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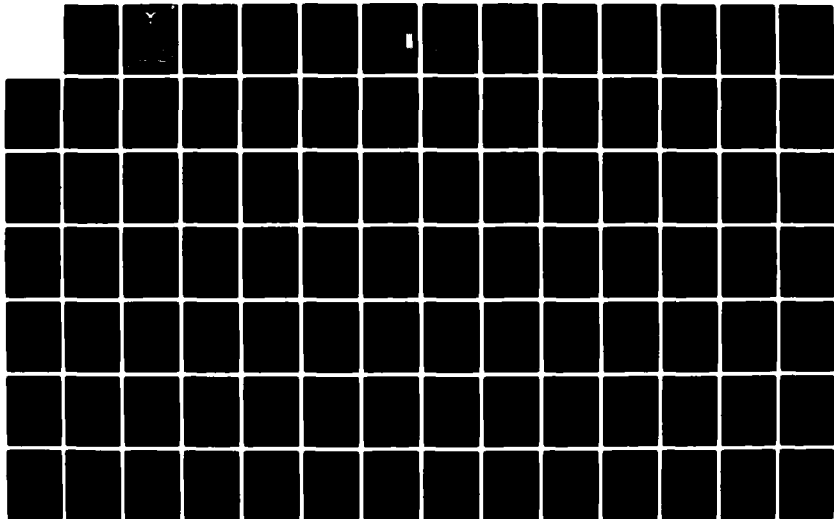
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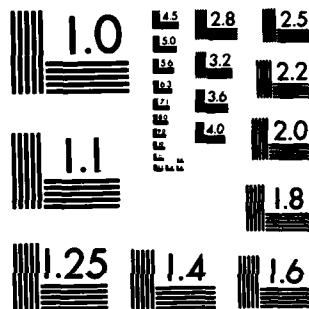
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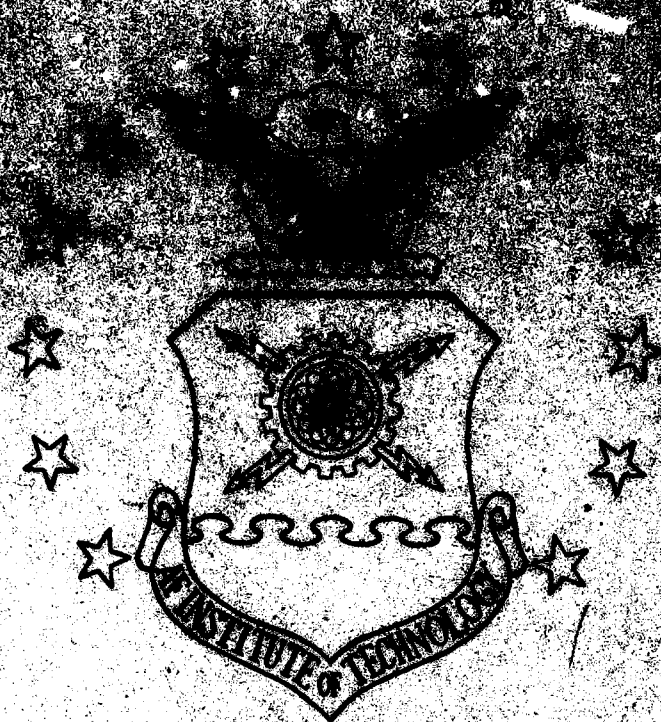
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THE LIFE-OF-TYPE INVENTORY
DECISION FOR DIMINISHING
MANUFACTURING SOURCE ITEMS:
A SENSITIVITY STUDY

Christine E. Fisher, GS-12
Walter F. Sheehan
Australian Department of Defence

LSSR 78-82

JAN 03 1983

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The Life-of-Type (LOT) Buy is required to resolve up to 50 percent of Diminishing Manufacturing Sources (DMS) electronic item problems, but an arbitrary buy method with no theoretical basis is currently used by the Defense Electronic Supply Center (DESC). A 1,772 DMS item historical data base was provided by DESC. The cost effectiveness of this method was projected; the method is estimated to over or under buy in 90 percent of cases. The assumptions of the current method were investigated. Simple linear regression results could not refute the assumption of constant mean demand over time. Situational variables were tested for predictive relationships for demand slope; no significant relationships were concluded. A single buy multi-period total cost optimization program was used to perform controlled sensitivity analysis of the LOT buy quantity to cost and demand variables. The buy quantity proved highly sensitive to demand mean, variance, and slope and sensitive within ranges of interest rate, holding costs, and a hypothetical stockout "penalty function." A more systematic buy approach which recognizes individual item characteristics and explicit and implicit situational costs was recommended.

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THE LIFE-OF-TYPE INVENTORY DECISION FOR
DIMINISHING MANUFACTURING SOURCES
ITEMS: A SENSITIVITY STUDY

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Logistics Management

By

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September 1982

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This thesis, written by

Ms. Christine E. Fisher

and

Mr. Walter F. Sheehan

has been approved by the undersigned on behalf of the
faculty of the School of Systems and Logistics in partial
fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

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CHAPTER I

RESEARCH PURPOSE AND DESIGN

Introduction and Purpose

United States Air Force Lieutenant General Robert Marsh, former Commander of the Electronic System Division, remarked that "It does not require an especially close look at the Air Force today . . . to note our great, and growing dependence on electronics [23:97]." The reason that the Air Force, and the entire Department of Defense, strive to incorporate the latest technological advances in their equipment is the need to maintain an increasingly effective military capability in spite of force reductions (23:97).

The effect of the continuing incorporation of state-of-the-art technology combined with the effect of rapidly changing technology presents a new challenge to the defense logistician (18:6). As technology advances, manufacturers phase out product lines which incorporate the "older" technology, striving to keep pace with current market demands. This production may be ceased dependent upon line profitability, regardless of continued use of the product in existing equipment. So today, the assumption that all spare parts are procurable throughout the

service life of the parent equipment is no longer valid. Defense managers must begin considering rapidly changing technologies from the earliest stages of equipment design; they must plan to protect against severe equipment support problems or premature equipment obsolescence caused by the discontinued production of critical components.

This study concerns Diminishing Manufacturing Sources (DMS) items, that group of inventory items for which the last known supplier for the items has ceased, or intends to cease, production (41:3). The concern, of course, is with those items which continue to be needed for use in the Department of Defense (DOD) supply system (41:3). Although this problem potentially exists across many technology bases, it is most acute in the electronics industry where the most rapid and revolutionary changes have been occurring (41:5).

The background of the DMS problem and of the DOD's efforts to manage the problem are described in Chapter III. It is of interest here to note that available figures indicate that as many as 50 percent of DMS situations encountered by the Defense Electronic Supply Center (DESC) are resolved by life-of-type buys--i.e., a one-time procurement of ". . . [a quantity of] material estimated to last until the end items being supported are no longer in use [41:18, Appendix 11, p.11]."

It is the purpose of this study to scientifically investigate the DMS Life-of-Type (LOT) buy as an inventory decision and to provide an increased and useful understanding of the LOT buy decision situation which may serve to increase the manager's ability to make an effective LOT buy.

Justification of the Study

The DMS problem is a relatively new phenomenon which has arisen largely as a result of rapid technology changes but also due to the DOD's retention of equipment in service for longer time periods as budget allocations are tightened or reduced (18:6-7). The problem, however, is not restricted to older end equipment but is occurring in relatively new equipment and equipment in the developmental stage, which often incorporate older, stock-listed items in their design (23:98; 41:3). The support impacts of DMS are only beginning to be felt as LOT buyout quantities for the earliest DMS items (approximately 1976) begin to reach low stock levels (23; 12). Further, the rapid changes in technology which create DMS items cannot be expected to slow. This means that LOT buy decisions may be made with increasing frequency, perhaps even becoming a more routine "day-to-day" decision. If such a decision is to be made quickly and wisely, much needs to be learned about the nature of this inventory decision.

However common the occurrence may become, the potentially "lost" equipment use created by DMS will never be easy to measure.

One measure of the DMS cost that can be observed is the investment in LOT buyouts. From 1976 to 1981, the Defense Electronic Supply Center (DESC), the DOD agency with the greatest DMS experience, invested \$100 million in stockpiling DMS items (41; 28; 12). Fifty million dollars has been allocated for DESC for 1982 alone (12). It is expected that investments may be as high as \$400 million in the period 1982-1986 if technology in the electronics industry lives up to expectations for rapid changes (28).

Although research has been performed in the general DMS area and in related areas, there has been little investigation of the method for making the costly and critical LOT buy. DESC has expressed interest in research in this area (12; 35; 41).

Thus, DMS is a current and continuing problem for DOD managers. In particular, increased understanding of the LOT buy decision should prove beneficial in ensuring long-term support and avoidance of unnecessary costs.

Scope and Limitations

As noted above, the problem of DMS affects the DOD across all technology bases, but is most acute in the

electronics industry. Because DESC manages a large number of consumable electronic components for the DOD, it has been the center of the largest DMS experience and research (41:4). For this reason, and in order to limit this study to a manageable base for investigation, the focus of this study is upon DMS electronic components managed by DESC. Despite this limitation, it is believed that the results and conclusions of this study will have application across the Services and the wide variety of DMS items.

An important part of achieving the research objective outlined below is an extensive review of literature (combined with personal interviews) in the areas of DMS background and management, forecasting techniques, and inventory models. The scope of this research included reviews of logistics, academic, and management periodicals and journals at the Air Force Institute of Technology (AFIT) and Wright State University libraries and of pertinent articles and studies obtained through DESC personnel. A DOD literature search was conducted through the Defense Technical Information Center (DTIC) and the Defense Logistics Studies Information Exchange (DLSIE). Personal interviews were limited to personnel assigned to DESC.

The research design for this study was developed in an attempt to use the most appropriate of available resources and techniques in reaching our research objective.

However, the limitations of time and available funds created constraints on research efforts. Further, although DESC personnel were extremely helpful and accommodating, natural limitations of "real world" data were encountered and are described more fully below.

Brief Research Background

In 1978 a study of the DMS problem was directed by the Office of the Secretary of Defense to be performed by a DOD working group led by DESC. The results and recommendations of this study were published in a report, Study of the Influence of Technological Change and Diminishing Manufacturing Sources on DOD Electronics Parts Support (41). This study provided an up-to-date, full scope report on the state of the DMS problem and the DOD efforts to minimize its impact on support. This study and other literature on the DMS problem is reviewed in Chapter II.

In 1981, an AFIT master's thesis studied the use of technology forecasting to aid in planning technology phaseout by predicting technology life. USAF Captain Brook's thesis investigated potential uses for this technique in "planning" to avoid DMS-related support problems (see Related Source).

A second 1981 AFIT master's thesis of interest is the "Comparison of Eight Demand Forecasting Models" by USAF Second Lieutenant Robert J. Pragg, Jr. (32). This study addressed "normal" item demand forecasting at

DESC and described demand behavior for DESC's replenishment and non-stockage objective items. The role of normal DESC item management is discussed in Chapter V.

Finally, an enormous amount of research has been performed on inventory models and forecasting methods appropriate for various situations. This research literature is reviewed thoroughly in Chapter II and its applications for the DMS situation are discussed.

The above briefly describes certain research efforts which have progressed research to the stage at which this study can begin. Despite the management attention, no research performed to date has addressed the DMS LOT buyout decision in any detail.

Problem Statement

The effectiveness of the LOT buy decision in the real world is, by definition, how well the buy provides the needed support over the years following the buy. This effectiveness is very difficult to measure or predict. The cost of overbuying could be estimated, once all demand truly ceases, by combining the price of the overbought items inflated to current value together with the cost of holding those items over the years; but the opportunity cost for having sunk dollars into unrequired items cannot truly be measured. Likewise, the cost of underbuying cannot be measured; loss of support may have effects

ranging from a minor inconvenience to the loss of use of an end item of equipment.

In an attempt to make an "effective LOT buy" a more manageable objective, the following is proposed. Although many forces play in making the LOT buy decision and in the demands that occur thereafter, the LOT buy effectiveness is ultimately the outcome of one factor--the LOT buy quantity. In turn, it is proposed that the LOT buy quantity is dependent upon two primary variables: (1) the future requirements for the item, and (2) the explicit and implicit cost considerations. (It is noted that each of these variables may be comprised of many factors.) It is believed that, even if future requirements were known with certainty, the costs associated with buying that quantity would have to be considered in making the buy decision. At some point, diminishing returns on investment in a quantity to buy will occur as the cost of holding, time value of money, and costs of stockout balance with cost to buy and the support advantage of higher quantities.

In an ideal world both variables--future requirements and costs--would be known with certainty for any given situation and a "perfect" buy could be made. Given that neither variable can be known with certainty, the best alternative is to operate within a range of values for the variables around which we can place some limits of

confidence. Towards this end it must be determined how the current LOT buy model treats and/or trades-off these two major variables which determine the LOT buy quantity. The behavior of these variables in relation to the LOT buy decision must be observed and measured. Finally, it is uncertain if and how other situational variables impact the major variables.

Research Objectives

The objectives of this research are:

1. To describe the current LOT buy "inventory model" used by DESC and to describe the situation in which that decision model operates.
2. To analyze the assumptions and effectiveness implications of the current model.
3. To determine the behavior of the two primary variables--future requirements and costs--in relation to the LOT buy.
4. To determine relationships among these and other situational variables.
5. To unify these findings so that ranges of variable values for operating can be demonstrated within confidence limits; to present findings in a clear, concise form for use by managers so that the complex and large-scale uncertainties posed by the DMS LOT situation may be systematically approached.

Research Questions

These questions are formulated to direct the research towards achieving the stated objectives.

1. Do forecasting methods and inventory models exist which may be applied to the DMS LOT buy situation?
2. What is DESC's current LOT buy quantity decision "model" and what are its assumptions?
3. Where does this model lead in terms of support and cost? (How effective is it?)
4. What is the nature of demand of DMS electronic components? What are the behavior and characteristics of "typical" DMS electronic items?
5. How do the costs, implicit and explicit, which play in the LOT buy decision trade off with LOT buy quantities needed for support?
6. How can the understanding of the behavior and characteristics of "typical" DMS items and the cost sensitivities be used to improve the efficiency and effectiveness of the LOT buy decision?

Methodology

The research methodology is only briefly addressed here, as it will be fully described in Chapter IV. This research design was developed as a means to develop answers for the research questions above.

First, the background of the DMS problem and the DOD's management of the problem are described through literature review and personal interviews. Extensive review of the literature on existing inventory models and forecasting methods is accomplished; the utility of these techniques for DMS LOT buy application is discussed. Thus, Chapters II and III provide the background necessary for understanding, both practically and theoretically, the environment in which the DMS LOT inventory decision is made.

To augment the information obtained in interviews, a review of files of DESC's DMS cases closed during 1981 was performed. These sources allow full description of the current LOT buy inventory "model" and the assumptions of that model. The case histories provided an understanding of the current context of DMS LOT decisions.

A DESC-provided data base of demand history for DMS items was used for testing current model assumptions and determining the characteristics and behavior of "typical" DMS items and the relationships of the situational variables. A FORTRAN simple linear regression and the Statistical Package for the Social Sciences (SPSS) Cross-tabulation programs were used for this effort. This data base also provided the means to capture a "photograph" of where previously procured LOT buy quantities stand today in relation to their actual and anticipated usage. Using

demand data for DMS items which have experienced LOT buys, LOT buy "effectiveness" may be described using constant demand assumptions and using simple linear regression results as noted above. SPSS histograms illustrate where the LOT buy decisions "over" and "under" procured based upon both approaches.

Next, a general stochastic model formulation for optimization of a single-buy, multi-period decision is presented and discussed. The experiment constituted use of a FORTRAN computer program which incorporates this multi-period model for computation of a range of LOT buy quantities for given input parameters. The input parameters were assigned for theoretical illustration of LOT buy quantity sensitivity using the model for both the Poisson and Normal probability distributions for demand. These parameters were obtained from within the relevant range of DMS item values obtained from the DESC data base.

Finally, the LOT buy quantity outputs of this multi-period model are graphically displayed against each given set of input parameters plotted in three-dimensional form as well as contoured on two-dimensional format. The three-dimensional plotting creates an "optimal response surface" of order quantities for a given set of input variables (13). This response surface allows easier (and visual) interpretation of those more flattened and thus "less responsive" areas where changing parameter values

results in less marginal quantity changes, as well as those areas that are highly responsive to each parameter's incremental changes.

To bring together the theoretical and practical considerations as they effect the determination of the Economic Lot Quantity (ELQ) decision, a step-by-step approach for the DMS manager is presented in the Conclusions, Chapter VII.

CHAPTER II

THE SINGLE-BUY INVENTORY MODEL AND DEMAND FORECASTING

An important part of this study is the effort to understand and explain the environment in which DESC makes the LOT buy decisions and the important variables which influence that situation. In order to do this an understanding of pertinent inventory models and of demand forecasting methods is necessary. This chapter provides a review of literature in these areas and a presentation of concepts from this literature important to the DMS buy situation.

This review will first describe the background of existing single-buy inventory models, focusing on the famous "Newsboy" or "Christmas tree" model. The characteristics and assumptions of this inventory model are presented in this discussion.

A general discussion of the nature of demand and a brief review of demand forecasting techniques follows. The applications and limitations of these techniques in the DMS situation are examined.

History of Single-Buy Models

Single-buy, single-period, single-item models evolved from the general economic lot size inventory

models (24:13). The economic lot size model was first published in its simplest form by F. W. Harris in 1915 (15:3; 22:11). This economic order quantity (EOQ) model is most popularly associated with its derivation by Wilson (16:3; 24:12), although a number of researchers were published discussing this model in the 1920s (24:12). Regardless of the name associated with the EOQ formula, a common assumption of deterministic (stable, known) demand was made in the general EOQ formulation.

Hadley and Whitin report that a useful stochastic model, a simple version of the "Christmas tree" problem, was developed during World War II (16:3). Further, they state that Whitin's book, The Theory of Inventory Management (1953), was the first English book "which dealt in any detail with stochastic inventory models [16:3]." In his master's thesis, Masuda cites Arrow, Harris, and Marschak's article "Optimal Inventory Policy" (1951) as the fundamental work in uncertainty models (24:13). Regardless of the originator, the important leap into inventory models incorporating probability (uncertainty of events) was made in the early 1950s (16:13) and created new research stimulus.

Masuda reports that the earliest description of the "Christmas tree" or "Newspaper Boy" problem (as it will be referred to in this study) was in Morse and Kimbal's Methods of Operations Research in 1950 (24:13). Whitin

and Young are believed to be the first to publish the mathematically derived solution to the newsboy problem (1955) (24:13). Since the derivation of this analytic solution, the newsboy problem has found increasing interest and application (16:297; 24:15-16). One important development is that of Stan Fromovitz in "A Class of One Period Inventory Models" (1964) (24:15). He uses the newsboy problem's general formulation; however, he discusses a "stock-out penalty function" related to the classic shortage cost. This penalty function is useful in the frequent instances where shortage cost is difficult to measure (24:15-16).

Research for the development of the single-item, single-period problem continues today, although it is not receiving the extended research attention devoted to multi-echelon, multi-item, multi-period models (15:10,24). This is natural, as the majority of day-to-day business inventory problems embody these multiple situation complexities; the single-buy situation is more specialized. This literature research did not reveal published work in the area of the single-buy inventory decision to provide for multiple-periods of support.

Newsboy Model: Characteristics, Assumptions and Variations

Generally, inventory system models use a cost-basis as a measure of effectiveness (16:10,21; 17:25). The operating doctrine chosen for a given inventory system

is, then, an optimization function, either to minimize costs or maximize profits (16:21-25). The relevant costs which may be included in the general form are procurement costs, inventory holding costs, costs of filling a customer's order, stockout costs (cost of stock outage when demand occurs), and costs of control procedures for the inventory system (16:10; 17:27-28; 22:28).

Consumable inventory items are most frequently managed using an EOQ-type formulation. As noted above, this model generally assumes deterministic demand (known, stable pattern of demand that can be predicted with certainty) and uses item procurement, holding, ordering and possibly stockout costs in the total cost formulation (16; 17; 22; 31). Reorders can be made whenever the reorder point is reached and in the predetermined optimal quantity (16; 17; 22; 31). An assumption of this model is, then, an infinite time horizon (16; 17; 46), permitting continued procurement of the item as the variables in the formulation change.

The newsboy problem differs from the above in that the time period which the inventory is required to support is usually finite (16:297; 24:88; 31:388-389; 39:19-20). This situation is characterized by having only one opportunity to procure the quantity required to satisfy total demand for the entire (demand) period of consideration (16; 17; 24; 31; 38; 39). The newsboy problem is one of

the simplest of stochastic models (16:297); in that it is one of the most straightforward of models which treat demand as uncertain (probabilistic).

The general formulation of the single-period, single-buy model, of which the newsboy problem is a special case, considers holding costs and shortage costs as costs subject to control. The cost of placing the order is not considered in this model as it is in the general total cost formula discussed because there is only one cost of ordering, assumed to be fixed for all possible decision quantities; i.e., ordering costs do not impact on this decision and so are ignored (17:20).

The single-period, single-buy model's general form for expected profit is as follows (16; 17; 22; 24; 31; 39):

$$\begin{aligned} \zeta(h) = & S \sum_{x=0}^h xp(x) + Sh \sum_{x=h+1}^{\infty} p(x) \\ & + L \sum_{x=0}^{h-1} (h-x)p(x) - Ch - \pi_0 \sum_{x=h}^{\infty} (x-h)p(x) \end{aligned}$$

Expected profit = sales volume

+ salvage value - purchase cost - loss of goodwill

where, h = Number of units procured,

C = Unit cost,

L = Salvage value,

S = Selling price,

Π_0 = Goodwill cost, and

x = A random variable, being the probability of
 x demands (of a known probability distribution).

If h and the demand variable are continuous, the optimal solution to h is

$$\frac{dZ}{dh} = 0, \text{ or } F(h) = \frac{C-L}{S+\Pi_0-L}$$

Thus, the newsboy model is optimized by setting the first derivative equal to zero and solving to find h , the point which approximates the tangent to the function at the optimal location.

This model assumes no minimum procurement quantity and no constraining budget figure.

Note that a pertinent cost in this general model is the cost for loss of goodwill. This replaces the standard stockout cost; in a newsboy model, the shortage cannot be "back ordered," it is associated with a lost sale and some amount of associated goodwill loss (16:20-21; 24:95).

It is also noted that the above analytic solution is used when demand is a continuous random variable of a known distribution (further discussion of probabilistic demand is provided in the following section). In cases where demand is discrete, a variation of the solution applies which seeks to minimize the expected value of the inventory levels; the optimal solution in this case is (24):

$$F(h-1) < \frac{C(x-h)}{C(h-x)+C(x-h)} < F(h)$$

Many forms of the general model above have been developed. Masuda calls the optimal solutions described above as "solutions under risk" because the demand density function is known (24:20). There are, unfortunately, instances in application where the demand density function is unknown; Masuda calls these "solutions under uncertainty" and relates W. T. Morris' solution formulation (24:23-24).

The above model form also assumes linear cost functions. Authors have now treated a variety of cost functions which may exist in the real world: quadratic, constant, linear, or combinations of these within one model situation (16; 17; 24; 31; 38).

Certain variations of the newsboy model derive solutions to meet a manager's "aspiration level"; that is, the inventory decision is set so that the chance of the manager not achieving his aspired cost level is minimized (24:22; 38:11). In general, as realistic constraints can be considered with optimizing solutions of the newsboy problem, the model has become more useful for various applications.

The single-buy model, and in particular the newsboy model, is discussed in this study because it represents a well developed, widely recognized inventory model designed to meet a situation similar to that faced when a FMS LOT

buy must be made. However, as indicated above, this literature research found no published inventory model which addresses the complex, multi-period characteristics of the DMS LOT buy. Thus, no specific theoretical model has been developed which DESC may apply in making this inventory decision.

The Nature of Demand

As noted above, the basic EOQ-type inventory models often assume that demand for items over time is deterministic (known, predictable and unchanging). In their classic work on inventory models, Hadley and Whitin assert that, in reality, it is almost impossible to know enough about the process generating demand to treat it as deterministic (16:8-9). "In general," they say, "the best that can be done is to describe the demand in probabilistic terms [16:9]." The single-period newsboy model described above is one of the simplest of stochastic (probabilistic) inventory models.

As the goal of inventory systems is to anticipate and meet future requirements, the demand function and its probabilistic nature are central to the working of the majority of inventory systems. Since demand realistically cannot be known with certainty, methods for using the probabilistic nature of demand to predict demand as accurately as possible must be employed.

Basically, probabilistic demands may be treated as discrete or continuous random variables (16:Ch.3). Discrete events may be represented as non-negative integers (16:86); continuous random variables can be described only as a probability (a value within an interval) and can take on any value, between zero and infinity (or minus zero and infinity) (16:91). This is of interest in this study in that two probability distributions are employed to describe demands in the experiment below: the Poisson and the Normal. The Poisson distribution is discrete and the probability for a given value will be denoted as $p(x;\mu)$ where μ is the mean of the distribution (16:91). Inventory items displaying low demand rates during the relevant demand period are represented by a discrete distribution and frequently are approximated by the Poisson (16:Ch.3; 10:9). In practice, when demand is sufficiently low as to be treated discretely, the process generating demands can frequently be approximated well by a Poisson process (16:112).

When the demand rate for an item is higher, the variable may be treated as continuous (16:140-141). The most frequently used continuous distribution to describe the quantity of items demanded in a given time period is the Normal (16:141). Empirically, the Normal distribution often well approximates demand distributions "over the relevant time periods which are encountered in

practice [16:141]." Normal probabilities will be expressed as the probability that x lies in the interval $a \leq x \leq b$ (16:92).

Hadley and Whitin propose that, for most applications, a mean demand rate over the demand period (often a year) of greater than or equal to twenty-five (25) are sufficiently approximated by the Normal (16:143). As will be further discussed in Chapter IV, this study will approximate demand of less than twenty-five a year with the Poisson and of twenty-five or greater with the Normal.

Forecasting Techniques

Forecasting methods attempt to deal with the uncertainties of the future by developing some reasonable prediction of it (44:170). The basis of forecasting is usually the past: historical data or experience of the situation of interest or of some similar situation. Although techniques with varied applications are discussed in this section, our interest is in demand forecasting techniques. The more accurately that demand can be forecast, the better control one has over the system.

Wheelwright and Makridakis describe two broad categories of forecasting techniques: qualitative and quantitative. These categories generally reflect the extent to which the technique depends upon use of historical data in a mechanical fashion (44:4). Those situations allowing

or calling for less use of historical data are better suited to the qualitative (more judgemental) techniques (44:4).

As defined by Wheelwright and Makridakis, another useful way of categorizing forecasting techniques is by the type of model represented by the technique: time series, casual, "statistical," or "nonstatistical" (44:22; 7:49). Time series models assume some pattern recurring over time and that this pattern can be identified on the basis of historical data. A large number of forecasting techniques represent this model (44:23; 14:Ch.2; 6:Ch.2). These models are of particular interest in this study as we are concerned with the pattern of item demand over time.

Demand probability was discussed above; time series forecasting models attempt to determine and predict the basic pattern of this demand and its form over time. Causal models "assume that the value of a certain variable is a function of several other variables [44:23]." Forecasting techniques using regression analysis exemplify causal models; these models are less widely used.

Two additional categories not exclusive of the above are "statistical" and "nonstatistical" models. "Statistical" models use methods and procedures of statistical analysis (44:23). "Nonstatistical methods" are based upon intuitive or judgemental factors (44:24; 7). Because

of this, "nonstatistical" techniques are often easier to understand and apply than statistical models; however, they are also more limited because of the inherent lack of confidence levels (44:24).

To aid in understanding the role of forecasting methods in DESC's normal item management and in the DMS situation, a brief description of some prevalent techniques follows.

As defined by Wheelwright and Makridakis, smoothing methods, including averaging techniques, are "nonstatistical" in nature. They are based upon the principle that the variable to be forecast has some underlying pattern which can be discovered, accompanied by random fluctuations or "noise," in historical data. Generally, these methods try to forecast as closely as possible to the "real" pattern by eliminating extreme values and forecasting on some "smoothed" intermediate values (44:Ch.3; 6:Sec.III). The basis for this technique is the application of varying weights to past and current historical data and averaging these values together to obtain the "smoothed" forecast (2:67). These methods have been widely developed and expanded; some variations include adaptive smoothing, which incorporates adaptive mechanisms to (theoretically) cause the forecasts to better respond to changes in the basic underlying pattern over time and multiple (double, triple, etc.), moving average or multiple

exponential smoothing, which actually apply a smoothing equation in an effort to further reduce the noise and better identify the "real" pattern (44:Ch.4; 6; 45). Among the prevalent "statistical" models are correlation, simple regression, and multiple regression techniques. The basis of these techniques is also that the underlying process follows some pattern. This pattern can be stated in an equation which relates the variable of interest to the behavior of one or more other variables (44:Chs.5,6; 14:79). These methods allow us to make predictions which are solely related to past values of the variable of interest (14:77). Further, this allows incorporation of some "real world" influences on pattern variations into the forecast; e.g., seasonal, cyclical, or longer term trend factors. In use, these methods increase in complexity and cost as additional variables and factors are incorporated (2:52; 44:130).

