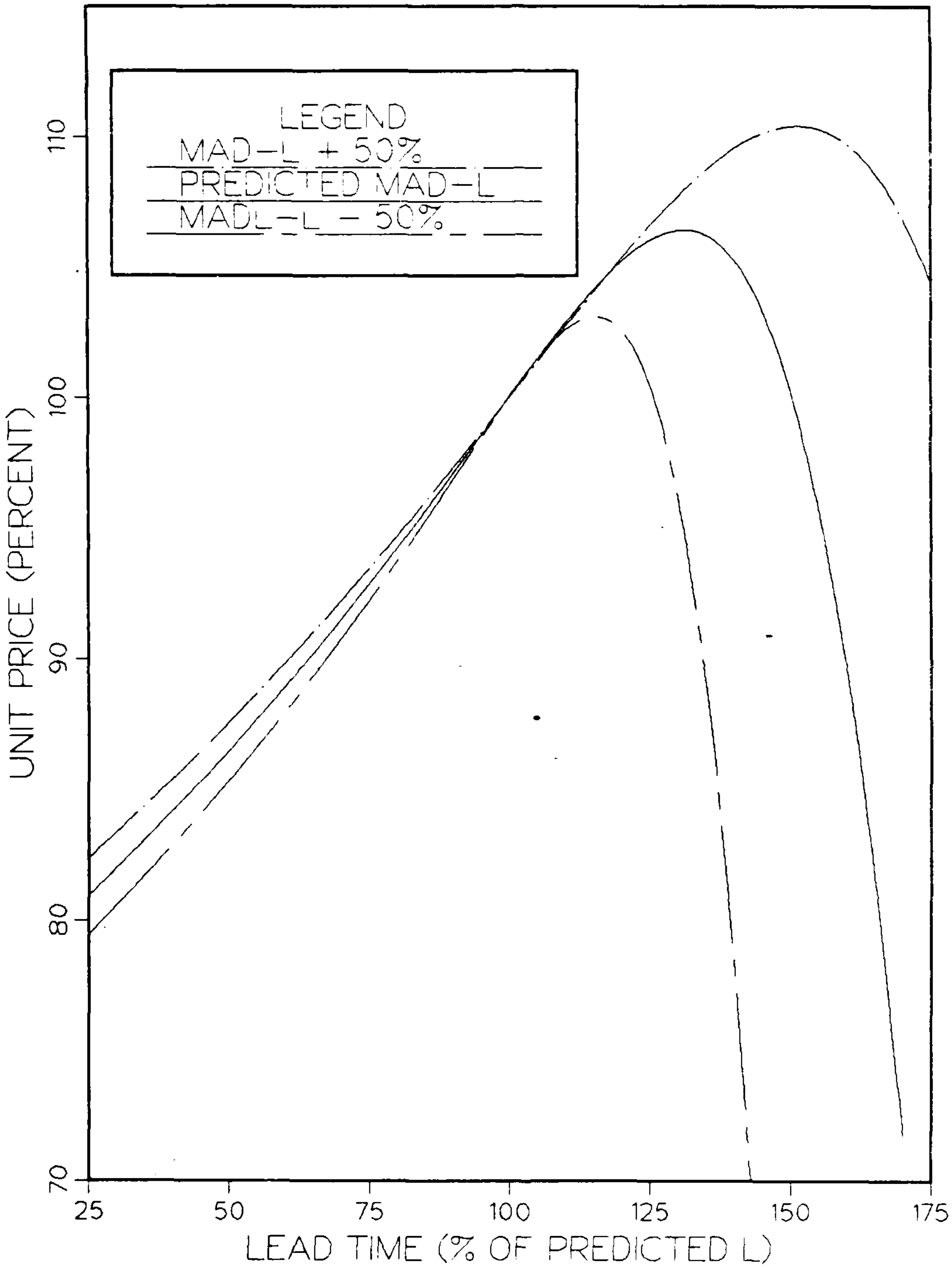

Figure 13

Sensitivity of the Isocost Curve to Forcasted MAD_D

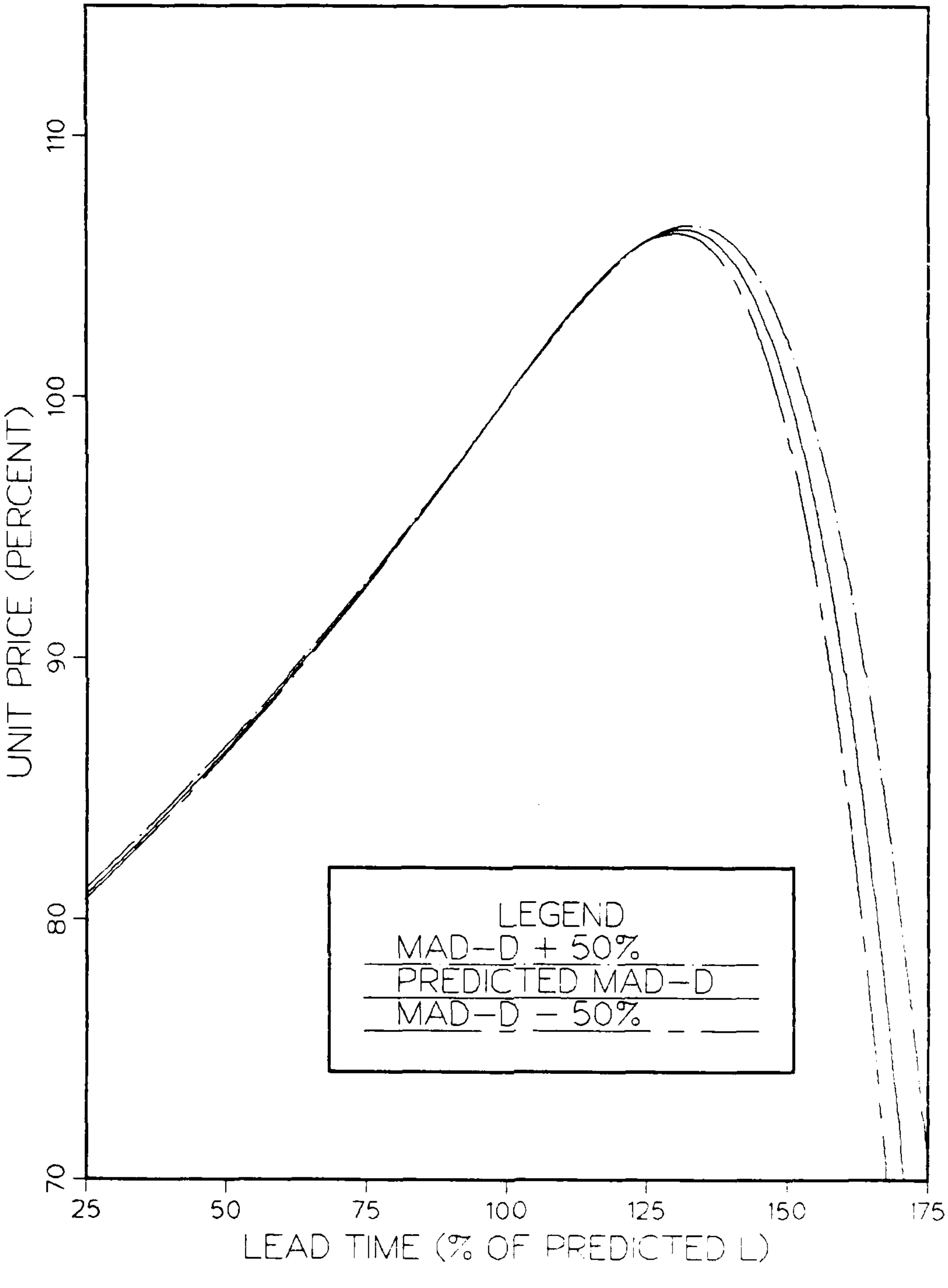

Figure 12

declines more quickly for less expensive items as lead time becomes more than 25% greater than forecasted. The abrupt endings of some of the isocost curves are a consequence of a minimum constraint of zero placed on average inventory on-hand in the thesis computer program to prevent the model from generating a perpetual backorder solution. Once the average on-hand quantity reaches the zero constraint holding costs cannot be further reduced and thus total costs must rise with the increased stockout costs associated with any further increase in lead time. Since an isocost solution is not possible past that point the curve terminates.

Figure 12 shows that the shape of the isocost curve is relatively insensitive to differences in MAD_D.

Figure 13 shows the considerably greater impact of differences in MAD_L on the curve shape. The lower the MAD_L, the faster the curve peaks after the forecasted L is passed, and the smaller the range in unit price that can produce the same total cost over the range of lead times considered.

Each figure has shown in isolation the impact of each of an item's characteristics. The combined impact of differences in the characteristics among items is likely to be considerably more complex, and should be studied further before the range of items that may be evaluated by one bid comparison graph can be accurately determined.

