INVENTORY MANAGEMENT: POSITIVE AND NORMATIVE MODELS OF DECISION-MAKING IN THE METALS SERVICE CENTER INDUSTRY

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ABSTRACT

INVENTORY MANAGEMENT: POSITIVE AND NORMATIVE MODELS OF DECISION-MAKING IN THE METALS SERVICE CENTER INDUSTRY

by John D. Demaree

Over the past ten to fifteen years there has emerged an increasingly widespread interest in inventory theory and practice. Among the reasons for this increased interest are the importance of inventory management, per se, and the use of the inventory problem as a means of developing models of decision-making within the firm. This study develops positive and normative models of inventory management in the metals service center industry. "Positive" models describe how decisions are actually reached, while the "normative" models are in terms of how decisions ought to be reached. The economic theory of the firm, inventory theory, and operations research approaches are considered normative in nature, since they prescribe how decisions ought to be reached.

Among the important questions underlying this study were: How _do_ firms reach basic inventory decisions? At what rate is inventory theory being put into practice? What are the problems involved in the implementation of inventory theory? Where no models are being used, is it because there are no appropriate models, or is it lack of knowledge of the existence of applicable models?

The early part of this study describes the nature of the metals service center industry, and provides _a priori_ reasons for anticipating

highly sophisticated inventory management practices. Two sources of data provided a basis for the development of the positive models of decision-making. A questionnaire was developed and sent to all member firms of the Steel Service Center Institute. The 240 questionnaire returns (a 53% response) provide an overall picture of inventory management practices, including the types of inventory record-keeping systems, use of computers, the basis for determining order quantities, how safety stocks are established, methods of forecasting, statements of inventory management problems, etc. Personal interviews in thirty firms provided the second source of data.

The normative models of decision-making include basic order quantity and re-order point models which either are or could be used in a wide segment of the metals service center industry. A computer program was developed to test the sensitivity of these models to errors in estimating the inventory holding cost and to determine the costliness of filling an arbitrary "percentage of demand to be filled during lead time."

This study reveals a wide diversity of inventory management practices, with a significant portion of the industry exhibiting a gap between inventory theory and practice. A review of the historical development of inventory theory provides insights into some of the reasons for such a gap. Conceptualization and implementation problems, centering around the need for the use of mathematics, difficulties in determining inventory holding costs, and overhead accounting problems have historically been troublesome, and a wide prevalence of these same problems was encountered in this study. In a number of cases the inventory problem was conceptualized by respondents in a manner that precluded the application of scientific inventory theory.

Other findings of this study provide evidence of the impact of the computer as a stimulus for the introduction of scientific inventory control, and the need for intra-company research to enhance the understanding of inventory management variables and models.

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By

John D. Demaree

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TABLE OF CONTENTS

CHAPTER | Page

I. INTRODUCTION AND RESEARCH GOALS 1

"Positive" and "Normative" Meanings
Inventory Theory Approach
Behavioral Theory Answer
Research Questions
Test of Hypotheses in Metals Service Center Industry
Summary of Chapter and Organization of Study

II. THE METALS SERVICE CENTER INDUSTRY . . . 9

Industry Description
Distribution, Processing, and Service
Specialty, General Line, and Complete Line Metals Centers
Structure of the Industry
A "Typical" Service Center
"Pickups" from Competitors
Quantity Extras
Cost of Possession Concept

Preliminary Research Data
Evidence of Inventory Problems

Data-Gathering Methodology
Company Visitation Data-Collection Procedure
The Questionnaire

III. DEVELOPMENT OF INVENTORY THEORY AND PRACTICE 22

Early Theory
Conceptualization and Implementation Problems
Interest Rate and Overhead Accounting Problems

TABLE OF CONTENTS - Continued

CHAPTER Page

Resistance to Use of Lot-Size Formulas
Later Developments

Recent Theory
Gap Between Theory and Practice
Reasons for Increased Interest in Inventory Theory and Practice

Summary of Chapter

IV. INVENTORY MANAGEMENT SURVEY 39

Introduction
Inventory Record-Keeping Systems
Determination of "When" to Submit Orders for Replenishment
Order Quantity Determination
Cost of Possession
Sales Forecasts
Criteria for Correct Inventory Level
Present Plans for Record-Keeping and Data-Processing Systems
Problem Areas
Summary of Chapter

V. COMPANY VISITATIONS 70

Smaller Metal Service Centers
Records Used in Reaching Ordering Decisions
Evidence of Rules Governing Ordering Practices
Low Alternative Capital Cost
Summary of Small Company Practices

Medium-Size Metals Service Centers
Example of a Well-Developed Program
Two Companies Using Intuitive Decision-Making
Remaining Companies in Medium-Size Category
Summary of Medium-Size Company Practices

TABLE OF CONTENTS - Continued

CHAPTER | Page

Large Metal Service Center Companies
Similarity of Basic Problems
Evidence of Transitional Stage
Varying Computer Uses
Non-Computer-Using Companies
Division of Inventory Responsibility by Commodity Groups
Summary of Large Company Practices

VI. NORMATIVE MODEL DEVELOPMENT 102

Order Quantity Model
Difficulty in Use of Classic EOQ Model
Total Annual Inventory Cost Formula
Points of Indifference
Return on Invested Capital Formula
Preparation of Indifference Tables
Computer Programs for Order Quantity Determination
Stock Purchases from Other Service Centers
Construction of Indifference Point Graphs
Use of Indifference Point Graphs
Importance of Consistent Ordering Policies
Inventory Holding Cost as a Management Control Variable

Safety Stock Model
Problems of Parameter Estimation
Lead Time Estimation
Estimation of Average Demand During Lead Time
Determination of Standard Deviation of Demand Distribution
Use of Estimators for Standard Deviation
Problem with Differing Forecasting and Lead Time Intervals

TABLE OF CONTENTS - Continued

CHAPTER | Page

Total Cost Model and Model Sensitivity
Test of Model Sensitivity
Model Sensitivity to Holding Cost Percentage
Model Sensitivity to Safety Stock Levels

Chapter Summary

VII. SUMMARY, CONCLUSIONS, AND NEEDS FOR FURTHER RESEARCH 148

Metals Service Centers
Historical Background
Inventory Management Survey
Company Visitations
Normative Models

Present Practices in Perspective
Economic Theory and Behavioral Theory Perspectives
Inventory Practices in Historical Perspective

Present Trends and Needs for Further Research
Reduction in the Cost of Calculations
Economic Impact of Inventory Theory Application
Need for Intra-Company Research
Other Research Needs

BIBLIOGRAPHY 167

APPENDICES 171

LIST OF TABLES

TABLE		Page
4-1	Number of Branch Plants per Company.	40
4-2	Gross Sales Distribution	41
4-3	Record-Keeping Systems by Company Size	42
4-4	Re-order Point and Periodic Review by Company Size	43
4-5	Guides in Determining Order Quantities	46
4-6	Cost of Possession Calculation by Company Size. .	49
4-7	Sales Forecasting Methods	52
4-8	Criteria for Inventory Levels	54
4-9	Order Cost Estimate and Items per Order	56
4-10	Stock Pickups from Competitors	57
4-11	Computer and/or Data Processing Plans	60
4-12	Inventory Problems by Company Size.	66
6-1	Indifference Points for Regular-Size Hot Rolled Bars	108
6-2	Service Center vs. Mill Indifference Points	113
6-3	Relationship of Average Inventory Level to Holding Cost Percentage	122
6-4	Safety Factors to Minimize Overstock and Understock Cost	126

LIST OF TABLES - Continued

TABLE		Page
6-5	Safety Factors Related to Profit Margin and Turnover.	128
6-6	Model Sensitivity to Errors in Holding Cost Percentage.	141
6-7	Sensitivity of Total Cost Model to Service Levels .	145

LIST OF ILLUSTRATIONS

GRAPH		Page
6-1	Order Quantity and Annual Inventory Cost.	105
6-2	Indifference Point Graph	116
6-3	Inventory Levels at Various Holding Cost Percentages	121

LIST OF APPENDICES

APPENDIX Page

A. Inventory Management Survey 172

B. Exponential Smoothing 178

CHAPTER I

INTRODUCTION AND RESEARCH GOALS

Over the past ten to fifteen years there has emerged an increasingly widespread interest in both inventory theory and practice. A review of the books and periodical literature in the area of inventory theory indicates that research and writing occurs widely in the fields of industrial engineering, operations research, business administration, economics, physical distribution, behavioral theory, information theory, accounting, etc. Because of this widespread interest in inventory theory it is particularly important that any further studies be carefully delineated in terms of where such research fits into the existing body of knowledge.

The present study, an empirical investigation of inventory management in the metals service center industry, was undertaken with some definite goals in mind. Fundamentally, the task of this research is to determine the basis upon which firms reach inventory management decisions, and to make use of these research results to set forth both positive and normative models of decision-making. Underlying this research objective are a number of specific hypotheses. Before discussing these specific hypotheses, the meanings attached to the terms "positive" and "normative" will be discussed.

"Positive" and "Normative" Meanings

In brief, a positive model refers to how firms do reach decision--whereas a normative model refers to how they ought to reach decisions.

Webster's Third New International Dictionary of the English Language provides definitions as follows:

positive: -concerned with facts and matters of practical experience rather than theory or speculation.
-actual or real rather than fictitious.
-subject to scientific verification; empirical--distinguished from speculative.

normative: -creating, prescribing, or imposing a norm. Predictive, didactic.

Cyert and March, in their book, A Behavioral Theory of the Firm,[1] use these terms. They use the term "positive model" to describe the empirical studies of decision-making within the firm, and they use the term "normative model" in reference to the operations research tools which have been used in prescribing normative solutions to problems of the firm.

In terms of this present study, the overall research focus is on the question: "On what basis are decisions made concerning when and in what quantity various stockkeeping units will be replenished?" A complete answer to this question involves a large number of interrelated economic and behavioral variables, so that what at first appears to be a simple question has a highly complex answer. The question itself is of central importance, and will be briefly discussed from several broad perspectives in terms of how it either is answered or should be answered.

Inventory Theory Approach to the Question

In its simplest form the inventory theory approach to the question would be:

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[1]Richard M. Cyert and James G. March, A Behavioral Theory of the Firm (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1963), p. 289.

It can reasonably be assumed that the goal is to minimize the sum of the costs of acquiring inventory, carrying inventory, and the cost of lost sales when there are inventory shortages. To accomplish this goal a set of ordering rules will be developed, and these ordering rules will determine when, and in what quantity, the various items of inventory will be replenished.

To arrive at these ordering rules it will be necessary to make use of a mathematical model which takes into account the pertinent variables. The use of the model will require appropriate data on demand, lead time, and costs. The use of the model will provide solutions and guidance in setting up the ordering rules as part of inventory policy.

The above description would fit the simplest EOQ model or it would fit a model of the complexity of Arrow's (s, S)[2] model. Arrow has commented on the inventory theory approach as follows:

> Ideally we'd like to find an optimal solution. Where no optimal solution can be found we seek to at least determine the value of the objective function for any given set of values of the decision variables. This later may be referred to as a descriptive solution.[3]

Behavioral Theory Answer to the Inventory Question

If managers behaved in accordance with the traditional economic theory of the firm, then one would expect to find a widely prevalent use of inventory theory in establishing ordering policies. At least under these circumstances there would be an attempt to develop marginal costs, including the marginal cost of additional information required to use a model of given precision, and to utilize these costs to arrive at an optimal solution. If it is assumed that firms infrequently

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[2]Kenneth Arrow, Samuel Karlen, and H. Scarf, Studies in the Mathematical Theory of Inventory and Production (Stanford, California: Stanford University Press, 1958).

[3]Ibid., p. 16.

use anything approaching the conventional marginal calculations of costs, then it is necessary to seek other means of explaining the basis for decision-making. Simon's answer would be something like this:

> Because of the limits of human intellective capacities in comparison with the complexities of the problems that individuals and organizations face, rational behavior calls for simplified models that capture the main features of a problem without capturing all its complexities.

Through this simplification process Simon says that the decision-maker is "satisficing,"[4] rather than maximizing as would be the case were he reaching decisions under an inventory theory and operations research approach.

Cyert and March suggest that decisions concerning inventory ordering policies must be at least partly explained in terms of such concepts as organizational slack and uncertainty avoidance.[5] They make a particularly relevant comment, however, under the label "supplement to operations research models," in which they state:

> Much of modern effort in operations research and management science is directed toward developing decision rules and strategies for making the classic decisions within business firms. These decisions--pricing, production, inventory, advertising, investing--overlap considerably with the decisions considered in the previous chapters from a positive point of view. Quite literally, therefore, widespread shifts in the decision rules used by firms would require us to reconsider the details--if not the basic framework--of our theory.[6]

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[4]James G. March and Herbert A. Simon, Organizations (New York: John Wiley and Sons, 1959), pp. 140-141.

[5]Richard M. Cyert and James G. March, A Behavioral Theory of the Firm (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1963).

[6]Ibid., p. 290.