Another quantitative forecasting method particularly useful when the data's underlying pattern is complex or difficult to distinguish is the Box-Jenkins method (44:131-132). This method allows the manager to assume a tentative pattern for the process and, through the use of autocorrelation techniques, determine iteratively the suitability of the assumed pattern (44:132). Finally, the basic pattern is optimally discerned with minimization of the noise of the pattern (44:133). Box-Jenkins is one of

the more costly, data consuming, and analytically complex methods (44:143).

Qualitative techniques are neither as widely used nor as extensively developed as are the quantitative methods (44:5). Some prevalent methods include the "Delphi" or "panel-of-experts" method, historical analogies, morphological (or interdisciplinary method similarity) research, and system analogies methods (44:207; 7:Ch.11). Generally, the foundation of these techniques is human logic, experience, and judgement. These have intuitive appeal but lack statistical confidence.

The quantity and range of forecasting techniques available vastly exceed this limited discussion. It is the goal here to give only a brief overview of some prevalent methods.

Limitations and Applications of Forecasting Techniques

As implied by the above discussion, forecasting techniques must be appropriately applied to be effective. Gross and Schrady note that, if the forecasting and past data collection are deficient, any inventory model is only a "garbage processor [15:33]."

Each technique has its potential limitations (cost, degree of complexity, predictions based upon relationships which are not relevant, etc.) which may make it inappropriate for a given situation.

Various authors provide criteria for selecting an appropriate forecasting technique: Chambers, Satinder, and Smith propose that the selection of a method be based upon six factors including the time period to be forecast and the amount of time available to make the analysis and the forecasting decision (7:45). The thrust of their research is that the particular stage of a product's life cycle determines the technique(s) most appropriate at a given point in time (7:50). Wheelwright and Makridakis establish similar technique selection criteria (44:6-9, Ch.12). Again, the time horizon for which the forecast is required is a critical factor.

It is this factor which makes existing forecasting techniques of limited value in resolving the DMS LOT buy situation. Forecasting time horizons may be divided into four categories: immediate-term, short-term, medium-term and long-term (44:205-213). Immediate-term (monthly) and short-term (one to three months) forecasting are simpler than longer-term situations. Usually, these short-term forecasting situations have historical data to call upon and seek to make only an incremental change from the previous period (44:205,210). Thus, time series methods are best suited for the short-term. Smoothing and averaging techniques are so well suited for short-term forecasts for a large number of items, that industry and the military

make wide use of them in their inventory systems (45:13; 15:32). In their study on the practical application of inventory theory, Gross and Schrady placed much of their emphasis on military applications; they concluded that "forecasting is always necessary and is generally accomplished by exponential smoothing [15:32]." As will be discussed below, DESC employs a smoothing method in their "normal" item management.

The time-series and statistical methods are based upon "the assumption that the existing pattern will continue into the future [7:50]." This assumption may be appropriate for the short-term, but may not be suitable for the long-term. The natural variability or "noise," plus any error in the assumed pattern that the forecast is based upon, increases over time and multiplies itself, causing increasingly larger error in the forecasts (2:179). Although the potential error can be partially calculated, these techniques generally degenerate over time, and so do poorly in forecasting further into the future (2:178; 7:50).

Some research has demonstrated that causal and smoothing techniques can have a degree of success in forecasting for the medium-term (three months to two years) situations (19:21-22; 44:212). However, it is generally demonstrated that qualitative techniques are often used for forecasting over one year (1; 44:212-213). Wheelwright

and Makridakis prescribe that, in certain instances, well-developed regression models may be appropriate for the long-term (over two years). However, the recommended long-term techniques include the qualitative methods mentioned above (Delphi, etc.), econometric models, and life cycle analysis (44:Ch.12). These techniques are appropriate for the types of long-term forecasting normally needed for long-range planning of trends in business. Unfortunately these long-range techniques do not satisfy the needs of DESC's situation in making a LOT buy. The DMS LOT buy decision requires a quantitative type of forecast, but one which can overcome the instabilities of the long-term situation. This literature research did not discover a forecasting technique suitable for application in the DMS LOT buy inventory decision.

CHAPTER III

THE DMS PROBLEM AND DESC DMS MANAGEMENT

This chapter provides background of the DMS problem in the DOD based upon a review of literature, DOD studies, and personal interviews. Further, an individual review of each DMS "case" closed by DESC during 1981 was performed in May 1982. This provided an understanding of the management of DMS at DESC and the problems encountered in this management on a day-to-day basis. This review consisted of reading case file correspondence.

The first section of this chapter presents a brief summary of the cause of the problem, a chronology of the major steps taken by the DOD in recognition of the DMS problem, a discussion of DMS as a DOD phenomenon, and a review of possible solutions as proposed by industry. The second section deals more specifically with the DOD's policy approach and day-to-day management of DMS and current DOD initiatives in this area. Since DESC is the focus of our research, a brief description of DESC and its mission comes next. This is followed by a description of how DMS items are managed by DESC. This discussion will show why and when a LOT buy is the required support action and establish the environment in which the LOT decision is carried out.

DMS Problem Background

Speed of Technological Change

The vacuum tube was the key electronic technology of the Services for forty-five years until it was replaced by the transistor. In ten years the transistor gave way to the integrated circuit (IC) which was replaced, after twelve years, by the silicon chip. After five years the silicon chip is presently on the verge of replacement by programmable function electronics (PFE) (21:4; 8:4-6).

The above time sequences reflect the introduction of the technology into the equipment's design. Logistically, it requires that the technology of the equipment be supported for the full service life of the equipment, which could range from eight to twenty years (8:2,3; 11:10; 23:98).

For economic survival, enterprises are required to move with this new technology, exploit its comparative advantage, and discontinue marginal or unproductive items (21:2).

Chronology of Major DOD Actions

The first major DMS case arose in 1970 when Wagner Electric announced its decision to close its Electron Bulb plant (11:1). Because of the impact it had on existing Service equipment, DOD established an Ad Hoc Vacuum Tube

Support Group to study the impact that closing the production line would have on the DOD (11:1).

In 1975, the DOD commissioned a new committee to recommend short- and long-range actions to deal with materiel shortages. In 1976, DOD Directive 4005.16 was issued outlining the DOD policy and management of DMS items (11:5; 41:22). In 1977, a working group led by DESC was commissioned by the Office of the Secretary of Defense (OSD) to investigate the DMS position in the DOD electronic spare parts inventory (11:5; 41:22). The study was completed September 1978, and a report was distributed by OSD in December 1979. Some study results and DOD current actions are discussed below.

DMS: A Problem of DOD and
Not of Industry

The Services depend, in their Command, Control and Communication function, on electronics. Technology advancement in electronics enables new and effective capabilities to be acquired with profound effect on military capability, tactics, and doctrine (23:94).

Equally as important is the need for existing equipment to be adequately supported over its service life if military needs are to be satisfied (23:98). This, therefore, means that full inventories of repair parts including DMS items are required.

In contrast, for reasons of economic survival, industry acquires new technology to ensure that its products are marketable. Unlike the DOD, industry has no reason to retain old technology and the speed in which it markets new products (with limited warranty periods) ensures that the problems of DMS occur infrequently (11:3-4; 21:2).

Implicit in the above, but not so readily apparent, is that DOD has lost its ability to influence industry after losing its position as industry's main customer in the 1960s (50 percent), to less than 10 percent of the market share in 1980 (21:1).

In summary, if DOD wishes to maintain old technologies in its equipment policies, and at the same time design its equipment for high performance and reliability, DMS problems will occur (41:44-46). Industry is adamant that it should not bear the cost penalty for DOD retention of phased-out technology (21:5; 41:6).

How to Manage DMS from Industry's View

Industry does not suffer the DMS problem to the same extent as the DOD for the following reasons (41:45-48; 21:6). The industries to which we refer include those major U.S. electronic and aerospace manufacturers included in the 1978 DESC study (41:Appendix).

1. Industry knows where and how its equipment is used, and what parts density is in each. DOD procures and maintains an extraordinarily wide range and depth of equipment; much more than any individual company attempts to manage. DOD's equipment is managed by three different Services using different systems, etc. This further complicates the problem of parts-to-equipment traceability.

2. Industry is acutely aware of the effect of technological change on their products and can respond quickly to change.

3. Industry takes active steps to avoid being confronted with a DMS situation by:

- a. avoiding single sourcing of components where practicable;
- b. ensuring financial viability of subcontractors;
- c. actively monitoring the industry-wide trends and technology; and
- d. staying in mainstream technology, with items having wide common usage, high population density, and less likelihood of becoming DMS.

DOD Management of DMS

DOD Policy

As noted above, the goals and operations of the DOD are such that the DOD cannot fully accept the methods

used or proposed by industry. The wide range of DOD-managed equipment, encompassing extremely varied technologies, makes certain industry practices almost impossible for the DOD to incorporate. The DOD data systems are poor to nonexistent in the areas of identifying the distribution of capital assets, linking items to end usage, or coding equipment or spare parts to technology levels (18:6). This is, in part, due to the very high cost and cumbersome nature of developing such systems for intra- and inter-service use. Regardless of the reasons, the poor data bases in these areas cause the DOD to be unable at present to align itself with many of industry's practices.

The DOD policy on DMS, as stated in the current DOD Directive 4005.16 is that, when faced with a DMS item, each responsible DOD component must initiate timely actions in accordance with stated procedures (see below) ". . . until the applicable end items have been replaced, modified, phased out. . ." or sufficient items are available to ensure end item life cycle support (42:2). The DOD Directive procedures by which DESC (and all responsible DOD components) must be governed are as follows (42:3-4). This is not a complete list; only items of greatest interest are included.

1. Establish a single organizational focal point to monitor DMS.
2. Develop plans to deal with DMS.

3. When faced with a DMS item:
 - a. Attempt to find a new source.
 - b. Encourage manufacturer to continue production.
 - c. Effect excess redistribution.
 - d. Attempt to find substitute items.
 - e. Consider redesign of equipment.
 - f. Cannibalize.
 - g. Modify equipment or part.
 - h. Initiate a LOT buy.
 - i. Insure cost/availability tradeoff of these alternatives is accomplished.

Current DOD Initiatives

Despite the difficulties in implementing industry's proposal, the DOD is investigating ways to minimize the occurrence of DMS as well as ways to control its impact. Current literature suggests that the DOD is supporting the last of industry's suggestions listed above--that of staying in mainstream technology--by working to reduce equipment procurement lead times and by greater acceptance of standard commercial items (18:8; 23:14,18). DOD Directive 4005.16 requires that DOD components reduce reliance on sole sources (42:4). Also, practices during the equipment design phase are receiving increased DOD attention (23:8; 26:14-18). Such design practices include use of standard

commercial items, use of DOD common (already in use) components, and planning for the obsolescence of a technology so that support is not interrupted by a "surprise" (18; 20; 21).

Specifically, the 1978 DESC Study resulted in immediate, mid-term, and long-term recommendations which sought to minimize both the occurrence and the impact of DMS. These recommendations called for consideration of positive actions such as use of "preferred for design" items in new equipment, development of a DOD standard (parts-to-end item) application data system, clauses for DMS "protection" in system acquisition contracts and other such moves which consider the "large spectrum" DMS problem (41:7-9). The study recommended that these actions be incorporated as an update to DOD Directive 4005.16; however, they were not incorporated at that time.

Today a new DOD working group, initiated by the Office of the Secretary of Defense (OSD R&E), Deputy Under Secretary (Acquisition Policy) and consisting of "permanent" membership by involved defense agencies, is taking a current look at the state of the DMS problem and its DOD management (37). (It should be noted that DESC is among the "permanent" members.) This group is also considering the updates needed to make DOD Directive 4005.16 a more effective tool (37).

Despite these positive actions, current policy reflects that DMS is considered a permanent problem and attention is primarily directed to "the means and methods to minimize this condition in an economical sense [8:6]."

DESC Mission

The Defense Supply Agency was established in January 1962 to provide support to the military services, other DOD components, federal, civil, and foreign governments (30:12,137,138). Renamed the Defense Logistics Agency (DLA) in January 1977, it is responsible to the Secretary of Defense (30:12,136). The Defense Electronic Supply Center (DESC), located in Dayton, Ohio, is the DLA supply center responsible for the acquisition, management, and supply of electronic components of twenty-seven federal supply classes (30:12-142). DESC manages approximately 700,000 electronic line items such as capacitors, resistors, tubes, connectors, and relays for use in weapons and communications systems (30:12-142). These electronic components are items with either common usage among the Services of federal agencies or items which the Services have elected DESC to manage (41; 12).

DESC DMS Management

Since 1976, roughly 7,000 items managed by DESC have experienced DMS, making DESC the DOD agency with by far the most experience in managing the problem (28).

Also, such a continuing occurrence of the problem makes it essential for DESC to have workable, responsive day-to-day DMS operating procedures. The dollar value of DMS has also become very significant for DESC; if the \$50 million allocated by DESC for DMS in 1982 is realized, it will represent close to 10 percent of DESC's commodity budget for that year, even though the percentage of "line" items (requiring LOT buys) is very small (41:Appendix 11; 36). A large majority (roughly 70 percent) of the DESC managed items which have experienced DMS fall within four Federal Supply Classes (FSC): 5950 (11.7 percent), 5960 (14.8 percent), 5961 (13.1 percent) and 5962 (32.3 percent); the major FSC being for integrated circuit boards (12).

As outlined above, basic policy and procedural steps for DESC's management are dictated by DOD Directive 4005.16. The DESC "single focal point" for DMS is the DESC Central Control Staff, established in 1976 (41: Appendix 11-3; 28). The Central Control Staff determines the general direction and specific procedures for operational management of DMS at DESC. Day-to-day management actions are carried out by four of the "normal" DESC operational directorates: Procurement, Technical Operations, Engineering Standardization, and Supply Operations (41; 28). Each of these directorates is represented on the Central Control Staff (41:Appendix 11-3; 28).

The detailed procedures are clearly and completely described in the 1978 DESC Study, Appendix 11. Our review of files of DMS cases which were completed in 1981 revealed that these procedures, as documented, are still reasonably up-to-date. It is not our goal here to reiterate this study; we provide only a basic description of the actions which, in many cases, ultimately lead to a LOT buy.

The majority of DMS cases begin when a contractor (manufacturer) advises DESC through normal procurement channels that it intends to cease production of one or more items (41; 28; 36). A case number is assigned for management purposes to track all items on a contractor's notification; the case cannot be closed until some resolution is found for all items on the case. (Since a case is assigned for a given contractor's notification, one case may contain many individual items.) Procurement makes certain that all information needed for identification of the item(s) is obtained; they also determine the date that production will cease and work with the manufacturer for the possibility of continuing production (41:Appendix 11-4; 28; 36). After initial notification, DESC actions among the four directorates listed above follow a basic pattern to satisfy DOD Directive 4005.16 requirements:

1. A cataloging check is performed to determine if the item has been procured under another National Stock Number (NSN) from a different manufacturer(s).

2. The item's past usage and technical characteristics are researched.

3. It is determined if an interchangeable or suitable substitute item(s) is available or if specifications for a suitable substitute item can be made available for potential manufacturers. Technical data on the item is obtained from the current manufacturer if it is available and if it is required.

4. The Services (and all previous users) are alerted of the problem and are provided with their annual past usage of the item. The users are asked to identify all future requirements for the items based upon their knowledge of end item usage, deployment, and service life. The users are told that, if they cannot provide such information, DESC must decide upon a quantity deemed necessary for future support. (It is also noted that any possibility for revised usage based on modification programs to the end item must be identified by the user.)

5. Existing assets held by the users and DESC are ascertained and reviewed to determine their adequacy to meet future needs.

At the point when no other source, no substitute item, no equipment redesign, etc., can resolve the problem,

a LOT buy must be made to meet a confirmed future need for the item. Information on past usage, manufacturer's lot production size, etc., are drawn together to make a LOT buy quantity decision. The "model" used by DESC to make this buy is fully detailed in Chapter V.

Major Higgins' study stated that over 30 percent of DMS cases closed in FY76-FY79 were resolved by buyout (including "level-loading"--a special sort of buyout) (19:8). The 1978 DESC study found, from a FY77-78 sample, that the percentage was more than 50 percent (41:Appendix 11). Thus, buyouts have resolved the DMS problem at DESC for possibly as many as 50 percent of the cases. Why is the LOT buyout the solution so frequently employed? There are many complexities in item use, design, procurement and many shortfalls in the DOD management which contribute to this occurrence (41:Appendix 11). However, of greatest interest here are the key constraints in the DMS decision situation: time and information. From our review of case files, it was determined that the average time allowed by a manufacturer from the date he provided notification to the "last lot" decision date is six months. This means that, although many items have up to a year to allow resolution action before a buyout must be made, many items allow much less time, some as little as two weeks. Little effective item research or creative problem resolution can be applied within these short time frames; even

notification to the users of the problem can scarcely be made in such cases.

The second and greatest constraint is information for decision making. Technical information on the item and information on other sources are critical to the final decision, but take time to collect and assess and are often still insufficient and incomplete. These constraints raise the occurrence of LOT buys; when no other means of support can be arranged, prudence requires DESC to buy from the manufacturer who is currently only too willing to oblige. Still, the information constraint has a great impact upon the LOT buy quantity decision itself. Although DESC manages these items, they do not have the detailed working knowledge of the application of these items among the wide variety of users. As noted above, no DOD application system exists for easy reference to end-item application and the distribution of end-item equipment. The users manage the end-item but do not track and manage their usage of the DESC-controlled items in question. Even when the users are allowed sufficient time to determine the population and distribution of the affected end-items, the service life of those end-items is often uncertain. In view of all these uncertainties and "missing links," the LOT buy becomes by necessity an estimate based upon estimates. In the 1978 Study, DESC cited insufficient information from the users as one of their major problems in the DMS buyout.

Our review of case files indicated that the users, particularly the military services, have grown increasingly aware of the importance and impact of DESC's DMS notifications and do succeed in providing responses in a reasonable proportion of the cases. However, because of constraints noted above, the user responses offer only an estimate from another point of view and frequently the users desire that DESC make the requirements determination for them.

It is in this very time and information constrained environment that the LOT buy is decided upon--often as a last resort in face of a manufacturer who is agreeing to produce "one last time" before abandoning the production line.

CHAPTER IV

METHODOLOGY

Introduction

The methodology for this research is designed to address the research questions stated in Chapter I. These research questions are restated here for clarity of the research design that follows.

1. Do forecasting methods and inventory models exist which may be applied to the DMS LOT buy situation?
2. What is DESC's current LOT buy quantity decision "model" and what are its assumptions?
3. Where does this model lead in terms of support and cost? (How effective is it?)
4. What is the nature of demand of DMS electronic components? What are the behavior and characteristics of "typical" DMS electronic items?
5. How do the costs, implicit and explicit, which play in the LOT buy decision trade off with LOT buy quantities needed for support?
6. How can the understanding of the behavior and characteristics of "typical" DMS items and the cost sensitivities be used to improve the efficiency and effectiveness of the LOT buy decision?

To provide necessary background of the DMS problem and DOD management of it, a literature review, a series of personal interviews, and a "reading" review of DESC files of DMS cases completed in 1981 were performed. The DESC files contain all pertinent correspondence on actions for all items on the case from contractor notification to case closure. The results of these efforts were documented in Chapter III. This review is also the source for description of DESC's normal item management and DESC's LOT buy methodology and assumptions as described in Chapter V. Chapter II documents results of research of inventory models and forecasting methods of interest in this study.

Data Source and Description

To determine where DESC's current LOT buy model leads in terms of cost and support and to study the nature and characteristics of DMS items, it was essential that "real world" DMS item data can be obtained for research. This data was provided through a special data file compiled from various DESC data sources by DESC/LOR, the Operations Research, Analysis, and Projects Division. The data was requested to incorporate all DESC DMS items (this means all DESC items which have undergone DMS LOT buys, were level-loaded, or for which no LOT buy was deemed necessary due to existing stock levels). The data was also requested to include the following data elements for each DMS item

(each element is defined for understanding of its importance in this research). Each element was provided, as defined, by DESC on a computer magnetic tape.

1. National Stock Number (NSN). This is a unique thirteen-digit number assigned to each item procured and managed by the U.S. Government. The NSN has two components: (a) the first four digits comprise the Federal Supply Class (FSC), which is a grouping of all items into established generic classes (for example, FSC 5962 contains all integrated circuits); and (b) the National Item Identification Number (NIIN) which is a nine-digit number assigned to each item when the item is "catalogued" into the federal system; the NIIN combined with the FSC appropriate to that item create a unique management control number for each item throughout the federal system.

2. DMS Code. This is a code established by DESC in its management system to create and maintain visibility of DMS items. The code is a two-digit numeric which represents the last year for which the item's LOT buy was intended to support (28). For example, an item for which a DMS LOT buy was made in 1976 and for which ten years of support coverage was planned will have a DMS Code 86. The DMS Code for this data was drawn from the DESC DMS Master file.

3. Unit Cost. This is the cost of each item by its standard unit of issue (each, feet, dozen, etc.) as

it is currently listed in the DOD stock list of items. This price reflects the cost of an item the last time that it was procured by DESC; thus if the item is procured frequently the stock list price provides a fair representation of current market price for an item. However, if the item has not been recently procured, the stock list price may greatly misrepresent the current market price. DESC provided unit cost as listed in their most current computer file. Therefore, since the DMS buy was the final procurement, it is expected that the cost at the time of the LOT buy is reflected in this column.

4. Demand History. All available demand history for DMS items was requested. Using their historical files, DESC provided six years (March 1976 to March 1982) of annual demand history. Using DESC Supply Control files, twenty-one quarterly demand periods were provided as follows (quarter ending:) March 1976, June 1976, September 1976, December 1976, March 1977, June 1978, September 1978, December 1978, March 1979, June 1979, September 1979, December 1979, March 1980, June 1980, September 1980, December 1980, March 1981, June 1981, September 1981, December 1981, and March 1982.

It is noted that the items on the tape were selected based upon being currently coded DMS; demand history since March 1976 was obtained for these items

regardless of the date the LOT buy was made. This is not a history of demand only since the LOT buy.

5. Current Asset Level. This is the level of stock of each item on the tape as of March 1982, drawn from the most current computer file.

6. VIP Code. This is a DESC code developed to aid in managing "high visibility" items. Literally this code indicates the "very important" items and is used as a classification of how often the forecast for that item's demand is smoothed (DESC employs double exponential smoothing for their item forecasting--see Chapter V (21; 4)). A "Y" code indicates highest dollar and highest demand rates. These high demand level items are smoothed monthly. An "M" code indicates any item which has over \$75,000 annual demand; these are also smoothed monthly. An "N" code includes all items not in the above categories; these items are smoothed quarterly or not forecasted at all (21; 4). Chapter V provides further description of VIP Codes. The VIP Codes for the DMS data tape were drawn from the latest computer files.

The data tape containing these elements was established as a file in the ASD Cyber computer system.

Sample Description, Limitations, and Generalizability

Because we desired a sufficiently large sample to enable acceptable confidence in drawing conclusions, we

requested that DESC provide the above data on all DMS-coded items. Of 2,190 NSNs on the DESC DMS Master file, DESC provided data on 1,772 items for this research. The remaining 418 were excluded due to missing or insufficient elements of requested data. Thus, the data file of 1,772 items represents 80 percent of DESC DMS item population. This large sample size provides statistical strength for the generalizability of the analysis derived from this data. All available quarterly demand data was provided by DESC; however, this resulted in only twenty-one demand data points for each individual item, a relatively small sample size for drawing conclusions with statistical strength concerning the nature of individual item demand. Quarterly demand data was not continuous; the quarters ending December 1976, March 1977, June 1977, and September 1977 were missing from the DESC files. For purposes of this study, it was assumed that the lack of historically continuous quarterly demand data would not distort the nature or behavior of demand in the long-term sense in which we are interested (i.e., the long-term demand pattern would not be distorted).

Aside from the above, the data base has no other known deficiencies. It is probable that uncontrollable human error factors, such as the wrong values recorded or input, may have some impact upon the data reliability.

However, for this study it is assumed that such errors are so minimal as to have no distorting effect.

As noted above, this data base represents over 80 percent of the entire DESC DMS population. As such, it is expected that the study results and findings should prove very applicable to future DESC DMS items and to similar electronic components not managed by DESC which experience DMS. There is no way to isolate the results of this study from the specialized nature of the population studied; the fact that all items researched are electronic components may or may not have bearing on the results. For this reason, the results may not be readily generalizable to other populations of DMS items. However, it is believed that the increased understanding of the nature of the DMS LOT buy decision and the sensitivity study resulting from this research will be useful for all DMS LOT buy situations.

Data Reduction and Manipulation:
Population Description

The data tape provided by DESC was converted from the DESC system to the ASD CDC Cyber system. The first step in working with the data tape was to print out the entire thirty-four fields of data (described in detail above) onto a paper listing. This allowed visual inspection and validation that the tape contained the requested data and suffered from no tape development or conversion problems.

The second goal was to manipulate and reduce the data to include the elements of interest in an easily manageable format. To do this, data elements of interest were recorded onto what we termed an "analysis" file. First, the FSC, NIIN, DMS Code, Unit Cost, Current Asset Level, and VIP Code for each item were recorded onto the analysis file. As a part of the methodology for observing and measuring the nature of demand over time, a statistical simple linear regression program coded in FORTRAN was developed. The details of this program and its use are discussed fully below; it is of interest here only to note that our next data reduction step was to run the regression program against the twenty-one quarterly demand data points for each line item. The elements of interest, the average quarterly demand (AQD) and the statistics resulting from the regression program (Beta factors and the computed t-statistic) were recorded for each item onto the analysis file.

In Chapter II, it was established that a theoretical and practical basis exists for representing demand for items displaying twenty-four or less demands a year with a Poisson distribution and for items displaying twenty-five or more demands a year with a Normal distribution. Based upon this demand characteristic, the analysis file was used to create two subfiles: a Poisson analysis file and a Normal analysis file. These files included all data

in the total population analysis file; they merely divided the population based upon their assumed demand distribution.

As basis for all following steps in this research, the ranges of characteristic values had to be determined. To do this, the Statistical Package for the Social Sciences (SPSS), a package software program existing on the Cyber system, was used to create and execute descriptive statistics programs. Condensive statistics were obtained for all three analysis files. Further, frequency distribution tables and histograms were produced on the three analysis files. The frequency distributions of each of the data characteristics were obtained using the natural categories for DMS, VIP Code and FSC and arbitrary categories (determined by the Condensive results) for AQD, Unit Cost, NIIN, slope and Student's t-statistic. The results of the frequency distributions based upon these initial arbitrary categories were reviewed. The concentration of the values was observed and then the frequency categorization was revised to allow better frequency distribution description. Basically, the categories for the frequency programs were revised to reflect the more natural categories inherent in the data which became apparent once the initial frequencies were reviewed. Frequency programs were run against the revised data

categories; the results and the use of these results are demonstrated in Chapter V.

Variable Identification and Definition

As identified in Chapter I, the variable which is critical in the effectiveness of the LOT buy is the LOT buy quantity. As such, the LOT buy quantity is considered the dependent variable or "output variable" in this study and will be referred to as the Economic Life-of-Type Quantity (ELQ). We also noted in Chapter I that the effective outcome of the LOT buy is extremely difficult to define and measure, except in the most explicit cost terms (see further discussion below). For this reason, the emphasis of this study is upon understanding the two independent variables proposed to determine ELQ and upon the varying sensitivity of ELQ to different levels of these independent variables.

So that we could deal with the relationship of the dependent and independent variables in a scientific manner, the independent variables were defined in such a way as to be observable and measurable (40:29). The ELQ is the quantity of a given DMS item to be procured to provide support for the projected support periods. The independent variable, future requirements, is the number of demands for a given item for each support period multiplied by the number of periods of support which will be

deemed and will be called "demand." For purposes of the results of this study a single support period is defined as one year, although the research is accomplished with use of quarterly demand data. Costs, the second independent variable, are broken down into the following elements:

1. Unit Cost--the procurement unit cost of a given item.
2. Holding Cost--the cost of holding an item in inventory over all periods that it must be held.
3. Interest Rate--the cost of the time value of money over the periods that an item is held in inventory.
4. Penalty Cost--the cost of the stock outage of an item when it is needed. As this cost is extremely difficult to quantify, a cost "penalty function" is used to represent an implied value for the tradeoff of buying additional stock against incurring a stock outage. This penalty function is more fully explained below. The elements are analyzed individually for ELQ sensitivity.

In addition to analysis of the two independent variables and their impact upon ELQ, the data population included other variables of interest. It was uncertain if these other variables might have a relationship to the independent variable demand and if so, what the nature of that relationship might be. These other variables are Unit Cost (considered as an item categorization method here, not in terms of its cost impact as an independent

variable), FSC, NIIN, DMS Code and VIP Code (these are defined above). We do not propose that these are variables with a direct influence on ELQ but rather that they may serve as "predictor" variables of demand. If a statistically significant, systematic relationship exists between demand and one or more of these variables, these might be viewed as variables which could "predict" some demand behavior or characteristic. In this study, any such relationship will be determined based only upon historical data. This will limit the confidence level for application of the concluded relationships, but may indicate that powerful and useful underlying relationships exist which could be tested in further research efforts.