Sensitivity of the Isocost Curve to Forecasted C

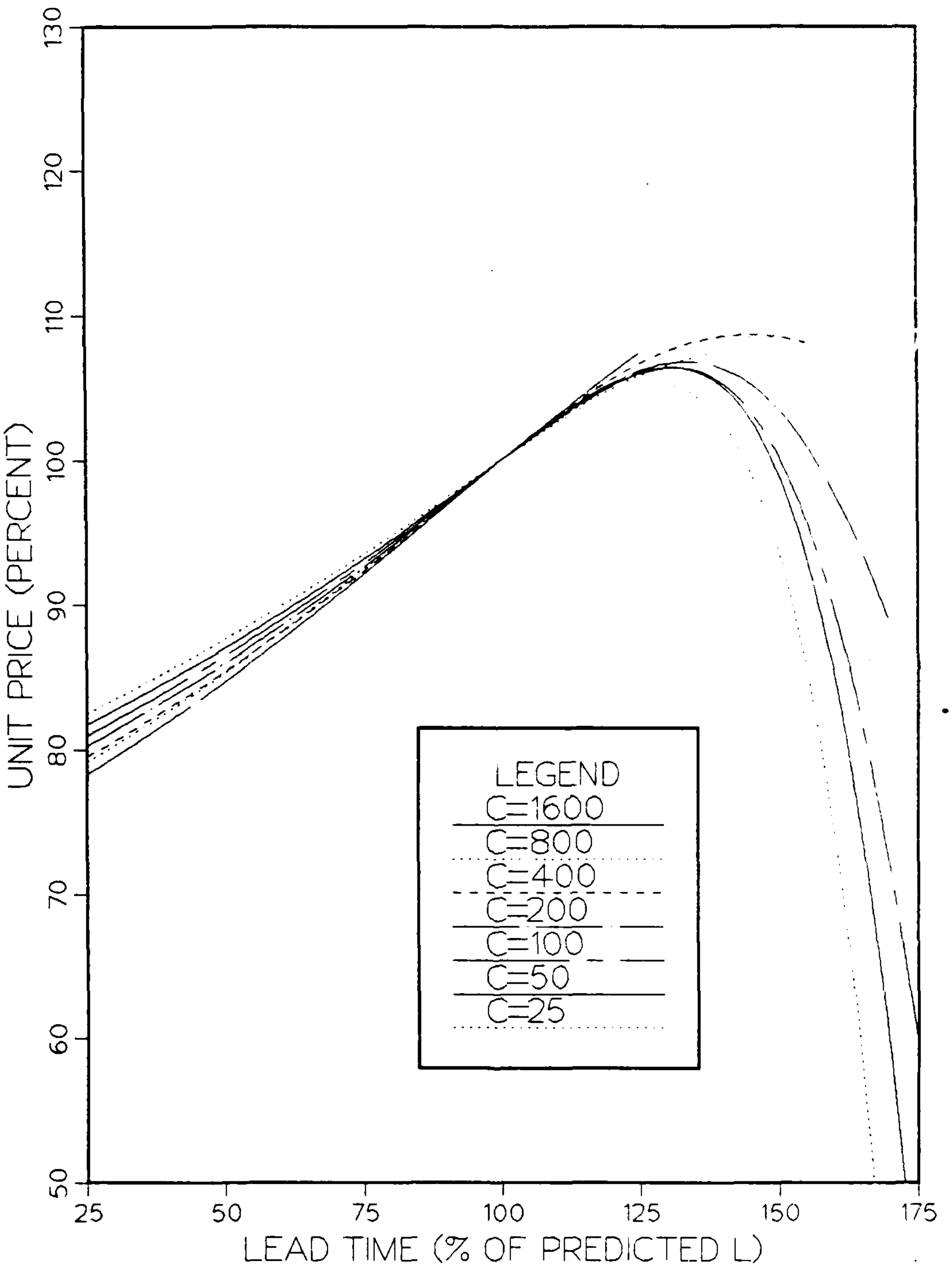

Figure 11

Sensitivity of the Isocost Curve to Forecasted D

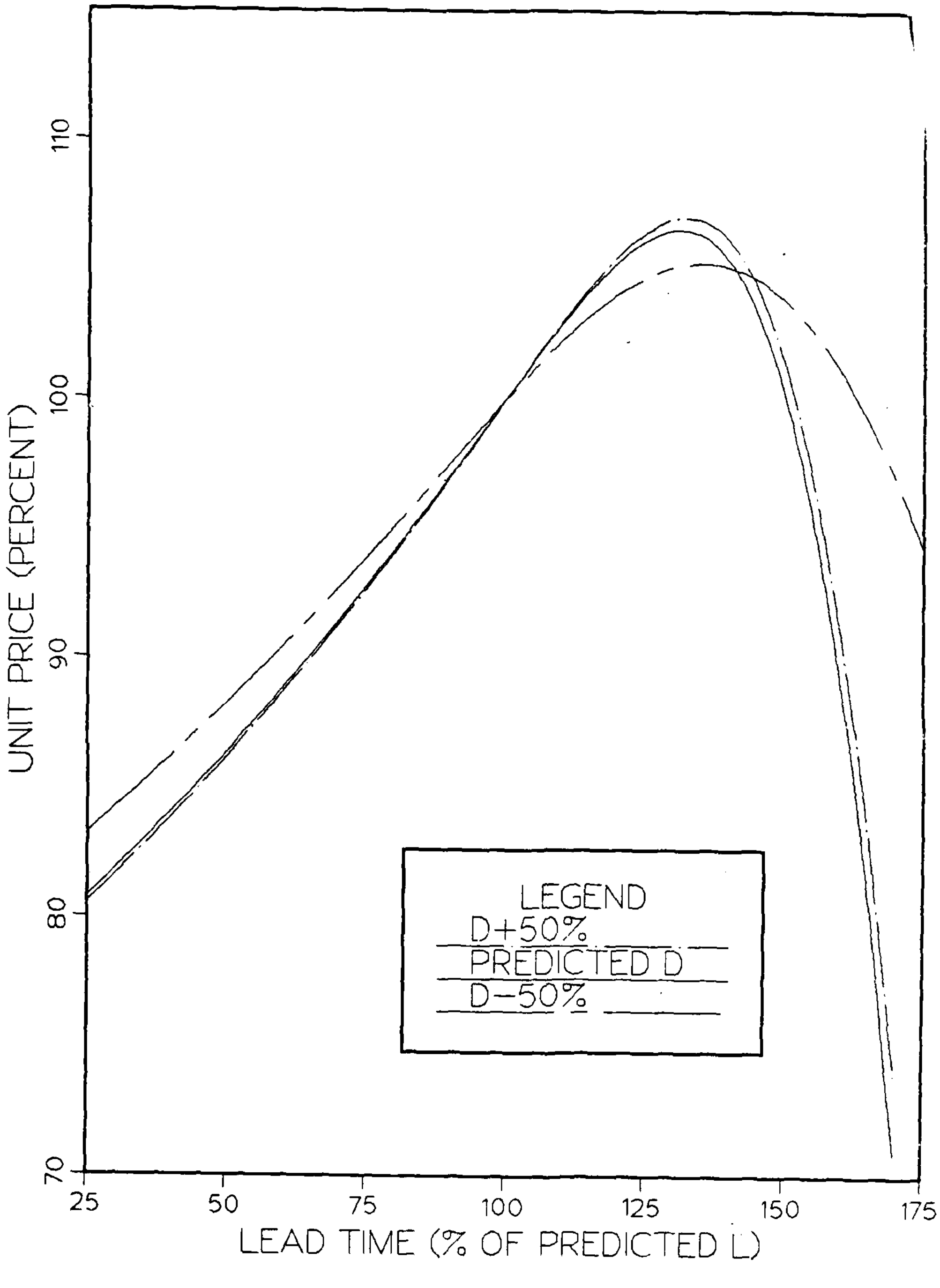

Figure 10

Sensitivity of the Isocost Curve to Forecasted L

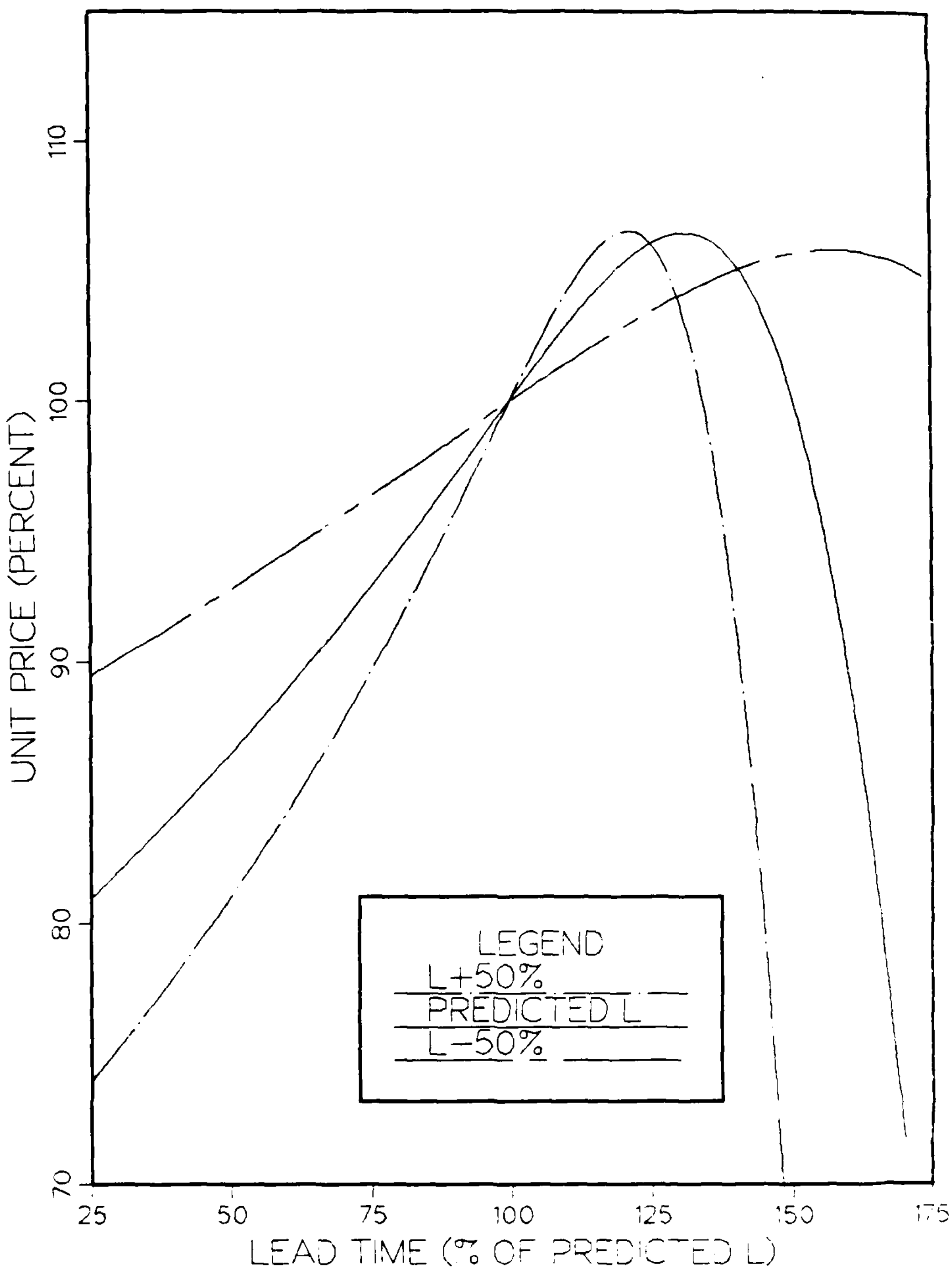

Figure 9

the 1H category maximum values allowed. Therefore, a further constraint on P_{out} should probably be imposed if the CNO goal of 85% SMA is to be met by the new model.

C. APPLICABILITY OF AN ISOCOST CURVE TO MULTIPLE ITEMS

The percentage units on the axes of Figure 7 permit it to be used in determining the least cost bid for items with differing predicted lead times, unit prices, and total costs as long as the differences in these and other item characteristics are not so great as to change the shape of those isocost curves. However, Figure 9 shows that the shape of the reference isocost curve is quite sensitive to differences in forecasted lead time between items[1] as L changes for any given item. As forecasted L increases, the maximum point of the curve shifts further to the right and the curve flattens out. The height (C value) of the maximim point declines somewhat as well.

Figure 10 shows the similar but less pronounced impact on the isocost curve's shape produced by differences in the average quarterly demand rate among items.