The preceding quotation is of interest in relation to a statement of Churchman, et al.:

> More operations research has been directed toward inventory control than toward any other problem area in business and industry. Applications to military inventory problems are becoming increasingly numerous as well. For this reason there are more models available for this class of problems than for any other.[7]

Operations research efforts, along with the inventory theory research carried out in many other disciplines, fits into what has been referred to as the "normative" approach. Yet, other theorists are suggesting that a behavioral theory, built upon "positive" models of decision-making, is required to explain the actual decision-making within the firm. This dichotomy raises a number of interesting and theoretically pertinent questions. For example: How do firms reach basic inventory decisions? At what rate is inventory theory being put into practice? What are the problems involved in the implementation of inventory theory? Where no models are being used, is it because there are no appropriate models, or is it because of the lack of knowledge of the existence of such models? The answers to these and other questions are of theoretical interest in terms of gaining an understanding of inventory theory implementation problems as well as to provide a guide for further research. As Cyert and March have suggested:

> If our analysis is correct, a behavioral theory of the firm has implications for operations research models at two different levels of generality. First, a model of a specific decision-making process could form a basis for identifying organizational constraints on a decision rule. Thus, it would be one basic device for defining the precise problem facing the organization. Second, the theory seems to indicate that

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[7]C. West Churchman, Russell L. Ackoff, and E. Leonard Arnoff, Introduction to Operations Research (New York: John Wiley and Sons, Inc., 1957), p. 426.

efforts to improve an organization as an adaptive system might be more relevant than efforts to generate some kind of optimizing decision rule.[8]

Research Questions

The preceding discussion has indicated some of the reasons for the theoretical importance of an empirical study of inventory management decision-making. Following are listed the precise goals and questions answered by this research study. In each case, the question or hypothesis is stated, and is followed by a discussion of the importance of the question, underlying hypotheses, etc.

1. What is the basis for reaching the inventory management decisions concerning when and in what quantities stock-keeping units will be replenished?

The precise manner in which such decisions are reached is a primary goal of this study. In those firms where "normative" models of decision-making are employed, it is hypothesized that there will be clear evidence of the inventory policy and ordering rules for guiding inventory replenishment. Another underlying hypothesis is taken from March and Simon: "The greater the repetitiveness of individual activities, the greater the programming."[9] Thus, because of the repetitiveness of inventory management decision-making, it is hypothesized that observation, interviews, and the examination of records will provide evidence to describe the basis for inventory management decisions.

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[8]Richard M. Cyert and James G. March, A Behavioral Theory of the Firm (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1963), p. 192.

[9]James G. March and Herbert A. Simon, Organizations (New York: John Wiley and Sons, 1959), p. 143.

2. Normative models of decision-making.

A second major goal is to suggest appropriate normative models for arriving at these basic inventory management decisions. Here, too, there are a number of underlying hypotheses. For example, it is hypothesized that models are available which either are being used or could be used. The availability of such normative models will serve as a basis for contrast with the positive models of decision-making, and will help identify some of the organizational constraints on a decision rule.

Test of Hypotheses in Metals Service Center Industry

There are a number of reasons why this industry provides an interesting opportunity to test these hypotheses. Most of these reasons center around the central importance of inventory management in this industry. For example, inventory investment makes up the largest investment in assets. In addition, the industry is aware of the "cost of possession" concept and this provides a further reason to anticipate their use of this cost in their own inventory management. As will be discussed in a subsequent chapter, there are other characteristics of this industry which should be known in order to adequately understand and interpret their inventory management practices. A further reason for a more detailed description of the industry is to point out some of the reasons why the results of this research may be generalized to apply to other distribution industries.

Summary of Chapter and Organization of Study

This chapter has described the meanings of the terms "positive" and "normative" in relation to decision-making models. The basic

research questions were pointed out, along with a discussion of the hypotheses underlying these questions and research goals.

Chapter Two is devoted to a description of the Metals Service Center Industry. Particular emphasis is given to those aspects of this industry which enhance the understanding of their inventory management problems. The latter part of this chapter includes a discussion of some preliminary research data covering inventory management problems in the industry; this is followed by a discussion of the methodology followed in the gathering of data for answering the questions concerning industry inventory management practices.

Chapter Three provides a description and analysis of the development of inventory theory and practice. This chapter serves several important purposes. First, it provides a basis for placing the present inventory management practices in historical perspective. In addition, it provides a basis for an interpretation of some of the current implementation problems.

Chapters Four and Five summarize the data and answers to the questions concerning "positive" models of inventory management, while Chapter Six is devoted to the development of normative models of decision-making. The last chapter serves as a summary of the study, and points out some of the overall conclusions, present trends, and the opportunities and needs for further research.

CHAPTER II

THE METALS SERVICE CENTER INDUSTRY

This chapter identifies the metals service center industry and describes some of the reasons why this industry has provided an interesting research opportunity for a study of inventory management decision-making. The latter part of the chapter is devoted to an analysis of some preliminary research data and the methodology used in gathering data in the industry.

Industry Description

While the first metals warehouse may be traced back to pre-Revolutionary days,[1] it has been primarily in the last quarter of a century that metals service centers have assumed an identity as an industry. With sales in excess of three billion dollars per year, this industry distributes in the range of fifteen to sixteen percent[2] of the steel used for industrial steel products in this country. These industrial steel products include structurals, bars, plates, sheets, strip, tubing, etc., in various grades of steel. Merchant steel products and semi-finished steel products make up additional categories of items distributed through metals service centers. Other important materials distributed through service centers include aluminum, copper, brass, magnesium, and plastics.

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[1] "All About Steel Distribution and Steel Service Centers," Kaiser Aluminum News, Volume 19, No. 5, p. 11.

[2] Robert G. Welch, "Revolution Brewing in Metals Distribution?" American Metal Market, Section 2, June 3, 1963, p. 8.

Distribution, Processing, and Service

To be described adequately the metals service center industry must be considered in terms of its functions in distribution, processing, and service. Historically at least, what are today's metals service centers were more appropriately termed warehouses, since their primary role was one of selling metals--with little processing. Today, however, "pre-production" processing is an increasingly important part of service center operations, and equipment such as saws, slitters, shears, levellers, coiling equipment, grinding and finishing equipment, and flame cutting equipment is used to meet customers' needs. Currently it is estimated that 68% of the orders shipped from service centers are processed in one way or another, and the forecast is that by 1970 this percentage will be in the range of 78% to 80% of service center shipments.[3]

It is an accepted industry practice to fill routine orders in one day or less time. This practice, when considered along with the increased amount of pre-production processing and the fact that essentially all manufacturing companies in the United States buy at least a portion of their metal requirements from metals service centers, establishes the service nature of this industry.

Specialty, General Line, and Complete Line Metals Centers

While it is difficult to precisely categorize the various companies in the metals service center industry, a broad division can be made in terms of the completeness of the line of metals carried. The specialty centers, as the name implies, carry a "specialty" line. For example, a company may specialize in tubes, carrying an inventory

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[3]Personal interview with Robert G. Welch, President, Steel Service Center Institute. June 24, 1964.

of as many as ten thousand different tubes. Another company may specialize only in stainless, aircraft alloy, and cold-finished carbon steel bars. A "general line" service center carries a general--but not necessarily complete--line. For example, it may carry hot-rolled items, some cold-rolled bars, some cold-finished sheets, some carbon plate, some aluminum, etc. While one or more of these lines may be quite "complete," they are not all complete, for if they were the company would be better described as a "complete line" company.

Structure of the Industry

Just how many companies there are in the metals service center industry is not precisely known, although in general terms it can be said that there are approximately 800 companies with a total of approximately 1300 "establishments" or locations.[4] These figures change as companies enter or leave the industry, as mergers take place, or depending upon one's definition of just what constitutes a metals service center. The point of interest here is that the metal service center industry is made up of a large number of "establishments" located close to their markets.

Among the largest companies in the industry are a number of divisions or wholly-owned subsidiaries of metals producers. For example, there is the U. S. Steel Supply Division, with 19 branches; Jones and Laughlin Steel Warehouse Division, with 12 branches; Joseph T. Ryerson & Son, Inc., a subsidiary of Inland Steel Company, with 21 branches; Reynolds Aluminum Supply Co. of California, with 21 branches; Chase Metals Service Division of Chase Copper and Brass Company, with 22 branches. In the parlance of the industry these companies are known as "captives."

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[4]"All About Steel Distribution and Steel Service Centers," Kaiser Aluminum News, Volume 19, No. 5, p. 11.

There are also a number of large independents, e.g., Central Steel and Wire Company, A. M. Castle and Company, Earle M. Jorgensen Company, Metal Goods Corporation, Edgcomb Steel Company, and Peter A. Frasse & Co., Inc. Many of these companies have a large number of branches, although it should not be inferred that the number of branches is the criterion of company size, since among the large independents are companies which do not have numerous branch plants.

A "Typical" Service Center

While it is easy to differentiate centers on the basis of whether they are captives or independents, complete line or speciality, etc., it is of perhaps greater importance in this study to point out what metals service centers have in common. In terms of inventory management each "establishment" is a stocking center for a line of metals carried by a particular company. Certain decisions must be made. For example, what items are to be carried in the line, how much of an item is to be ordered at one time, or how low must the stock be for given items before replenishment stock is ordered are questions which must be answered by all service centers.

A scene of great activity in a typical service center is the order or inside sales department where typically 85% of the orders for materials are received by telephone.[5] This department has been referred to as the "nerve center" of a service center. Naturally, in accepting orders, it is necessary for these people to know what material is available in stock for immediate delivery, and thus it is not surprising that the order department is frequently located near the

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[5]Personal interview with Robert G. Welch, President, Steel Service Center Institute, Cleveland, Ohio. September 27, 1963.

inventory records. In fact, it is not uncommon for the people on the order desks to maintain the inventory records.

"Pickups" from Competitors

One of the interesting industry practices has to do with what is referred to as a "pickup" from one's competitor. A service center may receive an order for material which either it doesn't carry or for which it is temporarily out of stock. Perhaps this particular item was only one of a number of items which a given customer had requested. What a service center will frequently do, under these circumstances, is to send a truck over to a competitor to pick up the required material. This way the material will probably still be delivered on time to the customer, who may not even know, or care, for that matter, that the material was not delivered from the service center's own stock. This is an advantage in dealing in what is essentially a non-differentiated material.

The opportunity to pick up material from another metal service center has an important bearing on the subject of stockout penalties. Because of this practice it is possible to develop a reasonable estimate of the penalty or loss from being out of stock. Several types of "losses" may occur. When a stockout occurs a company may go to a competitor and either get just enough material to fill the customer's order, or may purchase a larger amount of material so that the balance over the customer's requirement will serve to replenish the inventory. In either case there is a "loss" because the material purchased from another service center carries a higher price than the same material purchased from a mill. At the maximum the loss is closely approximated by the loss in gross profit margin, plus perhaps the trucking expense to pick up the material from a competitor. What is of great interest is that there is no loss of goodwill which would otherwise

accompany the out-of-stock condition. In fact, throughout the industry the opportunity to pick up material from other service centers is looked upon as a means of enhancing good will, since through this means any given service center draws upon the stocks of other service centers throughout the country in order to meet any type of metal requirements for its customers.

Quantity Extras

While some of the non-ferrous metals are distributed by the producing mills on a consignment basis, the general practice in the ferrous metals area is to purchase the materials outright. In general terms, steel is purchased under what could be referred to as an "all units" discount.[6] For example, if 40,000 pounds of regular size hot-rolled bars are purchased from the mills there is no quantity extra, i.e., the base price applies. If from 20,000 pounds through 39,900 pounds are purchased, then base price plus a "quantity extra" of \$.05 per one hundred pounds applies. If from 10,000 pounds through 19,999 pounds is purchased the quantity extra is \$.15 per hundred pounds, and if from 6,000 pounds through 9,999 pounds is purchased the quantity extra is \$.35 per hundred pounds. The above is all the relevant information required, since the mills normally accept no orders for less than 6,000 pounds of hot-rolled bars. While there are a number of different quantity extras schedules to fit the various classes of steel products, the problem is essentially the same, i.e., when should one take advantage of the material savings by buying in a higher quantity bracket? What quantity bracket to purchase in might be considered a universal problem in the industry, and one which would seem amenable to the EOQ approach.

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[6] G. Hadley and T. M. Whitin, Analysis of Inventory Systems (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1963), p. 62.

Cost of Possession Concept

In 1957 the dominant metals service center trade association, now known as the Steel Service Center Institute, commenced an advertising program built around the "cost of possession" concept. The heart of this concept is that there are costs attached to holding inventories, and that the "true" cost of metal is the sum of the initial purchase price plus the cost of possession. Since 1957 the Steel Service Center Institute, joined in this endeavor by the producing mills, has spent many hundreds of thousands of dollars advertising the cost-of-possession concept through newspaper and magazine media.

In addition to the advertising program, a booklet entitled "What's Your Real Cost of Possession for Steel?" was prepared and distributed through Steel Service Center Institute member companies. Among other features this booklet included a cost-analysis guide for steel purchasers. It might be added that this booklet showed great confidence on the part of this steel service center trade association that their function in the processing and distribution of metals was grounded in sound economics. A spokesman for the industry exhibited this confidence when he stated:

> By making these pre-processing and inventory-keeping activities their main economic function, centers can afford to develop the specialized skills, people and equipment needed to do these jobs at a cost which is attractive to manufacturers. And by spreading the cost of a varied inventory, specialized processing equipment and skilled manpower over hundreds or even thousands of customers and individual orders, service centers, in many instances, make steel available, ready for the final production processes, at a cost which cannot be duplicated by either the producers or the ultimate consumer.[7]

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[7]Robert G. Welch, "Revolution Brewing in Metals Distribution?" American Metal Market, Section 2, June 3, 1963, p. 8.