Research Computer Programs

Cost Effectiveness Outcomes of LOT Buys

Chapter I briefly described the difficulties encountered in attempting to quantify "how effective" a LOT buy proves to be. One method of interest is measuring the cost of units over- or under-bought using the most obvious of explicit costs--unit cost--as a basis. This general approach was adopted to allow us to measure the explicit cost effectiveness outcome of DESC's current LOT buy method.

A FORTRAN program was developed to perform the following basic methodology for each item for measuring

the cost effectiveness outcome. This program was run against our total item analysis file. Using the DMS code, the year to which the LOT buy quantity was intended to support is determined. 1982 is subtracted from this year, to determine the number of years remaining for which support is required. Next, using the DESC assumption that demand remains constant over time (see Chapter V for a full discussion), the AQD is assumed to continue in a constant manner over the remaining years. From this, the number of assets needed to support the remaining years is determined; this number is subtracted from the current asset level to arrive at a shortage or overage number of assets for that item. Next this shortage or overage number is divided by the AQD to determine the number of years (translated from quarters) that the item is short or excess. The results of this methodology, performed for every item, produced a data tape which was run with an SPSS frequency distribution program to display the total number and percentages of items which are short or surplus against time categories. The time categories used for this frequency were:

1. DMS code 1981 or less (support planned to terminate prior to 1982). These assets were assumed to be surplus.
2. AQD equals zero. (All assets are assumed to be surplus.)

3. A category for each year from -25 to +25 years.
4. A category for each ten-year period after +25.

The frequency distribution results are provided in Chapter V. The cost results for overages and shortages are also provided in Chapter V; these were obtained by (1) multiplication of the shortage or overage asset number for each item by its unit cost, and (2) totaling all shortages and totaling all overages to result in a single shortage cost and a single overage cost. These costs represent total overage and shortage costs which would result from the DMS sample of 1772 items (80 percent of population) given that demand remains constant at the computed AQD.

In the following section, a FORTRAN program to accomplish and test a statistical simple linear regression will be fully described. This program was designed to test the "constant mean demand over time" assumption used by DESC. Although it is not our intent to describe the regression at this point, the regression results were used to run the FORTRAN "effectiveness" program a second time. Briefly, the regression program resulted in estimated "Beta factors"--a Y-axis intercept and a slope value--for the regression line representing each item's demand behavior based upon the twenty-one data points for that item. These factors were included in a data file containing all the total analysis file data. The resulting Beta factors for each item were used to adjust AQD in the effectiveness

program methodology described above; all other aspects of the FORTRAN program remained the same. The goal of using the regression results in this way was to measure the overages and shortages (with associated costs) given the assumption that the regression line (Beta factors) represented the behavior of demand rather than the constant behavior assumed in the first (total analysis file) program above. Results of this second effectiveness program are also detailed in Chapter V.

Prior to running the FORTRAN effectiveness outcome program, the program computerization and logic was tested. This was accomplished by building "dummy" data files. For the first effectiveness run, the dummy file consisted of ten line items with simple numbers assigned for the AQD and current asset levels. The results for this dummy file were manually computed. Then the FORTRAN effectiveness program was run against the dummy file to verify that the program results matched the manual results. This verified the program's reliability for use with the total analysis file.

For the second effectiveness program (regression outcome), the dummy file also included simple numbers representing the estimated Beta factors for each of the ten line items. The results of this file were also computed manually. Running the FORTRAN effectiveness program against this second dummy data file verified the

program's reliability for use with the regression analysis file.

Simple Linear Regression Program

As discussed earlier and fully described in Chapter V, the DESC LOT buy quantity decision is based upon the assumption that demand remains constant at an average value over time. To test this assumption and to investigate the behavior and nature of demand over time of the items on the DESC provided file, a simple linear regression technique was chosen. This was a critical element in meeting our research objective to determine the behavior of the independent variable, demand.

Simple linear regression is a statistical method for modeling a straight-line relationship between two variables (25:293). The straight-line model formulation is:

$$Y_i = \beta_0 + \beta_1 X_i + \epsilon_i$$

where, Y_i = dependent variable (variable to be modeled);

X_i = independent variable (variable used as a predictor of Y);

ϵ_i = random noise component;

β_0 = Y-intercept of the line, i.e., the point at which the line intercepts or cuts through the Y-axis; and

β_1 = slope of the line, i.e., amount of increase or decrease in the deterministic component (excludes the error component) of Y for every one unit increase in X (25:294).

Simple linear regression analysis fits this model to a set of data by the "least squares" method, a method which minimizes the sum of the squared "errors" (SSE) (i.e., distances) of the data points from the straight-line model. The Beta numbers which result from fitting the data to the model are estimates of the real Beta factors, which would only be known if we had access to the entire population of (X,Y) measurements. So the results of the regression are estimates of β_0 and β_1 , which will be called $\hat{\beta}_0$ and $\hat{\beta}_1$. Finally, to determine how well the model describes the true relationship between X and Y, the random error component ϵ , must be estimated and four assumptions made about the distribution of ϵ : (1) the mean of ϵ is zero, (2) the variance of ϵ is constant for all values of X, (3) ϵ is distributed Normally, and (4) errors for any two observations are independent of each other (25:303).

For this study, we wish to test the assumption that the mean of demand is constant over time. Here, demand is the dependent variable (Y) and time is the independent variable (X). For demand to remain constant, the the slope of the line, β_1 , must be zero.

The hypotheses that we test is:

$$H_0: \beta_1 = 0$$

$$H_a: \beta_1 \neq 0$$

The Student's t-statistic is the appropriate test statistic for this situation (25:387):

$$t = \frac{\hat{\beta}_1 - \text{Hypothesized Value of } \beta_1}{S_{\hat{\beta}_1}}$$

where, $S_{\hat{\beta}_1}$ represents the population standard deviation of β_1 .

The hypothesized value of β_1 for our purposes is zero.

A two-tailed test is employed.

A FORTRAN program was developed to perform the simple linear regression analysis described above for each line item in our total analysis file. As briefly described in Data Reduction above, the program performed regression analysis against the twenty-one data points of demand available for each of the 1,772 line items. The program was also designed so that a Student's t-statistic was produced for each line item for use in testing the hypothesis. The AQD, Beta factors, and the t-statistics resulting from the program became a part of the total analysis file.

The program also includes a check for each item's t-statistic against the critical t-value for a two-tailed test at the 95 percent confidence level with 19 degrees of freedom. This critical value is 2.093; all items with t-statistic values greater than 2.093 rejected the null hypothesis that their line slope is zero. The 95 percent confidence level test was run against the total analysis

file to determine which items failed to reject, which items rejected displaying positive slopes, and which items rejected displaying negative slopes. The results of this run produced a new data file which held each item's demand characteristics--positive, negative, or zero slope. This tape was then used for further research computations.

Prior to use of the simple linear regression program, testing of the program computerization and logic was performed. This was done by use of a dummy data file containing simple, arbitrary demand data for ten line items. Regression analysis was performed on the dummy data file by use of an SPSS simple linear regression program which produced the Beta factors and t-statistics of interest. Next the FORTRAN regression program was used to perform regression analysis on the dummy data file and the results were compared to those produced by the SPSS program. This verified that the program was reliable for use with the total analysis file.

Data Characteristics and the SPSS Cross-tabulation Program

In Data Reduction we described the SPSS Con-descriptive and Frequency Distribution programs run for this study. The results of these programs and the results of the simple linear regression program provided some scoping of the raw data by categorization upon which some further analysis and measurement could be based.

As a part of our objective of characterizing DMS items, data tables were developed to display frequency distribution results for the data elements on the total analysis file, the Poisson analysis file, and the Normal analysis file: NIIN, FSC, AQD, VIP Code, DMS Code, Unit Cost, and the estimated slope ($\hat{\beta}_1$). The categories used in developing the frequency distributions were the inherent ones; i.e., the actual class or code for FSC, VIP Code, and DMS Code. For NIIN, AQD, Unit Cost, and estimated slope, the categories were made small enough to allow scrutiny of the "natural" categories apparent in the distribution.

Another part of our research objective was to determine if other situational variables are related to the demand variable in such a way as to assist in the prediction of demand behavior. Further, relationships among the variables in the LOT situation are of interest in themselves in characterizing "typical" DMS items. These "typical" DMS item characteristics are used in the sensitivity study described in the next section. Using the item frequencies determined from the program discussed above, the categories were again revised to make broader data categories which were more meaningful for use in measuring relationships among the variables. Although slope and FSC retained their class categories, AQD, Unit Cost, were reduced to a limited number of categories

(e.g., high, medium, and low cost). VIP, NIIN, and DMS codes were not used for reasons discussed in Chapter V.

The technique used to test for relationships among slope, AQD, FSC, and Unit Cost was a contingency table or "cross-tabulation" program. This table is a joint frequency distribution of cases according to two or more classificatory variables (29:218). An SPSS cross-tabulation program was used to perform the analysis. The SPSS program computes and displays two-way to n-way tables for discrete variables (29:218). In addition, the SPSS program provides summary statistics which measure the statistical significance among the variables in the cross-tabulation.

The output statistic of interest in this study is the Chi-Square test of statistical significance. The Chi-Square test is performed by computing the "cell" frequencies which would be expected if no relationship is present between the variables given the existing row and column totals (29:223). The SPSS program calculates the expected frequency (f_e) of each cell according to the following formula:

$$f_e = \frac{(c_i \cdot r_i)}{N}$$

where, c_i is the frequency in a respective column marginal,

r_i is the frequency in a respective row marginal,
and

N is the number of valid cases (29:223).

The Chi-Square statistic results from comparison of the expected cell frequencies to the actual values found in the table according to the following formula:

$$\chi^2 = \sum \frac{(f_o - f_e)^2}{f_e}$$

where, f_o equals the observed frequency in each cell (29:223).

The greater the discrepancies between expected and actual frequencies, the larger the Chi-Square becomes. If no relationship exists between two variables, then the deviations from expected values are due to chance or randomness. While randomness can cause small deviations, large Chi-Square values imply that a systematic relationship of some degree exists between the variables (29:223). The Chi-Square is limited in that it indicates only whether the variables are independent or are systematically related. It does not measure the strength, direction, etc., of the relationship (29:224).

In making conclusions based upon our results, it was noted that the cross-tabulation program treats input variables as nominal values; distances between categories are ignored in computation (29:224). Further, the statistical significance depends not only upon the strength of the observed relationship but upon the size of the sample. In very large sample sizes, weak relationships become significant and in small samples, results cannot be

relied upon (29:222). This was considered in the analysis of our cross-tabulations.

Cross-tabulation programs were run using the analysis file which resulted from our regression program; that is, the analysis file which indicated slope for each item as positive, negative, or zero. The testing was performed using the "broader" categories mentioned above for AQD, Cost, and Slope. As the variable of interest is AQD and its slope characteristics, the variables of Cost and FSC were tested against these variables in both two- and three-way cross-tabulations. Slope and AQD were also tested against each other. Chapter V discusses results.

Single-Procurement, Multi-Period Model and FORTRAN Program

In Chapter I we stated that, since neither of our independent variables--future demand and costs--can be known with certainty, the best alternative is to operate within a range of values. It was one of our research goals to investigate the sensitivity of the dependent variable ELQ to ranges of values of demand and cost. Thus, towards answering research questions five and six, the model described in detail below was used to perform a sensitivity study of ELQ.

As described in Chapter II, the Newsboy model is designed to meet demands for a single period, a period of finite length. Although these finite periods are, in most

applications, of short duration, Hadley and Whitin and Masuda describe military applications of buying spares over an aircraft's life (the aircraft's life treated as a random variable with a known distribution) (3:302-303; 6:42).

The Chapter II literature review did not discover a published formulation designed to meet the situation where the single-buy quantity must support demands for what would normally be many periods into the future. The stochastic, single procurement model described below is formulated with multiple-demand periods as a basis.

In military applications, inventory decisions are not profit-oriented. Instead, the military wishes to meet its mission within its budget constraints. Therefore, minimizing cost is consistently used for optimizing inventory decisions.

The goodwill costs described in the Newsboy model are also inappropriate in military applications. If an item is short when demanded, the effect is one of decreasing military capability. This may be little cause for alarm or may be so serious as to place the nation's fate in danger (24:42). Often this stockout cost is only calculable as an imputed, not an explicit cost, because it is difficult to measure (24:42; 39:45). In the single-procurement case, it is logical to view this as a "penalty cost" for shortage, as we refer to it.

Further, no salvage value is incorporated in the military application. If an overbuy is made, the only potential source for future use is Foreign Military Sales. The probability of this mode for regaining some of the investment in overstocked items is so uncertain that it cannot be incorporated. Often the military resorts to disposal of overstocked items. This implies a disposal fee; however, it is usually a very small percentage of unit cost and is not considered an impact in the buy quantity decision.

In view of these characteristics, along with the newspaper boy model characteristics, a general stochastic, single-period cost formulation to minimize costs is proposed as follows:

$$TC(Q) = CQ + \sum_{d=0}^Q (Q-d)p(d) \\ + B \sum_{d=Q}^{\infty} (d-Q)p(d)$$

Total cost of Q = Procurement cost + Holding cost
+ Shortage costs

where, B = Shortage or Penalty cost,

C = Unit cost,

H = Holding cost, and

d = A random variable for demand.

This, in the discrete probability case, reduces to:

$$P(d \leq Q) = \frac{B-C}{H+B}$$

optimized by the derivative of total cost formula.

An additional aspect of concern in a model making a cost decision over a long time period is the present value of money. A present value factor can be incorporated which makes all demand period costs in "now" year dollars and so enables true comparison among buy quantities.

A multi-period model, derived from the above total cost formulation and incorporating the present value factor, is as follows:*

$$\begin{aligned} \frac{\text{First Period}}{TC(Q)} &= CQ + H \sum_{d_1=0}^Q (Q-d_1)p(d_1) \\ &\quad + B \sum_{d_1=Q}^{\infty} (d_1-Q)p(d_1) \\ [\text{Second Period}] &+ PVF \left[\sum_{d_1=0}^Q \sum_{d_2=0}^{Q-d_1} H(Q-d_1-d_2)p(d_2)p(d_1) \right. \\ &\quad + \sum_{d_1=0}^Q \sum_{d_2=Q-d_1}^{\infty} B(d_2-(Q-d_1))p(d_2)p(d_1) \\ &\quad + \sum_{d_1=Q}^{\infty} \sum_{d_2=0}^{\infty} B d_2 p(d_2)p(d_1) \dots \text{etc. for} \\ &\quad \text{remaining periods.} \end{aligned}$$

*The single-procurement, multi-period, stochastic model described in this study and used in this experiment

The output of this model is optimization of the total cost function, providing economic LOT quantities (ELQs) for given probabilities of "running out" in each period of consideration. This algorithm is optimized in a way which varies from that described for the newsboy model. Again, the first derivative is taken in an effort to determine the marginal cost. We move along the total cost convex function solving for points until the solution indicates that we are at or have just passed the minimum point of the function. This is a "marginal analysis" type of approach and is highly accurate.

Although the mathematical formulation of this model becomes increasingly complex with each additional period, it is a recursive formulation from period to period and so is easily captured in a computer program formulation.

This model is the basis of the FORTRAN program used in the sensitivity analysis experiment described in Chapter VI. To provide a further definition of the functioning of the form of the model used in this experiment, the following information is provided.

The program uses the penalty cost formula: $B=C(2)^M$, where C is unit cost, and M is the exponent of the base 2. This relationship was chosen because it covered a broad

can be attributed to the work of Major James Masters, Assistant Professor of Logistics Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

range of costs (at $M=16$ the penalty cost was over a million times unit cost), ensuring that the true value of penalty cost would be within the range investigated. As noted above, determining a "realistic" penalty cost is extremely difficult; the formulation cited above is a function judged to be useful in measuring differences in relative penalty cost for varying ELQs; neither small nor very large values must be assumed correct, but instead a "realistic" range may be investigated. For this study, we refer to the value of a penalty cost by referring to the related exponent (M) of 2. For example, we refer to a penalty cost of unit cost times 2^4 as a penalty cost at the "4" level.

The model is developed and applied using two probability distributions to represent demand. The Poisson distribution form of the model is useful for items displaying lower demand; this was defined in Chapter II as items experiencing demands of twenty-four or less annually. The model basically functions by building a matrix of Poisson-based probabilities for the chance of running out in a given period, given a mean demand rate at various computed ELQ levels. A conditional probability matrix is developed; i.e., this matrix depicts the probability of running out in each period given that we did not run out in the previous period.

The Poisson probability distribution: $P(X) = \frac{\lambda^x e^{-\lambda}}{x!}$ is employed in the model. As the mean and variance of a Poisson distribution are the same (λ), only one parameter of demand is input into the program. The model is designed to compute values across ten (10) periods (years); Poisson demand is assumed to remain constant across those ten periods.

A second form of the model employs an approximation of the Normal distribution. As defined in Chapter II, the Normal distribution is useful in representing items with demand of twenty-five or greater over a year. Instead of using the Normal probability density function, which is very complex computationally, R. G. Brown's integer approximation of the Normal serves as the model's probability basis (5:92-94). This integer approximation has been validated in the relevant Normal "Z" range of roughly -4.0 to +4.0, which incorporates virtually 100 percent of the probability for Normally distributed random variables (25:67). The model-generated probabilities were verified against a Normal probability table. As described above for the Poisson version of the model, the Normal model program functions by building for a particular mean and variance a matrix of Normal-based probabilities for the chance of running out of the item in a given period given that the item had not run out in a previous period. A conditional

probability matrix is also developed as described for the Poisson program. Because a Normally-distributed random variable is described by the two parameters, mean (μ) and variance (σ^2), these two parameters are controllable input parameters for each run of the model.

Aside from their probability distribution bases, the Poisson and Normal versions of the model do not vary. The derivative of the total cost formula described above is used to optimize the ELQ solution in each. The input parameters controllable by the user include the number of periods (N) for which the model is to calculate output values, the mean demand per period (XMU), the variance per period for the given mean (SIG) per period for the Normal program, the item unit cost (C), the holding cost per period, which is a percentage of unit cost (H), and the discount rate (present value factor [R]).

As described earlier in this chapter, the frequency distributions of AQD and unit cost were carefully scrutinized to determine the ranges of values most characteristic of DMS items. This review served as the basis for determination of AQD and unit cost value ranges to be used as input parameters for the Poisson and Normal models. Basically, the frequency distributions developed from the Poisson analysis file were reviewed to determine the range wherein roughly 80 to 90 percent of the data lie; these values served as the outside limits for testing. Since

the Poisson distribution is theoretically assumed to represent items displaying twenty-four demands or less a year, all data points (1 to 24) for demand were tested with demand held constant across all ten periods. However, the range and incremental change of unit cost from run to run were drawn from the frequency data.

For the Normal model input parameters, the Normal analysis file frequency distributions were also used. The relevant range of values for AQD and the appropriate increments of change from period to period were derived from the frequency results, as were the cost ranges. The program was run using the appropriate mean values held constant over all ten periods. The standard deviation for these runs also retained a constant relation to mean. In each case, the standard deviation value was assigned as a value roughly equal to the square root of the mean (e.g., if the mean was 49, the standard deviation was assigned to be 7). The programs were run with the variance held constant over all ten periods of each run.

Next, a test was performed to ascertain the sensitivity of ELQ to an inconstant variance assumption. This was accomplished by maintaining the mean of demand at a constant level, but changing the variance over each run.

Finally, the assumption of the mean of demand remaining constant over time was tested in terms of ELQ sensitivity. This was done by starting each of a series

of runs with the same mean value of demand. Within each run the demand was altered in each of the ten periods according to an assigned "slope" value. (The "slope" assigned ranged from +2 to -2, see Chapter VI). Variance was held constant in a relative proportion to the mean across these runs.

Finally, percentage values for Holding Costs and the Interest Rate (Present Value of Money) were assigned based upon a range of values determined to be realistic. The ranges of values were the same for both the Poisson and the Normal models.

The assignment of a Poisson or Normal distribution based upon a "cutoff" value of twenty-five demands a year is based upon a primarily theoretical assumption (reference is made to Chapter II). To compare the performance of the Poisson model and the Normal model in the sensitive range of mean demand values, special program runs were accomplished. Each model was run starting at fifteen mean demands per period and incrementing by two per run (i.e., 15, 17, 19, 21, 25) until twenty-five demands per year was reached. The output of the Poisson and Normal models was then compared to determine the point of output convergence. This was used to help determine the appropriateness of each model within this "sensitive" demand range.

Graphical and Response Surface Analysis

Two important aspects of our research objective were (1) determining the sensitivities of the dependent variable to the independent variables so that ranges of values for operating may be considered, and (2) presenting these results in a clear form for ease of interpretation. Towards this end the results of the sensitivity analysis performed with the Poisson and Normal Multi-Period Models were translated into two-dimensional contour graphs and three-dimensional response surfaces.

The two-dimensional contour graphs display only the y and x_2 axes. These are the axes which display the dependent variable ELQ with the variable held constant during that particular program run; the independent variable is reflected on the contour line. This allows a straightforward analysis of the effect between y and x_1 and x_2 held at a constant value (as established for that run). The two-dimensional contour graph results are discussed in Chapter VI and copies of the graphs are provided in Appendix A. The two-dimensional graphs were accomplished by use of an ASD Hewlett Packard plotter.

Our use of three-dimensional response surfaces is only a very simple representation of the Response Surface Methodology (RSM). RSM is a technique employed in many research designs where the goal is to find those values or

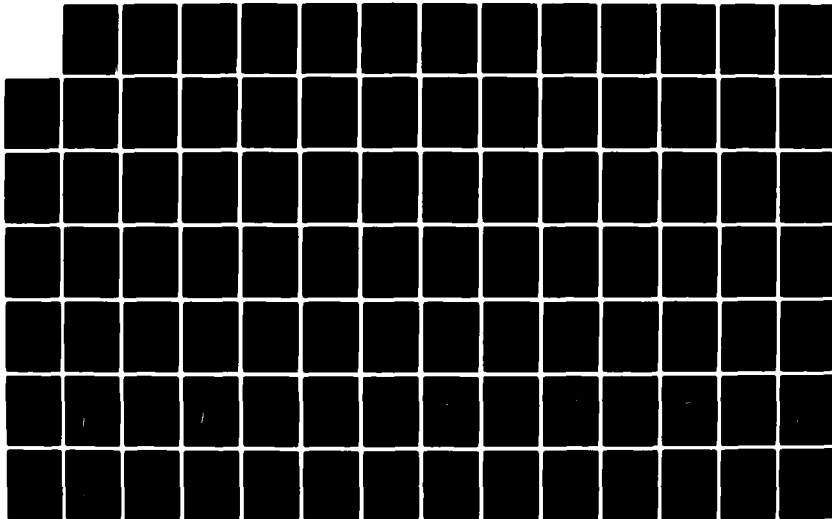
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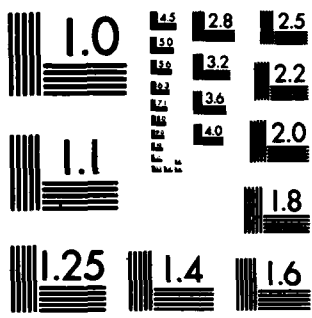
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levels of independent variables that will yield the "optimum" values of the dependent variable (34:169). The methodology was originally proposed by Box and Wilson in 1951 and has since been extensively developed in use and in literature (34:170). The basic concept of RSM entails a dependent variable (y) and independent variables ($x_1, x_2, \dots, x_n$) related in the expression

$$y = f(x_1, x_2, \dots, x_n) \quad (34:170)$$

The particular relationship in this study is three-dimensional, thus represented by $y = f(x_1, x_2)$. Geometrical representation may be made with a surface limited to three dimensions.

Visualization of behavior by use of the three-dimensional representation is useful. However, RSM can become extremely complex as the regions of the surface may be mathematically explored to determine optimum points. In using the Multi-Period Model, we use a traditional one-factor-at-a-time method (34:172) for representation of the model results. This involves fixing the value of the x_2 axis while varying the x_1 axis values and analyzing resulting outputs. In an iterative approach we then revise axis assignments and investigate a different variable on the x_1 axis.

The value of this type of approach was demonstrated by Gardner and Dannenbring (13). They noted that

real world "true" costs are nearly impossible to measure (13:709). They proposed that using "optimal policy surfaces" would allow "inventory decisions to be conceived as policy tradeoffs (on a three-dimensional response surface) [13:709]." They recall that Starr and Miller employed "optimal policy curves" between workload and aggregate cycle stocks for deterministic situations (13:710-711). Gardner and Dannenbring propose that, with stochastic demand, an optimal policy surface becomes the viable tool (13:711).

This methodology is believed to be a powerful aid in understanding those sensitive regions in the ELQ decision in regards to the parameters tested. Determination of regions may prove more realistic by implying "bounds" for an ELQ decision (13:709-710) versus attempting the more strictured attempts at calculating an ELQ. We developed the three-dimensional response surfaces by use of the input and output parameters of the different programs run using the Multi-period Model. These values were input to an existing software program in the AFIT School of Engineering, operative on the CDC Cyber system, the DISSPLA8 program.

Criteria for Research Evaluation

There is no quantifiable method for evaluating how well our research accomplished its purpose; there is no

way to measure "how much" understanding has been increased. What we can use as criteria for evaluation are the research objectives and questions set forth in Chapter I. We must verify that the research questions are addressed in the Research Methodology and in turn that each question is addressed in Chapters V and VI Analysis of Results. Finally, the conclusions in Chapter VII will be tied to the research question to which they contribute a partial, if not a complete, answer. The recommendations will help point out those areas where further actions could better serve to answer the questions.

One literal outcome of our research stated in our objective was to present findings in a clear, concise form for use by managers. This requirement was met in several ways: the two-dimensional graphs and three-dimensional surfaces present visual images for data interpretation and the final Summary of Results tables display the "real life" DMS data characteristics and the findings from the sensitivity study. These easily-referenced aids may prove useful for the manager in a DMS situation. The conclusions provide a systematic approach to determining a LOT buy quantity.

CHAPTER V

THE LOT BUY AND THE DEMAND VARIABLE

This chapter and the next provide a description and analysis of the results obtained using the methodology detailed in Chapter IV. The purpose of this chapter is to address research questions 2, 3, and 4 and so to contribute to meeting research objectives 1, 2, 3, and 4. The chapter begins by describing how DESC determines demand and buy quantities for normal items and how the LOT buy is made. The assumptions implicit in using this method are described. Then the results of the FORTRAN cost effectiveness demand assumption are provided.

The next section of the chapter provides results of our data manipulation, the simple linear regression, and the cross-tabulation program. This section achieves three goals: (1) to describe the nature of demand of DMS items, (2) to describe DMS item characteristics and particularly to describe "typical" DMS items, and (3) to determine if relationships exist among (demand) slope and other variables which might allow the other variables to "predict" demand behavior.

The final section of this chapter describes the results of the FORTRAN effectiveness program based upon

the assumption that the simple linear regression results describe demand behavior.

DESC LOT Buy: Method and Implications

To provide a context for understanding the approach used by DESC for making a LOT buy, a brief description of their "normal" demand forecasting and buy method is first discussed. Items at DESC are divided into three broad categories for management control (12; 3). Replenishment items are the most "visible" items, having demonstrated a relatively high demand and dollar value of demand. Any item which experiences at least three requisitions a year with a requisition quantity of at least four each and a single requisition of at least \$20 is designated as a replenishment item (3). Buy quantities for these 160,000 to 170,000 line items are determined by use of a version of the Wilson's EOQ formula discussed in Chapter II. The formula includes a constant factor called the "T" factor which includes a 15 percent holding cost and a \$105 ordering cost; these costs are averages which were determined across all five DLA supply centers (3). In addition to the EOQ-derived quantity, the DOD Variable Safety Level (VSL) formula is used to determine a "safety level" of stock for these items. The VSL formula used by DESC is based upon "Model IV" of Presutti and Trepp (the reader is referred to 33:248-249); this model assumes that demand

during lead time follows a Normal distribution (3). A second category of items is called Numeric Stockage Objective (NSO). These items do not meet the replenishment item criteria; they have an arbitrarily-assigned reorder point (3). The EOQ and VSL formulae are not used for these items. Non-stocked items are the third category. These are procured only upon receipt of an actual demand.

DESC uses double-exponential smoothing (see Chapter II) to forecast quarterly demand for all items except Non-stocked (3). (NSO items are forecast but a different determination of requirements is actually used (4)). Items are smoothed based upon their demand velocity and the required smoothing is indicated by the item's VIP Code. "Y" VIP Code items have over 200 annual demand frequency and are smoothed monthly using a .2 alpha (smoothing factor) (9; 3; 4). "M" items display over \$75,000 annual demand value and are also smoothed monthly using a .2 alpha (9; 3; 4). "N" VIP Code applies to all items not falling into the "Y" or "M" category; these items are smoothed quarterly using a .3 alpha (9; 3; 4). It is of interest to note that, when a LOT buy is made for an item, it is assigned a DMS Code in the DESC system but the VIP Code assignment remains unchanged. So, DMS item demand continues to be forecast in the DESC system despite the fact that no further procurement of the item will occur (4). Since item managers do periodically monitor the

remaining asset level of a DMS item, we presume that the demand forecasting may help "warn" managers when assets of a DMS item become so low as to threaten continued support ability so that users may be advised. VIP Codes for DMS items studied in this research are discussed in the next section.