The effect of an item's unit price on the shape of the bid reference curve is depicted in Figure 11. The curve

[1]In Figures 9 through 13 only the specified item characteristic varies between the items used to generate the curves. For Figure 9, for example, this means that D, C, MAD_D, and MAD_L, are the same for all 3 items.

where

W = Requisition frequency

RE = Requisition effectiveness

$$= 100\left(1 - \frac{\frac{4D}{Q}(EBO)\left(\frac{F}{D}\right)}{4F}\right)$$

At the UICP "optimum" solution, the associated value of SMA is computed to be:

$$SMA = 100\left(1 - \frac{\frac{4\cdot 32}{33}(.9271)\left(\frac{8}{8}\right)}{4\cdot 8}\right)$$

$$= 88.8\%$$

At the minimum point of the TC curve in Figure 1, where L equals 130%,

$$SMA = 100\left(1 - \frac{\frac{4\cdot 32}{33}(3.841)\left(\frac{8}{8}\right)}{32}\right)$$

$$= 53.4\%$$

Since TC at the minimum point is equal to \$4,466, a \$252 savings in expected annual total cost for the item has come at the expense of a 35.4% drop in SMA.

The value of the P_{out} is 0.1164 when L is equal to 130% of the forecasted L. This value is considerably under any of

Impact of L on TC and P_{out}
(Q, R, and C Constant)

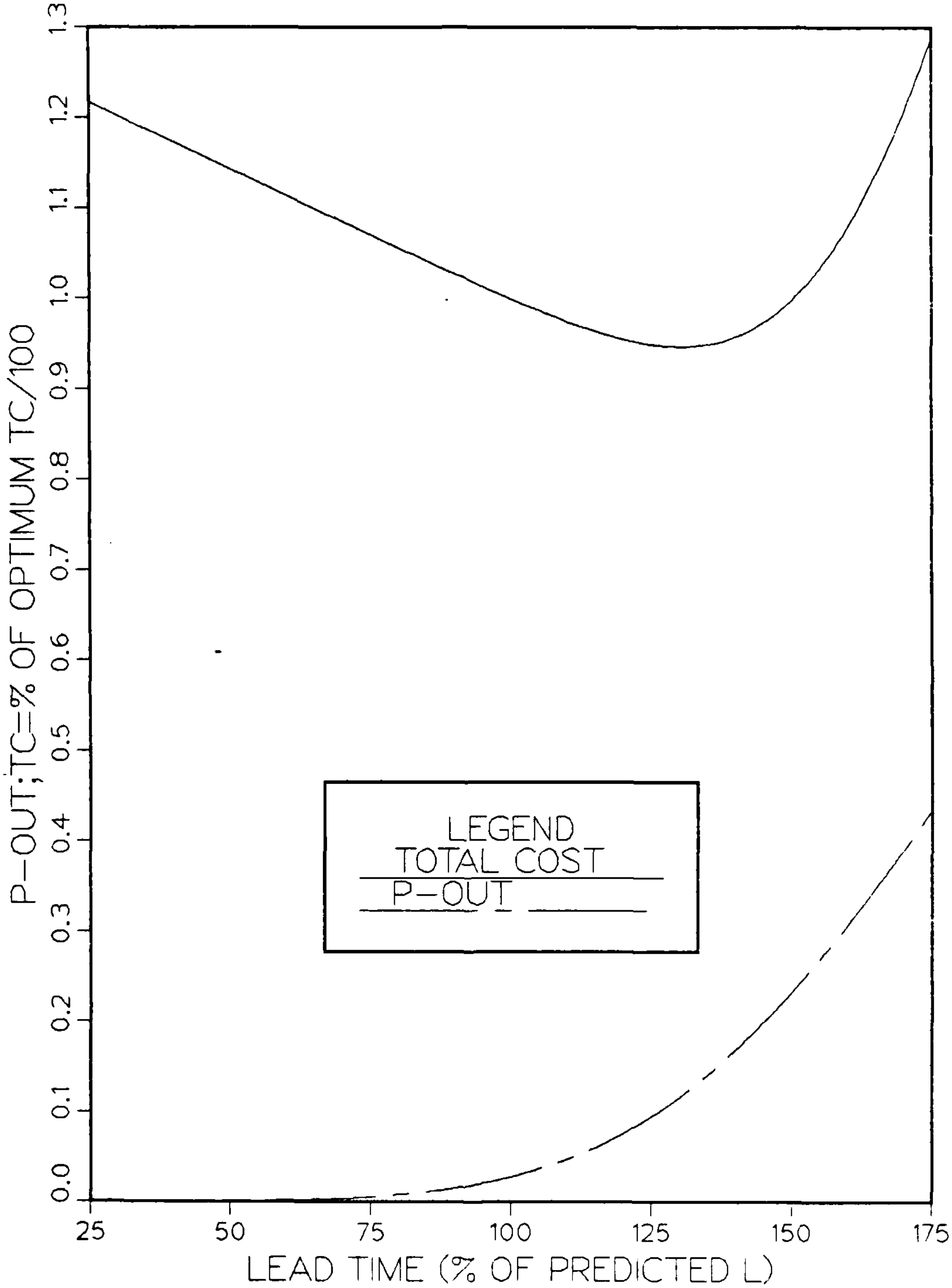

Figure 8

zero, while the already large holding costs rapidly increase due to the higher average on-hand stock quantities.