When the members of the Steel Service Center Institute were queried about how helpful the concept had been in their own selling and merchandizing, 90% of those who replied said that it was helpful, and many could trace additional business to its use. All of this is particularly pertinent to this study for several reasons. First, of course, the principles underlying this concept get to the very root of inventory theory. It could be reasoned that the industry's use of the cost analysis worksheets would have inspired the application of these same principles in their own inventory management. Then, too, the great majority of metal service center buyers are also combination mill-service center buyers, the group of buyers to whom the "cost of possession" message was particularly aimed. What is being suggested is this: it is necessary for a metals service center to know its own costs of possession in order to answer the same questions it has asked its customers to answer. An increase in the processing of metal users orders, coupled with metals users' reliance upon service centers to provide an increasing number of special sizes, types, and grades of metal, may very well have acted unfavorably to shift some of the "costs of possession" from the users to the service centers. Metal service center industry spokesmen[8] point out that there is continuing pressure on the metal service centers to maintain profit margins in the face of increased investment in materials and equipment required in assuming the costs of possession. All of this discussion is intended to provide additional _a priori_ reasons for expecting a widespread effort within the industry to evaluate alternative marketing and inventory management doctrines on the basis of the decision-making costs underlying the cost-or-possession concept.

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[8]Hi Howard, "Looking Ahead," _American Metal Market_, Section 2, May 4, 1964, p. 12.

Preliminary Research Data

In formulating the research design for this study, some valuable insights were gained through study of some data collected by Professor Charles Lawrence, of Michigan State University. In preparation for a seminar in finance to be offered to Steel Service Center executives, Professor Lawrence sent out sets of questionnaires to those who would be attending the seminar. One part of the questionnaire set was to be filled out by the top executive, while the second part of the questionnaire set was to be filled out by the person responsible for supplying financial information to the top executive. The questionnaires were designed to search out not only what type of financial reports were presently being submitted, but to indicate how the reports were used and their purposes, objectives, contents, etc. In addition, the questionnaires provided an "open end" question which asked for opinions concerning the current problems in the business that financial planning and reporting would help to solve.

Replies were received from twenty-six companies, and these reports were analyzed to see if they offered any insights, patterns, or emphasis relative to the inventory problem. On an *a priori* basis one would expect a number of references to financial reports dealing with inventory management. At a minimum, it would be expected that there would be numerous references to inventory investment and control as part of the current problems of financial planning and reporting.

Twenty of the twenty-six companies did specifically mention inventory reports, analyses, or problems. It was clear that most of these reports were designed to show the overall status of inventory. One of the more complete reports was described as follows:

> Monthly inventory analysis--by branch. By commodity, showing beginning inventory, receipts, sales, transfers, adjustments, and ending inventory in units and dollars. Average cost by commodity groups, average inventory investment, commodity investment percent of total inventory, inventory turnover by commodity and scrap loss, month and year to date.

The report described was produced through the use of electronic data processing. This leads to another interesting observation evident from the questionnaire responses. Ten of the twenty-six companies made reference to the use of EDP for accounting and sales analysis purposes, as deduced from replies such as "IBM summary of sales by product, by branch, by salesman; indicating pounds sold, sales dollars. . . ."

While there was this evidence of rather widespread use of EDP for accounting and sales analysis purposes, there was little evidence of any item-by-item inventory control making use of mechanical or electronic equipment.

Evidence of Inventory Problems

Seven of the twenty-six questionnaires specifically mentioned inventory problems. For example:

> Inventory control and planning--some method devised that would permit us to measure proper inventory turnover on an item and product basis, possibly some correlation between ordering pattern as to the relationship of quantity extras and final net acquisition cost in relationship to proper turnover.

> I believe that the control of inventories offers a great area for improvement in our industry. We are spending a good deal of time trying to develop methods through data processing whereby we can provide maximum service to our customers at the least possible investment in inventory dollars.

> Inventory maintenance demands careful planning and control to maximize turnover consistent with satisfying sales needs and return on investment.

> Formula to determine amount of steel to purchase at any time considering item quantity discounts, sales rate, interest, and added expenses or savings.

These four problem statements include most of the elements of the types of problems which inventory theory serves to help answer. It is of interest that two of these problem statements specifically refer to "item" analysis as a requirement.

Data-Gathering Methodology

Personal visits and a questionnaire provided the data for this study. The researcher visited thirty companies, for from one-half day to two days each, and mailed questionnaires (see Appendix A) to all member firms of the Steel Service Center Institute. Completed questionnaires were returned by 240 of the approximately 450 firms in the association, representing a 53% response.

Company Visitation Data-Collection Procedure

Through the SSCI, visits to a broad sample of firms were arranged. These companies ranged from very large companies, with many branches, to relatively small, single-plant service center companies. Included in the sample were companies from coast to coast, including specialty, general line, and complete line firms, as previously described.

The typical procedure followed in each of these visitations was to first meet the top executive, or at least the top operating executive. The interview with this executive was utilized to hear what the top operating executive's views were concerning his own company's inventory management, and how he maintained control of inventory investment and decisions, criteria used, plans for the future, etc.

In some of the smaller companies, and in fact even in some fairly sizeable companies, the top operating executive makes the decisions concerning when and how much to buy. In the larger companies the president introduced me to those responsible for inventory management, and it was from them that I gathered more detailed information concerning their day-to-day operating procedures. By dealing with two or three levels of management in many of these company visitations, it was possible to gain knowledge of the varying viewpoints on problems from one level of management to the next.

During these visits a variety of data were accumulated. In talking to the individuals actually managing the inventory records and taking care of stock replenishment, particular attention was given to the rules they followed, the constraints they were operating under, the devices they used to guide purchase quantities, their views of safety stock, how lead time was handled, the rules of thumb being used, and what they considered particular problem areas.

The Questionnaire

The researcher developed a four-page questionnaire, copies of which were sent to each member firm of the Steel Service Center Institute. The first items in this questionnaire dealt with the type of company, number of branch plants, gross sales, and type of inventory record-keeping system. This information made up the "control" variables against which to relate the remaining questions in the survey. These remaining questions were designed to elicit information concerning ordering rules, lead-time determination, forcasting methods, inventory holding cost percentages, the means of judging inventory levels, etc.

With the properly coded answers to the questionnaire punched on IBM cards, a computer program developed two-by-two contingency

tables. The "control" variables, e.g., type of center, gross sales, etc., served as a basis for analyzing the responses to the remaining questions in the survey. In this manner it was possible to analyze the relationships and patterns of practice which were dependent upon type of center, number of branch plants, gross sales, or type of inventory record-keeping system employed. Through the use of these contingency tables, which included cell frequency, row totals, column totals, and cell percentages of row and column totals, it was possible to establish differences in inventory management practices as related to the control variables.

Summary of Chapter

This chapter has served to identify the metals service center industry and to provide a basis for a better interpretation of the remaining part of the study. The industry is characterized by a large number of metal service centers, close to their markets, and each of which is a stocking center for a given line of metals. The opportunity to "pickup" from competitors, and hence to calculate with reasonable precision stockout costs, the quantity extras price schedules, the industry's emphasis on cost of possession, and the large percentages of total assets represented by investment in inventory would all provide *a priori* reasons for expecting highly sophisticated inventory management practices. The analysis of some preliminary research data raised some questions concerning the manner in which financial reporting reflected inventory management practices, particularly in terms of ordering rules. The latter part of the chapter presented the data-gathering methodology employed in the company visitations and inventory management questionnaire.

CHAPTER III

DEVELOPMENT OF INVENTORY THEORY AND PRACTICE

The purpose of this chapter is to review the main threads in the development of inventory theory and practice and to point out some of the reasons for the current widespread interest in scientific inventory control. With some justification, as will be discussed, the history of inventory theory can be divided into two periods, with the first period extending to approximately 1950, and the second period from 1950 to date. The principal developments during these two periods will be discussed, in turn, under the headings of "early" and "recent" theory.

Early Theory

Part of what is now referred to as inventory theory had its origin in the problems concerned with lot-size production. The growth of large scale production and repetitive manufacturing processes necessitated consideration of the problem of minimizing unit cost. More specifically, the question was: "How many units are to be manufactured on each setup?" The desired goal was to select a number of units to be manufactured on each setup so that either the yearly charges for setup and storage would be equal--which could be referred to as the "balancing" problem--or to achieve a minimum of the total charges for setup and storage--which could be referred to as the "minimum cost" approach.

The names of Babcock and Harris are two of the first individuals to deal explicitly with mathematical formulations of the variables

involved in the lot-size problem. In 1912, Babcock was attempting to equate setup costs and carrying costs, and in this endeavor he developed formulae to calculate standard lot sizes.[2] However, the first published lot-size formula as we know it today was used by Harris,[3] at Westinghouse Electric and Manufacturing Company. This formula was:

$$Q = \sqrt{\frac{MS}{C}\,k}$$

Where: Q is the economic lot size.
S is the daily rate of sales.
C is unit-production cost.
k is a constant which includes the cost of capital, interest, and depreciation.
M is the setup cost.

It is of interest to note that nearly fifty years ago Harris first emphasized the necessity for insuring that the assumptions upon which the economic lot size formula is based are applicable[4]--a practice which is standard today.

From 1915, when Harris began using his lot-size formula, until 1931, when Fairfield E. Raymond published his book, Quantity and Economy in Manufacture, a number of other individuals made contributions. Additional factors were added to the basic formula to allow for

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[2]G. D. Babcock, "Taylor System in Franklin Management" (New York: Engineering Magazine Co., 1917), p. 125, cited by Fairfield E. Raymond, Quantity and Economy in Manufacture (New York: McGraw-Hill Book Co., 1931), p. 120.

[3]F. W. Harris, "Operations and Cost" Factory Management Series (Chicago: A. W. Shaw Co., 1915), Chap. IV, pp. 48-52, cited by Ralph L. Disney, "A Review of Inventory Control Theory," The Engineering Economist, Vol. 6, No. 4, Summer, 1961, p. 2.

[4]Fairfield E. Raymond, Quantity and Economy in Manufacture (New York: McGraw-Hill Book Co., Inc., 1931), pp. 121-122.

semi-continuous production, to allow for space charges, etc. In his book, Raymond pointed out:

> Thus the theory of economic lot sizes has received impetus and has been developed until there are extant some thirty-eight or more individual attempts to devise a suitable formula, as well as numerous tables, charts, and other mechanical devices, not to mention untold schemes which have been copied from these.[5]

Because today the lot-size formulas are perhaps more often thought of in terms of purchasing than in terms of production, it is of interest that in 1928 R. C. Davis presented his paper, "Economic Purchase Quantities," to the Management Section of ASME.[6] Prior to this paper the analysis had been in terms of the production problem, and Davis's contribution was to suggest a lot size formula for use in determining economic purchase quantities.

Conceptualization and Implementation Problems

Raymond's book, written when he was Assistant Professor of Industrial Research at Massachusetts Institute of Technology, is a scholarly work which fully summarizes the development of what is now referred to as the "classical" model. In his book, in addition to summarizing developments up to 1931, he developed a series of models by means of which a large number of variables could be considered in arriving at an economic production quantity. In the present context, however, his book seems most interesting for the insight it gives into the conceptual, or methodological, problems which accompanied the

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[5] Ibid., p. 123.

[6] R. C. Davis, "Determination of Minimum-Cost Purchase Quantities," Transactions of the American Society of Mechanical Engineers, Vol. 49-50, Part II, Management Section, pp. 41-44.

development and the use of the first models. Of further interest is a closely related problem--that of implementation of the use of lot-size models into management practice.

Interest Rate and Overhead Accounting Problems

Two problems which caused difficulty in the early development and introduction of lot-size models were the problems of "interest rate as an item of cost" and "overhead accounting." The original Harris formula included the interest rate in a factor, "k," which also included other cost factors, such as depreciation. Subsequently, those who revised and modified this early formula made specific references to the interest charges on work in process, and the interest rate factor appeared in the denominator of the lot-size formula. But there was the problem of what value to use for the interest rate. Raymond pointed out that:

> In the beginning it was customary to use only the cost of capital, but it was soon appreciated that other items pertaining to the costs of doing business ought to be added to it. Such values, where they amount to 10 to 15 per cent, usually reflect the burden of taxes, storage space charges, depreciation losses, and allowances for obsolescence in addition to the cost of capital. Following this came the use of values from 18 to 25 per cent into which were accumulated a multitude of similar charges under the heading of a percentage allowance for the risks of business. From this conception has grown the idea of the real importance for a special treatment of the problem upon the basis of the expected return upon capital employed.[7]

A problem which arose when the cost of capital was put into the formula at too low a value was that very large lot sizes and lower

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[7]Fairfield E. Raymond, Quantity and Economy in Manufacture (New York: McGraw-Hill Book Co., Inc., 1931), pp. 85-86.

capital turnover resulted. In his book Raymond deals with this problem at some length--repeatedly pointing out the importance of capital turnover and the need to distinguish between the cost of capital and the expected return on capital. In one of his lot-size models he makes allowance for his distinction by including a factor, *r*, which is defined as: "The rate of return normally expected on capital invested in manufacturing operations in excess of the interest rate *i*." Thus, this is basically the opportunity cost of capital consideration; Raymond defines it:

> The total amount of this gross return R_t, which will be satisfactory to all, can be expressed as a percentage of the capital invested, and the determination of the rate which is normally expected in excess of the interest rate is a matter of executive policy and should be fixed by the directors in accordance with the expectations of the stockholders and the recognized risks of the business.[8]

In two full chapters devoted to the "cost of capital," Raymond makes it abundantly clear, both by what he has written and by inference, that dealing adequately with the interest rate factor is one of the--if not the most--important requisites for use of a lot-size model.