Chapter III described DESC's actions when a DMS situation occurs and a LOT buy must be made. For the LOT buy quantity calculation, the item's type (replenishment, etc.) and VIP Code are not considered. DESC requests projected requirements from the users; if all users provide requirements estimates, DESC will buy the combined requirements (12). If only one or some users respond, DESC will incorporate that quantity into their buy quantity. Unfortunately, for reasons stated above, DESC receives no requirements estimates for the vast majority of items. For this study, it may be safely assumed that DESC applies the following "formula" to all LOT buys:

$$AQD \times 40 = \text{LOT buy quantity}$$

where, AQD is an average based upon the last eight quarters of actual demand.

The last eight quarters of demand are used because this amount of demand history is maintained for an item at any given point in time in files accessible to the item managers. The forty results from four (quarters per year)

multiplied by 10 to represent ten years of projected support. As discussed in Chapter III, the item's end-application is unknown by DESC, so the number of end-items and the projected end-item life cannot be known. Thus, the factors which really determine the demand level and years of required support are not known. DESC arbitrarily selects ten years as an estimate of the years of required support and the AQD as the demand level because no other basis for developing a quantity has been found.

No cost considerations are an explicit part of the DESC method. The item unit cost and total quantity cost to procure the LOT buy from the manufacturer are determined and established in the contract. Sometimes this price may be considerably higher than the previous unit procurement cost (36). No other explicit or implicit costs--holding costs, interest rates, stock outage function, etc.,--are considered. In fact, no instance was found where cost really played a role in deciding upon the quantity to be procured. In brief, once the LOT quantity is determined, this amount is procured. Still, it is anticipated that, if the LOT buy cost was extraordinarily exorbitant and/or caused DESC to overrun its DMS budget, a quantity adjustment downward might be made.

The following assumptions are implicit in the DESC method:

1. Mean demand is constant over time. This assumes that, although demand will fluctuate from period to period, it will fluctuate about a mean value. The fluctuations over the forty periods will "average out" to roughly the predicted mean value thus giving us the effect of a constant mean over time.

2. The ten-year factor provides a sufficient amount of stock in most cases. The cost of overbuys resulting from this policy is less important than the cost of underbuys which would occur if a shorter time factor were used.

3. All items are treated the same for purposes of making a DMS buy. DESC does not consider the importance of the item to a weapon system, or its velocity of demand, or other individual characteristics of the item in its purchasing decision for the LOT buy.

4. The buy quantity support is "worth" whatever explicit and implicit costs are associated with it.

Since no inventory or forecasting model exists to meet DESC's DMS need, their method is admittedly an arbitrary method for quantity "guessing" (41:Appendix 11). Still the support and cost implications of their method operate in reality and so require investigation. The FORTRAN effectiveness program was used to help "measure" the cost outcome of those items currently DMS coded by DESC. Using the program described above, an AQD was

determined for each item. Using the DESC assumption that the mean of demand is unchanged over time, this AQD was extended over the remaining years for which support for that item was required. The program results using this assumption are graphically displayed on a time histogram, provided as Appendix A, Figure A-1. It is noted that the AQD used in our research was based upon twenty-one quarters of demand history, in contrast to DESC's original quantity decision based upon an average from the last eight quarters just prior to the LOT buy. This slightly alters our results from that which would be obtained if DESC's projected AQD was used in the effectiveness program. We are not using the program results as representations of the "real" overages or shortages costs but rather to demonstrate the direction in cost and support towards which this method of buying leads. Thus, we do not feel the difference in AQD detracts from the validity of our approach.

The results tell us that only roughly 10 percent of the items will reach zero stock levels during the year projected for their support to end, thus causing no overages or shortage. Twenty-five percent of DMS items fall short of satisfying the purchasing objective. Sixty-five percent of DMS items are overbought against the stocking objective. Approximately 47 percent of the DMS item percentages are included in the range of -7 to +8 years,

meaning that they will fall short by 7 to 1 years of support or that 1 to 8 years of overage will result. A fair percentage of items fall at the extremes; approximately 8 percent of items were in a surplus state at the time of this study, and approximately 10 percent are projected to have over twenty years of overage stock. (Items displaying zero demands across the twenty-one quarters were assumed to be surplus.) On the whole, a larger number of items were overbought rather than underbought.

As described in Chapter IV, the program multiplies each item's unit cost by its overage or shortage figure and these costs are totaled. The total cost of underbuys which result if the assumptions of this program are realized is \$20,337,055; the cost of overbuys is \$27,177,227. It is repeated that this is only a measurement based upon unit cost; other costs such as holding cost, inflation rates, cost of lacking support when items "run out," etc., are not measured. These results imply that the assumptions underlying DESC's method lead to a cost and support outcome of only limited cost effectiveness, although the resultant outcome of 25 percent underbuying and 65 percent overbuying tends to err on the side of conservatism. This may not be unrealistic given the nature and quality of information available at the time of determining the LOT buy quantity.

DMS Item Characteristics and the Demand Variable

Constant Demand Assumption

To determine the nature of demand of the DMS items studied and to test DESC's constant demand assumption, the simple linear regression program was used. Using the t-statistic for each item compared to the critical t-value, the 1,772 items provided the following results. At below the 80 percent confidence level, 1,156 items failed to reject the H_0 . At the 95 percent confidence level (used for our further study investigation), 1,493 items failed to reject the H_0 , meaning that only 279 items rejected the H_0 . The findings of this study do not allow us to reject the hypothesis that the vast majority of these items display zero slope when fitted to our straight regression line. Based upon available data and within the limits of power of our statistical tools, we could not refute the assumption of constant demand. This suggests that the nature of these items is to experience demand as constant about a mean over time.

In his AFIT master's thesis, Second Lieutenant Praggy found roughly similar results (32). He studied the DESC items in two of their management classes--replenishment and NSO. Except for very high demand items, he noted that the replenishment item demand tended to follow a stable pattern (32:32-33). Although the NSO items in his

study displayed some peaks, he noted that the basic pattern of demand is horizontal and was best represented by straight-line forecasts (32:33-34). We did not have data which allowed us to determine which of our DMS items were replenishment and which NSO. We do know that only 1.4 percent of the 1,772 items had a "Y" VIP Code which indicates very high demand. Based upon this and the actual demand figures in our data file, we conclude that our DMS item demands fall into the medium and lower demand categories. Our findings thus tend to support Praggy's observations that these categories display a stable, constant demand pattern over time.

Based upon the regression testing results, each item was assigned a slope characteristic--zero, positive, or negative. Because the regression program is a tool of limited validity and because we propose that an item's slope of demand could potentially have an important impact upon the support effectiveness of a LOT buy, our research continued to investigate the slope characteristic. Below we discuss the results of our cross-tabulation investigation of the possible relationships among slope and other variables. Also, slope as a DMS item characteristic is documented in the frequency distribution results following.

DMS Item Characteristics

The initial phase of the data analysis was directed towards breaking down the global classification of "a DMS item" into either natural categories such as FSC, or computed categories; i.e., Unit Cost, demand, slope, NIIN, etc. The procedure employed was a recoded SPSS frequency program which generates a wealth of descriptive statistics which enables the observer to gain greater understanding of a "DMS item."

Because little descriptive statistics have, to date, been published on DMS items, they are presented in Appendix A, Tables 1 to 8.

Frequency Results Discussion

FSC Results. The frequency table indicates the following points of interest:

1. Six FSCs contain 86 percent of DMS items:
5962, 5960, 5961, 5950, 5930, 5910.
2. Nearly one out of three DMS items is from the relatively new FSC 5962, which contains integrated circuit boards.
3. Based upon our sample, the following FSCs have a high probability of being:
Low Demand--5905, 5910, 5915, 5925, 5950, 5999.
High Demand--5960, 5961.

It is noted that our sample size for certain classes is small, limiting generalizability of those findings.

NIIN Results. The process of assigning a unique number to a particular item offered scope to the researchers to analyze the data to determine if the NIIN was time related in an important way. Our investigation indicated that before 1975, when an item became obsolete, its NIIN may have been reassigned to a new item. This research did not verify these findings nor attempt to pursue investigation in this area (see Chapter VII, Recommendations).

VIP Code Results. The frequencies for VIP Code indicate that 95.5 percent of the total items in the DMS data base are "N" codes. As discussed above, this means that the vast majority of DMS items do not meet the very high demand or dollar demand criteria needed to merit forecasting monthly as a "fast-moving" item. Since almost all of our items fell into this one class, no further testing was performed in relation to this characteristic.

DMS Code Results. The pattern established by the frequency of high concentrations in the 1986 and 1991 range (75.5 percent), demonstrates the DESC approach of making the LOT buy decision for ten years (i.e., buys were made during the 1976-1981 period). Only 10 percent

of all items were identified to have a need in service of less than the ten years, while particularly high concentrations are noticed in the 1997 and year 2000 level.

Because the frequencies of DMS codes could not provide additional information concerning the other variables of interest, no further research was performed in relation to this variable.

Unit Cost Results. We propose that the best way to gain an appreciation of the relative cost of a DMS item was to break cost into four categories, each containing approximately 25 percent of the items. This resulted in the following broad classifications: up to \$4, \$4 to \$12, \$12 to \$50, and \$50 and above. It is worth noting that 70 percent of all DMS items fell below the \$35 mark.

In comparing the cost and Demand characteristics, it was noted that items in the over \$50 (i.e., the top 25 percent) were more likely to be of a Poisson or zero demand pattern.

Regression Results. This classification was particularly useful in that it was important for us to know the effect of setting a particular test confidence limit in the acceptance or rejection of the null hypothesis (H_0) concerning the slope. In determining positive, negative and zero slope for use in cross-tabulations, we established a 95 percent confidence level for the two-tailed

test (i.e., a one in twenty chance of rejecting the H_0 when it should have been) in our methodology prior to the commencement of this analysis. These results permitted us the opportunity to reflect on the sensitivity of that particular decision as it determined the classification of slope. This sensitivity is reflected in the following figures:

<u>Confidence Level</u>	<u>Items Rejecting H_0</u>	
	<u>No.</u>	<u>%</u>
99% Level	117	6.6
98% Level	179	10.1
95% Level	279	15.7
90% Level	428	24.1
80% Level	616	34.7

The major point to be drawn from the above is that the majority of items would fail to reject the H_0 as having a zero slope at all of the acceptable confidence levels.

The sensitivity of setting the confidence level at 95 percent instead of, say, 90 percent did play a role in determining the number of items that would reject the H_0 . Use of a different confidence level may provide an alternative direction for further study.

Slope Results. This frequency was obtained by using the computed Beta ($\hat{\beta}_1$) figure from the simple linear regression of the twenty-one quarters of demand data.

Appendix A, Table 7, indicates that the Normal demand items are subjected to wider deviation of the slope, while the Poisson items do not tend to diverge. This result is not unexpected for the Poisson items because of their demand characteristics, but the Normal items reflected an unexpected result wherein 58 percent either had a slope greater than +1 or less than -1. Accordingly, it would appear that Normal demand items represented the greatest chance of error in trying to forecast future requirements, if the forecast is based upon a constant demand assumption.

Cross-tabulation Results for Item Characteristics

SPSS cross-tabulation programs were run for two purposes. The first purpose, and that discussed at this point, was to determine if relationships implied by the percentages resulting from the frequency programs were statistically significant. The second purpose will be discussed in a later section.

To enable the use of cross-tabulation programs, the value of the variables Unit Cost and Demand were placed into broad categories on the following basis:

Unit Cost. Cost was categorized to use the approximated quartiles of: up to \$4, \$4 to \$12, \$12 to \$50, and over \$50.

AQD. As the Poisson/Normal cutoff for demand (twenty-five per year) represented approximately 50 percent of the items, it was chosen as the first breakpoint. Then the Poisson and zero demand items were divided into two categories at the 25 percent mark, and similarly the Normal demand items were dissected. As a final breakdown, the zero demand items were separated from the low Poisson demand items. The final result was five categories: (1) zero demand, (2) low Poisson, (3) high Poisson, (4) low Normal, and (5) high Normal.

SPSS cross-tabulations were then performed against the total analysis file using the FSC as the common variable, based on the belief that all items can be identified to a particular FSC. The results of these two-way cross-tabulations are detailed below:

<u>Crosstab</u>	<u>Chi-Square Result</u>	<u>Significance</u>
FSC by Unit Cost	1111.08	0.0000
FSC by Demand	849.97	0.0000
FSC by Slope	199.96	0.0000

These results indicate that there is a significant statistical relationship between the variables and FSC.

The actual results of the cross-tabulations have been summarized in Appendix A, Tables 9 to 11, to add to the statistical knowledge on DMS items.

To investigate whether we could pinpoint this statistical relationship at smaller subclassification

levels, two three-way cross-tabulations were conducted using the variables Demand by unit cost, and then Unit Cost by Slope, with the third slow-moving variable in each case being FSC. The results of these three-way cross-tabulations could not prove that a statistically significant relationship existed at this level. These results indicated that, although a statistically significant relationship was established in the broad sense between FSC and the variables Unit Cost, Slope and Demand, subclassification reduced the cells to too small a number to permit statistical significance to be accurately tested.

Typical DMS Items

Using the results of the frequency programs and the statistical significance demonstrated by the two-way cross-tabulation programs, "typical" DMS items could be characterized. We describe the most frequent relationships for those six FSCs which contain 86 percent of the DMS items at DESC. We point out the tentative nature of our findings concerning slope.

Typical DMS Characteristics by FSC.

1. 5910. This class will in general be Poisson demand items, with unit cost less than four dollars and will display a zero slope.
2. 5930. This class will in general be Poisson demand items, with costs over \$12 and more likely to be

over \$50. The slope of demand is 80 percent likely to be zero, but 15 percent of the time it goes negative.

3. 5950. This class will in general be Poisson demand items with a unit cost in excess of \$50, and a demand slope of zero.

4. 5960. This class will in general be Normal demand items with demands over 120 a year. The unit cost would be expected to be between \$4 and \$50. The demand slope is likely to zero 73 percent of the time, and negative 24 percent.

5. 5961. This class will in general be Normal demand items with annual demand over 120 per year. The unit cost is generally low; i.e., below \$4. The slope characteristics of demand are: 80 percent zero and 13 percent negative.

6. 5962. Approximately one in three DMS items fall in this class. The items display general characteristics of being Normal demand items with demand below 120 per year, and most likely to cost in the medium range (between \$4 to \$50). The slope of demand tends to be zero.

Cross-tabulation Results for Predictor Variables

The second purpose for performing the cross-tabulation among the variables was to determine if the unit cost, FSC, or AQD variables could prove to be statistically related to the slope variable. If such a relationship

existed, it might be useful in predicting the behavior of demand of a given DMS item and thus assist in determining the LOT quantity. Particularly, positive or negative slope, if indicated, could enable us to adjust our buying method away from the constant demand assumption.

As noted above, the two-way cross-tabulation of FSC by slope (positive, negative or zero) against the total data set provided statistically significant results. These results indicated that 84.3 percent of all items displayed zero slope (recall that slope was defined for each item by use of the 95 percent confidence level t-test). This was naturally consistent with the results of our simple linear regression.

To determine if a predictor relationship might exist between AQD and slope, a two-way cross-tabulation was performed on the total data base using AQD by Slope. The resulting Chi-square 87.75, Significance 0.0000 indicated a statistically significant relationship within the table as a whole. However, such results are difficult to use for individual relationship conclusions. Using numerical results for column and row observed frequencies, we manually calculated the frequencies expected for each column and row (these are not displayed in the SPSS output although they are used in SPSS table computation). We then computed a deviation value $((\text{observed} - \text{expected})^2 / \text{expected})$ for each block of the cross-tabulation. Because

of our definition of zero, positive, and negative slope, the large majority of the observations fell into the zero slope category; so, based upon the row and column observed figures the expected figures were equally high and small deviation values resulted. This held throughout the table except in one instance. A marked deviation existed between expected and observed for the high normal AQD with negative slope. The percentage of items falling into the high normal block was much higher than any other number in the negative slope column, causing this block to have a 28.78 Chi-square (deviation) value. This indicates a possible relationship between high normal AQD (over fifty per year) and negative slope; this relationship may prove interesting for future research direction.

Based upon our estimated Beta value frequency distribution results, Poisson distributed items rarely displayed slope, whereas Normally distributed items displayed positive or negative slope for as high as 58 percent of the time. To investigate the possibility that some predictor variables might exist for the Normally distributed items, we performed a two-way cross-tabulation for the Normal analysis file of AQD by slope. The following results were obtained: Chi-square 15.49, Significance 0.0004, slopes 78 percent zero, 8.8 percent positive, 13.2 percent negative. Again, the findings were significant for the table as a whole but not indicative of the strength of the slope

relationship. It is pointed out that the cross-tabulation was performed using the slope characteristic as determined by the 95 percent confidence level. Results which signify a relationship between Normal demand and positive or negative slope might be obtained if slope were defined by a less stringent criteria.

To determine if a statistically significant relationship might be found between AQD and slope in smaller categories, a three-way cross-tabulation was run for the Normal analysis file testing AQD by slope by FSC. Again, the categories by FSC became so small as to make unreliable any conclusions which might be drawn from the results. The following are results of interest which might be used to direct future research with larger sample sizes; it is repeated that statistical significance of these results was not demonstrated in this study.

<u>FSC</u>	<u>Zero</u>	<u>Positive</u>	<u>Negative</u>
5815	66.7	22.2	11.1
5930	68.2	4.5	27.3
5960	73.0	2.5	24.5
5961	78.0	9.2	12.7
5962	78.3	15.4	6.3

(These items are expressed as percentages of Normal demand items in that FSC.)

In summary, the results of the cross-tabulations of variables for possible prediction of demand slope did

not produce statistically significant results upon which to base recommendations of situations in which slope be considered in ELQ computation. Sensitivity of ELQ to slope is investigated in Chapter VI.

Simple Linear Regression (SLR)
Effectiveness Outcome

Our results did not allow us to refute the constant demand assumption. However, an estimate Beta (slope) factor was computed for each item as a result of the simple linear regression (SLR) program. Theoretically, the Beta factor represents the linear nature of demand over time based upon a twenty-one-data point regression analysis.

For this reason, we used the SLR program slope results for each item to represent what would happen to AQD over time if the linear regression estimated factors represented the real behavior of demand. This was done using the FORTRAN effectiveness outcome program previously described. The constant AQD assumption was replaced with AQD moving over time along the proposed regression line. The results of this program run were produced in a histogram similar to that produced for the constant demand assumption; see Appendix A, Figure A-2.

The program results based upon this assumption indicate a worse effectiveness outcome for the current LOT buys. In the previous program, roughly 10 percent

of the items would achieve zero stock level during the year in which support was projected to cease. In the SLR effectiveness outcome, only 5.7 percent of the items fell into this desirable category. The percentage of items underbought did not vary markedly from the previous result; i.e., increasing from 25 percent to 27.3 percent. Also, the percentage overbought did not vary significantly, increasing from 65 percent to 67.6 percent. In the previous program, approximately 47 percent of the DMS items fell within the -7 to +8 years range. The SLR program results in only 37.3 percent of DMS items within this range. This indicates that the SLR program assumptions result in a wider spread of items away from the (desirable) center (the center representing zero stock experienced during the year usage was projected to end). Further, the first effectiveness program resulted in 23.9 percent as +1 to +8 years; i.e., 1 to 8 years overage. The SLR program resulted in only 12.8 percent in this same range. In the -7 to -1 (shortage) years, the SLR program resulted in 24.8 percent of items, slightly more than the first program.

The cost of underbuys for the SLR program was \$47,540,116; the cost of overbuys is \$32,506,315. Obviously the cost balance has shifted to the left, creating more underbuy costs. It is interesting to note that as stated above, the actual percentage of items

experiencing underbuys is almost equal for both programs, while at the same time the cost of underbuys greatly increases with the SLR program. This indicates that either more high cost items fell short as a result of the second run, or, greater quantities for particular items were required. The results indicated an additional 2 percent of items fell in the years -3 to -7 years, supporting this increased quantity proposition.

The results of the cost effectiveness outcome program run using the SLR factors imply that, if the SLR represents the "long term, real" nature of demand, the cost effectiveness of the current LOT buys becomes poorer from a cost and performance effectiveness viewpoint.

CHAPTER VI

ELQ SENSITIVITY TO INPUT VARIABLES

As outlined in Chapter I, one objective of this study was to perform sensitivity analysis of the single-buy, multi-period situation using the model described in Chapter IV. More specifically, the purpose of this chapter is to address research questions 5 and 6 which contribute to meeting research objectives 3, 4, and 5. The results of this experiment are presented and discussed. Basically, the FORTRAN computer program for the multi-period model was run to produce optimal ELQs for a range of input parameter variations. This program was then plotted as a three-dimensional response surface, with ELQ as the central axis and the output variable of interest. The value of this type of approach was discussed in Chapter IV. The response surface can be viewed as an aid to sensitivity analysis; i.e., determining the range that one's decision can fall within and still have roughly the same situational effect. Viewed another way, sensitivity analysis tells "how close we have to be," or "what effect an incorrect ELQ has." In addition to this purpose, the response surface might be employed by the manager as a way to "back into" a desired output variable

value (13:711-712). For ease of interpretation, results are also presented in two-dimensional contour form.

Experimental Design and Procedure

As described in Chapter IV, two FORTRAN programs were developed (one for the Normal demand items and one for the Poisson demand items), to determine for a given penalty cost, the appropriate Economic Life-of-Type Quantity (ELQ) in relation to the manipulated input variable. The input variables to the program were mean and variance of Demand, Unit Cost, Holding Cost and Interest Rate. The experimental design entailed determining from the condescriptive statistics presented in Chapter V the range for a particular input variable. Then, by holding all other variables constant in relation to that variable, the variable under investigation was subjected to incremental changes to determine the resultant effect upon ELQ, across a hypothetical penalty cost range. The results of each computer run were then plotted in both three-dimensional form (using the DISSPLA8 plotting program on the CDC computer), as well as in two-dimensional form with contour lines (using a Hewlett Packard plotter from ASD).

Input Variables

Demand.

1. Selection Criteria. Because of the inherent assumption of a Poisson distribution for demand, demand

has a range of 1 to 24 per year. Seven hundred seventy-nine items (44 percent) of the sample falls in this category. Accordingly, because of its relative importance, the affect on ELQ across the full range of demand was determined and is presented in Appendix B, Figures B-1 and B-2.

For the Normal demand items, the FORTRAN program experienced computer time constraints which made it difficult to expand the program greater than 1000 vector size for probability storage, limiting the scope of investigation to below seventy-five demands per year (38 percent of the sample size exhibits this characteristic). Nevertheless, the pattern established by single incrementation over the range 24 to 39 (Figure B-4), was consistent with the pattern determined in the incrementation over the range 25 to 75. This indicated that the findings would appear to be generalizable over higher demand ranges. These results are presented in Appendix B, Figures B-3 to B-6.

2. Findings. The results obtained indicated that the findings were generalizable across both the Poisson and the Normal distribution in that error in the calculation of actual demand does represent a distinct variation in the ELQ determined. Secondly, the ELQ was sensitive to the penalty cost over the range of 1, 2, and 3 (i.e., two, four, and eight times the unit cost), and thereafter

reduced markedly in its resultant impact on ELQ. Further, in the penalty cost range of exponents 4 to 16, the higher the demand for the item the lower its resultant marginal change in ELQ.

If you consider DESC's approach in purchasing ten times the mean of demand, this equates in Figures 2, 4, and 6 to implying a penalty cost function of exponent 4 (i.e., sixteen times the unit cost). At this level of assigned penalty cost, an error of one in the demand of a Poisson demand item would result in an ELQ error of 10, while a Normal demand item in the range 25 to 39, an error of one would result in an error of 10 to 13 in the ELQ.

Variance.

1. Selection Criteria. DESC does not consider variance in their calculation of ELQ. Nevertheless, for a Normal demand distribution item it is an important variable in determining the correct ELQ. Accordingly, we investigated ELQ sensitivity as the standard deviation for a model item was increased from 1 to 10. This represented a range of .025 to 2.500 on a variance to mean ratio. The results are presented in Appendix B, Figures B-7 and B-8.

2. Findings. ELQ determination was insensitive to increases in standard deviation in the penalty cost

range of exponents 1 to 3. In the range of exponents 4 to 16, incorrect assessment of the variance resulted in a marked variation to the ELQ. Further, as the penalty cost increased, the marginal effect on ELQ increased, making the error more significant in determining the ELQ.

DESC's approach to ELQ determination of ten times the mean represents, in Appendix B, Figure B-8, a point equivalent to a penalty cost of exponent 4 (i.e., sixteen times the unit cost) for all values of variance. As demonstrated in Appendix B, Figure B-8, this is a unique point where at one particular value of the penalty cost all lines converge. Therefore, only at this particular penalty cost value could DESC chose to ignore variance.

The conclusion reached in considering demand and variance is that DESC's approach implies a penalty cost value of exponent 4 for all items; i.e., their inventory buy decision is optimal if the penalty cost for an item is sixteen times the unit cost. Regardless of the validity of this penalty cost value, DESC implies this cost for every item, according to our model findings.

Holding Cost.

1. Selection Criteria. Individual information on the holding cost of an item is not maintained in the USAF or DESC supply system. In the "normal" USAF base level supply system it is input into purchasing calculations at

a standard rate of 26 percent (27:11-4A). For the purposes of this investigation, the holding costs were varied from 10 percent to 100 percent of the unit cost, and the results are presented in Appendix B, Figures B-9 to B-12.

2. Findings. The results of both the Poisson and Normal runs indicated the same general slope. Within the range of exponents 1 to 4 of penalty cost, the ELQ was sensitive to change in the holding cost, whereas after this point, the sensitivity of ELQ to holding cost dissipated.

These results indicated also, that in percentage terms, the higher the demand level, the narrower would appear the range of ELQ for penalty cost. While DESC's current ELQ determination does not include consideration of holding costs, DESC's policy of buying ten times the mean implies as indicated in Figures B-10 and B-12 (Appendix B), a range of holding costs which directly relate to implied penalty cost. For both the Poisson and Normal demand items, this equated to a range of penalty costs of 3 to 5 (i.e., eight to thirty-two times the unit cost).

Interest Rate.

1. Selection Criteria. To our knowledge the USAF and DESC do not input a rate for the present value of capital in their consumable item inventory

calculations (27:11-4A). The purpose of this study is, however, to determine a feasible range for considering interest rates based on open market considerations. Accordingly, the range of 5 percent to 23 percent per annum was selected as being indicative of recent prime rates charged by the major lending institutions over the previous ten years.

2. Findings. The results of the Poisson and Normal runs were generalizable in that in Appendix B, Figures B-14 and B-16 were of the same general shape. Within the penalty cost range of exponents 1 to 4, the ELQ was sensitive to changes in the interest rate, whereas, after that point, the sensitivity to ELQ dissipated.

Similar to the discussions in Holding Costs, while DESC does not consider interest rates in its present determination of ELQ, DESC's policy of buying ten times the mean implies, as indicated in Figures B-14 and B-16, a range of holding costs which directly relates to implied penalty cost. For both the Poisson and Normal demand items, this equated to a range of penalty costs of 3.5 to 5 (i.e., approximately twelve to thirty-two times the unit cost).

Unit Cost.

1. Selection Criteria. From the condescriptive SPSS results, the range for unit cost for both Poisson and

Normal items was from below \$1 to over \$200 per item. The range selected for examination was \$1 to \$100, which represented 85 percent of the sample size. The results are presented in Appendix B, Figures B-17 to B-20.

2. Findings. The results indicate that for both Poisson and Normal items, variations in unit cost do not impact on the determination of ELQ. This outcome was not surprising when it is considered that the unit cost is not subjected in the model to either optimization or a constraining factor.

DESC's approach of procuring ten times annual usage equates for both Poisson and Normal demand items (Figures B-17 to B-20), as all items having a single penalty cost of exponent 4 (i.e., sixteen times the unit cost).

As advised in Chapter V, DESC has little information about the end usage of DMS items. Accordingly, this arbitrary assignment of a penalty cost across the board for all items, Normal and Poisson, appears questionable, as is the level at which the penalty cost is set.

Other Factors

As referred to in Chapters I and IV, the line of demarcation between the application of a Normal or a Poisson distribution is not rigidly defined in the literature, but is expected to occur at/or around the twenty-five

per year mark. To ensure that both the Normal and the Poisson models did reasonably approximate each other at this point, demands for both the Poisson and Normal were computed for twenty, twenty-two, and twenty-four demands per year. The results demonstrated that no significant difference was apparent between the two models over this range.

Constant Variables

During the many iterations of the Normal and the Poisson models, it was necessary to hold all variables constant, except for the variable under study. Accordingly, the following selection criteria was employed in determining the constant value for the variable in relation to representing a DMS item.

Demand. For the Poisson, a demand of ten per year was chosen for computational ease because it was high enough to be mid-range (between 1 to 24), and because it was a fair measure of central tendency (58 percent). For the Normal, a mean of 40 was chosen, mainly in view of the constraining influence of computer time. The probability tables calculated in the FORTRAN program at vector size 600 took 400 seconds per iteration on the CDC Cyber computer. As fifty iterations were required to complete the initial investigation, this represented a significant time requirement from the CDC computer system.