B. EFFECT OF LONGER LEAD TIMES ON P_{OUT} AND SMA

Figure 8 shows that the reduction in total cost produced by lengthening procurement lead time for an item (when Q and R are fixed) is accompanied by an exponential increase in P_{out}. Most items examined showed similar reductions in total costs at longer lead times until the value of P_{out} reached, or in some cases considerably exceeded, the maximum P_{out} permitted by the UICP model for that item's category. This indicates that even if the UICP constraint is used in selecting the lowest cost bid (C,L) combination, it can be expected that the average P_{out} for all items in each category will approach the maximum value allowed. This overall increase in P_{out} means that a substantial drop in SMA will occur.

Using the CARES computation for SMA in Reference 7 - the number of requisitions satisfied immediately divided by the number of requisitions received for the item - the SMA for the example item would be computed using the following formula:

For one item,

$$SMA = \frac{W \cdot RE}{W} = RE$$

IV. DISCUSSION

A. LOCATION OF THE MINIMUM TOTAL COST POINT

The minimum total cost for the item examined occurred at a lead time longer than that forecasted at the time the order quantity and reorder level were computed. The risk of stock-out, or P_{out}, increased with the lead time, but at the minimum cost point it was still below the maximum value allowed by the UICP model for the item category. The reason for the longer lead times producing lower total costs can be seen in Figure 1. The P_{out} used in calculating $\hat{Q}$ and $\hat{R}$ is so small (.0298) that the backorder cost term is of very little significance in the UICP's "optimum" total cost ($11 out of $4,718). The bulk of the TC (aside from the constant purchase cost) consists of the holding cost.

The high holding cost immediately and rapidly decreases from its $1,139 "optimum" value as lead time, and thus the expected lead time demand quantity, increases. On the other hand, it isn't until the lead time approaches a 25% increase over the forecasted value that the increased backorder cost term becomes large enough to counteract the holding cost's decline and cause the total costs to level off and then rise.

The reverse effect is seen for lead times shorter than the predicted length. The backorder cost offers little in the way of savings as the expected backorders drop towards isocost curves for the comparison of vendor bids for items whose demand rate, forecasted lead time, or other characteristics vary from those of the example item.

Long Term Impact of Fixed R in Bid Selection
(C and Q Fixed)

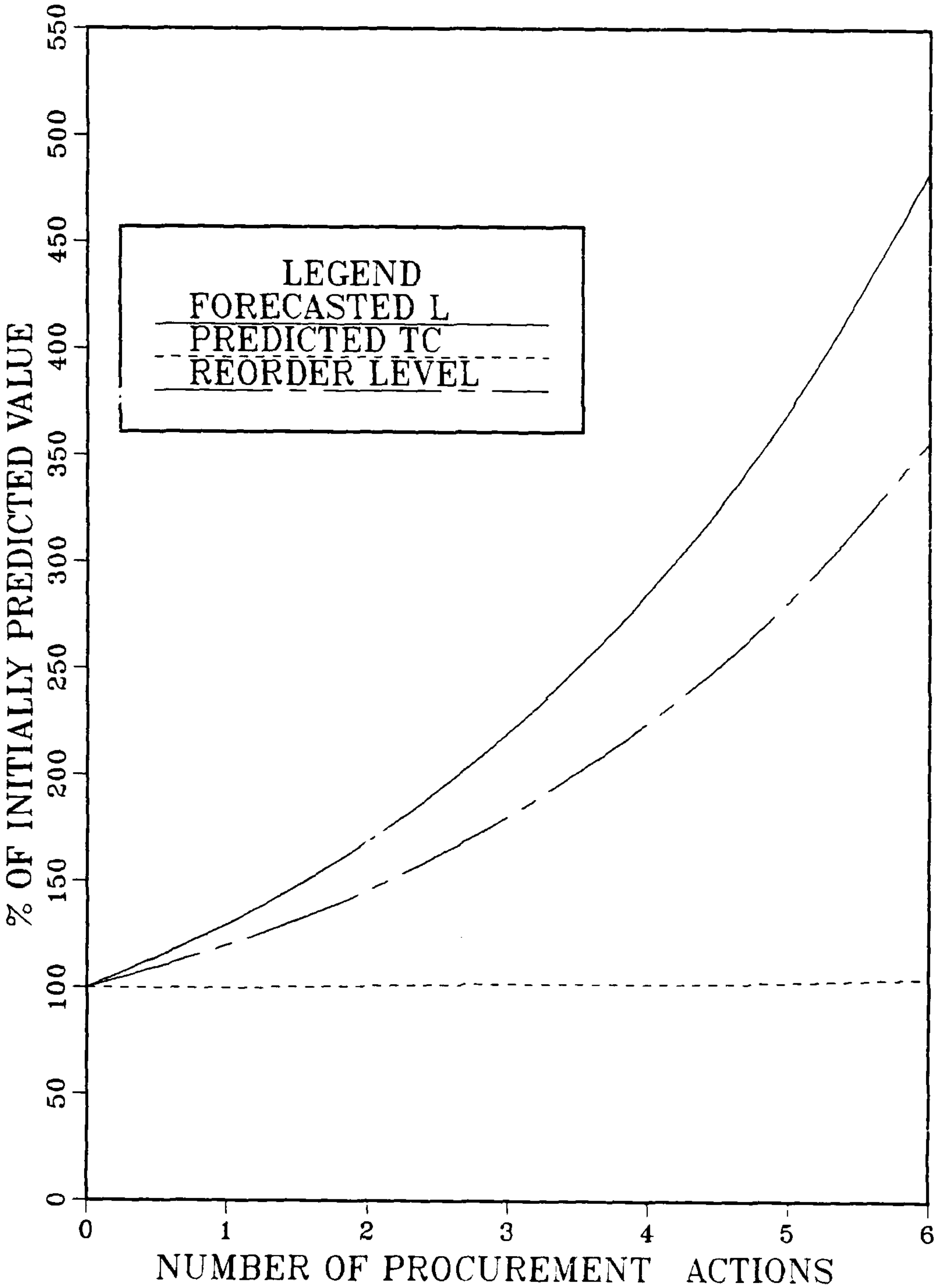

Figure 14

could now be evaluated on the basis of the total costs associated with the $\hat{R}$ that would be set by that bid's lead time, not the $\hat{R}$ in use at the time the bid was received as in Chapter III. If this procedure were used the optimum bid lead time for any unit price would be the shortest offered rather than the longest. The UICP model would reduce $\hat{R}$ as less safety stock would be needed to obtain the same protection. The holding costs would decline due to the lower average on-hand inventory as would the total cost. This effect is shown in Figure 15, which assumes that C is fixed (and therefore that Q is fixed) and that the lowest bid L is 30% below the forecast.

The reduction in total costs associated with shorter lead times is even more pronounced if MAD_L is also recalculated on the basis of the bid lead time using the SPCC power rule method of forecasting MAD's.

3. Variable $\hat{Q}$ and $\hat{R}$

Since the unit price submitted by the vendor in each bid is the principal criterion for bid comparison in the present system, it seems logical to use the bid C to adjust $\hat{Q}$ when evaluating total costs associated with the bid, as with L and $\hat{R}$. Figure 16 depicts the costs associated with bid (C,L) points when the $\hat{Q}$ and $\hat{R}$ used in the TC computation are those determined by the bid (C,L). A lower unit price is still associated with a lower total cost, as it was with

Long Term Impact of Variable R in Bid Selection
(C and Q Fixed)