Overhead Accounting

It is not surprising that one of the major problems involved in the application of lot-size models was to obtain proper cost factors to use in the model. Raymond's model necessitated the classification of cost factors in accordance with detailed descriptions of the characteristics of these cost factors. In regard to this requirement he stated: "Herein lies the whole essence of the principle underlying the choice of the best quantity to produce in any lot."[9] He further pointed out that

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[8] *Ibid.*, p. 142.

[9] *Ibid.*, p. 163.

the outstanding example of fallacious accounting practice was to include set-up and dismantling costs in the unit costs of production. A number of other problems and fallacies were mentioned, but the important point would seem to be that the usefulness of this model was dependent upon the right type of accounting and cost data for decision-making purposes.

Resistance to the Use of Lot-Size Formulas

In commenting on Raymond's book, one writer has said:

> This book is probably the most complete treatment on the subject of economic lot sizes, including the recent treatments by operations research oriented people. Very few of his recommended procedures for determining economic lot sizes were applied to production problems in the following years, possibly due to the economic conditions of the thirties.[10]

In view of this statement it is of interest to look at some of the entreaties used by Raymond to gain acceptance for his approach. The first chapter of his book was titled, "A Scientific Approach to Production Control," and in this chapter he both pointed out the advantages to be gained by the use of economic lot-size formulae and offered a rebuttal to some of the criticisms then being directed at the use of formulae for determining economic-production quantities. Raymond viewed the use of lot-size models in terms of what would today be described as a systems approach, since he pointed out that:

> During this period of development in scientific methods of management, however, it is quite evident that the tendency has been to attack each phase of manufacture as an individual problem in accordance with the exigencies of the situation,

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[10]Thomas L. Newberry, "A Classification of Inventory Control Theory," Journal of Industrial Engineering, Vol. XI, No. 5, Sept.-Oct., 1960, p. 393.

> without any particular regard to the manner in which the fundamentals underlying each phase may be related in a comprehensive and properly integrated scheme for the conduct of all manufacturing activities.[11]

It was Raymond's belief that:

> The mathematical treatment automatically disposes of the necessity for any individual consideration of the various factors and their relationship for every part to be processed. No longer need manufacturing schedules be maintained in estimates of an uncertain origin, generalizations, and the demands of insistent customers. Management can thus maintain a greater control of working capital, only tying up such amounts as the actual market conditions warrant, thereby maintaining inventories in the most liquid condition.[12]

Following these statements, which pointed out the potentially great benefits of scientific control, Raymond admonished those production executives who were reluctant to use any "aids in their management which savored of mathematics or employed formulae."[13] Since mathematics was a tool of management, he asked:

> Can management longer afford to postpone the opportunity offered by a mathematical approach to its problem if the soundness of economic structure which underlies any business enterprise can be more reliably determined by the same methods that the safe loading and strength for each member in the structure of a bridge or the framework for one of our modern skyscrapers?[14]

Further evidence of early resistance to the use of lot-size formulae was presented by Alonzo Flack of Emerson Engineers who,

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[11]Fairfield E. Raymond, Quantity and Economy in Manufacture (New York; McGraw-Hill Book Co., Inc., 1931), p. 4.

[12]Ibid., p. 6.

[13]Ibid., p. 7.

[14]Ibid., p. 8.

in discussing the paper which R. C. Davis presented to the ASME in 1928, stated:

> There are thousands of purchasing agents, their assistants, and storekeepers. The abilities vary widely. Many are of limited education and training. Some are of great ability but have forgotten their mathematical teachings. Some would find an easier way to determine the quantities to purchase even though not as accurate.
>
> In the writer's 20 years of service to industry, he has not found it practical to reduce the determination of minimum-cost purchase quantities to a mathematical formula.[15]

As an indication of the emotional undertones accompanying this resistance, the second discussant of Davis's paper, who interestingly enough was the general manager of the Bridgeport Brass Company, severely attacked the first discussant, stating:

> Mr. Flack illustrates a point of view that has probably done more to obstruct the advancement of good management methods than anything else. Mr. Henry L. Gantt, one of the keenest minds that this society ever had coined an epigram which fits very closely individuals of the type of this "practical" purchasing agent. The epigram is: "The way we have always done it is probably wrong."[16]

Later Developments

Raymond's work essentially sums up the developments in inventory theory up to the early thirties. With only a few exceptions, two of which will be described shortly, these models could be described

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[15] R. C. Davis, "Determination of Minimum-Cost Purchase Quantities," Transactions of the American Society of Mechanical Engineers, Vol. 49-50, Part II, Management Section, p. 43.

[16] Ibid.

as dealing with deterministic (as contrasted to stochastic) variables and as being essentially static in nature.

In the literature it is not uncommon to see the EOQ formula referred to as the "Wilson" formula. While Wilson did make a contribution to inventory theory, as revealed in published articles starting in 1934,[17] it was two other theorists, largely unheralded in the literature, who carried out the work leading up to Wilson's development. The first of these men, Gordon Pennington, dealt with the problem of the non-expected condition that sales might suddenly increase and use up one lot before the next arrived. This led him into the problem of determining the reserve stock for the non-expected conditions. His criterion for the establishment of the reserve stock, M, was described in a 1927 magazine article:

> If too low a reserve stock M is carried to provide for possible delays in the processing or receipt of product, or to allow for an increase in sales beyond expectations, shortages of stock will be frequent. If, on the other hand, M is made large enough to insure against a shortage under any and all possible conditions, interest, storage, depreciation and obsolescence charges will usually be excessive. The best value of M will be that which most nearly balances the probable losses resulting from occasional failure to make prompt shipments against the cost of maintaining the reserve.[18]

The following year a man by the name of Fry established a model wherein demand for the product was allowed to be a random variable. With this as a basis he developed the probability of running out of stock as a function of the maximum quantity stocked.[19] Six years later

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[17] R. H. Wilson, "A Scientific Routine for Stock Control," Harvard Business Review, Vol. 13, No. 1, Oct., 1934, pp. 116-128.

[18] Gordon Pennington, "Simple Formulas for Inventory Control," Manufacturing Industries, Vol. 13, No. 3, March, 1927, p. 18.

[19] T. C. Fry, Probability and Its Engineering Uses (New York: Van Nostrand Co., 1928), pp. 229-332.

Wilson, in an article published in the Harvard Business Review, presented his model for determining re-order points. His contribution, as revealed in this article, was to suggest a means of establishing re-order points, taking into account such variables as the size of orders, number of demands per period for an item, and the level of protection desired. Re-order points were established to provide one of five different levels of protection against stockout, the number of orders per period were assumed to decrease exponentially as the size of the order increased, and the number of demands was based upon a Poisson distribution. In this early article Wilson did point out a limitation to his model:

> It is recognized that special conditions such as that of an item for which a number of requests for small amounts (4, 3, 6, 5, etc.) and some requests for comparatively large amounts (100, 500, 2000, etc.) are received cannot be controlled by the use of the calculator.[20]

Although not exactly in the manner in which he predicted, Wilson did foresee the development of what has become increasingly common practice in the last ten years:

> A system which can efficiently establish ordering points and ordering amounts will obviously effect many economies and may change methods at present employed. For instance, the manager of the stock-room, instead of estimating the amount of stock he requires for the coming week, would submit to the district warehouse his list of sales for the past week. The control clerk at the warehouse would by means of this system determine the amount of replacement stock needed and send the manager this amount. The store-room would be fewer times out of stock and carry a smaller amount of stock more advantageously distributed.[21]

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[20] R. H. Wilson, "A Scientific Routine for Stock Control," Harvard Business Review, Vol. 13, No. 1, Oct., 1934, p. 128.

[21] Ibid.

Recent Theory

Whitin's book, The Theory of Inventory Management, published in 1953, made note of the beginning of a renewed interest in inventory theory. In the preface of this book he remarked about the number of research projects which were being undertaken at that time. His avowed purpose for writing the book, as indicated in the preface, was:

> Business men are also becoming increasingly aware of the need for efficient inventory control. Likewise, economists are beginning to realize the pressing need for incorporating inventory behavior in both the theory of the firm and in business cycle theory. It is hoped that this volume will stimulate further interest among these groups.[22]

An article in the July, 1951, issue of Econometrica, written by Arrow,[23] Harris, and Marschak, and entitled simply, "Optimal Inventory Policy," has already attained somewhat the status of a "classic." In this article they dealt with the problem of finding the optimal inventory parameters for a dynamic system, and in this endeavor they introduced two parameters, (s, S). Their model, frequently referred to as the (s, S) model, might be categorized as a hybrid of what had historically been known as the two-bin and ordering-cycle systems, since it involved checking stocks at the end of a period and if they were less than s to order to bring them (immediately) up to S. If, however, the stocks were greater than s, no stock would be ordered. Their model was designed to determine those values of s and S and the interval between reviews in order to minimize a loss function.

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[22]Thomson M. Whitin, The Theory of Inventory Management (Princeton, New Jersey: Princeton University Press, 1953), preface, p. v.

[23]Kenneth Arrow, et al., "Optimal Inventory Policy," Econometrica, Vol. 19, No. 3, July, 1951, pp. 250-272.

Before continuing with the outline of recent development in inventory theory, it is of interest to note what Arrow had to say about the focus of current (1958) research. Following a review of the historical background of inventory theory, he wrote:

> Most of the elements of modern inventory theory are found somewhere in the preceding discussion. The interrelation of decisions in different time periods and the possibility of changes in demand and supply conditions, whether known in advance or random, were recognized. The cost factors isolated include those of storage, penalty, and production or ordering, the last including possibly a cost independent of the size of the order. The possibility of lag in delivery appears clearly in some discussions of the transaction motive.
>
> It is the integration of those elements into consistent wholes, and the determination of optimal policies for models encompassing numerous features, that have been the focus of current research in inventory theory.[24]

Dvoretsky, Kiefer, and Wolfowitz, in papers appearing in 1952 and 1953,[25] critically examined the paper by Arrow, *et al.*, showing that the (s, S) policy need not be the best of all policies and examining other problems, including the problem of randomly-arriving supply, the assumptions placed on the demand distribution in the classical structure of the inventory problem, etc.

Another approach to the inventory problem was introduced by Simon in 1952.[26] Having noticed that the inventory process is similar

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[24]Kenneth Arrow, Samuel Karlen, and Herbert Scarf, *Studies in the Mathematical Theory of Inventory and Production* (Stanford, California: Stanford University Press, 1958), p. 14.

[25]A. Dvoretzky, J. Kiefer, and J. Wolfowitz, "On the Optimal Character of the (s, S) Policy in Inventory Theory," *Econometrica*, Vol. 21, 1953, pp. 586-596.

[26]Herbert A. Simon, "On the Application of Servomechanism Theory in the Study of Inventory Control," *Econometrica*, Vol. 20, No. 2, April, 1952, pp. 247-268.

to problems in the servomechanism field, Simon developed general problem solutions based on electronic concepts. This analytical approach was continued later in an article by Simon and Holt,[27] in which they dealt with random demand and non-linear cost functions.

Any complete analysis of inventory theory developments during this period would have to include the work of such men as Beckman, Muth, Bellman, Karlin, Scarf, and many others. In fact, right up to the present there has been a heavy production of papers appearing in such periodicals as Management Science, Operations Research, and Econometrica.

Inventory Theory and Inventory Management Practice

The foregoing discussions of "early theory" and "recent theory" included only incidental references to the practices actually being used in the business world. It is worth noting that the early inventory theory development was carried out by engineers and others who were thinking primarily in terms of specific industrial problems. Harris, for example, was working at Westinghouse Electric when he developed his model, R. C. Davis presented his purchasing model to the ASME, and Raymond directed much of the effort in his book toward convincing managers of the benefits from using lot-size models.

In contrast, many of the theoretical developments since 1950 have been the result of efforts by economists, mathematicians, and others frequently far removed from the field where implementation and verification of models are being carried out.

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[27]C. C. Holt, and H. A. Simon, "Optimum Decision Rules for Production and Inventory Control," Proceedings of the Conference on Operations Research in Production and Inventory Control, Case Institute of Technology, Cleveland, Ohio, Jan., 1954, pp. 73-89.