Nevertheless, vector sizes of 1000 using 600 seconds were performed which validated the demand pattern established in the range 25 to 39. The uppermost limit of our runs (seventy-five per year) represented approximately 35 percent of the normal items.

Variance. In order to make the results comparable between the Normal and Poisson, it was necessary to ensure that the variances were equal. Accordingly, the standard deviation used for the Normal was set at the square root of the mean.

Holding Cost. The USAF in accordance with AFM67-1, Volume II (27:11-4A), uses 26 percent as the cost to hold both local purchase and centrally-procured items. In view of the incremental nature of our analysis a figure of 30 percent of unit cost appeared to be a reasonable value.

Interest Rate. Little attention is provided in the literature to the setting of an interest rate to reflect the current cost of capital. The rate used in this study was that prescribed by the Office of Management and Budget (OMB) for use in discounting federal investments (10 percent) (43).

Unit Cost. Ten dollars was set as the constant unit cost variable. It represented a quickly computable

number, and was a fair measure of central tendency (45 percent).

Extended Analysis. In the condescriptive output in Chapter V, it was noted from the simple linear regression statistics for the Normal demand items, that a majority of the items (58 percent) had computed slopes outside the range +1 to -1. To investigate this further, the FORTRAN program was adjusted to permit the inputting of positive and negative demand slopes into the model, in order to determine the impact on ELQ.

1. Selection Criteria. Eight iterations were performed to demonstrate the variation of slope from +2.0 to -2.0, and the results are provided in Appendix B, Figures B-21 and B-22.

2. Findings. An error in the assessment of the long-term slope of demand does affect the ultimate choice of ELQ. The results using a mean of 40 indicated that an adjustment of 0.5 to the slope of demand varied the ELQ as follows:

<u>Penalty Cost</u>	<u>0 to .5</u>	<u>.5 to 1.0</u>	<u>1.0 to 1.5</u>	<u>1.5 to 2</u>
4	18 (4.5%)	28 (6.7%)	17 (3.8%)	28 (6.0%)
10	19 (4.2%)	29 (6.2%)	18 (3.6%)	29 (5.6%)
16	20 (4.2%)	30 (6.1%)	18 (3.4%)	30 (5.5%)

In DESC's calculation of ELQ, the slope of demand is ignored. The potential therefore exists that if we

again employ the penalty cost value of exponent 4, determined previously in our investigation of demand and variance, this would result in an error in the calculation of ELQ as indicated in the above, i.e., 11.2 percent at the +1 slope level.

Summary Findings

The purpose of this chapter was to treat the input variables to the ELQ decision in a theoretical sense to understand each's relative impact upon the ELQ decision. Figures B-1 through B-22 of Appendix B aptly display the relationships of all these input variables.

In each section's findings, DESC's current purchasing policy has been discussed and interpreted on the models. In summary, the single, most important finding is that DESC's purchasing policy of procuring ten times the annual mean demand for all items, implies for demand and variance a penalty cost value of exponent 4 (i.e., sixteen times the unit cost). Secondary, but following directly from the above, is that the interest rates, Holding Costs, and slope, do impact the ELQ decision and, therefore, need to be estimated to a reasonable degree of accuracy.

The question which now can only be answered by management, is whether a penalty cost value of sixteen times unit cost is assignable to all DMS items in order to

provide an optimal/effective supply inventory. The results of our analysis on effectiveness in Chapter V would suggest that the assignment of a single penalty cost value to all DMS items does not provide an effective supply inventory. Accordingly, it would appear to us, more beneficial to view the item in terms of its particular characteristics and within the model sensitivities in the formulation of its ELQ.

CHAPTER VII

CONCLUSIONS

The purpose of this chapter is to tie together the objectives, methodology, and findings of this study to provide meaningful conclusions from this research. The chapter begins with a brief summary of the study. The conclusions and recommendations section unites findings of Chapters V and VI and culminates the research by outlining a systematic approach for the DMS manager in facing the LOT buy situation. Next, we evaluate how well the research met its stated objectives. Finally, recommendations for further research are enumerated.

Summary

This research combines empirical findings and a theoretical study in a methodology designed to increase the understanding of the DMS LOT buy and to provide the manager with a systematic approach for handling this problem. The experiment investigated a dependent variable--ELQ--and the two independent variables proposed to determine ELQ: future demand and costs. A data file of DMS items provided by DESC was used with statistical tools to characterize DMS items and to investigate demand behavior over time. Sensitivity of ELQ to demand and cost

variables was examined by use of a probabilistic total cost optimization model designed by single-buy, multi-support period scenarios. The results of the empirical data analysis and the sensitivity analysis were used to define and test the assumptions of DESC's current LOT buy decision methodology. Finally, analysis of the findings in both areas allows the definition of a systematic approach to ELQ determination which may prove helpful to the manager. This approach is provided in our Conclusions and Recommendations.

Conclusions and Recommendations

Our research design was based upon the proposal that future demands and costs are the independent variables which determine ELQ. In describing the DESC method for determining a LOT buy quantity, we discussed their treatment of these variables. Basically, they treat demand as constant over time with a mean based upon the average of the eight quarters immediately preceding the LOT buy. To date, they have not found it necessary to consider unit cost as a constraint. In Chapter VI, we noted the costs "implied" by their approach as calculated by the sensitivity model.

The LOT buy cost effectiveness outcome program based upon the constant demand assumption demonstrated that DESC's method may not be cost effective and in fact may

lead to overbuying as much as 65 percent of the time. In addition to the cost implications of this, one wonders what items are underbought and how this impacts support. In testing the assumption of constant demand, we were unable to disprove the assumption that the mean of demand remains constant over time. Although individual items revealed slope (many with slopes over +1 or -1) the regression analysis did not statistically demonstrate slopes significantly different than zero. Still, when using the actual regression slopes to adjust AQD over time, the cost effectiveness outcome program revealed that our current LOT buy quantities may be even more insufficient in terms of underbuys than the constant demand assumption program led us to believe.

So, despite our inability to show that the demand of these items on the whole does not have zero slope, it is apparent that the current method does not buy appropriate quantities in too many instances. It is possible that this might be explained by the demand slope of certain items; i.e., although the items as a whole have constant demand over time certain items do not and should be bought differently. However, we could not establish or conclude important relationships among the variables which might have enabled us to use other characteristics to predict which items might be incorrectly procured (i.e., which items do have significant slope). Another possibility is

that demand is constant about a mean value over time but that the mean value used by DESC is incorrect. Our study used AQD based upon all available quarterly demand data (twenty-one quarters). DESC uses the last eight quarters of demand history only; it is possible that this results in a distorted long-term mean demand value. This study did not investigate this possible distortion.

Because our ELQ sensitivity analysis demonstrates vividly that demand mean, variance, and slope are variables to which ELQ responds with high sensitivity, we recommend that the largest amount of demand history practicable be made available to the manager determining the DMS item's AQD. We also recommend that the ten-year support arbitrarily applied in the current method be further investigated. Any manager could simply analyze the differences in buy quantity that would result from planning eight years support, or twelve years, etc., instead of ten years. The sensitivity of the buy quantity to this factor could be used with the cost sensitivities discussed below to analyze the range of ELQ values for a given buy situation. (It is, of course, also recommended that further study and DOD action be taken in regard to end-item application--see Recommendations for Further Research.) Our study did not enable us to provide the manager with a better means of predicting demand, but we

do conclude that demand is the critical independent variable that we proposed it to be.

The sensitivity analysis allowed us to demonstrate that the demand and cost factors are important to ELQ within relevant ranges of sensitivity. The findings of Chapter VI led us to recommend that a manager approach the LOT quantity decision using the following steps:

1. The manager begins with the DMS item's unit cost and FSC. AQD is determined using all available demand history as recommended above.

2. The manager reviews the demand history: Does it appear to display a trend or is it stable around a mean? Does the VIP Code suggest that it is a fast or slow moving item? Do the relationships resulting from this study (see Chapter V) indicate that the slope might be important? (It is noted that our results were not conclusive.) If positive or negative slope is indicated the manager may wish to consider step 7 below.

3. The manager determines a penalty cost value. He may do this based upon the estimated cost of restarting a production line, special set-up costs or acquiring the technology from another source. In essence, he recognizes that there is a point beyond which the value of not running out is not so high as to merit buying additional quantities. Viewed from another perspective, a penalty cost value means, "I will buy this quantity because it is

worth that much to me not to run out, but I will buy no more than that." The penalty function is useful in giving the manager a sense of relative values concerning stock outage.

4. The manager considers the item's unit cost. While in Appendix B, Figures B-17 to B-20 indicated that the ELQ is not directly influenced by unit cost, it must be remembered that unit cost (C) in our analysis is always related to penalty cost (B) by the formula, $B=Cx2^M$, where M is incremented from 1 to 16.

5. The manager must consider holding costs for the items in question. Will this item have special storage requirements? Which might require a higher holding cost percentage? What percentage is appropriate for this item and how does that effect ELQ in terms of quantity/cost range?

6. The manager considers the time value of money. How might inflation effect the long-term value of the quantity bought today? What rates are appropriate?

7. If step 2 indicated slope as a possible factor, how might slope effect the quantity the manager might buy? (How much of an increase or decrease over time?)

As each one of these factors is considered, they help to establish a range of values within which the ELQ may be determined. Basically, the manager could make an ELQ decision within these ranges and be fairly certain

that the resulting outcome (cost/support) will be relatively the same. Given different levels of these variables, ELQ displays a different sensitivity.

Although discussed in a very theoretical sense here, this approach is displayed using actual figures in a case study of a DMS item provided at Appendix C. These are results based upon use of the total cost optimization model used to perform our sensitivity study. In the "real world," we recognize that the manager does not have a theoretical model at his disposal, nor the time to perform sensitivity analysis on each of his decisions. It is believed that the results of the analysis performed in this study may serve to demonstrate those areas to which ELQ is most sensitive: (1) demand mean, variance and slope, and (2) penalty cost value (expressed in an exponential relationship multiplied by unit cost in our study).

If the model is to be used immediately, we suggest two major conclusions from our study:

1. The manager should recognize that by not explicitly considering cost functions today, he is implicitly assigning them. We recommend that the manager recognize the cost tradeoffs and impacts of his buy quantity and make them reflect what he chose them to be. In this way he may also give himself a range of decision quantities which may offer different "prices." Further,

he could determine the ELQ range in which a lower or higher ELQ will offer little cost or effectiveness advantage.

2. The manager needs to consider a DMS item as an individual item with unique characteristics and behaviors. A decision may be made appropriate for that situation instead of applying the across-the-board "AQD x 40" rule.

For long-term use, we recommend that some of the further research suggested below be used to help develop a clean, concise approach to DMS LOT decision making which incorporates the ELQ sensitivity to costs and demand and the cost optimization approach recommended in this study. A decision method can be fully developed which could either be used as a step-by-step algorithm or a computerized program to aid the manager in DMS LOT buy decision making. In this way, the DOD can recognize and deal with DMS LOT inventory decisions as the continuing, day-to-day problem that it is instead of managing it by an "exception" method.

Research Evaluation

It is difficult to quantify the increased understanding of DMS to which this study contributes. We may evaluate our study in two ways: (1) how thoroughly did we address our research questions and did this allow our

research objectives to be met? and (3) how applicable are the study conclusions to a real management situation?

The research questions were fully addressed in both our methodology and results. Chapter II addressed question 1 in concluding that no published inventory model could be found which was readily appropriate for DESC's use. Further, the demand forecasting methods reviewed in Chapter II proved too limited for use in the LOT buy situation. Questions 2, 3, and 4 were addressed in Chapter V by the full description of the DESC LOT buy and its assumptions, the FORTRAN cost effectiveness program, the Simple Linear Regression analysis and by the characterization of "typical" DMS items. Chapter VI presented sensitivity study results which addressed question 5. Finally, our conclusions address question 6, serving to demonstrate how the study's findings may be used. The research questions were thus fully addressed.

As the questions were designed to help meet the study objectives, addressing each question insured that our objective was at least partially met. However, the study findings did not allow us to fully meet research objectives 3 and 4. Objective 3 called for the study to determine the behavior of future demands and cost in relation to the LOT buy. Because we used historical data in our study of demand and were unable to know end-item application and planned end-item use/life, demand behavior

for these items cannot be said to be fully characterized nor understood. It is this same limitation that allowed us to only partially meet research objective 4 to determine relationships among demand, costs, and other situational variables. Our study was unable to statistically ascertain significant relationships among the variables in any but the intuitive areas and, more importantly, unable to demonstrate that demand slope may exist and may be a relevant factor. Our findings are valid for the research approach that we used but, we feel, do not conclusively negate the existence of other important relationships among these variables (see Recommendations for Further Research below).

The second criteria for evaluation concerns the applicability of our findings. We have tailored our conclusions to be useful to the manager making the LOT buy decision and particularly to serve as an expansion of the method now used. The theoretical bases for our conclusions are not expected to be translated for everyday use but the simple concepts underlying the logic of our approach are believed to recommend themselves to the user. The limitations mentioned in the discussion of our objectives obviously impact our conclusions; we feel that our research is only a first step towards improving the LOT buy methodology.

Recommendations for Further Research

Throughout this study we have pointed out problems and limitations which make the DMS LOT buy a difficult problem to manage. In addition to this, our study was limited by time, money, and available data. All of these areas contributed in drawing up the following list of areas for further study.

1. Demand prediction would be dramatically improved if the end-item application of a part were readily known. In addition, the quantity and projected life of the end item must be known. Development of a data base with such information has been suggested in earlier studies and continues to be suggested as an invaluable aid in making this decision.

2. The development of further regression lines for demand over time for each item could be attempted in lieu of fitting the data to the straight-line model used in this study. This may be of limited value, however.

3. The variables FSC, Unit Cost, and AQD could be regressed with Slope in determining relationships instead of using cross-tabulations.

4. Slope could be again studied in relation to the other variables by redefining "slope." In our study, slope was defined as zero, positive, or negative by use of the t-statistic at a 95 percent confidence level. It was then tested in cross-tabulations using this definition.

Slope could be redefined by use of Beta factor characterization.

5. The cost effectiveness outcome program could be run using the AQD upon which DESC's "real" buy was based in lieu of our calculated AQD (based upon twenty-one quarters). We did not have the data to perform this investigation.

6. Related to the first area, we recommend that the arbitrary "ten years of support" be investigated. Is this a meaningful figure? Of course, end item projected life would aid in providing this information. But even if end item projected life were unknown, factors could be developed for use in projecting end-item usage based upon its age, deployment, etc.

7. The age of an item may be a variable with an important relationship to demand slope. The NIIN of each item could be used to determine the date of cataloging of each item. Investigation revealed the existence of a data base at HQ AFLC which may be able to provide the cataloging date of each USAF-managed item. This variable could then be tested as a possible slope predictor.

8. DESC is operating with an implied penalty cost of roughly sixteen times the unit cost, according to our findings. Is this desirable or accurate from the DESC perspective? If so, is it accurate for all items?

Research could be performed to work with DESC managers to determine feasible and desirable penalty cost ranges.

We feel that research into the above areas, combined with findings of this study, can lead to a DMS LOT buy approach which can markedly improve the support and cost effectiveness of the buy.

APPENDICES

APPENDIX A

DMS CHARACTERISTICS, CROSS-TABULATIONS, AND EFFECTIVENESS

TABLE 1

DMS CHARACTERISTICS BY FEDERAL SUPPLY CLASS (FSC)

FSC	Total Items		Low Demand (0-24)		High Demand (25 and Over)	
	No.	%	No.	%	No.	%
5805	3	.2	--	--	3	.3
5815	11	.6	2	.2	9	1.0
5820	1	.1	1	.1	--	--
5905	75	4.2	64	7.4	11	1.2
5910	124	7.0	89	10.3	35	3.8
5915	18	1.0	15	1.7	3	.3
5920	2	.1	1	.1	1	.1
5925	39	2.2	34	3.9	5	.5
5930	120	6.8	76	8.8	44	4.8
5935	6	.3	4	.5	2	.2
5945	52	2.9	37	4.3	15	1.6
5950	208	11.7	177	20.5	31	3.4
5960	262	14.8	25	2.9	237	26.0
5961	233	13.1	60	7.0	173	19.0
5962	573	32.3	241	28.0	332	36.5
5985	1	.1	--	--	1	.1
5999	44	2.5	36	4.2	8	.9
Total	1772	100.0	862	100.0	910	100.0

TABLE 2

DMS CHARACTERISTICS BY NATIONAL ITEM
IDENTIFICATION NUMBER

FSC	Total Items		Low Demand (0-24)		High Demand (25 and Over)	
	No.	%	No.	%	No.	%
0-1M	143	8.1	70	8.1	73	8.0
1-2M	239	13.5	101	11.7	138	15.2
2-3M	161	9.1	80	9.3	81	8.9
3-4M	117	6.6	70	8.1	47	5.2
4-5M	253	14.3	114	13.2	139	15.3
5-6M	194	10.9	101	11.7	93	10.2
6-7M	146	8.2	82	9.5	64	7.0
7-8M	135	7.6	62	7.2	73	8.0
8-9M	191	10.8	93	10.8	98	10.8
9-Over	193	10.9	89	10.3	104	11.4
Total	1772	100.0	862	100.0	910	100.0

TABLE 3

DMS CHARACTERISTICS BY VIP CODE

	Total Items		Low Demand (0-24)		High Demand (25 and Over)	
	No.	%	No.	%	No.	%
"Y"	25	1.4	1	.1	24	2.6
"N"	1693	95.5	861	99.9	832	91.4
"M"	54	3.0	--	--	54	5.9
Total	1772	100.0	862	100.0	910	100.0

TABLE 4
DMS CHARACTERISTICS BY DMS CODE

	Total Items		Low Demand (0-24)		High Demand (25 and Over)	
	No.	%	No.	%	No.	%
No Buy	84	4.7	55	6.4	29	3.2
Level Load	68	3.8	3	.3	65	7.1
1970	1	.1	1	.1	--	--
1979	1	.1	--	--	1	.1
1981	5	.3	5	.6	--	--
1982	38	2.1	25	2.9	13	1.4
1983	37	2.1	24	2.8	13	1.4
1984	24	1.4	9	1.0	15	1.6
1985	76	4.3	31	3.6	45	4.9
1986	230	13.0	179	20.8	51	5.6
1987	101	5.7	32	3.7	69	7.6
1988	148	8.4	64	7.4	84	9.2
1989	107	6.0	58	6.7	49	5.4
1990	490	27.7	224	26.0	266	29.2
1991	261	14.7	98	11.4	163	17.9
1992	4	.2	1	.1	3	.3
1994	3	.2	--	--	3	.3
1995	2	.1	--	--	2	.2
1996	1	.1	--	--	1	.1
1997	64	3.6	37	4.3	27	3.0
2000	24	1.4	16	1.9	8	.9
2001	2	.1	--	--	2	.2
2002	1	.1	--	--	1	.1
Total	1772	100.0	862	100.0	910	100.0

TABLE 5

DMS CHARACTERISTICS BY UNIT COST RANGES

	Total Items		Low Demand (0-24)		High Demand (25 and Over)	
	No.	%	No.	%	No.	%
Up to \$2	269	15.2	123	14.3	146	16.0
\$ 2-4	188	10.6	71	8.2	117	12.9
\$ 4-6	146	8.2	52	6.0	94	10.3
\$ 6-8	107	6.0	39	4.5	68	7.5
\$ 8-10	88	5.0	38	4.4	50	5.5
\$ 10-15	149	8.4	56	6.5	93	10.2
\$ 15-20	111	6.3	48	5.6	63	6.9
\$ 20-25	95	5.4	29	3.4	66	7.3
\$ 25-30	66	3.7	37	4.3	29	3.2
\$ 30-35	38	2.1	18	2.1	20	2.2
\$ 35-40	26	1.5	16	1.9	10	1.1
\$ 40-45	26	1.5	16	1.9	10	1.1
\$ 45-50	25	1.4	18	2.1	7	.8
\$ 50-60	46	2.6	27	3.1	19	2.1
\$ 60-70	37	2.1	19	2.2	18	2.0
\$ 70-80	20	1.1	11	1.3	9	1.0
\$ 80-90	36	2.0	22	2.6	14	1.5
\$ 90-100	23	1.3	17	2.0	6	.7
\$100-120	26	1.5	16	1.9	10	1.1
\$120-140	23	1.3	14	1.6	9	1.0
\$140-160	25	1.4	19	2.2	6	.7
\$160-180	21	1.2	18	2.1	3	.3
\$180-200	12	.7	9	1.0	3	.3
Over \$200	169	9.5	129	15.0	40	4.4
Total	1772	100.0	862	100.0	910	100.0

TABLE 6

DMS CHARACTERISTICS BY STUDENT'S t-STATISTIC

t	Total Items		Low Demand (0-24)		High Demand (25 and Over)	
	No.	%	No.	%	No.	%
Reject at 99%	79	4.5	12	1.4	67	7.4
Reject at 98%	42	2.4	16	1.9	26	2.9
Reject at 95%	52	2.9	25	2.9	27	3.0
Reject at 90%	85	4.8	42	4.9	43	4.7
Reject at 80%	113	6.4	67	7.8	46	5.1
Accept	1156	65.2	614	71.2	542	59.6
Reject at 80%	75	4.2	34	3.9	41	4.5
Reject at 90%	64	3.6	26	3.0	38	4.2
Reject at 95%	48	2.7	14	1.6	34	3.7
Reject at 98%	20	1.1	5	.6	15	1.6
Reject at 99%	38	2.1	7	.8	31	3.4
Total	1772	100.0	862	100.0	910	100.0

TABLE 7

DMS CHARACTERISTICS BY SLOPE COEFFICIENT

β	Total Items		Low Demand (0-24)		High Demand (25 and Over)	
	No.	%	No.	%	No.	%
$x < -1.0$	256	14.4	1	.1	255	28.0
$-1.0 < x < -0.5$	100	5.6	17	2.0	83	9.1
$-0.5 < x < 0.0$	641	36.2	538	62.4	103	11.3
$0.0 < x < 0.5$	422	23.8	290	33.6	132	14.5
$0.5 < x < 1.0$	82	4.6	16	1.9	66	7.3
$x > 1.0$	271	15.3	--	--	271	29.8
Total	1772	100.0	862	100.0	910	100.0

TABLE 8

DMS CHARACTERISTICS BY AVERAGE QUARTERLY DEMAND

AQD	Total Items	
	No.	%
Poisson Items:		
Zero	83	4.7
To 1	311	17.6
2	146	8.2
3	102	5.8
4	96	5.4
5	70	4.0
6	54	3.0
Normal Items:		
7	45	2.5
8	41	2.3
9	49	2.8
10	27	1.5
10-15	120	6.8
15-20	65	3.7
20-25	61	3.4
25-30	40	2.3
30-35	29	1.6
35-40	23	1.3
40-45	28	1.6
45-50	24	1.4
50-60	31	1.7
60-70	27	1.5
70-80	31	1.7
80-90	8	.5
90-100	15	.8
100-150	51	2.9
150-200	31	1.7
200-250	15	.8
250-300	20	1.1
Over 300	129	7.3
Total	1772	100.0

TABLE 9

CROSS-TABULATIONS BY FEDERAL SUPPLY CLASS
UNIT COST CATEGORIES

FSC	# Sample	Unit Cost			
		Low Cost	Low-Medium	Medium-High	High Cost
5805	3	--	--	--	100.0
5815	11	--	9.1	27.3	63.6
5820	1	--	--	--	100.0
5905	75	24.0	30.7	21.3	24.0
5910	124	86.3	9.7	2.4	1.6
5915	18	5.6	--	--	94.4
5920	2	50.0	--	--	50.0
5925	39	25.6	5.1	25.6	43.6
5930	120	4.2	16.7	39.2	40.0
5935	6	--	--	16.7	83.3
5945	52	--	1.9	5.8	92.3
5950	208	1.4	5.3	21.6	71.6
5960	262	13.7	45.8	27.9	12.6
5961	233	57.5	25.8	13.7	3.0
5962	573	24.4	27.6	37.0	11.0
5985	1	--	--	--	100.0
5999	44	4.5	6.8	47.7	40.9
Total	1772	25.8	23.2	26.3	24.7

TABLE 10
CROSS-TABULATIONS BY DEMAND CATEGORIES

FSC	# Sample	Demand				
		Zero	Low Poisson	High Poisson	Low Normal	High Normal
5805	3	--	--	--	66.7	33.3
5815	11	--	--	18.2	18.2	63.6
5820	1	--	--	100.0	--	--
5905	75	2.7	50.7	32.0	12.0	2.7
5910	124	8.1	34.7	29.0	21.0	7.3
5915	18	5.6	22.2	55.6	11.1	5.6
5920	2	--	--	50.0	--	50.0
5925	39	23.1	43.6	20.5	10.3	2.6
5930	120	2.5	30.0	30.8	26.7	10.0
5935	6	--	--	66.7	16.7	16.7
5945	52	5.8	32.7	32.7	25.0	3.8
5950	208	6.3	38.0	40.9	14.9	--
5960	262	--	3.1	6.5	19.5	71.0
5961	233	1.3	6.4	18.0	27.0	47.2
5962	573	4.0	14.1	23.9	35.4	22.5
5985	1	--	--	--	100.0	--
5999	44	36.4	20.5	25.0	18.2	--
Total	1772	4.7	19.6	24.4	25.3	26.1

TABLE 11
CROSS-TABULATIONS BY SLOPE

FSC	# Sample	Slope		
		Zero	Postive	Negative
5805	3	66.7	33.3	--
5815	11	63.6	18.2	18.2
5820	1	--	--	100.0
5905	75	96.0	--	4.0
5910	124	94.0	2.4	3.2
5915	18	83.3	--	16.7
5920	2	50.0	50.0	--
5925	39	92.3	--	7.7
5930	120	80.8	4.2	15.0
5935	6	100.0	--	--
5945	52	80.8	1.9	17.3
5950	208	94.7	.5	4.8
5960	262	72.9	2.7	24.4
5961	233	79.8	7.7	12.4
5962	573	83.6	11.7	4.7
5985	1	100.0	--	--
5999	44	100.0	--	--
Total	1772	84.3	6.0	9.7

SUPPLY EFFECTIVENESS DIAGRAM Constant Demand Policy

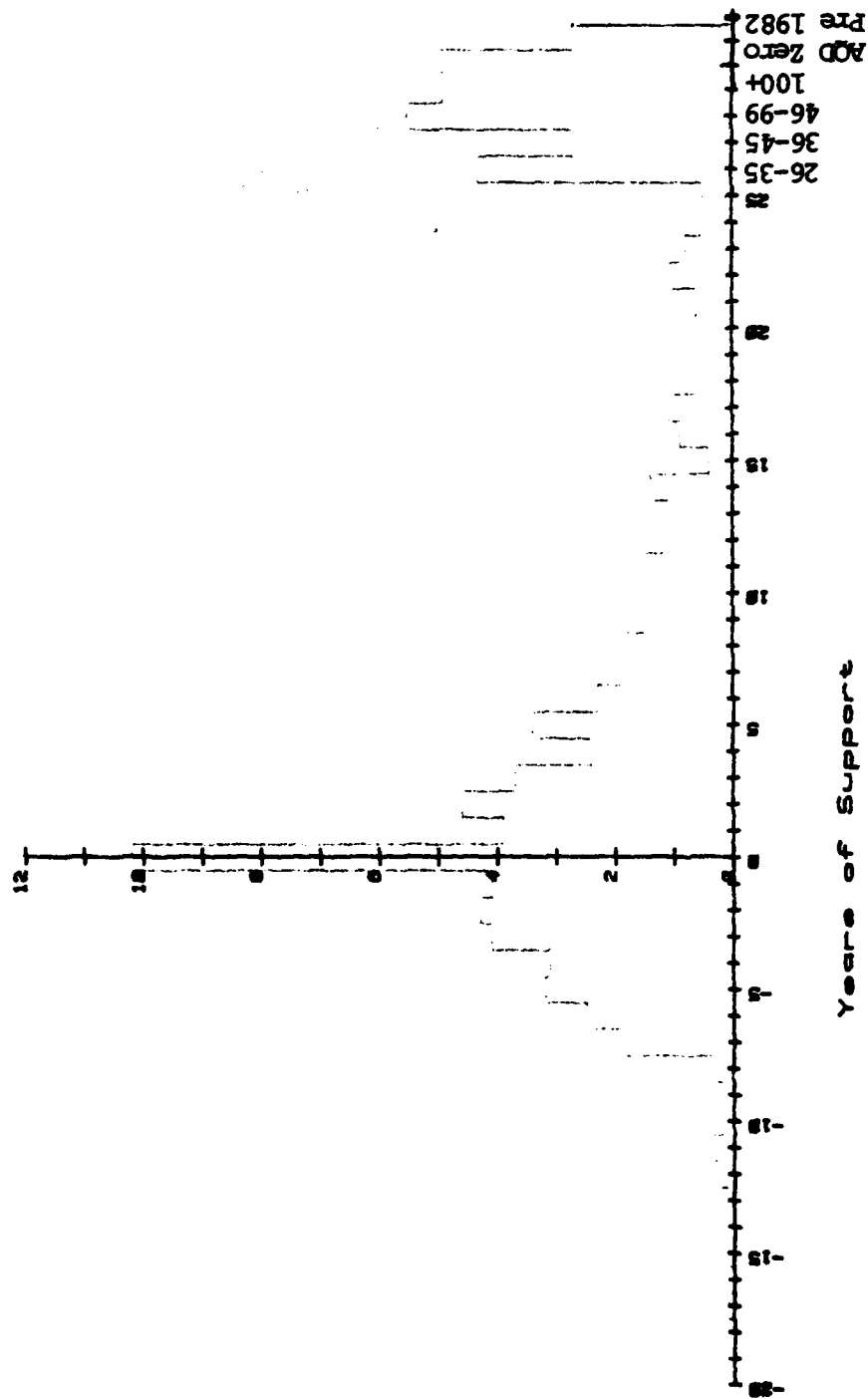


Fig. A-1. Supply Effectiveness Diagram--Constant Demand Policy

SUPPLY EFFECTIVENESS DIAGRAM

Simple Linear Regression

Note: 40 percent of DMS items went surplus because (based on slope) they went into a negative demand simulation; 33.2 percent went negative before their DMS data, while 7.7 percent after. They were not included in this diagram.