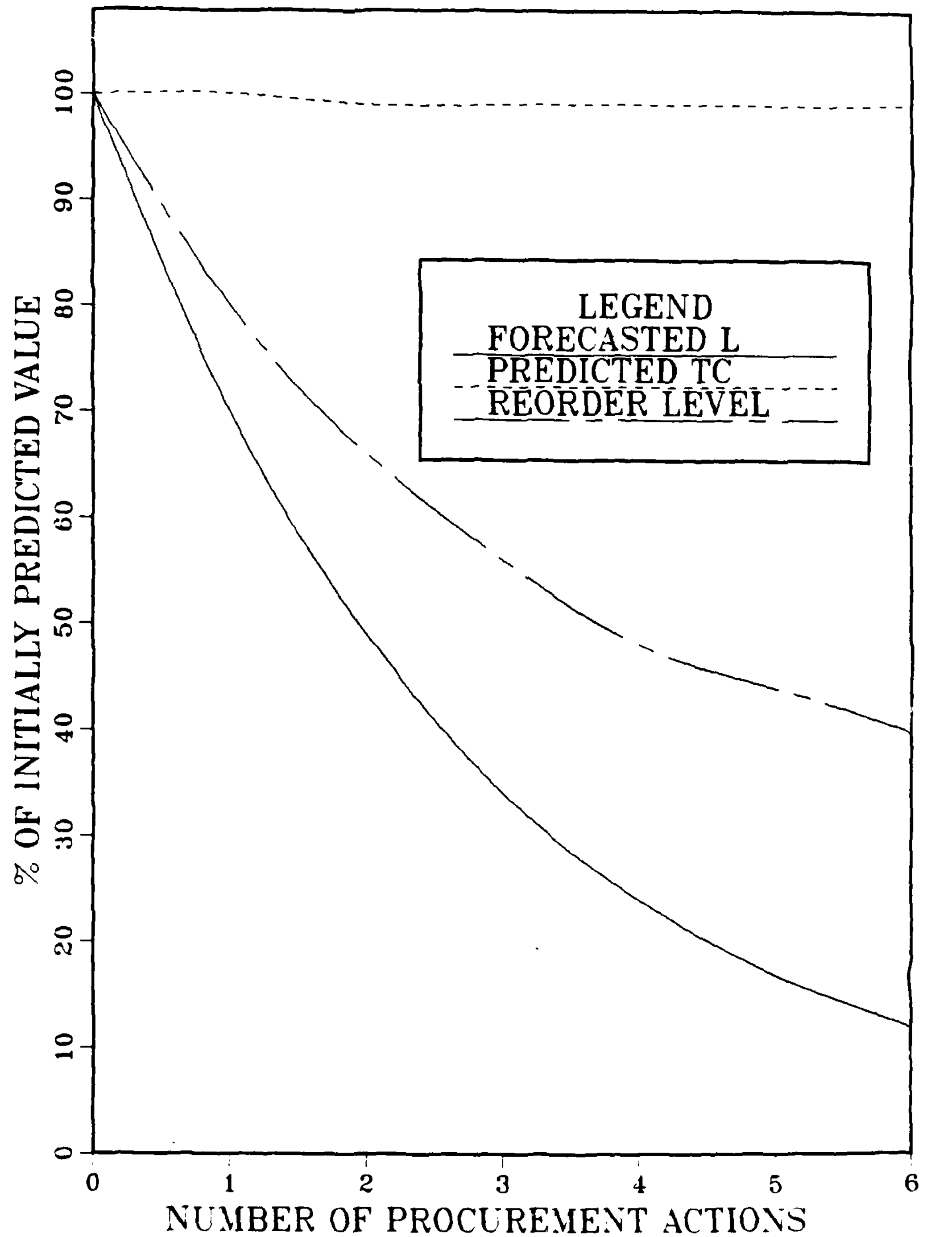

Figure 15

Impact of C and L on TC with Variable Q and R

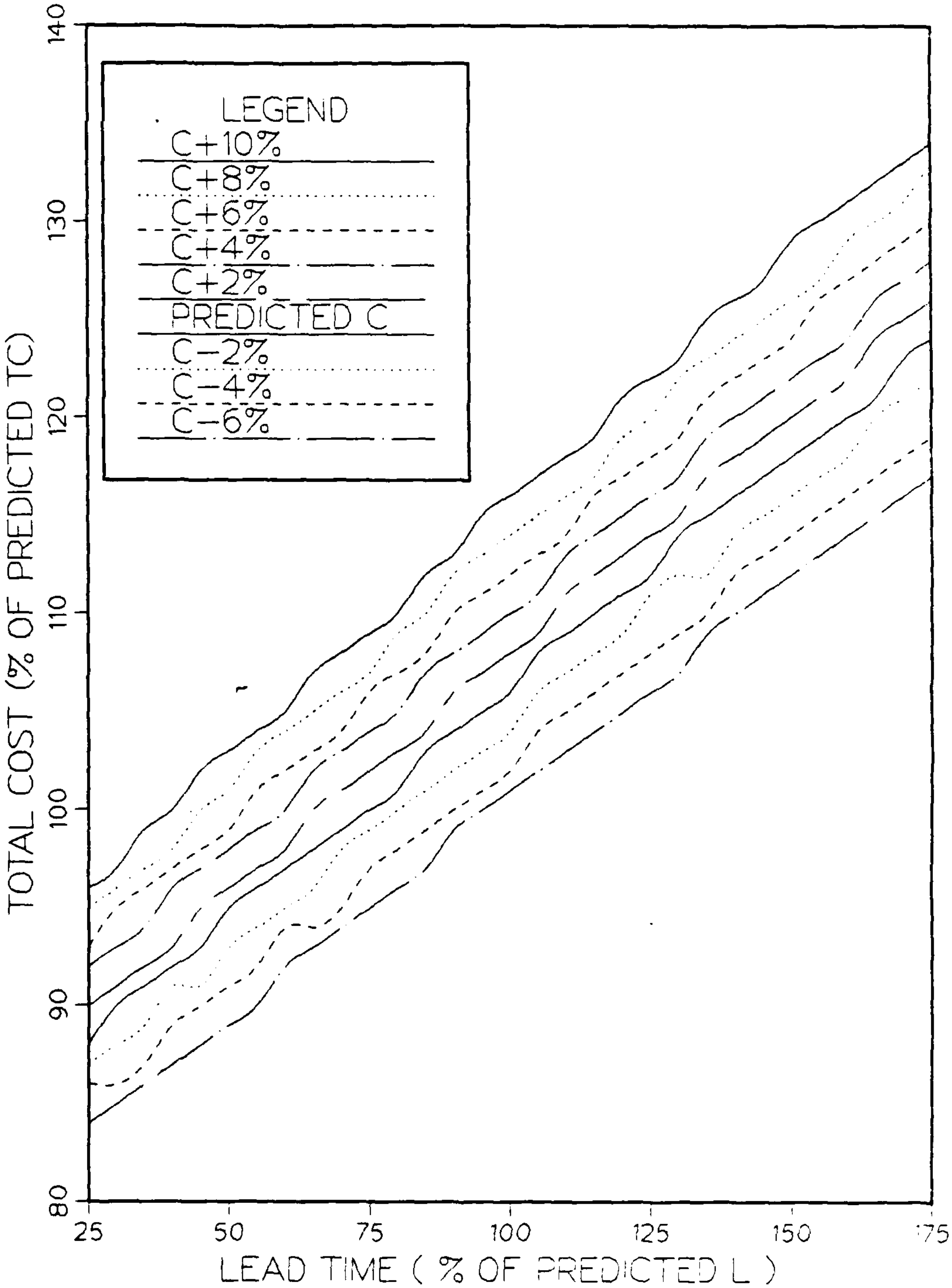

Figure 16

the fixed $\hat{Q}$ and $\hat{R}$ for that same item in Figure 3. MAD_L was permitted to vary with L in Figure 16, using the power rule method of computation. If MAD_L is held constant at 2.5 quarters, a point is quickly reached past which $\hat{R}$ ceases to decline significantly as L shortens because safety stocks are now being held for protection against the increasing percentage of uncertainty in the expected lead time value.

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 its optimization method 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 procurement lead time and unit price, along with other factors such as the item's demand rate. Finally, the limitations of minimizing only average annual variable costs without considering the effects of the annual purchase cost and the control over lead time and price in a competitive bidding environment were discussed.

Chapter III developed a total cost modification of the UICP model by adding the purchase cost term to the UICP's TVC equation. A change in the decision variables from Q and R to C and L was explained, and the effect of differences in C and L from their forecasted values on the various terms of the total cost equation was demonstrated graphically. The algorithm for determining all of the C and L combinations which would yield the same expected average annual total cost for an item was presented.

Finally, a methodology was developed from that algorithm which could be used to determine the lowest cost bid on the basis of comparing bid C and L values.

Chapter IV discussed this methodology and the reason why the average annual total costs could be reduced by changes in procurement lead time as part of the competitive bidding process. It was shown that if the order quantity and reorder level of the item are fixed then a cost savings can be obtained through reduction in average stock on-hand by making lead times longer than the forecasted length. It was found that those savings with fixed $\hat{Q}$ and $\hat{R}$ came at the expense of greatly reduced SMA. The shape of the isocost reference curve developed to analyze total costs associated with bid (C,L) points was found to be highly sensitive to variations in the item's demand rate, unit price, forecasted lead time, and MAD_L. It was also shown that if the reorder level was reset immediately upon awarding the new contract, using only that contracted lead time, then total cost would be reduced by using lead times shorter than forecasted.

B. CONCLUSIONS

Total inventory costs can be reduced through modification of the UICP model and the procurement process to include lead time as well as unit price in selecting the winning bid for stock replinishment contracts. The methodology developed in Chapter III does not appear to be the best way to determine the total costs associated with each vendor bid, however. The short term savings produced by temporarily reduced safety stocks will eventually be more than compensated for by higher safety stocks and costs in the future. Additionally the reduced SMA, although not quantifiable in dollar terms, seems likely to outweigh the benefits that might be obtained from the alternative use of funds freed from safety stock investment.