Gap Between Theory and Practice

One could assert with some justification that there has been a rather wide gap between inventory theory and the actual practices of inventory management. Reference has already been made to Raymond's book, published in the early 1930's, in which he presented some compelling arguments for using lot-size formulae, and yet there is doubt concerning how many of his recommended procedures were applied during the following years.[28] In fact, insofar as lot-size formulae are concerned, it may be questioned if they have ever been widely used. Franklin Moore has stated that economic-order-quantity formulae went into eclipse in the 1930's and 1940's, and have only come back into practice with the use of computers.[29] In 1961, Factory magazine published a summary of questionnaire returns received from members of the American Production and Inventory Control Society. Less than 40% of the companies represented by these members made use of economic order quantities in their inventory control, even though 88% of the responding companies had 200 or more employees and were large enough to have staff who were members of an "inventory control" society.[30]

In any discussion of relatively recent theoretical developments, the (s, S) model is usually mentioned. One author has commented upon this model as follows:

> Contrary to our frequent use of plausible approximate criteria in previous models, it [(s, S) model] addresses itself

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[28]Thomas L. Newberry, "A Classification of Inventory Control Theory," Journal of Industrial Engineering, Vol. XI, No. 5, Sept.-Oct., 1960, pp. 391-397.

[29]Franklin G. Moore, Production Control (New York: McGraw-Hill Book Co., Inc., 1959),

[30]"Exclusive Survey of Production and Inventory Control," Factory, Vol. 119, No. 4, April, 1961, pp. 80-87.

> to a rigorous minimization of long-run expected cost. The price paid for such generality and rigor is that--except in the most simple cases--the solutions cannot be obtained in explicit form, and numerical solutions can only be obtained with a computational burden rarely warranted in practice.[31]

Another author, discussing re-order systems, noted that:

> A number of analysts have attacked the problems of obtaining minimum-cost levels for the characteristics of a re-order system of this general type. These have been useful in a theoretical sense in contributing to a deeper understanding of the issues in question, but the direct results in the form of usable techniques for practical problems have not been important.[32]

These quotations are of interest because they refer to the divergence between theory and practice--in the first case because of computational burden, and in the second case because of the difficulty of translating the theory into the form of usable techniques.

Reasons for Increased Interest in Inventory Theory and Practice

A number of reasons may be suggested to account for the recently increased interest in inventory theory and practice. One frequently mentioned reason is the relatively large amounts of working capital invested in inventory. In a period of business expansion such as we have had since World War II there has been pressure for increased operating capital and this has helped bring about an awareness that inventory must be looked upon as a form of earning investment.

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[31]Fred Hanssmann, Operations Research in Production and Inventory Control (New York: John Wiley and Sons, Inc., 1962), p. 51.

[32]John F. Magee, Production Planning and Inventory Control (New York: McGraw-Hill Book Co., Inc., 1958), pp. 85-86.

The use of return on invested capital as a criterion of business performance is another closely related reason for close attention to the inventory problem.

Another major reason for the increased interest in inventory theory is the growth of the fields of operations research and management science. The inventory problem proved interesting and challenging to those engaged in these fields. In 1957, Churchman, et al., stated:

> More operations research has been directed toward inventory control than toward any other problem area in business and industry. Applications to military inventory problems are becoming increasingly numerous as well. For this reason there are more models available for this class of problems than for any other.[33]

The rise of the computer is a further reason for the current interest in inventory theory and control. It will be recalled that Franklin Moore had pointed out that slight use had been made of EOQ models, but that they were coming back into use through use of the computer. This is true not only because the computer is an efficient tool for making what would otherwise be burdensome calculations, but also because the installation and implementation of computer systems stimulated further research in systems development and control. The computer has also helped make simulation a powerful tool, and solutions to an inventory problem frequently depend upon the use of this tool. Arrow commented on this as follows:

> The acceptability of a solution is thus relative to computing technology. With modern developments, straightforward simulation of intricate situations with little or no loss in

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[33] C. West Churchman, Russell L. Ackoff, and E. Leonard Arnoff, Introduction to Operations Research (New York: John Wiley and Sons, Inc., 1957), p. 426.

essential features is sometimes possible so that descriptive solutions are possible with little abstraction or preliminary mathematical analysis.[34]

The universal nature of the inventory problem is yet another reason for the widespread attention it is getting. In one form or another inventories are important in almost every business. Furthermore, the problem is interesting because it provides a means of bringing into focus the conflicting interests in an organization. For example, the maximization of gross sales, the minimization of direct cost of material purchases, the minimization of stockouts, and the maximization of the return on capital invested in inventory are all worthy objectives. Optimizing any one of these worthy goals by itself will almost inevitably result in suboptimization in terms of an overall objective function to be optimized. Hence, an inventory model also helps focus attention on what the real objectives are and on how they may be measured.

Summary of Chapter

This chapter has presented some of the main threads in the development of inventory theory, from the early lot-size models to the present time. Drawing heavily on the book by Raymond, the evidence of early resistance to the use of lot-size formulae was discussed. The gap between theory and practice was pointed out, along with some of the reasons for the recently increased interest in inventory theory and practice.

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[34]K. Arrow, S. Karlen, and H. Scarf, Studies in the Mathematical Theory of Inventory and Production (Stanford, California: Stanford University Press, 1958), p. 17.

CHAPTER IV

INVENTORY MANAGEMENT SURVEY

Introduction

This chapter is devoted to the presentation and analysis of the results of the "inventory management survey" replies which were received from 240 companies, representing in excess of 500 "establishments," or individual metals service centers. Among the returned questionnaires were replies from twenty-five of the thirty companies personally visited, thus providing a cross check between the visitation and the questionnaire responses. With the summary results of this chapter as a base for reference, chapter five discusses typical models in somewhat more detail.

Sample Size and Distribution

The number of companies in this sample comprise slightly over 50% of the member firms in the Steel Service Center Institute. The number of individual service centers represented is in the range of 35% to 40% of the estimated 1300 to 1400 metals service centers in the United States.

The largest number of replies, in terms of type of center, was from those described as "Steel--100%," with sixty-nine replies. The next largest number of replies was from centers which had steel as a major product, with aluminum as the next most important metal, with a total of fifty-five replies. The remaining replies were distributed in accordance with whether the major or minor product was steel;

wholesale hardware and merchant products; non-ferrous metals; fabricating; or brass, copper and miscellaneous.

The number of branch plants per company made up another distribution of companies. As would be expected, the number of branch plants is closely related to the gross sales of the company, with the larger companies frequently having a number of branch plants. Thus, only five--of thirty-five companies reporting gross sales in excess of ten million dollars per year--reported "no branch plants." In the next smaller size company, however, with sales of from five to ten million dollars per year, sixteen of the thirty-three companies reported "no branch plants." Following is a distribution of the number of branch plants per company:

Table 4-1. Number of Branch Plants per Company

Number of Branch Plants		Number of Companies
0		150
1		24
2		18
3		7
4		11
5		9
6		5
7		0
8		2
9 or more		6
	Total	232

The distribution of the replies, in terms of gross sales per company, is as follows:

Table 4-2. Gross Sales Distribution

Gross Sales (Dollars)		Number of Companies
Less than one million		36
One to two million		59
Two to three million		33
Three to four million		23
Four to five million		13
Five to ten		33
Over ten million		35
	Total	232

The type of metal service center, number of branch plants, and gross sales level made up the three principal control variables used for analysis of the questionnaire replies. As mentioned in the preceding chapter, a computer program was used to develop a series of contingency tables. Among the uses of these tables was an attempt to explain which control variables would best help explain differences in inventory management practices. As will become more evident as the results of the questionnaire are presented, it seems quite clear that the size of the company, in gross sales, is the best control variable for indicating differences in approach to inventory management practices. But even this variable serves as a relatively poor predictor of practice.

Inventory Record-keeping Systems

Nearly ninety percent of the responding companies use a manual system of inventory record-keeping. "Kardex, Acme Visible, or Post Index" records are kept in 75% of the companies, and "loose-leaf books" are used in another 14% of the companies. Punched cards for inventory were in use by 5% of the respondents, one company reported magnetic tape as the basic inventory record-keeping system, and eleven companies are using "other" systems of one type or another. It should be pointed out that several companies are presently engaged in or are approaching the conversion to either magnetic tape or punched card systems.

It is of interest that there is little difference between the large and small companies in terms of the type of record-keeping system used. This is shown in Table 4-3.

Table 4-3. Record-Keeping Systems by Company Size

Gross Sales (millions)	Kardex, Acme Visible, Post Index		Loose-leaf Books		Punched Cards		Magnetic Tape		Other		Row Tot
	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Less than 1	29	81	5	14	0	0	0	0	2	5	36
1 to 2	45	76	11	19	2	3	0	0	1	2	59
2 to 3	24	73	7	21	0	0	0	0	2	6	33
3 to 4	18	78	1	4	4	17	0	0	0	0	23
4 to 5	10	77	0	0	1	8	0	0	2	15	13
5 to 10	23	70	4	12	2	6	1	3	3	9	33
Over 10	26	74	5	14	3	9	0	0	1	3	35
	175	75	33	14	12	5	1		11	5	232

The above table is the type of contingency table prepared to relate each control variable to each of the dependent variables. The percentages shown are percentages of the row totals, and these percentages may be compared to note differences between classes of the control variable, in this case the gross sales. As will be noted, manual record-keeping systems predominate, and do not vary in relationship to the gross sales of the reporting companies. As will be pointed out later, the carrying out of presently conceived plans will substantially increase the number using punched card and magnetic tape systems.

Determination of "When" to Submit Orders for Replenishment

The question was asked: "In deciding 'when' to submit orders for items you stock, do you make use of;

> Re-order point (i.e., minimum) listed on stock records?
>
> Periodic review each _____ weeks? (during normal periods)"

This question was intended to be a means of determining how many companies actually make use of re-order points listed on the stock records. This question is of great interest in terms of not only how many make use of re-order points, but in terms of how such re-order points are calculated. Table 4-4 shows the breakdown of answers.

Table 4-4. Re-order Point and Periodic Review by Company Size

Gross Sales (millions of dollars)	Percentages Answering Yes: Re-order Point (percent)	Percentages Answering Yes: Periodic Review (percent)
Less than 1	50	61
1 to 2	46	81
2 to 3	55	55
3 to 4	61	48
4 to 5	23	77
5 to 10	76	48
Over 10	60	66
Total	54	64

The total percentages add to to more than 100% because some checked more than one answer. What is surprising is that 54% of the respondents, or 126 companies, stated that they used a re-order point to signal when stock is to be replenished. This statistic should not be interpreted to mean that 126 companies are calculating re-order points in the inventory theory sense. From company visitations it was learned that "re-order" point is a loosely-used term, with widely varying meanings. For example, one company used re-order points to indicate that the colored slide on a Kardex visual index system was at a given position. This mark, however, was in no sense anything other than the stock status relative to the amount of stock on hand following receipt of a replenishment order. In another case, the re-order point was forty-five days of normal usage, for all items. In this particular case the re-order point was actually listed on the stock card, and was revised on a ten-month moving average basis. In other cases, however, the usage figure on which a "re-order" point was based was the monthly usage figure posted on the monthly usage record card. Thus, the re-order point might be, as was true in one case, "one month's usage plus the largest order normally received." Of the 126 companies who stated that they made use of re-order points, 76 companies also answered that their buffer or safety stocks were based upon "a given number of days or weeks of normal demand for all items" which is a further indication that only a small fraction of the 126 companies are calculating the buffer or safety stocks as thought of in the scientific inventory theory sense. Further evidence for this assertion is shown by the fact that only three of the 126 companies stated that they made use of "k factors, special slide rules, or record of fore-cast errors" in determining buffer or safety stocks.

Lead-Time Guides

Following is the distribution of answers to the question: "What do you make primary use of in determining 'lead times' for the routine ordering of stock from the mills?"

Primary Use of:	Number Answering
Average lead times based upon delivery information in records. . . .	99
Rolling schedules	103
Telephone or other direct contact with mill personnel	123

Some companies answered more than one category, and others indicated that they used all three, depending upon the line of metal being considered.

Since lead time is such an important consideration in determining re-order points, and since lead time variation is one of the reasons often supplied for not calculating re-order points, it was of interest to see how many of the 126 companies who said they used re-order points also relied on "average lead times based upon delivery information in records." There were sixty-six companies who answered in the affirmative, or conversely, sixty of those who indicated the use of a re-order point did not indicate the use of this means of determining lead times. It would seem reasonable to assume that a calculated re-order point would almost certainly require lead time data based upon past delivery information. Here, then, is another bit of evidence to suggest that the re-order points referred to by many respondents are really more in the nature of flags or signals that a review is necessary.

Order Quantity Determination

Table 4-5 presents the distribution of the answers to the following question:

In deciding "how much" to buy, do you make use of:

Tables or graphs to show the quantity to buy?
Economic order quantity formulas?
Cost of possession balanced against quantity extras costs?
Turnover goals?
Historical records and averages?

Table 4-5. Guides in Determining Order Quantities

Gross Sales (millions)	Tables or Graphs	EOQ Form-ulae	Cost of Poss. vs. Quantity Extras	Turn-over Goals	Hist. Records and Avgs.	Total Number of Companies
	percent					
Less than 1	11	28	14	36	69	36
1 to 2	7	20	15	34	78	59
2 to 3	6	18	12	24	85	33
3 to 4	0	22	26	52	70	23
4 to 5	8	8	8	45	85	13
5 to 10	6	39	21	39	70	33
Over 10	9	51	26	43	83	35
Total	7	28	18	37	76	232

Once again the row totals add up to more than 100% because more than one answer could be specified. In view of the large number of companies using record-keeping systems of the Kardex type, it is not surprising that 76% use historical records and averages in determining order quantities, since the standard systems of this type provide the pre-printed forms for recording usage data.