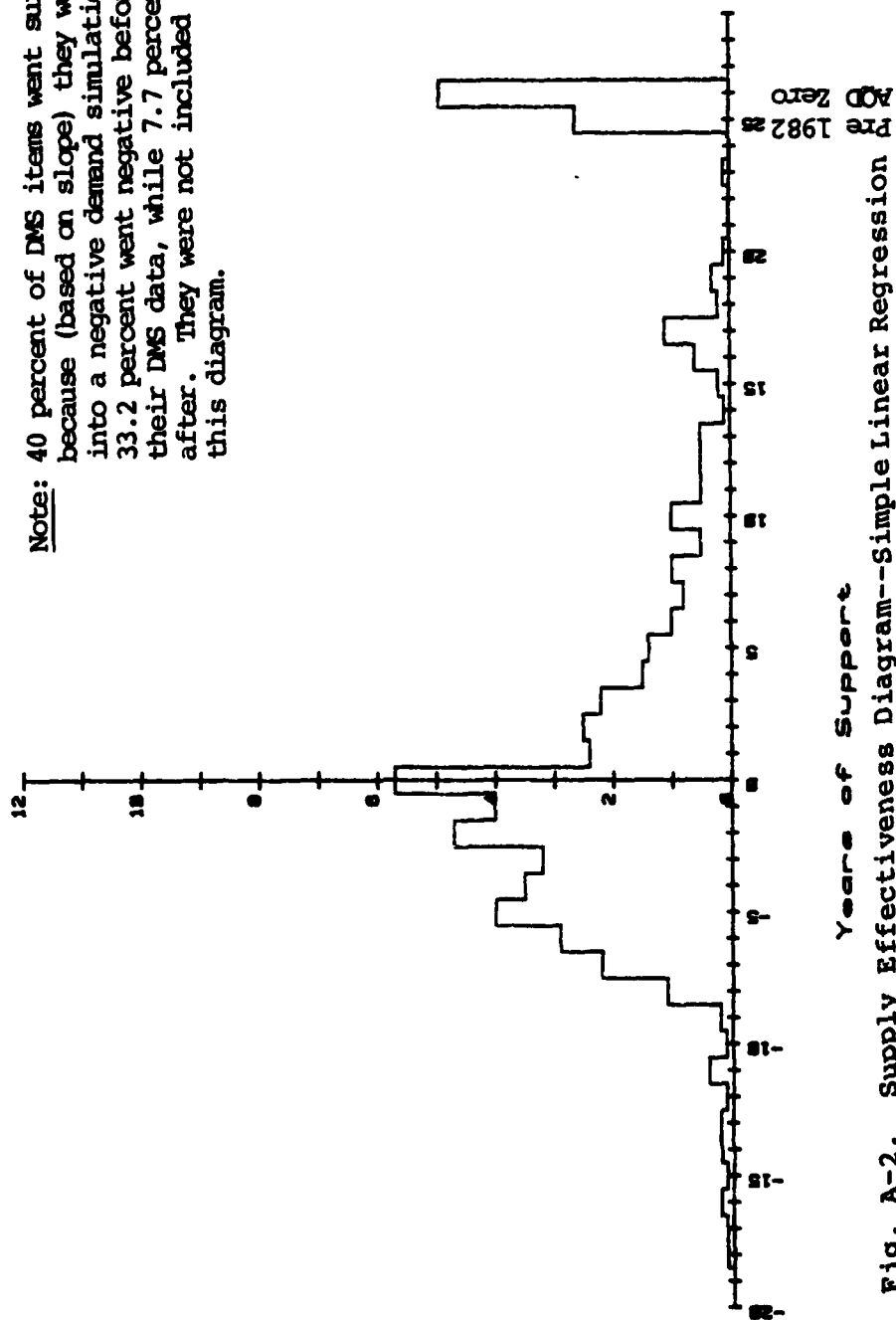


Fig. A-2. Supply Effectiveness Diagram--Simple Linear Regression

·APPENDIX B

THREE- AND TWO-DIMENSIONAL PRESENTATION
OF SENSITIVITY ANALYSIS

Three-dimensional and two-dimensional contour lines are presented to depict the sensitivity of each variable to the ELQ determination.

It is important to note, that in all the figures presented in this appendix, Penalty Cost is determined by the formula $B=Cx2^M$, where C is unit cost and M ranges from 1 to 16. For ease of representation on the axis, the exponent M is plotted on the Penalty Cost axis.

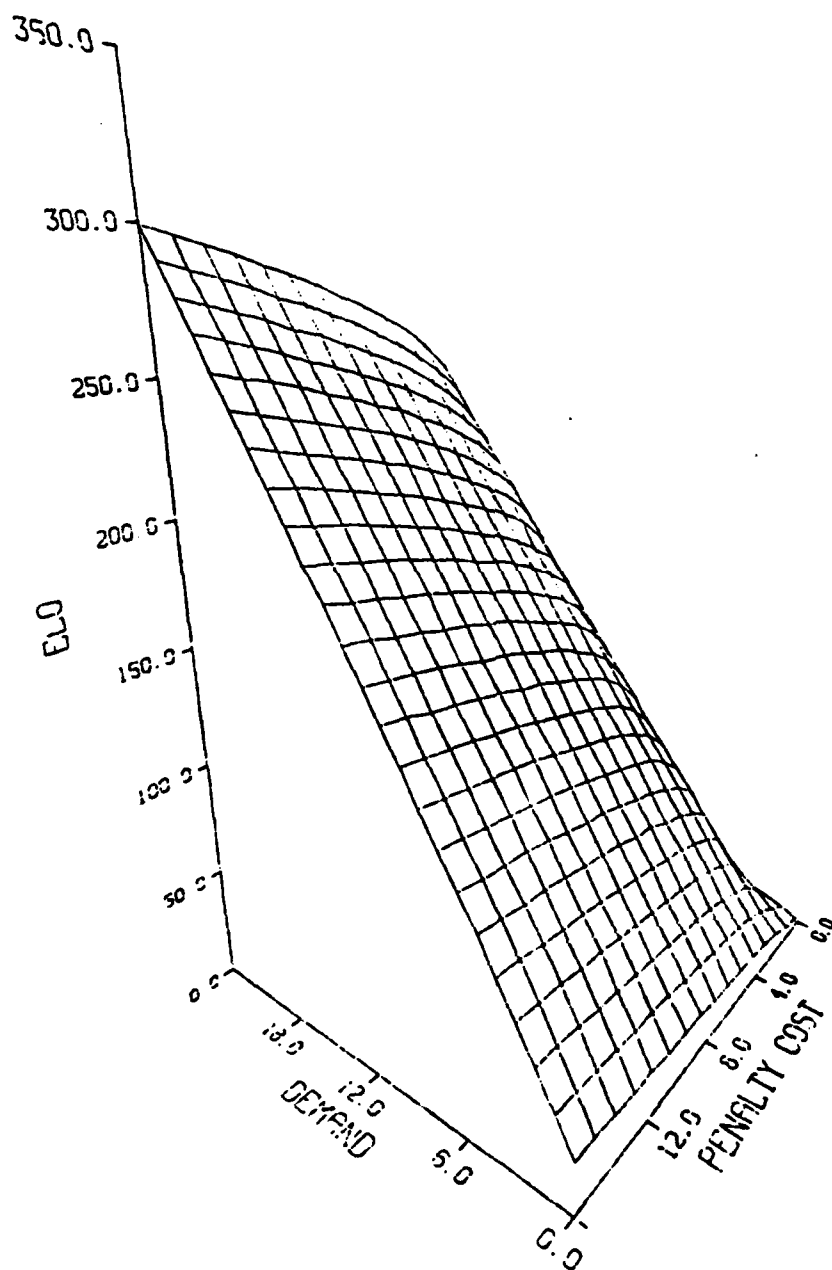


Fig. B-1. Poisson Demand Distribution--Three-Dimensional
(Range 1 to 24)

POISSON DEMAND DISTRIBUTION

Demand varies from 1 to 16 per year

Other variables held constant

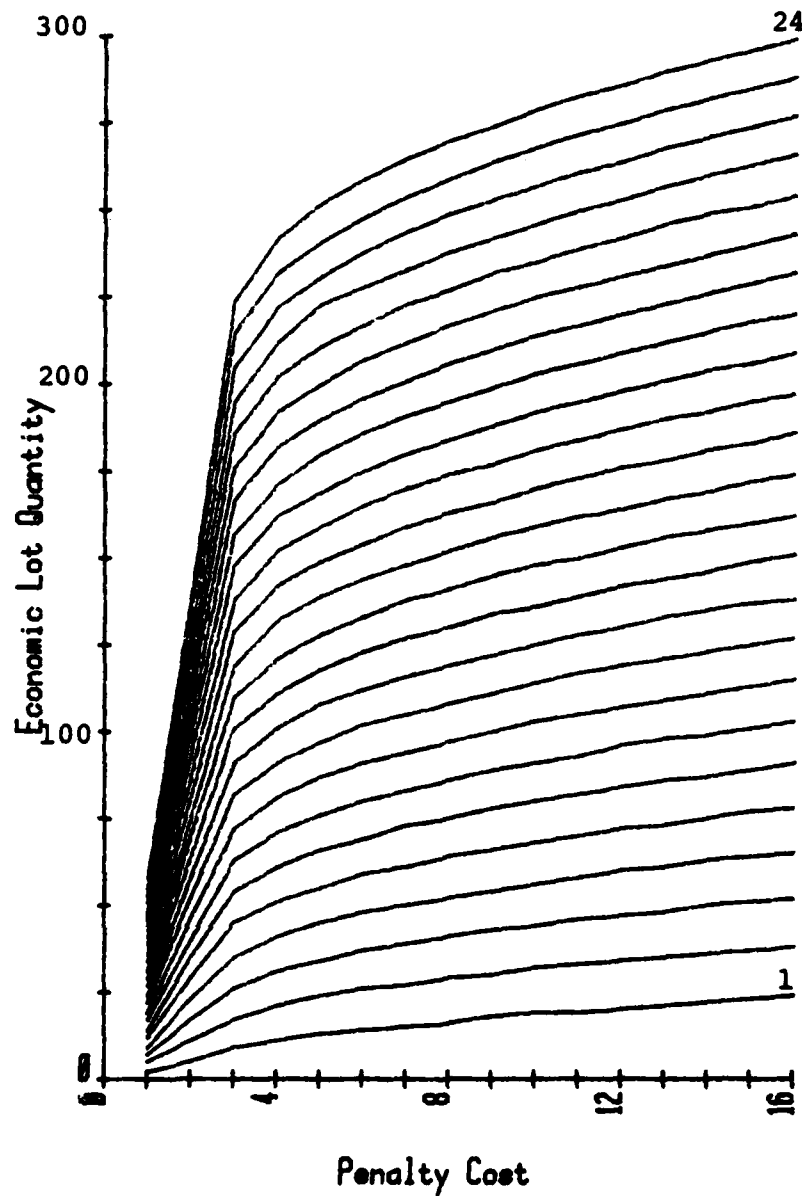


Fig. B-2. Poisson Demand Distribution--Two-Dimensional with Contour Lines (Range 1 to 24)

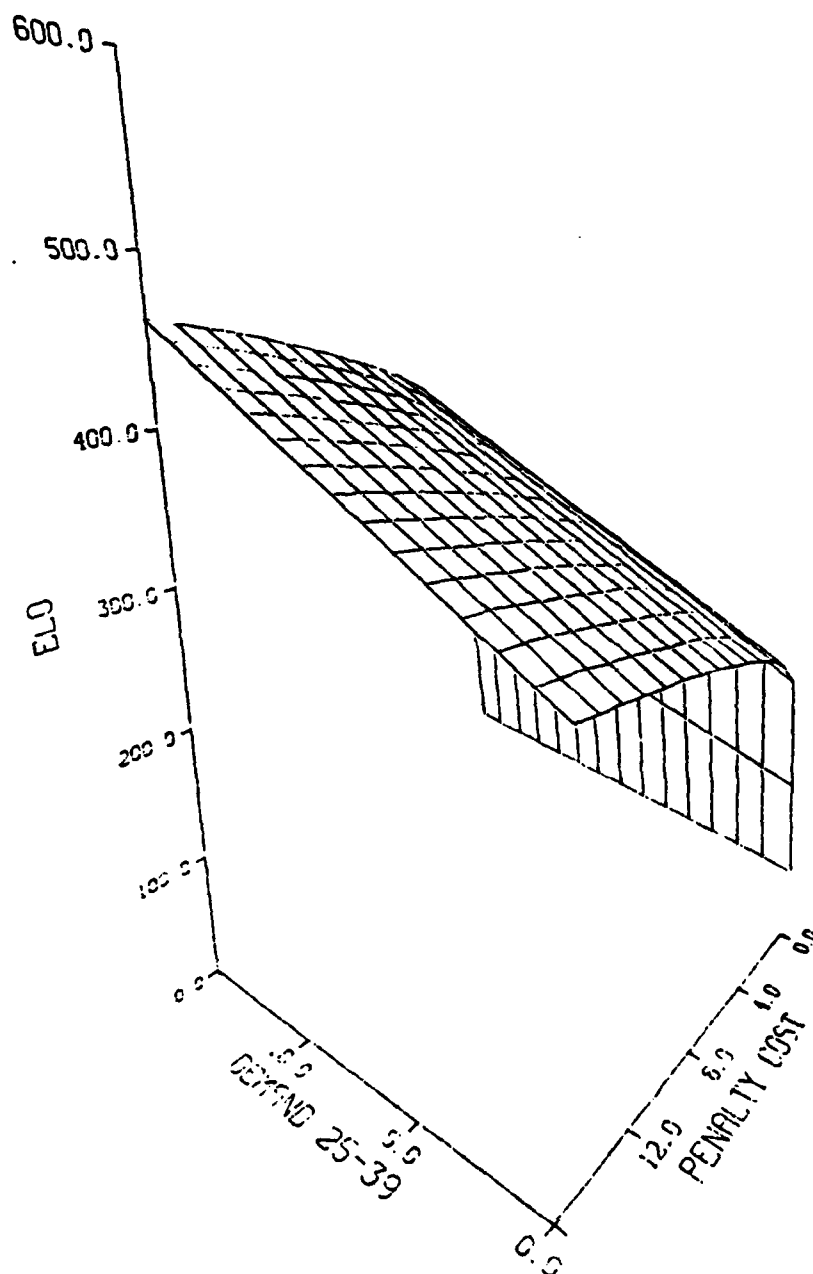


Fig. B-3. Normal Demand Distribution--Three-Dimensional
(Range 25 to 39)

NORMAL DEMAND DISTRIBUTION

Annual Demand varies from 15 to 50

Other variables held constant

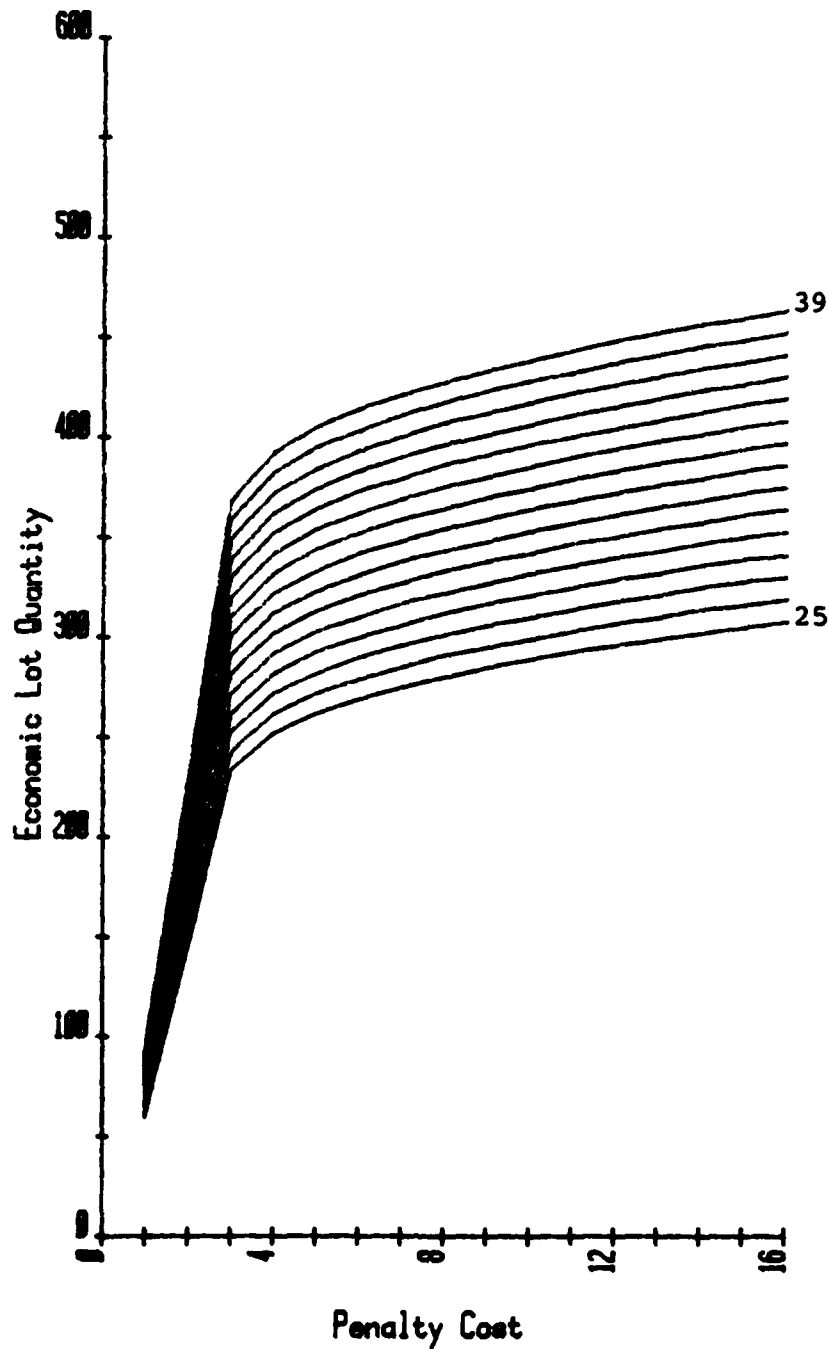


Fig. B-4. Normal Demand Distribution--Two-Dimensional
with Contour Lines (Range 25 to 39)

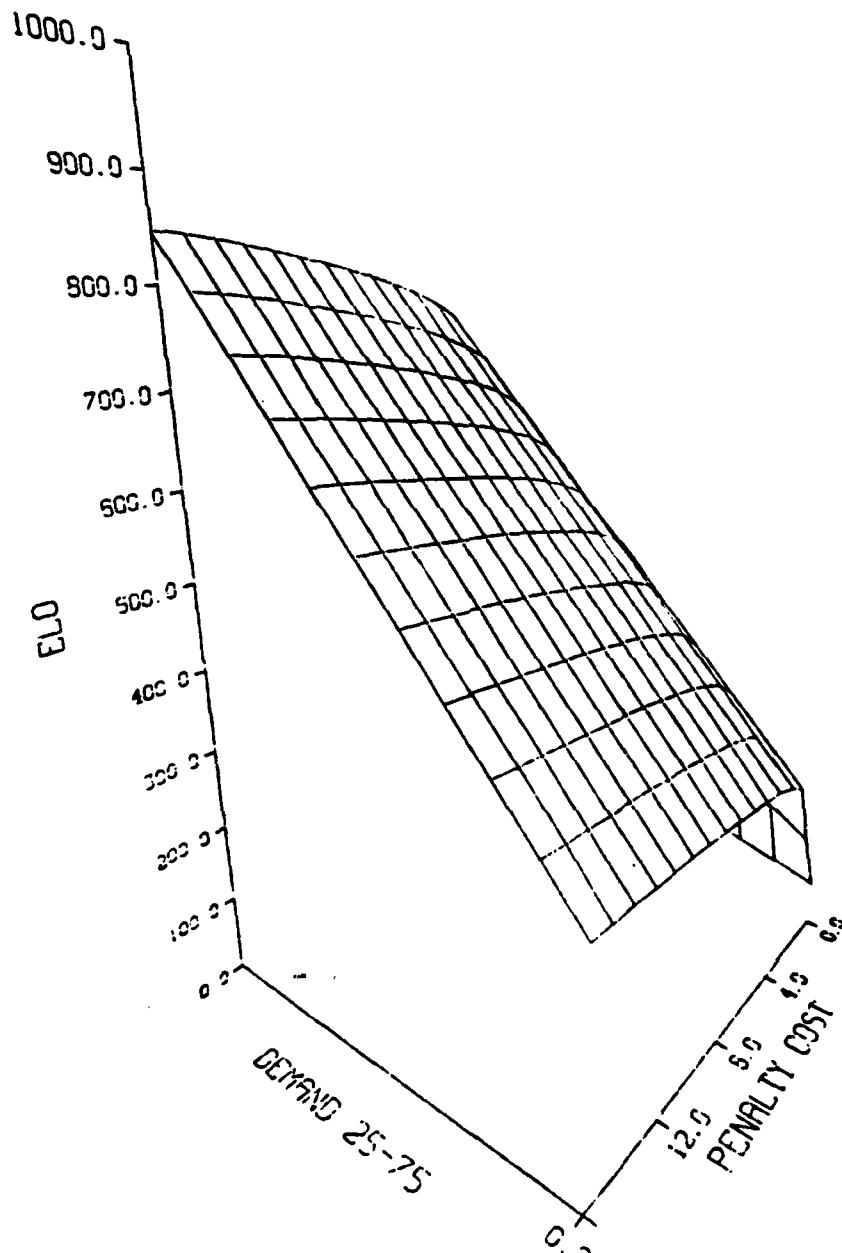


Fig. B-5. Normal Demand Distribution--Three-Dimensional
(Range 25 to 75)

NORMAL DEMAND DISTRIBUTION

Annual Demand varies from 10 to 15
Other variables held constant

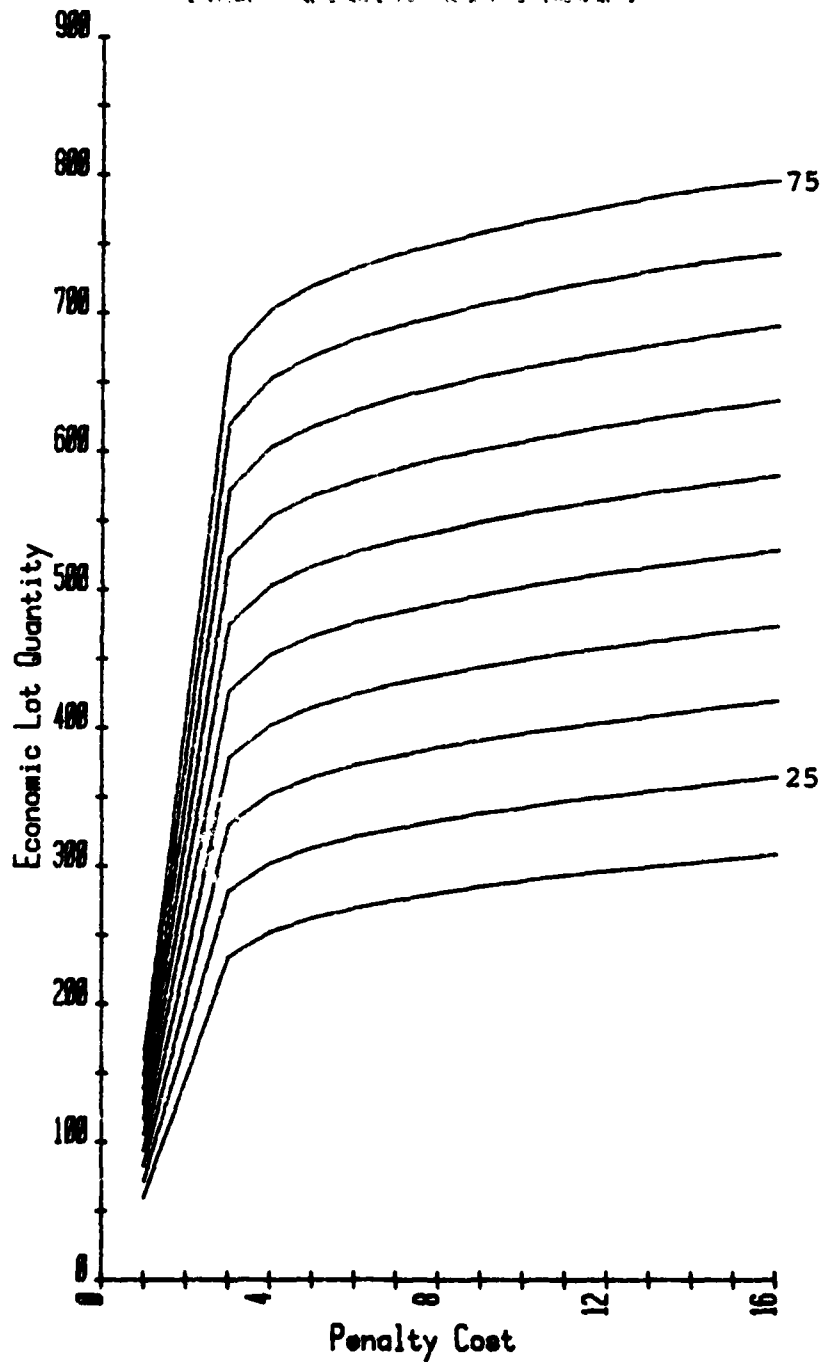


Fig. B-6. Normal Demand Distribution--Two-Dimensional with Contour Lines (Range 25 to 75)