Evaluating vendor bids on the basis of minimizing total costs by finding the optimal Q and R for each bid's C and L pair appears to be a promising methodology which should be the subject of further research. The principal improvement from using those Q and R values, rather than keeping Q and R values fixed when the procurement action was initiated, will be due to the role of L in determining R. The difference in optimum Q for each bid is likely to be insignificant as Q varies only with the square root of C. The principal differences in the TC resulting from each bid's C can thus be expected to occur in the purchase cost term where the impact of C is linear. On the other hand, differences in L between bids can be expected to have a greater impact on R, and thus the variable cost portion of TC, than with C and Q. The impact of lead time will be increased over that shown in the thesis model if MAD_L does in fact vary with L as assumed by the forecasting power rule. Since the size of the safety stock portion of R is directly related to the magnitude of MAD_L for any given L, a shorter bid L will reduce both the average lead time demand and safety stock portions of R.

This method makes intuitive sense as a faster delivery justifies a premium price, as opposed to the lower prices (purchase costs) required to offset the increased variable costs associated with shorter lead times in the fixed Q and R bid comparison method. The variable Q and R method should also offer lower total costs without increasing P_{out} and lowering SMA.

The behavior of total cost when lead time and unit price are used as decision variables needs to be more rigorously defined and quantified. The impact on the magnitude and frequency of level revisions resulting from using the most recent value experienced for a variable instead of exponential smoothing for forecasting when managing a large population of items should also be investigated.

Finally, if further research indicates that total cost savings are theoretically possible, a trial program should be conducted by the ICP procurement section for a sample group of items. The additional workload (and possible increase in administrative ordering costs) that might result from the more complex bid process should be determined. The ability of vendors to estimate their own price and production time relationship in submitting bids, as well as their acceptance of the modified bid evaluation process, will be critical to the realization of the theoretical savings and must therefore also be determined.