The number of responses indicating the use of EOQ formulae is noteworthy for two reasons. First, an economic order quantity requires the use of cost figures, <u>including</u> the inventory holding cost. This holding cost figure is essentially the "cost of possession" figure. Yet, while 28% of the replies, or 65 companies, indicated that they

used EOQ formulae, only eight of these 65 companies said that they calculated a cost of possession figure. This apparent contradiction can be explained in a number of ways. As was true with the use of the "re-order point" term, the EOQ term is loosely used. To some it connotes a lot-size formula, and this would be particularly true for those in the wholesale hardware business where the traditional EOQ formula has wide applicability. In the typical metals service center, however, little use of traditional lot-size formulae has been observed, even though the term "EOQ" was used in reference to the determination of what was the best or "economical" quantity to purchase.

A second reason for questioning the number who state that they use EOQ formulae is because of the unwieldiness or inapplicability of the formula in so many classes of metals items. For example, were one to attempt the use of the traditional EOQ formula for the purchase of hot-rolled bars it would be found that the formula would rarely develop a mill-purchase quantity which would have a unit price to match that quantity. In fact, of course, this is one of the problems with the use of EOQ formulae when purchase prices are based on an "all units" type discount as described in chapter two. Thus, for hot-rolled bars as well as for many other classes of items, it is necessary to make use of total-cost calculations. This is the reason for asking how many used "cost of possession balanced against quantity extras costs," since this is essentially what is done in the total-cost comparison approach. Here again it is of interest to note that while 18%, or a total of forty-one companies, reported the use of this approach, only eight of the forty-one companies answered that they calculated a cost-of-possession figure.

Use of Historical Records and Turnover Goals

It is of further interest to analyze the number of companies who use "historical records and averages" and "turnover goals" to determine purchase quantities. Following are the number of companies which indicated use of the listed factors for determining order quantities.

Order Quantity Guide	Number of Companies
Tables or graphs	16
EOQ formulae	65
Cost of possession balanced against quantity extras	41
Turnover goals	86
Historical records and averages.	176

As was indicated earlier, it is not surprising that so many make use of historical records and averages as an aid in determining order quantities. A further check was made to determine how many of the 176 who checked this category did not check any of the other categories, thus implying that they used only historical records and averages in determining order quantities. The analysis shows that there were 97 companies who listed no other guide to purchase quantity decisions other than "historical records and averages." A similar type of analysis was performed for the 86 companies who indicated the use of "turnover goals" to guide purchase quantities, except in this case the analysis was to determine how many of these 86 companies answered that they used tables, graphs, EOQ formulae, or cost of possession balanced against quantity extras cost, in addition to the use of turnover goals. Of the 86 companies there were 44 who checked only the "turnover goals" as their guide in determining order quantities. Adding the 97 companies which rely only on historical records and averages to the 44 companies which rely only on turnover goals as a guide to

purchase quantities results in a total of 141 companies, or 61% of the respondents. In other words, 61% of the respondents are primarily guided in their purchase quantity decisions by the use of techniques other than tables, graphs, EOQ calculations, or cost of possession balanced against quantity extras costs.

Cost of Possession

A total of eighteen companies replied in the affirmative to the question: "Do you calculate a standard 'cost of possession' figure?" The distribution of the answers is shown in Table 4-6.

Table 4-6. Cost of Possession Calculation by Company Size

Gross Sales (millions of dollars)	Number of Yes Answers	Percentage of Yes Answers	Total Companies in Sales Category
Less than 1	3	8	36
1 to 2	1	3	59
2 to 3	2	3	33
3 to 4	0		23
4 to 5	2	15	13
5 to 10	2	6	33
Over 10	8	22	36
Total	18	8	232

Earlier comments have indicated the relatively small number of companies reporting the calculation of the cost-of-possession figure, particularly in relation to the relatively large number of companies reporting the use of techniques whose calculation requires the use of an inventory holding cost. Undoubtedly some of those who reported they did <u>not</u> calculate a cost-of-possession figure meant that they did

not calculate the type of cost-of-possession figure suggested in the industry's advertising program. In one of the companies visited it is known that they were using an inventory holding cost for purposes of various calculations, even though they reported in their questionnaire that they did not calculate a standard cost-of-possession figure. In another case of a "no" answer, the comment, "We do, however, consider 1% per month a minimum cost figure to carry," indicates the informal use of a cost-of-possession figure. In yet another case a company stated that they used EOQ but did not calculate a cost-of-possession figure because it was "Too complicated for the Steel Service Center to be of actual use."

Cost-of-Possession Percentages

While the number of companies supplying cost-of-possession figures was too small to provide an adequate sample, it is interesting to note the range of percentage figures actually being used. Of the nineteen companies who said they calculated a cost-of-possession figure, thirteen supplied the percentage figures used, either in total or both in total and a breakdown of the percentage into its components. The percentages varied from a low of three percent to a high of thirty percent. The overall average was twelve percent.

The company reporting the thirty percent figure was using a basic cost-of-possession of ten percent, with the thirty percent figure being the opportunity cost to be applied when considering whether to buy in larger mill quantities. In other words, minimum mill quantities would be purchased unless the demand rate was sufficiently high so that purchases in larger quantities would provide a thirty percent return on the extra invested capital. The three percent figure at the low end of the range is difficult to explain. It certainly could not be considered a true cost of possession except in the very short run when

the opportunity cost of capital was placed at zero. Otherwise the alternative use of capital in government bonds alone would produce more than the three percent figure.

Two other figures reported are of particular interest. One company reported the use of a 23% cost-of-possession figure, but then reported that this figure was only used for EOQ. In another case a "cost-of-possession" figure of 20% was reported, and in this case it is known that the figure is being used as what may be termed a "management control variable." It can reasonably be assumed in the former case as well that the 23% figure is being used for purposes of controlling aggregate inventory. In essence, the use of the cost-of-possession figure as a "management control variable" is what the textbooks refer to as the Lagrange technique, which is the means of calculating the factor to use in a lot-size formula to keep aggregate inventories within constraints on total capital and/or total space.

Following, from lowest to highest, are the cost-of-possession percentage figures reported: 3.0, 8.0, 9.0, 10.0, 11.97, 12.0, 12.0, 12.0, 14.0, 15.9, 16.0, 20.0, 23.0. As was previously pointed out, the company reporting the ten percent figure was using a 30 percent opportunity cost in considering purchases above the minimum mill-purchase quantity, and the companies reporting the 20% and 23% figures were apparently using them for aggregate inventory control. The three percent figure was also discussed, and would clearly seem to have meaning only under special circumstances. Eliminating these percentage figures from the above array reveals that a range of from 8% to 16% is the result, with the average of the remaining figures being twelve percent. As was previously pointed out, this figure is of doubtful meaning because of the small sample size, but it is highly interesting that this same twelve percent figure is the most commonly mentioned percentage figure, is the average of the percentages listed,

and has been mentioned in a couple of company visitations as a "rough estimate" of the inventory holding cost.

Sales Forecasts

Table 4-7 lists the number and percentages of companies answering the question: "How are sales forecasts developed?"

Table 4-7. Sales Forecasting Methods

Method	Number of Companies	Percentages of Total (232)
By estimates from:		
Customers	77	33
Salesmen	113	49
Sales Executives	117	50
Other Executives	55	24
Outside Consultants	10	4
By statistical methods:		
Correlation with economic indicators	35	15
Trend and cycle analysis	34	15
Leading series	3	1
By historical averages:		
Without adjustment	9	4
Adjusted for current demand or latest sales information	130	56
Adjusted by statistical formula smoothing	3	1

An analysis of the answers by company size showed little to distinguish the large companies from the small companies. While the smaller companies did list "estimates from customers" more frequently than did the larger companies, this is partly explained by the

manner in which many of the larger multi-branch companies develop their sales forecasts. These larger companies frequently ask for sales forecasts from their branch and/or divisional managers. These branch and divisional managers, however, in supplying these forecast figures, perhaps rely on customer estimates as much as do those developing forecasts in smaller metals service centers.

Out of the 232 returned questionnaires, there were 18 companies which filled in no answers for the sales forecasting question, thus implying no use of sales forecasting for financial and/or inventory planning. Of the remaining 214 companies, sixty-seven used only one or more of the factors in the "estimates" category, while another fifteen companies used only one or more of the factors in the "historical averages" category. All of the remaining 132 companies used "estimates" along with statistical methods and/or the use of historical averages. Not surprisingly, the most common basis for making sales forecasts was through the use of estimates from various sources combined with an adjustment for current demand and latest sales information.

One point of interest concerns the use of statistical formula smoothing.[1] This was one of the items listed in the "by historical averages" category, and was inserted to determine how many companies were using exponential smoothing as a short-term forecasting tool. Somewhat surprisingly, only three companies reported the use of this technique. Exponential smoothing is an essential part of the IBM IMPACT program, for example, and is widely discussed in the literature as an efficient means of item-by-item forecasting. With the relatively large number of companies which are presently introducing computerized systems there would seem to be little doubt that a

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[1]See Appendix B.

number of additional companies will soon report the use of statistical formula smoothing.

Criteria for Correct Inventory Level

The question was: "Which of the following do you find the most useful in judging the 'correct' or 'best' level of inventory for a class of items."

Turnover rates?
Gross inventory investment by classes of items?
Return on investment?
Inventory investment based upon: (Sum of EOQ's/2) plus safety stocks?

It was anticipated that a large number would check turnover rates, since the use of this criteria is so much a part of the industry tradition. From an inventory theory viewpoint, of course, the turnover rate is a function of the economic order quantity and safety stock calculations. Following is a tabulation of the answers.

Table 4-8. Criteria for Inventory Levels

Criterion	Number Answering
Turnover rates	182
Gross inventory investment by class of items	17
Return on investment	46
Inventory investment based upon: (Sum of EOQ's/2) plus safety stocks	9

The above tabulation indicates the widespread use of turnover as the basis for judging inventory levels. The fact that only nine companies checked the last category adds further evidence that many of the 65 companies which state that they use EOQ formulae for determining

order quantities are perhaps only thinking of economic order quantities in figurative terms. Otherwise, it would seem reasonable to expect a larger number of responses indicating awareness that "correct" inventory levels are a function of the cost parameters used in EOQ formulae.

Turnover Rate Comparisons

In anticipation of a widespread use of turnover rates, the question was asked: "Which do you find the most useful in determining the 'correct' or 'best' turnover for a class of items?"

Comparison with own historical turnover rates?
Comparison with other centers through use of SSCI statistics?
Goal or target of a given number of times turn per year?

A total of 160 indicated that comparison with their own historical turnover rate was most useful, while a total of 33 indicated the use of SSCI statistics was most useful. Another 65 indicated that a "goal or target of a given number of times turn per year" was the most useful.

Order Cost and Items per Order

An estimate of the cost to submit an order to the mills was asked for. It was realized that there would be some questions concerning the definition of the term "cost." As expected, one respondent stated: "Polemical--what is saved by not issuing an order?" Another asked, "What do you include in 'cost'?" Because of the legitimacy of these questions, and because of expected differences in ordering costs depending upon size of company, ordering methods, lines of metals carried, etc. the answers must be interpreted only as a broad measure of the cost to submit an order to the mills.

Another question asked for the average number of items per order, and a check was made to see if the average number of items per order varied in relation to the order cost estimate. The following table summarizes the results of this analysis.

Table 4-9. Order Cost Estimate and Items per Order

Number Answering	Cost Estimate	Overall Average Items/Order	Range in Items/Order	Mode in Items/Order
44	Less than $5.00	6.3	2-18	5
96	$5.00 to $10.00	7.1	1-30	10
66	Over $10.00	9.2	1-50	10

Stockout Penalty

Fifty-five companies answered that they had calculated (or estimated) the financial loss or penalty resulting from being "out-of-stock" of an item normally carried in stock. The question following this one asked what was included in this "penalty." The answers are listed below:

Number	Penalty Included:
19	Gross profit only
15	Expense required to get material from competitors
20	Both gross profit loss plus expense required to get material from competition

In addition, one answered that added delivery trips were included in the penalty, and another added "customer confidence in delivery source." It is of interest that only one answer mentioned what could be considered in the nature of a loss of good will. One of the reasons for this, of course, is the practice of getting "pickup" items from one's competitors. In many--if not most--cases, the customer never knows that the material was obtained from a competitor. The widespread use of "pickups" is brought out in the next question.

Pickup Orders from Competition

The question was: "On what basis do you purchase from other service centers?"

1. "Pickup" orders as needed?
2. Periodically review stock records and for "slow moving" items purchase a quantity of stock of those items for which an inventory is to be maintained?

In Table 4-10, by company size in gross sales, is the distribution of the answers to this question.

Table 4-10. Stock Pickups from Competitors

Gross Sales (millions of dollars)	"Pickups" as needed	Periodically Review Records and Purchase Items to Add to Inventory	Total Number of Companies
	------------per cent	-------------------	
Less than 1	92	22	36
1 - 2	85	25	59
2 - 3	100	9	33
3 - 4	100	30	23
4 - 5	100	23	13
5 - 10	88	24	33
Over 10	94	11	35
Total	92	21	232

As will be noted, there is no particular difference between the large and small companies in following this practice of picking up material from competitors.