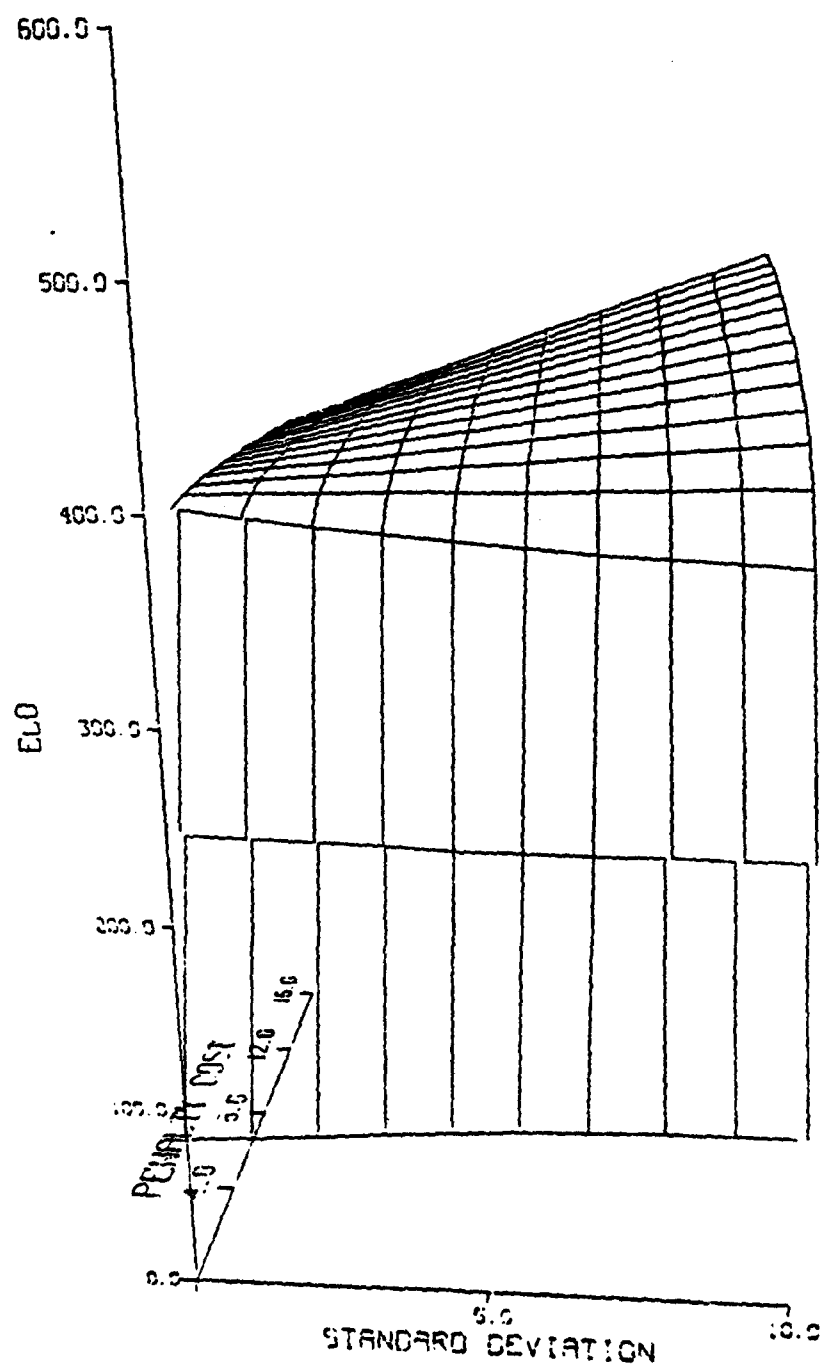


Fig. B-7. Standard Deviation (1 to 10) for Normal--
Three-Dimensional

NORMAL DEMAND DISTRIBUTION

Standard Deviation (1 to 10) for Normal--
Two-Dimensional with Contour Lines

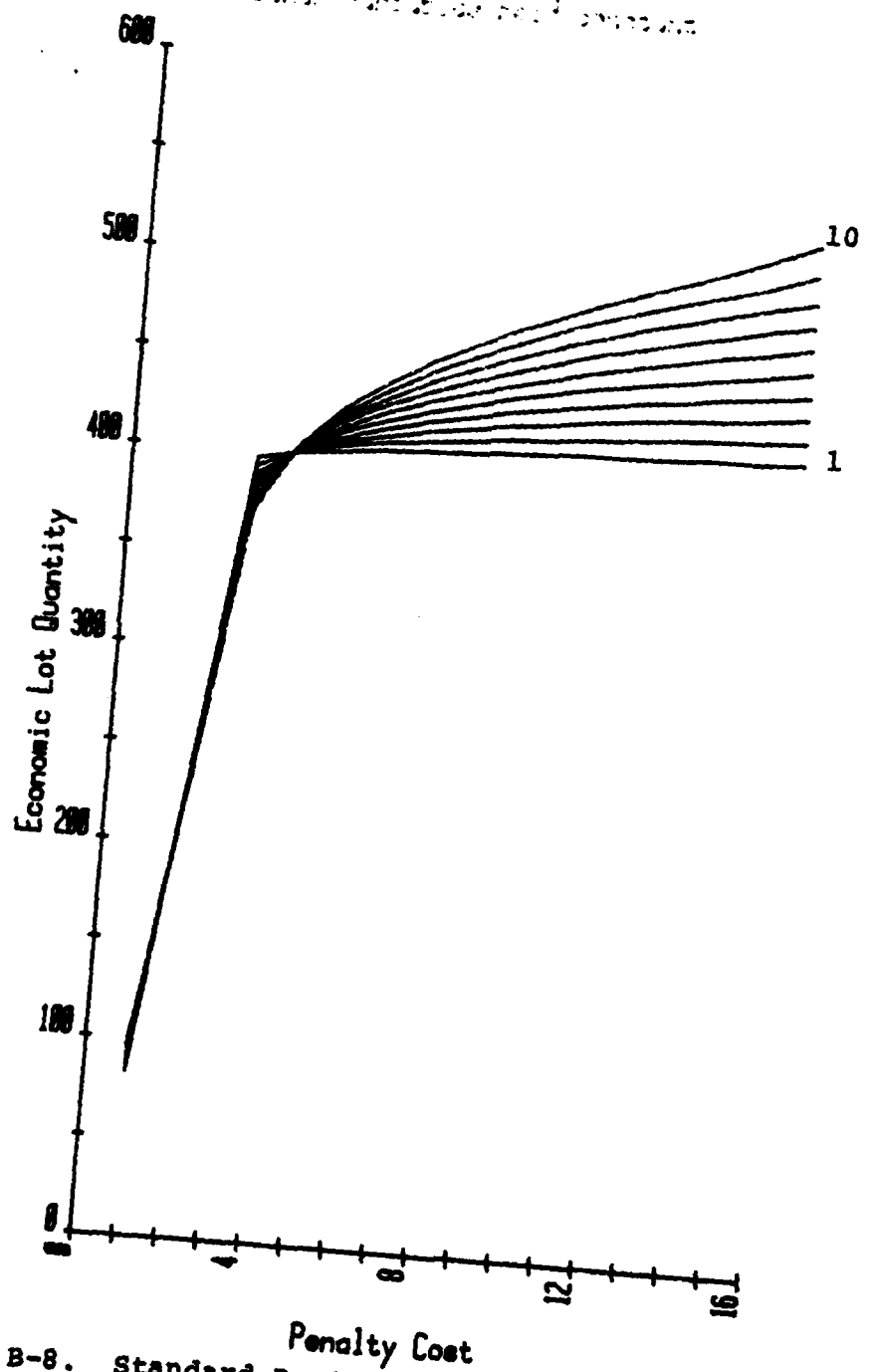


Fig. B-8. Standard Deviation (1 to 10) for Normal--
Two-Dimensional with Contour Lines

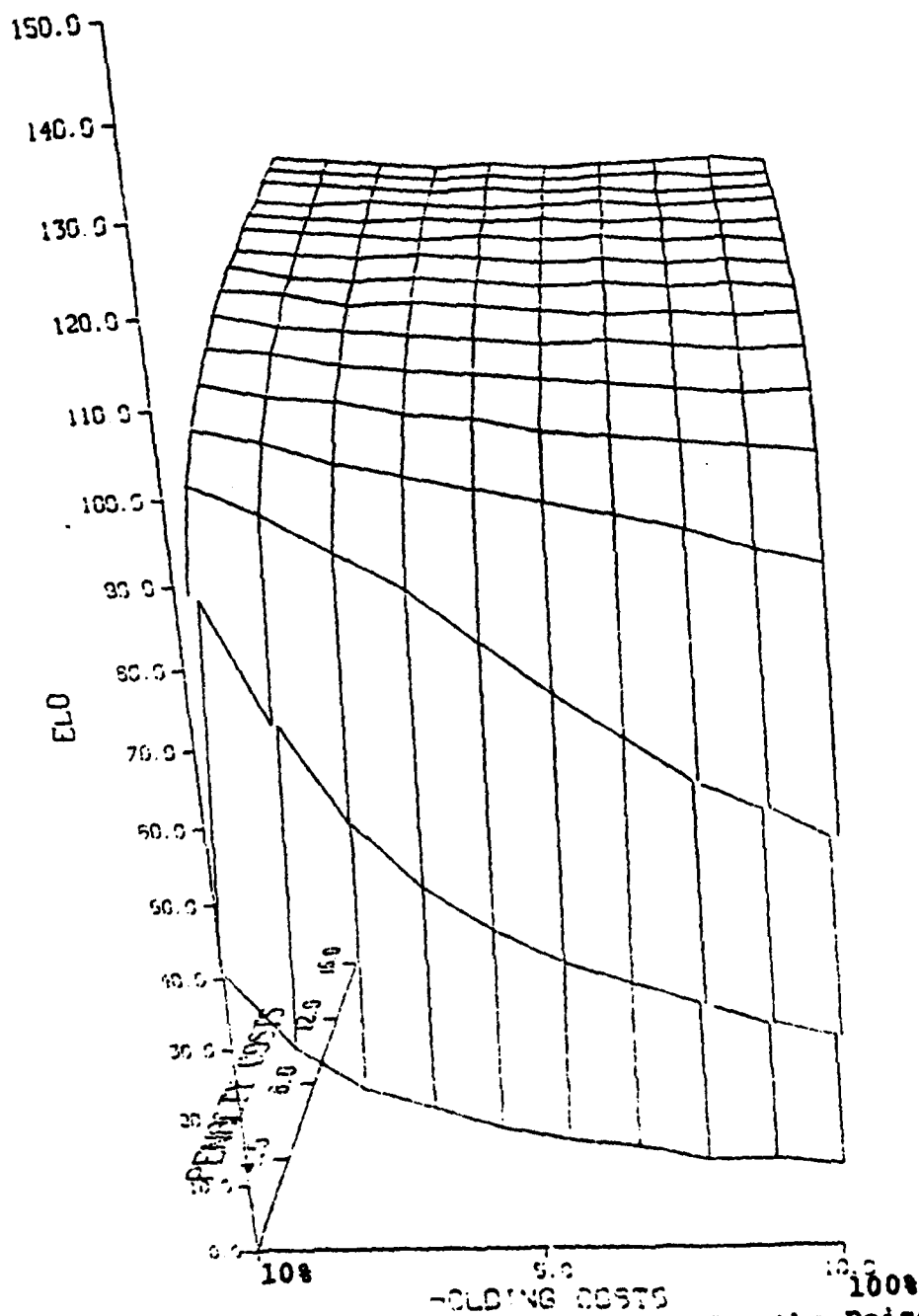


Fig. B-9. Holding Costs (10% to 100%) for the Poisson--
Three-dimensional

POISSON DEMAND DISTRIBUTION

Holding Cost varies from 10% to 100% of Unit Cost

Other variables held constant

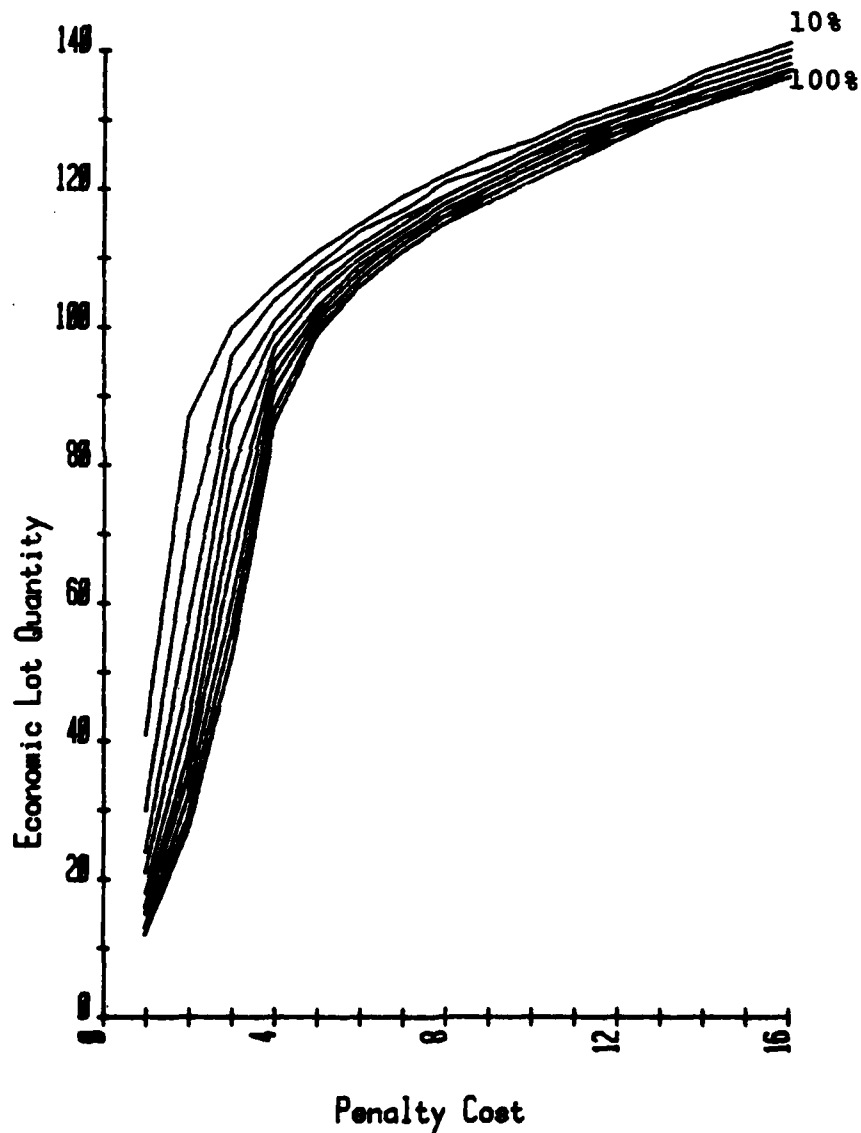


Fig. B-10. Holding Costs (10% to 100%) for the Poisson--
Two-Dimensional with Contour Lines

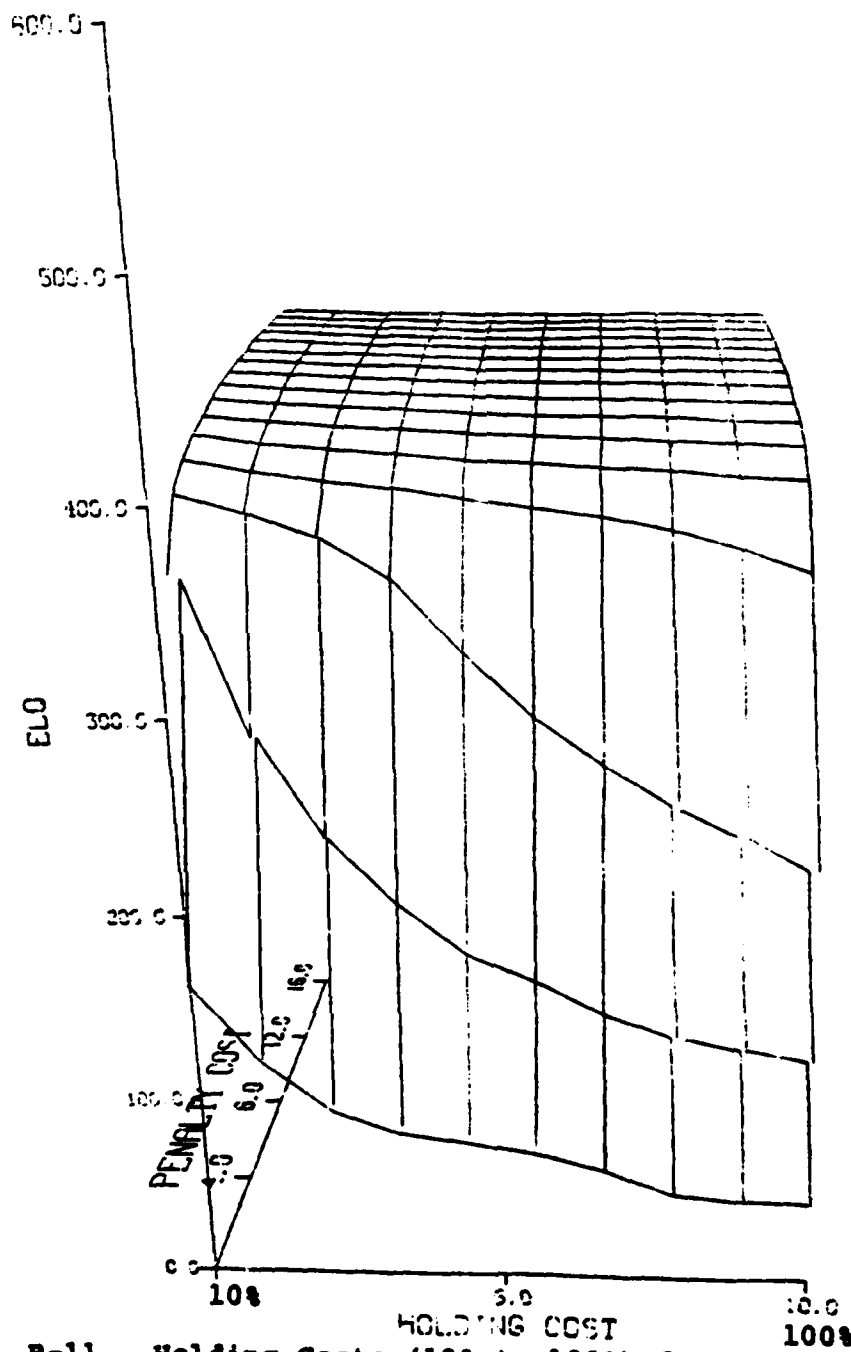


Fig. B-11. Holding Costs (10% to 100%) for the Normal--
Three-Dimensional

NORMAL DEMAND DISTRIBUTION

Holding Cost varies from 10% to 100% of Unit Cost
Other variables held constant

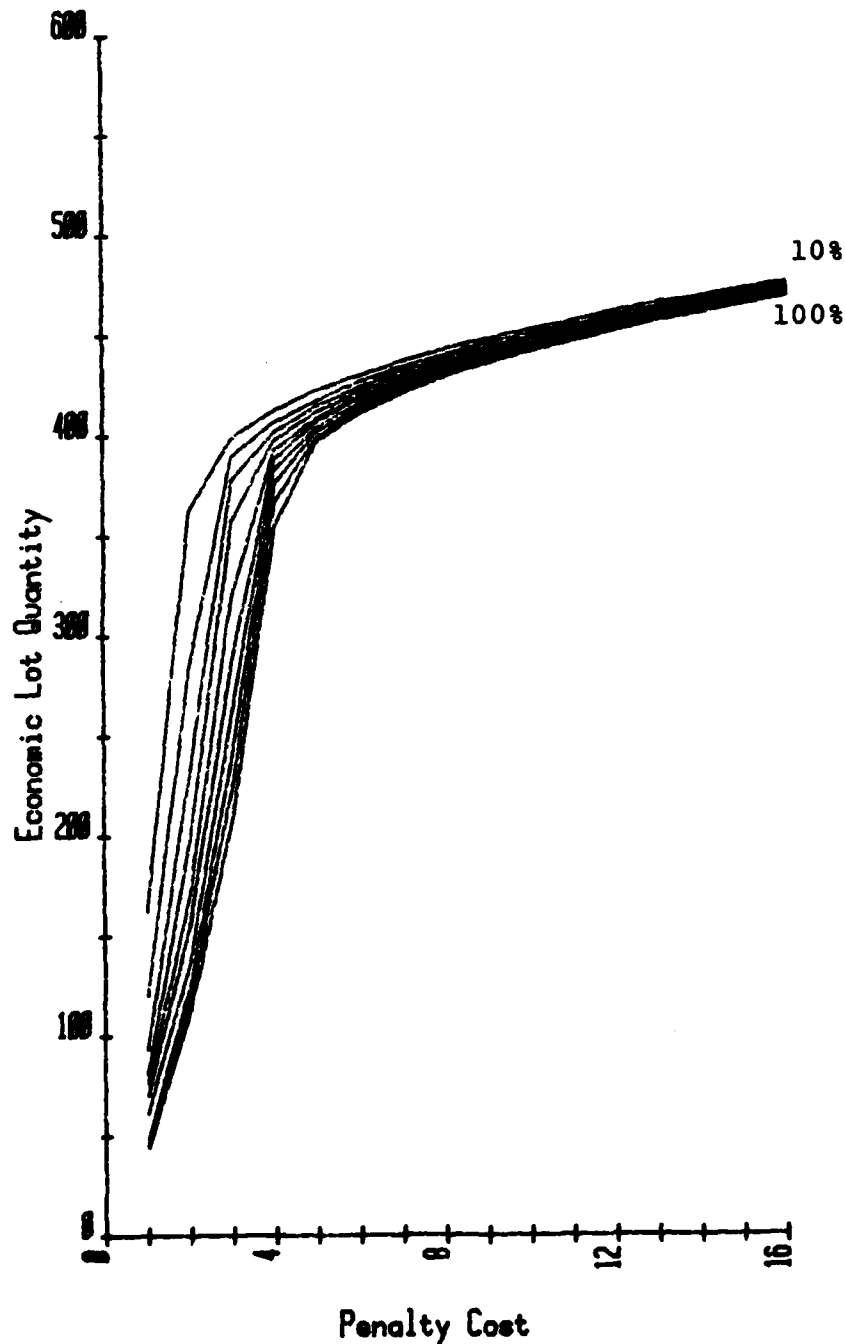


Fig. B-12. Holding Costs (10% to 100%) for the Normal--
Two-Dimensional with Contour Lines

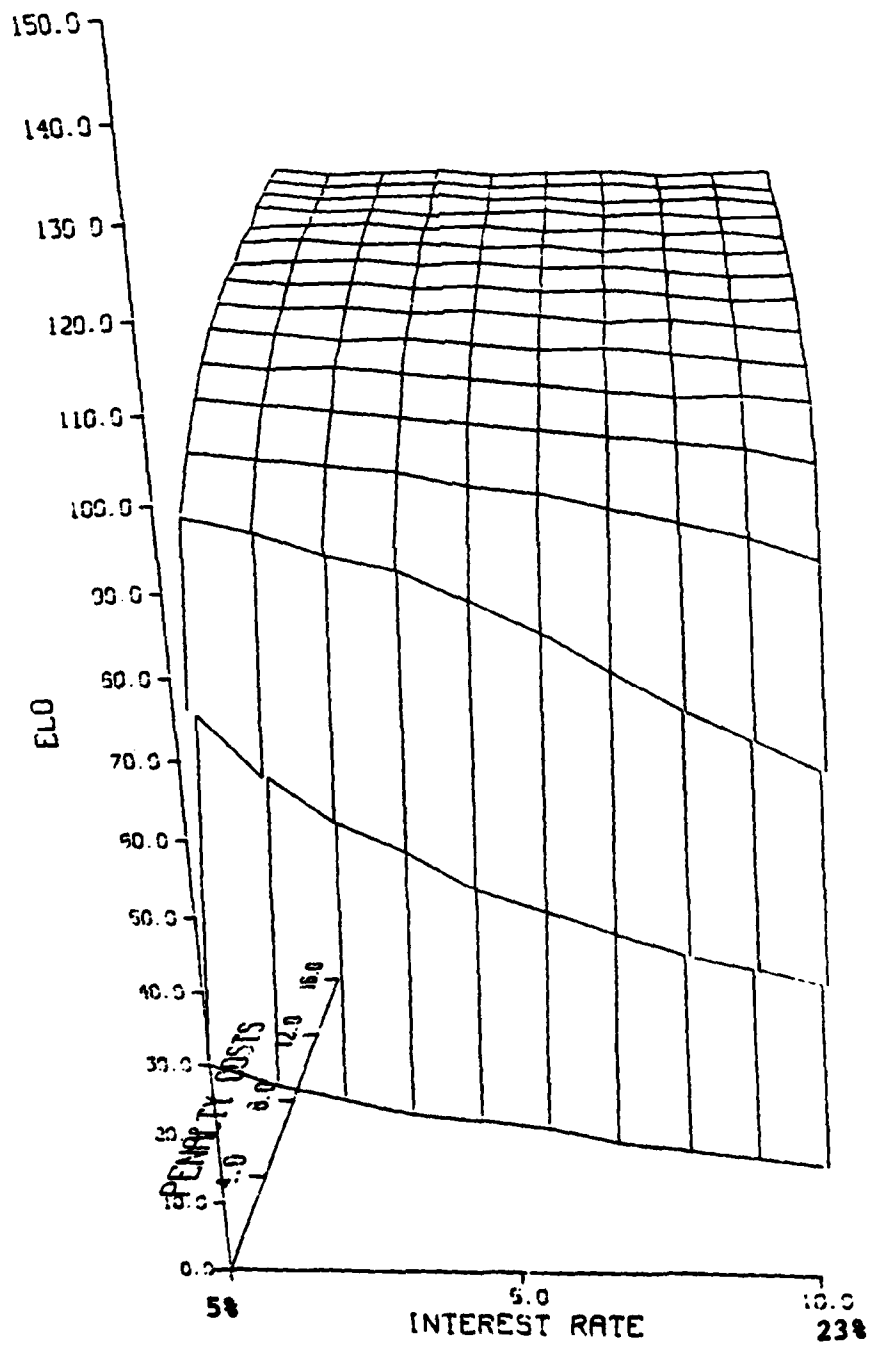


Fig. B-13. Interest Rates (5% to 23%)
for the Poisson--Three-Dimensional

POISSON DEMAND DISTRIBUTION

Interest rates (5% to 23%) for the Poisson--Two-Dimensional with Contour Lines

Order distribution with interest rates

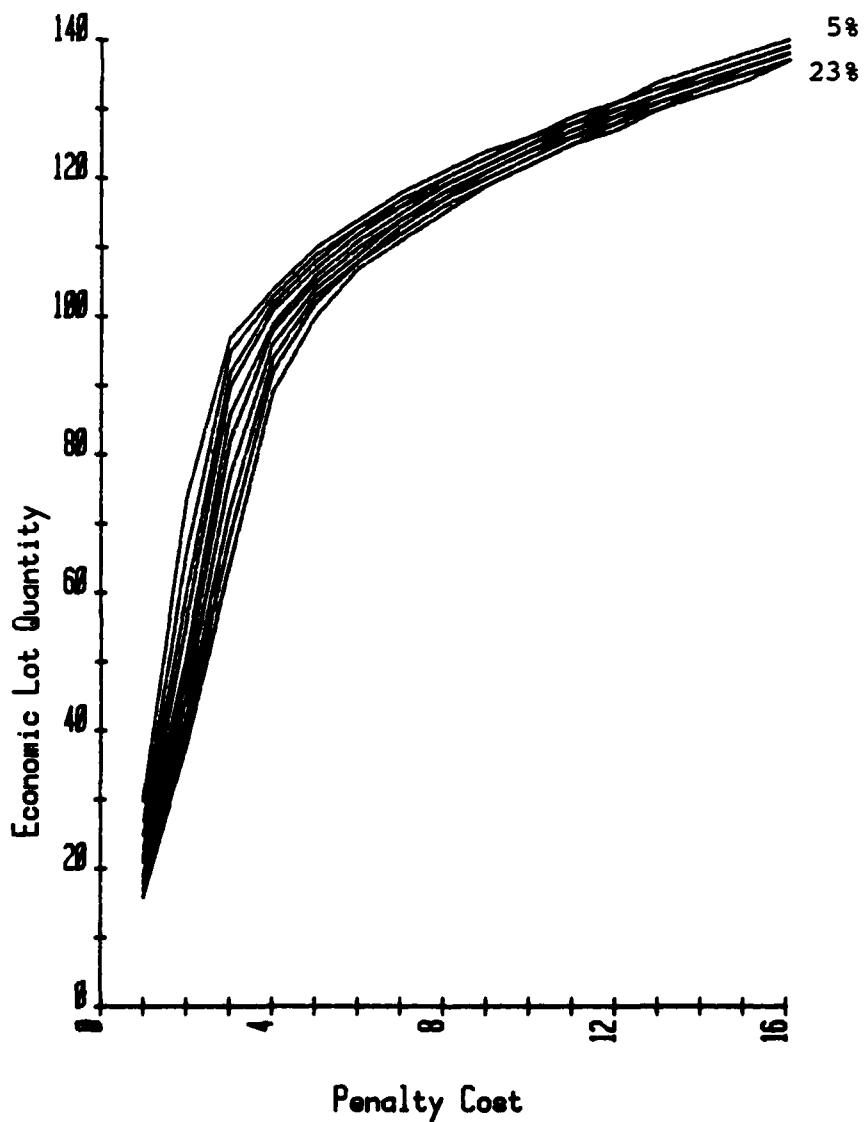


Fig. B-14. Interest Rates (5% to 23%) for the Poisson--Two-Dimensional with Contour Lines