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APPENDIX A

COMPUTER PROGRAM FOR GENERATING ISOCOST (C,L) POINTS

```
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 .  IT FOLLOWS THE ALGORITHMS*
C OF THE UICP WHOLESALE CONSUMABLES REPLENISHMENT MODEL AS CONTAINED   *
C IN CHAPTER 3 OF NAVSUP PUB 553. ONCE THE OPTIMUM Q, R, AND TC HAVE   *
C BEEN COMPUTED THE PROGRAM DETERMINES OTHER COMBINATIONS OF UNIT PRICE*
C AND PROCUREMENT LEAD TIME WHICH WILL PRODUCE THE SAME TC, GIVEN R AND*
C Q. THE IMPACT OF ANY OF THE ITEM'S CHARACTERISTICS ON OPTIMUM Q, R,  *
C AND THE SHAPE OF THE ISOCOST (TC) CURVE MAY ALSO BE DETERMINED. THE  *
C PROGRAM IS ACTIVATED BY AN EXEC FILE WHICH DEFINES THE OUTPUT FILES  *
C AND LOADS THE IMSL SUBROUTINES.  THE PROGRAM READS FROM USER DISK    *
C DATA FILES; WRITES THE ITEM COST DATA AND WARNING MESSAGES REGARDING *
C ACTIVE CONSTRAINTS ON ORDER QUANTITY OR REORDER LEVEL; AND WRITES    *
C LEAD TIME, PRICE, AND COST DATA TO DATA FILES AS DEFINED IN THE EXEC *
C FOR LATER PLOTTING OF COST CURVES WITH A GRAPHICS PROGRAM.           *
C***********************************************************************
C
C ********** VARIABLE DEFINITIONS **********
C  A = ADMINISTRATIVE COST OF PLACING AN ORDER
C  AI = AVERAGE QUANTITY OF STOCK ON-HAND
C  B = EXPECTED NUMBER OF UNITS BACKORDERED AT ANY RANDOM POINT IN TIME
C  BOC = AVERAGE ANNUAL COST OF BACKORDERS
C  C = UNIT PRICE
C  D = AVERAGE QUARTERLY DEMAND RATE
C  E = ITEM ESSENTIALITY (MILITARY WORTH)
C  EBO = EXPECTED NUMBER OF BACKORDERS JUST BEFORE AN ORDER ARRIVES
C  F = REQUISITION FREQUENCY (D/S)
C  H = SHELF LIFE
C  HC = AVERAGE ANNUAL HOLDING COST
C  I = INVENTORY HOLDING COST RATE (FRACTION OF UNIT PRICE PER YEAR)
C  IN = SOURCE OF INPUT DATA-DETERMINED IN VARIABLE DECLARATION
C  J = OUTPUT DATA FILE IDENTIFIER (AS DEFINED IN EXEC)
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 = MINIMUN RISK CONSTRAINT
C  POUT = CONSTRAINED RISK
C  PPV = PROCUREMENT PROBLEM VARIANCE
C  Q = UNCONSTRAINED ORDER QUANTITY
C  QTIL = CONSTRAINED ORDER QUANTITY USED TO COMPUTE REORDER LEVEL
C  QHAT = FINAL CONSTRAINED ORDER QUANTITY
C  R = UNCONSTRAINED REORDER LEVEL
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  U = INTEGER INCREMENT FOR LOOP EVALUATING IMPACT OF VARIATIONS IN
C      ITEM CHARACTERISTICS ON QHAT,RHAT,AND TC
C  W = COUNTER FOR THE NUMBER OF ISOCOST POINTS GENERATED FOR EACH CURVE
C  X = INTEGER INCREMENT FOR TC VARIATION LOOP (ISOCOST CURVES)
C  XX = COUNTER FOR WRITING ITEM MARK CODE AND CATEGORY MESSAGE
C  Y = INTEGER INCREMENT FOR LEAD TIME VARIATION LOOP
C  Z = PROCUREMENT PROBLEM VARIABLE  (MEAN LEAD TIME DEMAND QUANTITY)
C  ZI = ROUNDED INTEGER VALUE OF Z
C *** SENTINEL VALUES FOR GENERATING ERROR/WARNING MESSAGES TO THE USER
C  ERR,WARNCQ,WARNQ,WARNR
C *** GENERAL NOTE - ADDING 'A' TO ANY VARIABLE NAME IDENTIFIES IT AS
C  A NEW EXPECTED/ACTUAL VALUE FOR THAT VARIABLE VICE THE VALUE INITIALL
C  USED/DETERMINED IN THE PROGRAM ( CA,LA,TCA, ETC.)
C
C ************ VARIABLE DECLARATIONS *******************
      REAL   A,C,D,E,F,H,I,L,LAMBDA,MADD,MADL,OC,P,PC,PMAX,PMIN,POUT,
     *PPV,Q,QTIL,QHAT,R,RHAT,S,TC,TVC,Z,CA,LA,OCA,PCA,TCA,TVCA,ZI,LPVAR
      INTEGER   ERR,IN,J,OUT,WARNCQ,WARNQ,WARNR,W,XX,X,Y,V
      DOUBLE PRECISION   B,BOC,BOCA
      DATA   IN/4/,OUT/6/
C
10    CALL FRTCMS ('CLRSCRN')
C
C *** READ INPUT DATA FROM FILE ***
C
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
C *** LOOP FOR EXAMINING THE IMPACT OF VARIATIONS IN ITEM CHARACTER-
C *** ISTICS (C,D,MADD,MADL, ETC.) ON ISOCOST SOLUTION. IF USED TO
C *** EVALUATE LAMBDA, REPLACE LAMBDA WITH DUMMY VARIABLE NAME IN
C *** CALLING ARGUMENTS OF DATACK IN LINES 30 AND 104.
CC    LAMBDA= 15.625
CC    DO 110 V=1,8,1
```

```
CC        IF (V.GE.6) GO TO 211
CC        LAMBDA = 2*LAMBDA
CC        GO TO 212
CC211     LAMBDA = LAMBDA + 500
CC212     CONTINUE
C *** WRITE INPUT DATA TO TERMINAL ***
22    WRITE (OUT,645)
23    WRITE (OUT,650) A,C,D,E,H,I,L,MADD,MADL,S
C
C *** DETERMINE ITEM COG/ASSOCIATED VALUES,CALCULATE PROCUREMENT PROBLEM
C *** VARIABLE AND PROCUREMENT PROBLEM VARIANCE                       ***
C
      XX = 1
30    CALL DATACK (C,D,F,I,L,LAMBDA,MADD,MADL,PMAX,PMIN,PPV,S,Z,ERR,
     *             OUT,XX)
      XX = 2
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
C
C *** CALCULATE AND CONSTRAIN THE OPTIMUM ORDER QUANTITY ***
50    CALL QTY (A,C,D,I,POUT,QTIL,WARNQ,Q)
C *** ADJUST ADMIN ORDER COST IF TOTAL BUY IS $8,000 OR MORE, THEN
C *** RECOMPUTE Q ACCORDINGLY
        IF (C*QTIL.LE.8000.) GO TO 54
           A = 1050.00
           WRITE (OUT,605)
           CALL QTY(A,C,D,I,POUT,QTIL, WARNQ,Q)
C
```

```
C *** WRITE WARNING MESSAGE FOR CONSTRAINTS APPLIED TO Q ***
54      GO TO (55,56,57,58),WARNQ
55          WRITE (OUT,621)
            GO TO 58
56          WRITE (OUT,622)
            GO TO 58
57          WRITE (OUT,623)
58      CONTINUE
C
C *** CALCULATE AND CONSTRAIN THE OPTIMUM REORDER LEVEL ***
60    CALL RLVL (POUT,PPV,QTIL,RHAT,Z,EBO,D,H,WARNR)
C *** WRITE WARNING MESSAGE FOR CONSTRAINTS APPLIED TO R ***
          IF (WARNR.EQ.1) WRITE (OUT,627)
          IF (WARNR.EQ.2) WRITE (OUT,628)
          IF (WARNR.EQ.3) WRITE (OUT,629)
C
C *** CONSTRAIN Q (TILDE) TO Q (HAT) ***
70    CALL COTY (D,H,QHAT,QTIL,RHAT,Z,WARNCQ)
      IF (WARNCQ.EQ.2)  WRITE (OUT,624)
C
C *** COMPUTE THE EXPECTED NUMBER OF BACKORDERS AT ANY RANDOM POINT
C *** IN TIME - B(Q,R)
80    CALL BKORD(POUT,QHAT,B)
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,L,LAMBDA,QHAT,RHAT,TVC,OC,HC,BOC,S)
      PC = 4*D*C
      TC = TVC + PC
C
C *** WRITE HEADING AND ORDER/COST DATA TO TERMINAL ***
C
95    WRITE (OUT,625)
100   WRITE (OUT,630) QHAT,RHAT,TVC,LAMBDA,Q,P,POUT,PPV,EBO
      WRITE (OUT,655)
      WRITE (OUT,670) C,L,POUT,B,HC,BOC,TVC,TC
      EPOUT=EBO/QHAT
      WRITE (OUT,675) EPOUT
      WRITE (OUT,680)
C
C *** VARY TOTAL INVENTORY COST TO GENERATE MULTIPLE ISOCOST CURVES ***
C *** ( QHAT AND RHAT ARE FIXED, C AND L WILL VARY INSIDE THE LOOP) ***
102   DO 109 X=1,3,1
      TCA=TC * (.80+.1*X)
CC    TCA = TC
C
C *** WRITE HEADING FOR OUTPUT DATA TO TERMINAL
      WRITE (OUT,680)
```

```
      WRITE (OUT,660)
C
C *** VARY ITEM LEADTIME  AND COMPUTE UNIT PRICE REQUIRED TO PRODUCE ***
C *** THE TCA (ASSUME Q,R FIXED) - IE.,GENERATE ISOCOST (C,L) POINTS ***
103      DO 107 Y = 5,35,1
            LA =.05 * Y * L
CC          LA=L
C
104         CALL DATACK  (C,D,F,I,LA,LAMBDA,MADD,MADL,PMAX,PMIN,PPV,S,
     *                    Z,ERR,OUT,XX)
C
C ***COMPUTE NEW LEAD TIME DEMAND QUANTITY AND ITS STANDARD DEVIATION
C
            SIGC = SQRT (PPV)
C
            REMZ = AMOD (Z,1.)
            IF (REMZ.GE.0.5) Z=Z+1.
            ZI = AINT (Z)
C
C ***USE FOLLOWING ZI VALUE TO SMOOTH CURVES BY ELIMINATING INTEGER  ***
C ***VALUES/CONTINUOUS DISTRIBUTION ROUNDING ERRORS (IN EBOCAL)      ***
CC          ZI = Z
C
C *** COMPUTE EXPECTED NUMBER OF BACKORDERS, B(Q,R), AND IMPUTE RISK ***
            CALL EBOCAL (EBO,QHAT,SIGC,RHAT,ZI)
C
            POUT = EBO / QHAT
C
            B = EBO*EBO/(QHAT*2.)
C
C *** COMPUTE NEW UNIT PRICE TO MATCH EQUAL COST/NEW LEADTIME ***
C
            AI = QHAT*.5 + RHAT - LA*D + B
            IF (AI.LE.0) GO TO 108
C
            CA = (TCA-A*4*D/QHAT-E*LAMBDA*B/S)/(4*D+I*AI)
C
C *** COMPUTE NEW VALUES FOR VARIABLE COST TERMS, THEN COMPUTE TCA
C *** USING THE NEW UNIT PRICE AS A CHECK ON THE COMPUTATIONS ABOVE
C
      CALL TVCOST (A,B,CA,D,E,I,LA,LAMBDA,QHAT,RHAT,TVCA,OC,HC,BOC,S)
      PCA = 4*D*CA
      TCA = TVCA + PCA
C
C *** WRITE UNIT PRICE, LEAD TIME, AND TOTAL COST DATA TO TERMINAL ***
            WRITE (OUT,700) CA,LA,TCA,BOC,HC,OC,PCA,POUT
C *** WRITE LEADTIME/TOTAL COST DATA TO DATA FILES CRVE01 TO CRVE03***
C *** (DATA IS IN PERCENTAGES FOR LEADTIME AND UNIT PRICE)
```

```
            LA = LA/L * 100.
            CA = CA/C * 100.
            J = 7+X
            IF (X.GE.8) J = X - 7
            WRITE (J,700) CA,LA,TCA,BOC,HC,OC,PCA,POUT
C
107         CONTINUE
C
            GO TO 109
C
C *** COUNT NUMBER OF POINTS COMPUTED BEFORE MINIMUM AI CONSTRAINT
C *** IMPOSED AND WRITE WARNING MESSAGE TO TERMINAL
108         W = Y-5
            WRITE (OUT,626) W
C
109         CONTINUE
C
110      CONTINUE
C
111      CONTINUE
C
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')
C
605      FORMAT(' ','A EQUALS $1,050.00')
C
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')
C
621      FORMAT (' ','QTIL CONSTRAINED TO MINIMUM QUANTITY OF ONE',1X,