A total of 21% of the companies "periodically review their records and purchase items to add to inventory." One would expect the largest companies to follow this practice less often than the smaller companies, and the percentages of "yes" answers confirms this.

Widespread Use of Punched Cards

In magazine articles and metals service center meeting proceedings, as well as from company visits, it was noted that many companies

were making use of punched cards for sales analysis and/or other purposes. This was of interest in an inventory management study because it seemed that here might be the rudiments of a system upon which could be built a more complete program to include inventory record keeping and control. For this reason the questionnaire included two questions to determine how widespread the use of punched cards was. A total of 104 companies answered that they use punched cards, and of this number 69 use their own equipment for processing, while 35 companies make use of a service bureau for processing the cards. Following are the answers received, by company size in gross sales.

	Percentages of Yes Answers		
	Use Punched Cards	Of Those Who Used Punched Cards	
Gross Sales (millions of dollars)	and Sales Analysis and/or Other Purposes	Processed through Own Equipment	Processed through Service Bureau
Less than 1	11	25	75
1 - 2	27	50	50
2 - 3	42	43	57
3 - 4	43	80	30
4 - 5	62	63	37
5 - 10	70	70	30
Over 10	83	90	10
Total	45	67	33

No doubt there were differences in interpretation of what is meant by "processed." Some of the smaller centers send their invoices to a service bureau to have the punched cards prepared, and for them this is having the service bureau "process" the cards. Another company may prepare their own cards, and in this case would have reported that the cards were "processed" through their own equipment, even though they had no other equipment than a key punch. For this reason

the percentage "processed through own equipment" must not be taken literally.

It is of interest that there is a direct correspondence between company size and both the use of punched cards and the number of those who process these cards through their own equipment. It is of further interest that while 104 companies make use of punched cards for sales analysis, only twelve of these companies reported the use of punched cards for inventory record keeping.

Present Plans for Record-Keeping and Data Processing Systems

Two related questions were asked, as follows:

1. Are you presently planning any changes in your basic inventory record-keeping system?
2. Is the purchase or lease of a computer or other data-processing equipment part of your present or forward planning?

A total of fifty-six companies answered yes to the first question, while a total of 78 answered yes to the second question. A total of forty-one companies answered both questions in the affirmative, indicating in most cases that the data-processing equipment or computer being considered would include inventory record-keeping. Of the fifty-six companies who planned changes in their basic record-keeping system, there were a total of fifteen who were considering method changes not requiring a change in equipment. For example, establishment of re-ordering points and improving accuracy were two of the reasons given.

Reasons for Planned Changes in Inventory Record-Keeping System

A variety of reasons were given for changing inventory record-keeping systems. Some of the representative answers were:

the percentage "processed through own equipment" must not be taken literally.

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Reasons for Planned Changes in Inventory Record-Keeping System

A variety of reasons were given for changing inventory record-keeping systems. Some of the representative answers were:

- Speed, accuracy, inventory analysis.
- To adopt scientific inventory management methods.
- Need greater accuracy and speed in totalling inventory and better ordering information.
- Better control, lower investment, higher turnover factor.
- To centralize inventory control; to provide management control reports more current than now possible; to improve service and/or inventory levels.
- Improve our purchasing procedure.

The following table shows the distribution of answers to the two questions in relation to company size in gross sales.

Table 4-11. Computer and/or Data Processing Plans

	Percentage of Yes Answers	
Gross Sales (millions of dollars)	Changes in Basic Inventory Record-Keeping System	Planning for a Computer or Other Data-Processing Equipment
Less than 1	8	8
1 - 2	17	29
2 - 3	15	24
3 - 4	13	39
4 - 5	23	8
5 - 10	30	45
Over 10	63	71
Total	24	34

Not surprisingly the larger companies show a much higher percentage in both categories, and one of the reasons for this is because these companies are large enough to be thinking in terms of medium-size computers.

Problem Areas

The final question on the inventory management survey was stated as follows:

> "What do you consider as the major present (or foreseeable) problem(s) in inventory management in your company and/or the industry?"

A total of 167 companies listed one or more answers, and these "problems" were placed in one of nine categories for analysis by company size, type of company, etc. The responses to the question varied all the way from "foreign policy" to a "We have no inventory problem" statement. The wide range of answers is of interest for several reasons. First, looking over the answers provides some clear reasons why the inventory problem has attracted such widespread interest from so many disciplines. Through the analysis of the inventory problem one can discuss company organization, foreign trade policy, finance, marketing, systems analysis, etc. Secondly, the numbers of problems mentioned provides a basis for observing which types of problems predominate, both overall as well as by different size companies. Thirdly, and of most importance for this particular study, the "problems" mentioned can be viewed in terms of how inventory theory offers potential help in conceptualization and/or solution phases of the problems mentioned.

Following are the nine categories of problems listed, in descending order in terms of the number of times the problem was mentioned, and including several representative statements of each problem. As will be noted, some of the statements actually reflect more than a single problem category, and in some cases the same statement was included in two separate categories.

<u>Product Line</u>

There were forty-seven problems which were placed in this category. Following are some representative problem statements.

Determination of which sizes and commodities to carry in competitive market to best utilize capital available for this purpose.

In addition to being continually aware of the changing markets in any territory and the responsibility for stocking sizes of material to meet these requirements, I feel that the slow turn-over on many items which we stock, because we feel we must be competitive, is a very major problem in inventory management.

The small quantities that we can afford to buy and still give 100% coverage on types of materials we carry. It forces us to overstock (against turnover) on many items and buy at higher cost in small quantities from larger service centers.

Altering mix to keep abreast of demand change, to hold to minimum obsolesence while raising other levels to service new requirement.

As requirements arise for the installation of more and different equipment to process orders (shearing, burning, sawing, etc.), decisions must be made to adjust balance of inventory-reduction or elimination of low profit items, etc.

Need for Better Methods of Decision-Making and Control

A total of forty-three answers were placed in this classification. Following are representative statements.

Our present problem is to set up proper guides for reordering points and reorder quantities and an improved method of review of inventory classification.

We know this is the area where cash can be released for other use. We must learn more about the best methods for accomplishing this.

Present problem--lack of knowledge on which to base inventory management decisions.

Realistic measurement of how much it really costs to be out of stock on a given item.

In our company we need a formula for determining ordering point and quantity.

Maintaining proper inventory levels to get:
(1) Maximum turnover.
(2) Maximum return on dollars invested.
(3) Minimum occasions of being "out of stock."

The lack of understanding that inventory and its control is a definite factor in profitability. In our business we buy and sell--unfortunately we spend 90% of our time selling, and delegate the buying to clerical employees. In order to grow and develop, the conservation and use of cash will be more and more important in the future.

Forecasting

Forecasting as a problem was listed forty times. Following are representative statements:

Forecasting future needs (or lack of needs) of a large number of customers for items they don't ordinarily use, or may need in larger quantities than ordinary, when they themselves don't know if and/or when they will have need of the material or in what quantities, with what lead time, and whether it will be a mill and/or service center buy.

Sudden changes in mill lead times disrupts our method of determining when to order.

The extraordinary quantity of one size ordered by our customer needed for a job they have taken which cleans out our stock. This happens but can not be anticipated.

Changing demands of customers resulting in sudden obsolescence of inventory items.

Foreign Steel, Price Instability, etc.

Nineteen companies listed problems in this area. Frequently the foreign steel and price instability were mentioned as part of the same problem. Following are typical statements:

> With the increasing demand for cheaper imported steel, we find determining our inventory needs, as far away as six months, a major problem in purchasing for inventory.
>
> Having sufficient capital to carry all items requested and attempting to carry two inventories (foreign and domestic) in order to meet your competition.
>
> A constant survey will become necessary to control the inventory level of those sizes and grades where our sales will diminish due to increasing local stocks of foreign steels.

System Design and Organization Problems

Fifteen companies answered with problems which fitted in this category, with representative comments as follows:

> Our present problem is to implement our new inventory system. It's much more complex and technical than our present system.
>
> To supply adequate and current information from a central data processing operation to our six other branches.
>
> Have found no way to automate record-keeping without sacrificing versatility, flexibility, etc.
>
> Installing an operable system.
>
> To program our computer to handle the job the way we want it done.

Constraints--Capital, Space, etc.

Thirteen companies listed problems in this category. For example:

> Necessity of expanding range of inventory within same or lower investment in total inventory.

> The financial burden caused by constantly increasing inventories and space needed to compete in the metal consuming market.

> Lack of space.

Changing Industry Structure and Competitive Conditions

Thirteen companies listed problems in this category. Such problems as "combating the economics of inventories of mill-owned warehouses," and the ramifications of changing mill practices were problems mentioned in this category.

People

For want of a more descriptive term, one type of problem mentioned was placed in a "people" problem category. Several of the problems mentioned could also have been listed under "implementation" problems. Representative problems were:

> To arrive at a balance between customer service and cost of inventory procurement and possession and have the sales department accept such balance.

> Convincing field organization of desirability and necessity of scientific inventory management.

> Personnel ability to change from long used systems.

> Accurate recording of transactions (record keeping).

> Employees not wanting to recommend a purchase.

Return on Investment

Seven companies specifically mentioned the problem of maintaining return on invested capital. Two representative statements were:

To achieve a decent turnover rate to allow for a reasonable return on the investment.

Maintain competitive service with full inventory range and at the same time get acceptable return on investment.

Distribution of Problems by Company Size

The distribution of types of problems by company size is of interest. In Table 4-12, which follows, the responding companies were divided into four groups in terms of gross sales. The four major problem areas are listed across the table. The first category includes problems in both the "system design and organization" and "need for better methods of decision-making and control" categories, since these were quite closely related. Across the table are the percentages of the total problems mentioned by these respective groupings of companies, thus providing a basis for comparing the relative number of times the various problems were mentioned in the four different gross-sales groupings of companies.

Table 4-12. Inventory Problems by Company Size

	Percentages of Total in Gross Sales Grouping				
Gross Sales (millions of dollars)	System Design; Need for Methods of Decision-Making and Control	Product Line	Forecasting	Constraints	Total Problems Mentioned
Less than 2	16	27	23	6	74
3 - 5	32	25	13	5	60
5 - 10	27	24	27	3	33
Over 10	43	10	14	2	42
Total	28	22	19	6	209

The clearest contrast is between the "less than two million gross sales" group and the "over ten million dollars sales" group. It is not surprising that the most common problems listed by the larger companies have to do with system design and methods of decision-making and control, since 71% of these companies reported that their present or forward planning included the use of a computer or other data-processing equipment. The smaller companies, by contrast, tended to list product line and forecasting problems more often than problems of decision-making and control. Nor is it surprising that the proliferation of new sizes, alloys, shapes, and kinds of metals has produced relatively more of a problem for the smaller companies.

Summary of Chapter

This chapter summarized and analyzed the inventory management survey responses. As was discussed throughout the chapter, a great many of the questions in the survey were of such a nature that the answers required careful interpretation. This is perhaps best illustrated by the answers to the question regarding the use of EOQ formulae and "cost of possession balanced against quantity extras" for purposes of determining order quantities. There were ninety-one companies who stated that they use one or the other or both of these as guides in determining order quantities. Yet, only eighteen companies stated that they calculated a standard cost-of-possession figure, which would seem to be a requirement for the use of either of these guides.

The answers to the questions were analyzed by company size, number of branch plants, and type of service center. Company size, in gross sales, seemed to account for some differences in practice, although for most questions there was little to distinguish the inventory

management practices in the large companies from the practices in single-service-center companies.

In terms of the overall summary of the 232 responding companies, the following overall description is provided.

1. Slightly over one-half of the responding companies were either "steel-100%," or "steel, with aluminum."

2. One hundred fifty companies were single-service-center companies.

3. One hundred twenty-eight, or slightly over one-half of the respondents, had sales of less than three million dollars per year.

4. Nearly ninety percent are using one or another of the manual inventory record-keeping systems.

5. Fifty-four percent make use of a re-order point, although in most instances this is "a given number of days of normal demand for all items." Only three companies indicated that they made use of "k factors, special slide rules, or record of forecast errors."

6. Only eighteen companies stated that they calculated a "standard cost of possession figure," with 12% being both the mode and average of the reported percentage figures.

7. Ninety-one out of the 233 companies replied that they used either EOQ formulae or "cost of possession balanced against quantity extras costs," which seems contradictory in view of the few who state that they calculate a cost of possession figure.

8. One hundred forty-one companies, or 61% of the respondents, determine order quantities only on the basis of "historical records and averages," and/or "turnover goals."

9. Turnover rates are used by 182 of the 232 companies as a criterion for judging the "correct" or "best" level of inventory for a class of items, with 160 companies further responding that "comparison with own historical turnover rates" was the guide most used.

10. Ninety-two percent of the companies "pickup" material from competitors, while only 21% "periodically review records and purchase items to add to inventory" from other service centers.

11. Forecasting is largely by estimates from salesmen and sales or other executives, adjusted for current demand or latest sales information. At this time only three of the 232 companies are using statistical formula smoothing.