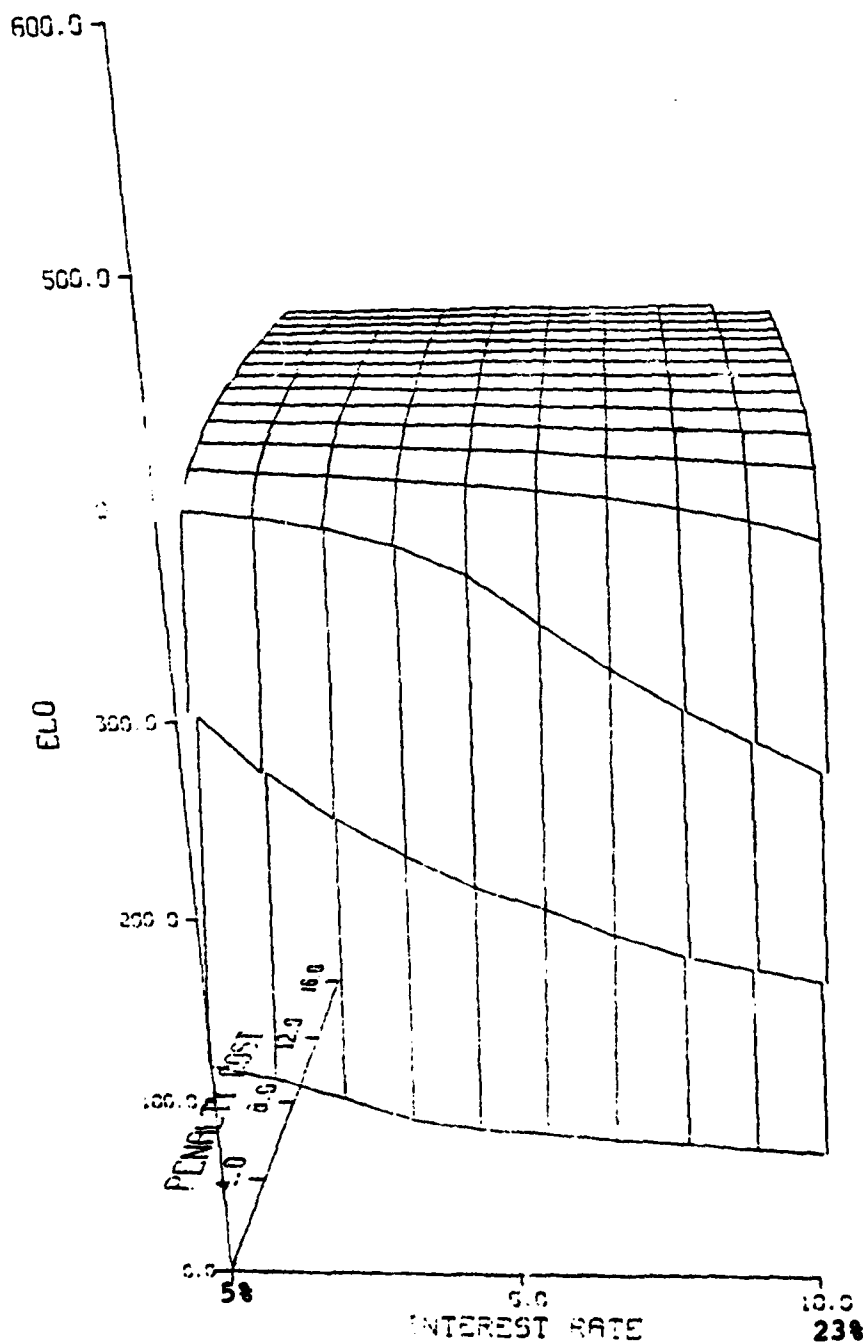


Fig. B-15. Interest Rates (5% to 23%) for the Normal--Three-Dimensional

NORMAL DEMAND DISTRIBUTION

Interest rates varied from 5% to 23%

Standard deviation held constant

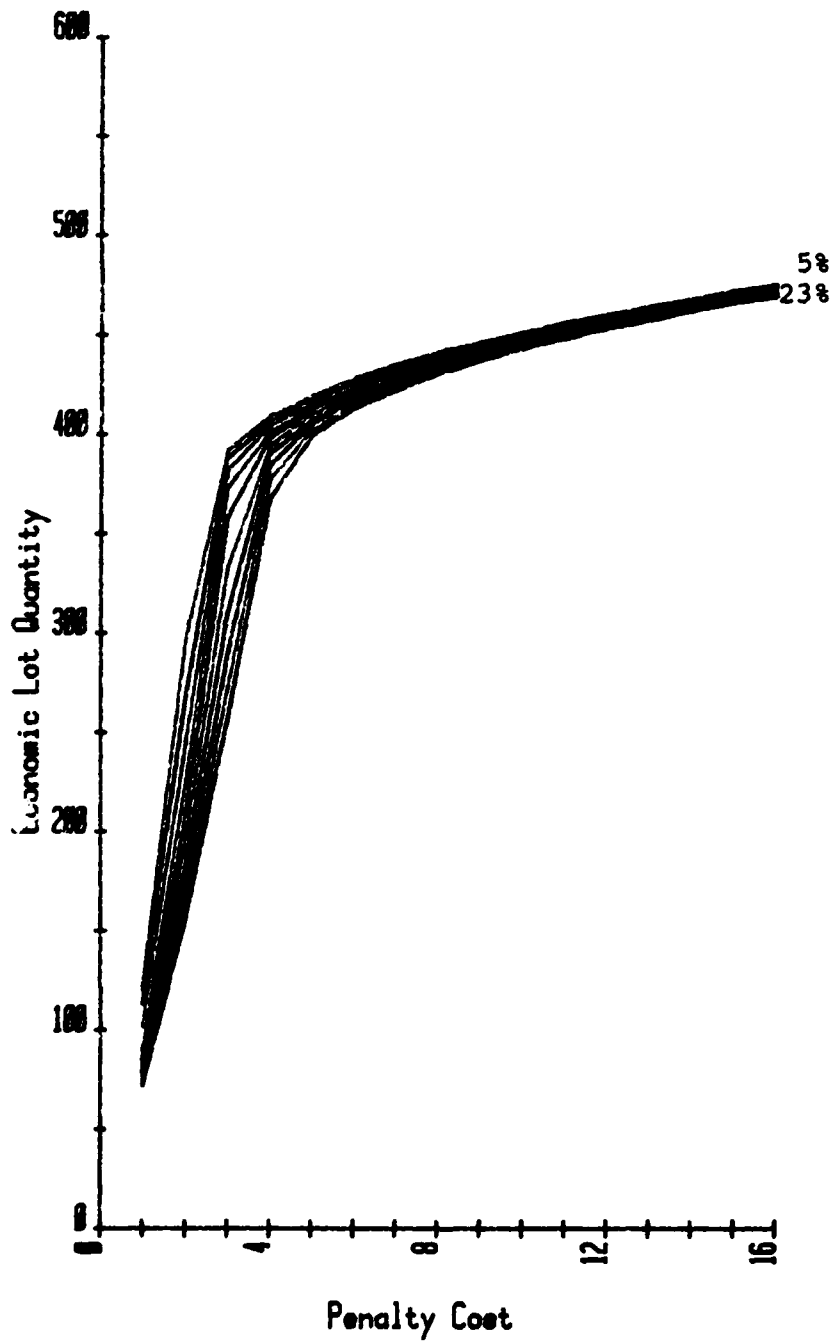


Fig. B-16. Interest Rates (5% to 23%) for the Normal--Two-Dimensional with Contour Lines

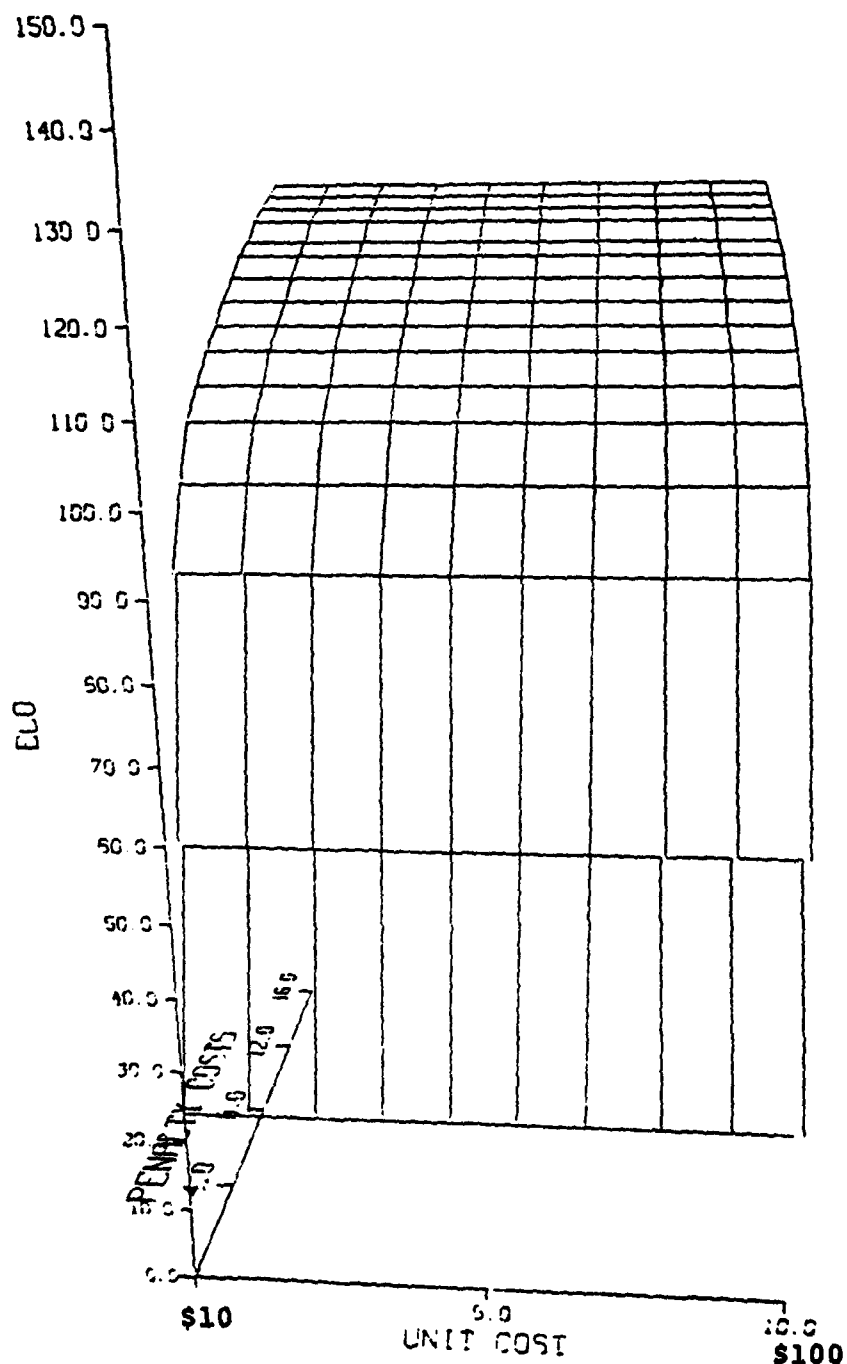


Fig. B-17. Unit Cost (\$1 to \$100) for the Poisson--
Three-Dimensional

POISSON DEMAND DISTRIBUTION

Unit Cost varies from \$1 to \$100

Order quantity is constant

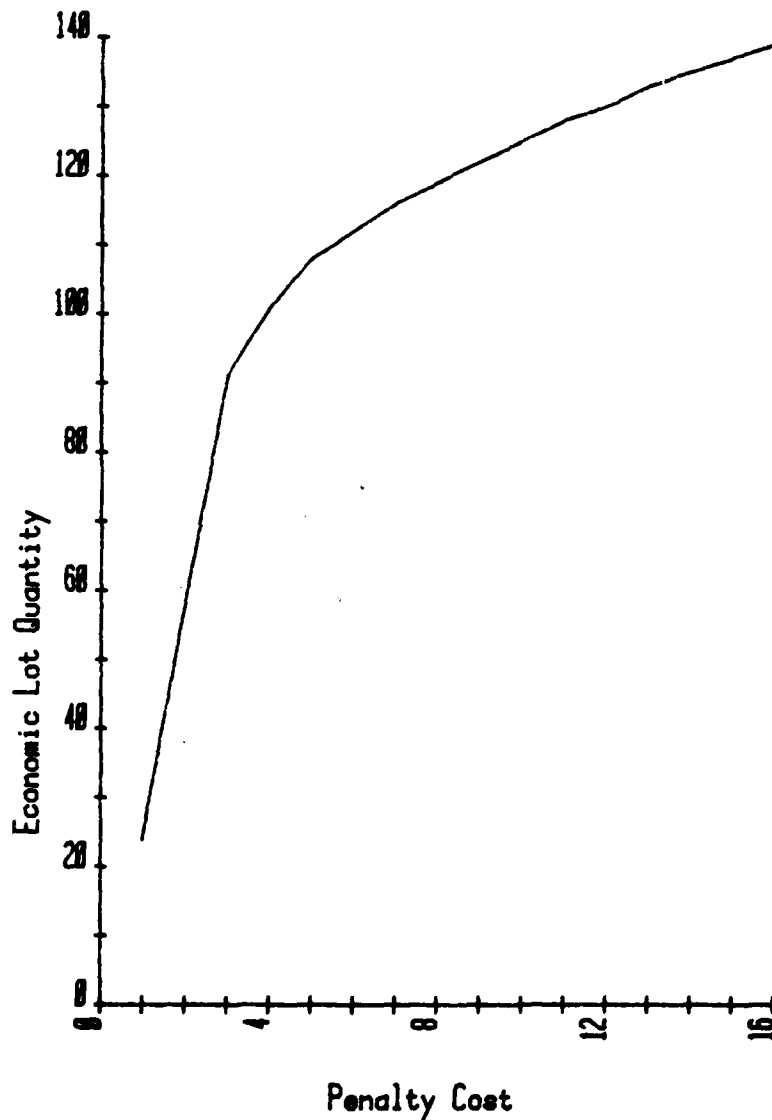


Fig. B-18. Unit Cost (\$1 to \$100) for the Poisson--
Two-Dimensional with Contour Lines

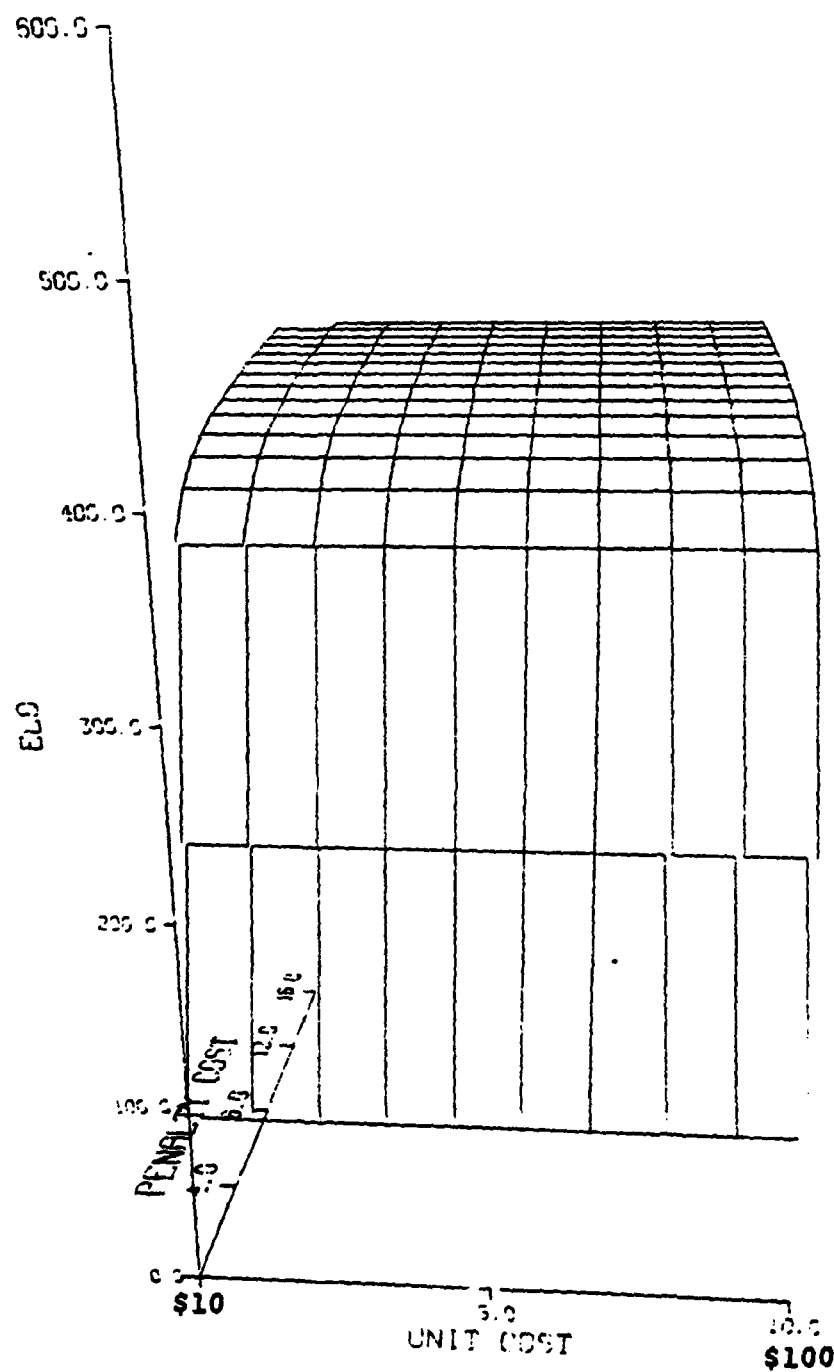


Fig. B-19. Unit Cost (\$1 to \$100) for the Normal--
Three-Dimensional

NORMAL DEMAND DISTRIBUTION

Unit Cost varies from \$1 to \$100

Normal distribution with constant

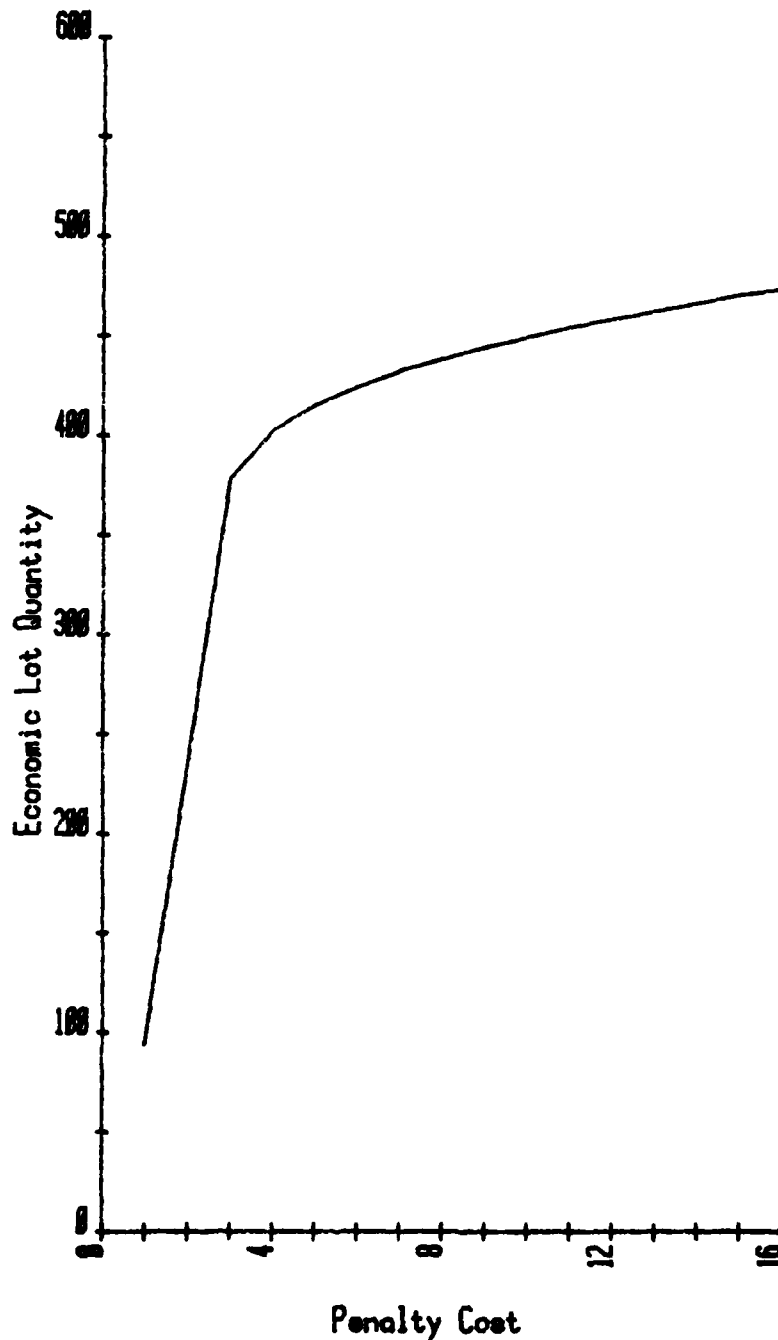


Fig. B-20. Unit Cost (\$1 to \$100) for the Normal--
Two-Dimensional with Contour Lines

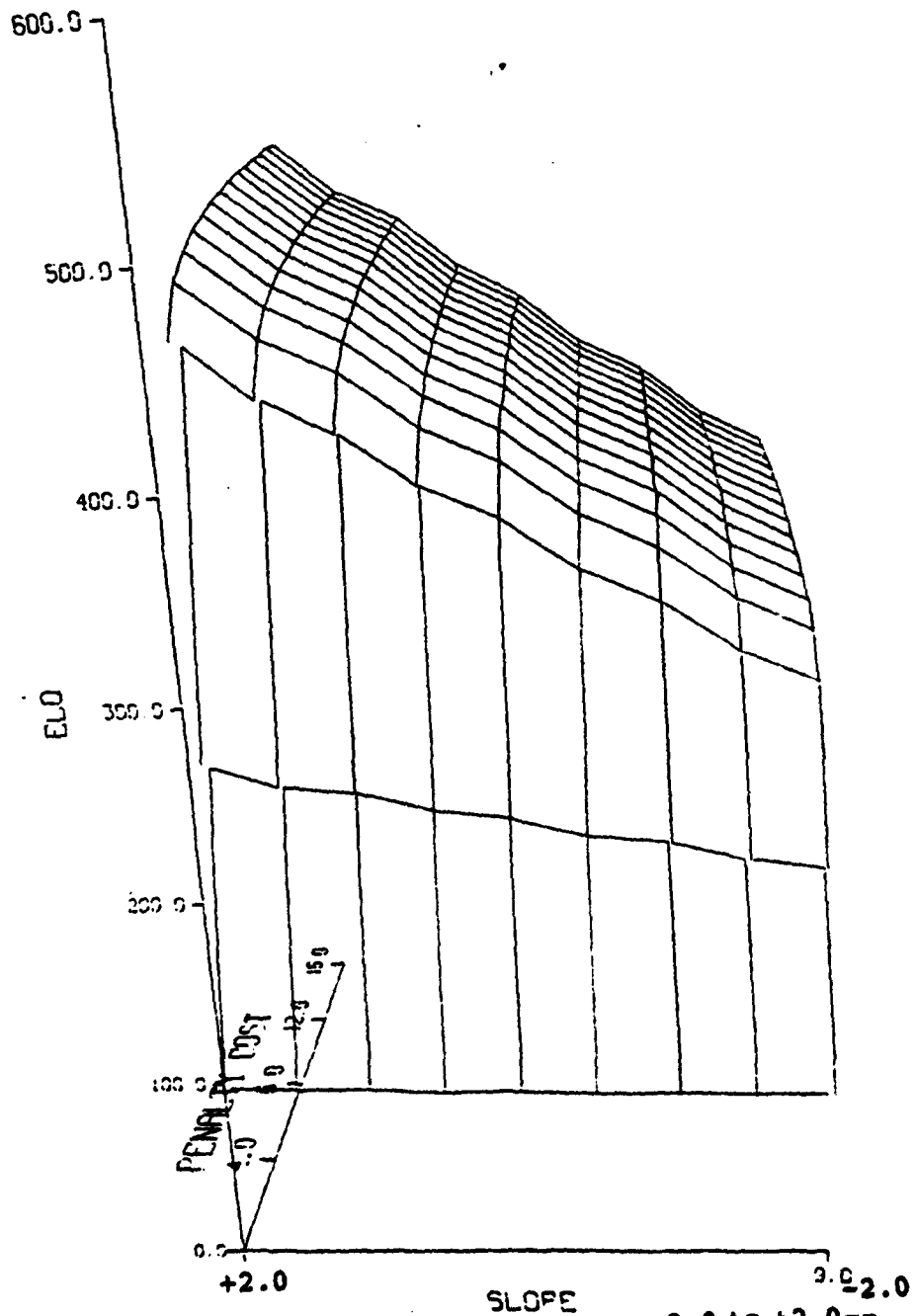


Fig. B-21. Slope Varies from -2.0 to +2.0--
Three-Dimensional

NORMAL DEMAND DISTRIBUTION

Slope of Demand curve from -2.0 to +2.0
Other variables held constant

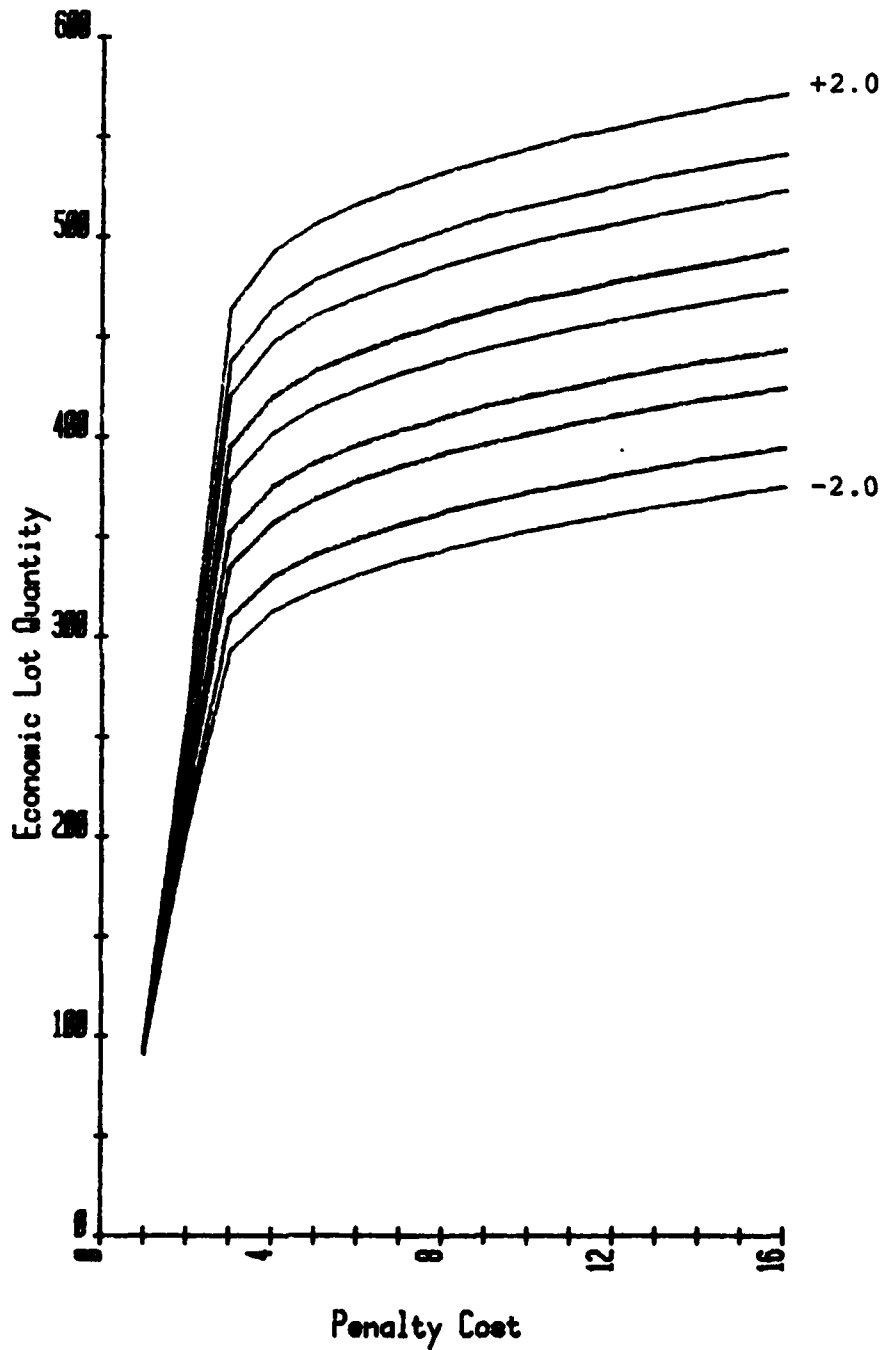


Fig. B-22. Slope Varies from -2.0 to +2.0--
Two-Dimensional with Contour Lines

APPENDIX C
CASE STUDY OF A DMS ITEM

Case Study of a DMS Item Using Sensitivity Analysis

Let us suggest that an item in FSC 5960 is reported as being declared DMS. What action should be pursued to ensure full future support?

Under DESC procedures, the AQD for the last eight quarters would be determined, and, unless information to the contrary arose, a buy of ten times the yearly demand would be purchased. If this was 40 per year, the buy would be 400.

From Chapter VI, the first question we propose the manager to seek to determine is: how much is it worth to him not to be out of stock of this item or, looking at it another way, how much would it cost him in the future to procure this item? The manager must decide, so let us assume he says 100 times its present value, or in our penalty cost scale, approximately 7.

The next part of the analysis is to consider the effect of the various input variables. Based on the input variables of variance equal to the mean, interest rates at 10 percent and holding costs at 30 percent of unit cost, the ELQ would be computed as 432. The actual ranges of ELQ associated with each variable at the penalty cost value 7 are:

Interest rate	5% to 23%	ELQ	435 - 422
Holding cost	10% to 100%	ELQ	437 - 421
Variance	150% to 50%	ELQ	445-415

The manager must look to determine which input variable will effect his decision by the greatest amount. In this case it is variance. If variance is determined to be at the high end (130 percent), equating to an ELQ of 440, the other two input variables appear satisfied.

From our Chapter V results, we note that the probability associated with slope for FSC 5960 were zero (73 percent), positive (3 percent) and negative (24 percent). This implies that the slope of the demand line should enter the manager's considerations. The effect on ELQ of negative slope would be: 0.0 (432), -0.5 (403), -1.0 (385), -1.5 (356), -2.0 (338). In view of the importance of slope on ELQ the manager should determine the trend line from past data to accurately consider future direction.

All of the above steps are designed to make the manager more aware of his range values on each variable, making it possible for him to weight the facts as they relate to the item in his final determination of the ELQ.

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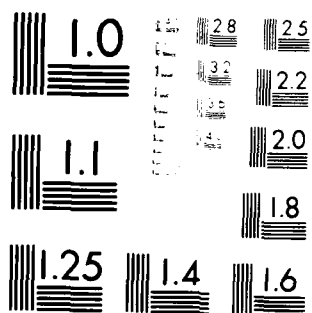
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