        *         'QUARTER OF DEMAND.')
C
622      FORMAT (' ','QTIL CONSTRAINED TO MINIMUM QUANTITY OF ONE UNIT.')
C
623      FORMAT (' ','QTIL CONSTRAINED TO MAXIMUM QUANTITY OF 12 QUARTERS',
        *        1X,'OF DEMAND.')
C
624      FORMAT (' ','QHAT CONSTRAINED TO SHELF LIFE DEMAND LESS LEADTIME',
        *        1X,'DEMAND QUANTITIES.')
```

```
625   FORMAT('0',2X,'QHAT',4X,'RHAT',6X,'TVC',4X,'LAMBDA',5X,'Q',6X,
     *' P ',5X,'POUT',4X,'PPV',7X,'EBO')
C
626   FORMAT(' ','AVERAGE ON-HAND INVENTORY IS LESS THAN OR EQUAL TO',
     * 1X,'ZERO.'/' ','LOOP TERMINATED AS SELECTED TOTAL COST CANNOT',
     * 1X,'BE MAINTAINED WITHOUT '/' ','PERMANENT BACKORDER SITUATION.',
     * 1X,'PLOT',1X,I3,1X,'POINTS.')
C
627   FORMAT(' ','RHAT CONSTRAINED TO MAXIMUM OF SHELF LIFE DEMAND',1X,
     *       'QUANTITY.')
C
628   FORMAT(' ','RHAT CONSTRAINED TO MINIMUM OF LEADTIME DEMAND',1X,
     *       'QUANTITY.')
C
629   FORMAT(' ','RHAT CONSTRAINED TO MINIMUM OF ZERO.')
C
630   FORMAT (' ',F7.2,1X,F7.2,1X,F10.2,1X,F7.2,1X,F7.2,1X,F6.4,2X,
     *F6.4,1X,F9.3,1X,F8.4)
C
645   FORMAT (' ',//,' ',3X,'A',8X,'C',8X,'D',5X,'E',5X,'H',4X,'I',4X,
     *       'L',4X,'MADD',3X,'MADL',3X,'S')
C
650   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
655   FORMAT (' ',4X,'C',6X,'L',4X,'POUT',6X,'B',8X,'HC',8X,'BOC',7X,
     *       'TVC',9X,'TC')
C
660   FORMAT (' ',3X,'C',6X,'L',8X,'TC',7X,'BOC',6X,'HC',7X,'OC',6X,
     *       'PC',5X,'POUT')
C
670   FORMAT (' ',F8.2,1X,F5.2,1X,F6.4,1X,F7.3,1X,F10.2,1X,F10.2,1X,
     *       F10.2,1X,F11.2)
C
675   FORMAT (' ','EXPECTED POUT= ',F6.4)
C
680   FORMAT ('0')
C
700   FORMAT (' ',F7.2,',',F6.2,',',F8.0,',',F8.0,',',F8.0,',',F8.0,
     *       ',',F8.0,',',F8.4)
C
      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,XX)
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,XX
      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.
         IF (XX.EQ.1) WRITE (OUT,400)
         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
         IF (XX.EQ.1) WRITE(OUT,410)
         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
      IF (XX.EQ.1) WRITE(OUT,420)
220   CONTINUE
C *** EXCESSIVE VARIANCE SCREEN ***
      VS = PPV / Z
      IF (.NOT.VS.GT.150.) GO TO 230
         PPV = 4.112 * (Z**1.402)
         IF (XX.EQ.1) WRITE(OUT,430)
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
      IF (XX.EQ.1) WRITE(OUT,500)
      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
      IF (XX.EQ.1) WRITE(OUT,500)
      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
      IF (XX.EQ.1) WRITE(OUT,510)
      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
      IF (XX.EQ.1) WRITE(OUT,520)
340   CONTINUE
350   CONTINUE
      RETURN
400   FORMAT (' ','ITEM IS MARK CODE 1 OR 3')
410   FORMAT (' ','ITEM IS MARK CODE 2')
420   FORMAT (' ','ITEM IS MARK CODE 4')
430   FORMAT (' ','EXCESSIVE VARIANCE SCREEN APPLIED TO PPV VALUE')
500   FORMAT (' ','ITEM IS CATEGORY "A" MATERIAL')
510   FORMAT (' ','ITEM IS CATEGORY "B" MATERIAL')
520   FORMAT (' ','ITEM IS CATEGORY "C" MATERIAL')
      END
$EJECT
C
      SUBROUTINE QTY (A,C,D,I,POUT,QTIL,WARNQ,Q)
C**********************************************************************
C   THIS SUBROUTINE CALCULATES THE ECONOMIC ORDER QUANTITY AND THEN    *
C   APPLIES UICP MODEL MINIMUM AND MAXIMUM ORDER QUANTITY CONSTRAINTS, *
C   RETURNING THE CONSTRAINED ORDER QUANTITY TO THE MAIN PROGRAM.      *
C**********************************************************************
C
C ***  VARIABLE DECLARATION ***
```

```
      REAL  A,C,D,I,POUT,Q,QT,QTIL,REMQ
      INTEGER  WARNQ
C
      WARNQ = 4
C
      IF (.NOT.POUT.GT.0.5) GO TO 10
C
         Q = SQRT((16.*D*A) / (I*C))
C
         GO TO 11
C
10    CONTINUE
C
      Q = SQRT((8.*D*A) / (I*C*(1.-POUT)))
C
11    CONTINUE
C *** ROUND Q TO WHOLE NUMBER ***
      QT = AINT (Q)
      REMQ = AMOD (Q,1.)
      IF (REMQ.GE.0.5) QT = QT + 1.
C
      IF (QT.GE.D) GO TO 12
         QT = D
         WARNQ = 1
12    IF (QT.GE.1.0) GO TO 13
         QT = 1.0
         WARNQ = 2
13    CONTINUE
      IF (QT.LE.12*D) GO TO 14
         QT = 12*D
         WARNQ = 3
14    CONTINUE
C
      QTIL = QT
C
      RETURN
C
      END
$EJECT
      SUBROUTINE RLVL (POUT,PPV,QTIL,RHAT,Z,EBO,D,H,WARNR)
C*********************************************************************
C  THIS SUBROUTINE CALCULATES THE OPTIMAL REORDER POINT USING A       *
C BISECTION SEARCH METHOD.                                            *
C*********************************************************************
C
C *** VARIABLE DECLARATION ***
      INTEGER  WARNR
      REAL  POUT,PPV,QTIL,RHAT,Z,M,J,EST1,EST2,EST3,REMR,RHT,ZI,R
```

```
C
      WARNR = 0
C
      REMZ = AMOD (Z,1.)
      IF (REMZ.GE.0.5) Z = Z+1.
      ZI = AINT(Z)
C
C *** USE THE FOLLOWING ZI VALUE TO REMOVE INTEGER VALUE/CONTINUOUS
C *** DISTRIBUTION (IN EBOCAL) IMPACT ON SMOOTHNESS OF PLOTTED CURVES
CC    ZI = Z
C
      X = ZI
      SIGC = SQRT(PPV)
      CALL EBOCAL(EBO,QTIL,SIGC,X,ZI)
      IF (EBO.LE.QTIL*POUT) GO TO 30
         M =3.
10       X = AINT(M*ZI*.5)
         CALL EBOCAL(EBO,QTIL,SIGC,X,ZI)
         IF (EBO.LE.QTIL*POUT) GO TO 20
            M = M + 1.
         GO TO 10
20       CONTINUE
         EST1 = AINT((M-1.)*Z*.5)
         EST2 = AINT(M*Z*.5)
         GO TO 40
30    CONTINUE
      EST1 = -1.
      EST2 = ZI
40    CONTINUE
50    IF (EST2-EST1.LE.3.) GO TO 80
         EST3 = AINT((EST1+EST2)*.5)
         X = EST3
         CALL EBOCAL(EBO,QTIL,SIGC,X,ZI)
         IF (EBO.LE.QTIL*POUT) GO TO 60
            EST1 = EST3
         GO TO 70
60       CONTINUE
         EST2 = EST3
70       CONTINUE
      GO TO 50
80    CONTINUE
      J = EST1 + 1.
90    X = J
      CALL EBOCAL(EBO,QTIL,SIGC,X,ZI)
      IF (EBO.LE.QTIL*POUT) GO TO 100
         J = J + 1.
      GO TO 90
100   CONTINUE
```

```
      RHT = J
      IF (RHT.LE.(4*D*H+Z-D)) GO TO 105
         WARNR = 1
105   CONTINUE
      IF (RHT.GE.Z) GO TO 110
         RHT = Z
         WARNR = 2
110   CONTINUE
      REMR = AMOD (RHT,1.)
      IF (REMR.GE.0.5) RHT=RHT + 1.
      RHAT = AINT(RHT)
      IF (RHAT.GE.0.0) GO TO 115
         RHAT = 0.0
         WARNR = 3
115   CONTINUE
      RETURN
C
      END
$EJECT
      SUBROUTINE CQTY (D,H,QHAT,QTIL,RHAT,Z,WARNCQ)
C***********************************************************************
C   THIS SUBROUTINE CALCULATES THE OPTIMUM CONSTRAINED ORDER QUANTITY *
C   BASED ON SAFETY STOCK LEVELS AND ITEM SHELF LIFE.                 *
C***********************************************************************
C
C *** VARIABLE DECLARATION ***
      INTEGER  WARNCQ
      REAL  D,H,QHAT,QTIL,REM,RHAT,SS,Z
      WARNCQ = 1
      SS = AMAX1(0.,(RHAT-Z))
C
      IF (QTIL.LE.(4.*D*H-SS)) GO TO 10
          QTIL = 4.*D*H-SS
          WARNCQ = 2
10    CONTINUE
C
      QHAT= AINT(QTIL)
C
      REM = AMOD(QTIL,1.0)
C
      IF (REM.GE.0.5)  QHAT = QHAT + 1.
C
      RETURN
C
      END
$EJECT
      SUBROUTINE BKORD (POUT,QHAT,B)
C************************************************************************
```

```
C  THIS SUBROUTINE CALCULATES THE EXPECTED NUMBER OF BACKORDERS AT ANY *
C  RANDOM POINT IN TIME - B(Q,R) - USING AN APPROXIMATION TECHNIQUE    *
C***********************************************************************
C
C *** VARIABLE DECLARATION ***
      DOUBLE PRECISION  B
      REAL  POUT,QHAT
C
      B = POUT * POUT * QHAT * .5
C
      B = DMAX1(B,0.00000000)
C
      RETURN
C
      END
$EJECT
      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
      REAL  A,C,D,E,I,L,LAMBDA,QHAT,RHAT,TVC,OC,S
C
      OC = A*4*D/QHAT
C
      HC = I*C*(QHAT*.5 + RHAT - D*L + B)
C
      BOC = B*E*LAMBDA/S
C
      TVC = OC + HC + BOC
C
      RETURN
C
      END
$EJECT
      SUBROUTINE EBOCAL (EBO,QTIL,SIGC,X,ZI)
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 ZI 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
      REAL X,SIGC,EBO,ZI,QTIL
C
      PI = 3.1415926535
C
      A1 = (X - ZI) / SIGC
C
      B1 = (X + QTIL - ZI) / SIGC
      PA1=1./DSQRT(2.*PI)*(DEXP(-A1*A1/2.))
C     PA1 = 1./SQRT(2.*PI)*(EXP(-A1*A1/2.))
      PB1 = 1./DSQRT(2.*PI)*(DEXP(-B1*B1/2.))
C     PB1 = 1./SQRT(2.*PI)*(EXP(-B1*B1/2.))
      CALL MDNORD (A1,CDFA1)
C
      CCDFA1 = 1. - CDFA1
      CALL MDNORD (B1,CDFB1)
C
      CCDFB1 = 1. - CDFB1
C
      EBO = SIGC*(PA1-PB1+B1*CCDFB1-A1*CCDFA1)
C
      EBO = AMAX1(EBO,0.0)
C
      RETURN
C
      END
```

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