12. Thirty-four percent of the respondents indicated that their present or forward planning included the purchase or lease of a computer or other data-processing equipment. Seventy-one percent of the companies with gross sales of over ten million dollars were represented among those planning changes.

13. A great variety of problems were mentioned, with the most common problems listed by the larger companies falling into the category of "system design and need for methods of decision-making and control," while "product line" and "forecasting" problems were the most commonly listed problems by the smaller companies.

CHAPTER V

COMPANY VISITATIONS

The previous chapter pointed out the characteristics and inventory management practices of the broad sample of companies which answered the questionnaire. With the answers to this questionnaire as a foundation, this chapter goes into somewhat more detail, making use of data accumulated during company visitations.

The latter part of the preceding chapter clearly indicates the breadth of the problems which industry executives conceive of as "inventory management" problems. While it is true that, directly or indirectly, nearly all the problems mentioned are a part of the overall inventory management problem, it was necessary in this study to focus attention upon somewhat narrower objectives. As previously mentioned, this focal point was the ordering rules in use to determine "when" and in what "quantity" to replenish stock-keeping units. Through observation, interviews, and examination of documents it was possible to gain insights into the manner in which these decisions were reached. As expected, in those companies which had *explicitly* attempted to achieve an economic balance among holding costs, ordering costs, material costs, stockout costs, etc., it was reasonably easy to determine the basic ordering rules. In the great majority of cases, however, it was necessary to infer the basis upon which the ordering rules were based.

Division of Companies into Three Classifications

While a number of bases could be used to analyze the various companies visited, the gross sales seemed the best basis for grouping the companies visited. As will be pointed out, some of the largest metal service center companies operate essentially on a decentralized basis in terms of inventory record-keeping and basic inventory management practices, and thus the inventory decision-making process may be essentially the same in a branch of a large company as in a much smaller single-service-center company. There were some differences, however, and thus the companies visited were divided into three groups, on the basis of gross sales. The first group included the ten companies visited whose gross sales were up to four million dollars per year, the second group included the six companies with annual sales of from four million dollars to ten million dollars, and the third group included the fourteen companies visited with sales over ten million dollars per year.

Diversity and Similarity of Practice

As shown in the summary of the questionnaire results, there are many areas of inventory management where there is a great similarity, irrespective of company size--for example, the use of manually posted perpetual inventory records by nearly ninety percent of the companies in all size groups. Within the groupings of companies, as they have been divided for this analysis, there are some characteristics or common practices which seem to stand out, and mention will be made of these. Of particular interest, of course, are the differences in approach to what is essentially a common problem. These differences in approach will be pointed out.

Smaller Metal Service Centers

Of the ten companies visited whose gross sales ranged up to four million dollars per year, all were single-service-center companies. Seven of the ten were in the one-to-two million dollars gross sales range, and all were using manually posted perpetual inventory record-keeping systems.

Records Used in Reaching Ordering Decisions

From the very first company visits it became apparent that the source of most of the "information" used in reaching decisions was contained in the cards making up the perpetual inventory record-keeping system. While there are some variations among the record-keeping systems described as "Kardex, Post-Index, Acme Visible," or "loose-leaf" book systems, the typical system includes certain basic types of information. Each system usually has a minimum of three cards for each stock-keeping unit. One card is used for the current activity and balance of stock on hand. Each time an order is filled an entry is made, showing date, frequently showing the customer name and/or account number, pieces and/or pounds of material sold, and the new balance on hand. Then, when material is received it is posted to this record, frequently in a different color of ink to have the receipts stand out from the disbursements. In addition, inventory adjusting figures are entered on this card as physical inventories are taken, frequently on either a continuing or spot-check basis.

The second card for each stock-keeping unit is a record of orders and receipts of material, showing date ordered, purchase order number, quantity, and frequently the mill and due date. Then, when the material is received another entry is made indicating the date and pounds and/or pieces received. Frequently the price per pound is

also shown. This record then provides both source and lead time data, and is useful when considering subsequent purchases.

The third card is a record of usage. The standard card provides space for usage by months by years. Thus the months, from January through December, are listed along the left-hand vertical side of the card, and the years are listed across the top. At the end of each year the yearly total is then placed at the bottom of each column. This record is intended to provide a visual record of usage variation from one month to the next, thus providing evidence of variability in usage as well as seasonals and trends. It should be pointed out that some companies do not use such a record, or possibly make use only of quarterly or yearly totals.

Evidence of Rules Governing Ordering Practices

The following extracts from notes taken during company visits perhaps best illustrates some of the different ideas and approaches followed in the maintenance of stock levels.

The vice-president of one company stated: "We think carefully before buying in 10,000 pound vs. 6000 pound quantities. The $3.00 per ton saved doesn't make up for the extra investment." In this same company a periodic review of the stock cards was made approximately each two weeks, and a typical rule was: "Re-order when roughly a 90-day inventory remaining. Thus, if a 60-day lead time results, we have a safety stock of 30 days."

The executive vice-president of another company stated: "I'm able to look at those cards [Kardex] and in a glance take in the pertinent details necessary to make a decision." He further stated that: "Inventory reduction would lose sales." As an example of a rule he further stated that he would use a 6% interest charge in determining

whether or not to purchase a cold-rolled item in a 4000 pound or 6000 pound quantity.

In another case the president of the company did the ordering and seemed very skeptical that any "programing" of such activity could be satisfactorily accomplished. To prove this point he made five separate trips to the inventory record files, each time bringing back a tray to use in indicating the complex relationships among the variables. He indicated that inventory levels were determined by "executive opinion" and "financial considerations." Following a discussion of the cost of possession as applied to order quantities, he made the further point that: "As far as I'm concerned the inventory is a cost of doing business."

Another small company operated with primary regard for maintaining turnover, and this appeared to be the primary criterion underlying ordering policies. Even so, the president of the company characterized their situation as "inventory control by guess." Through growth this company had capital needs which required close attention to inventory levels, as reflected by such close attention to turnover.

One of the outstanding examples of "intuitive" decision-making was exhibited by a company president who took care of all the ordering. The Kardex was the standard setup with the exception that he kept track of yearly-sales-to-date. Thus, each time the number of pounds sold was subtracted from the balance on hand listed on the inventory record, the amount sold was added to strike a new balance of yearly sales to date. In addition, the total sales for preceding years was shown on the usage card for each stock-keeping unit. By demonstration he indicated how "easy" it was to go through the cards and determine whether there was a need to re-order. Basically only three figures were glanced at, i.e., balance on hand, yearly sales to date, and total

sales for the preceding year. Such variables as "lead time" were described as being dealt with by "common sense," and it was further suggested that any attempt to program ordering decisions was a waste of time and money. As far as ordering quantities were concerned, one comment was: "We don't have the room or money to save on 20,000 lbs. vs. 10,000 pounds."

In another company the officer of the company who was responsible for purchasing was quite uncertain about what rules the "buyer" was following in terms or order quantities and re-order points. While there was no evidence of any minimums, maximums, re-order points, etc., there did appear to be a reasonably well-established concern for the need to keep inventory investment down. This was perhaps best evidenced by the practice of buying substantial requirements of slow-moving items from a larger metal service center rather than going to the mill where 6000 pounds is a typical minimum item quantity. Yet, a vice-president of this same company commented that their inventory had been built up to too high a level, and one of the reasons for this was because their recently-retired purchasing man had too often bought 10,000 pound quantities because of the lure of the two dollars per ton saving over the 6000 pound quantity. This seemed clear evidence of management's failure to provide the purchasing man with holding costs to use as a guide in determining when to purchase in the larger quantities.

Evidence of Low Alternative-Capital Cost

Three of the companies visited, in particular, could be described as having placed a low cost on the money invested in inventory. This could be inferred from remarks concerning the availability of capital along with the lack of any tight control over ordering quantities and/or

safety stock levels. The officer of one company, for example, in answer to a question concerning holding costs and cost of possession, replied: "This company has never been capital tight and no explicit calculations have been made of holding costs compared to quantity extras savings." In this particular company hot-rolled bars were not a big part of their business, with a good many slow turnover items. For this reason it might have been expected that the stocking of some of these items would have been by means of purchases from other service centers. In response to a question about this the answer was: "We have to buy in 6000 pound quantities from the mills in order to make our margin." It was further stated by the purchasing agent that they normally buy hot-rolled items in 10,000 pound quanties. These practices are not surprising if the interpretation of "not capital tight" is inferred to mean that no alternative or opportunity capital costs are assigned to money tied up in inventory.

In the second of these three companies the president referred to the company as being "adequately financed." It turned out that he was well aware of the low imputed interest on the money tied up in inventory, and that his return on invested capital was low as a result. However, because of tax laws the money stripped out of inventory would either have to be taken out of the business or be invested in buildings or equipment to avoid the tax rate applied to excess reserves. In this case the decision was to leave the money tied up in inventory. This decision greatly simplified the problem of order quantities. Hence, a couple of the ordering rules being followed were: "When stock is down to about a six months supply--reorder. Try to buy a minimum of five tons." The result was that stock levels were sufficient to supply an estimated 98% to 99% of all demand.

The third company, like the preceding two, was an internally financed company. During the company visit quite a bit of time was

spent discussing inventory holding costs and how such costs could be used to help determine ordering policies. It was clearly stated that no explicit or implicit cost of possession was being used. At the same time the basic criterion used in ordering rules was to maintain a service level, which was running between 97% and 98%.

Summary of Small Company Practices

While the foregoing brief descriptions of company practices provide evidence of a diversity of approaches, there are certain patterns or practices which seem to predominate. First, as has been mentioned, manual record-keeping systems predominate, and periodic reviews of these records is the primary basis for determining when and how much to order. In only a couple of cases were re-order points in use, and these were based on "a given number of days or weeks supply of normal demand." None of these companies has calculated a cost-of-possession figure, although several were using estimated cost of capital figures when considering whether to buy in the larger quantity brackets. Turnover goals were the predominant criteria mentioned as a guide for order quantities, although there were several companies who were sacrificing turnover to gain the material cost savings from buying in larger quantity brackets.

Predominance of Intuitive[1] Decision-Making

Intuitive decisions, usually on the part of the president or an officer of the company, predominate. As pointed out, this is perhaps

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[1]The meaning attached to "intuitive" is taken from Webster's New International Dictionary, second edition, which defines intuition as: "The power of knowing, or the knowledge obtained without recourse to inference or reasoning; innate or instinctive knowledge."

best illustrated by the manner in which the inventory record cards are reviewed for purposes of replenishing stock. As the top operating executive of one company said: "I'm able to look at those cards and in a glance take in the pertinent details necessary to make a decision." In a number of cases these "pertinent details" were said to be handled with the use of what could be called "rules of thumb." For example, the statement, "We think carefully before buying in 10,000 pound quantities vs. 6000 pound quantities," is interesting, but provides little evidence of the weighting of economic factors as suggested by inventory theory.

Medium-Size Metals Service Centers

Six of the companies visited, with sales of from four to ten million dollars per year, were placed in this category. As one would expect, in comparing this group to the group of smaller companies, the pattern of inventory practices changes somewhat. First, of course, a number of companies in this size range have branch plants. Secondly, as the size of the management organization increases, a further division of the management tasks is required. No longer is it as common to find the president of the company ordering stock. Instead, as will be pointed out, he is more likely to give thought to the rules to be followed by those who do take care of the ordering. Some of these differences will stand out clearly in the following descriptions of the practices followed by these companies.

Example of a Well-Developed Program

One company in this size group has a well-developed inventory control program. This company, with two branches, uses punched cards for the basic inventory record-keeping system, with each item

in each location represented by a card in an inventory "deck." Three to four times per month this inventory deck is updated, and once per month an overall inventory report is prepared. Included in this report are item descriptions, the monthly sales rate and trend coefficients, the maximum reasonable demand during lead time (i.e., the re-order point), the balance on hand, pertinent information about material on order, etc.

Procedures are in use in this company to provide explicit guides in the determination of "when" and in what "quantities" stock-keeping units will be replenished. Through the use of a cost-of-possession calculation, EOQ formulae, and total cost calculations, a series of tables have been developed for use in determining order quantities. These tables reflect all the variables found in the classic lot-size formulae, including: unit cost, rate of sales in demand per year (per month in this case), holding cost, and ordering cost.

The determination of "when" to order is based upon an exponentially smoothed average of the mean absolute deviation of forecast errors,[2] as will be further explained. At the end of each month the IBM cards are processed to develop an overall inventory report. Through the use of a program developed for use on the company's own IBM equipment, this inventory report includes a forecast. This forecast is based upon the use of single and double exponential smoothing to provide both an average sales rate and the trend in sales on an item by item basis. Thus, at the end of each month when the inventory deck is updated, three important figures are developed. The key figure for purposes of establishing the re-order point, is the smoothed value of forecast error. The other two figures are coefficients reflecting the smoothed monthly sales rate and the trend in monthly sales.

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[2]See Appendix B.

The use of these coefficients, along with the average "lead time plus review time," provides a basis for estimating the average demand during lead time. The smoothed value of the mean absolute deviation of forecast error provides a basis for establishing safety stocks, which, when added to the average expected demand during lead time, established the re-order point.

The cumulative normal probability distribution and a calculated figure, "probability of filling all demand during lead time," are used in establishing the safety stock on an item-by-item basis. The determination of the optimum "probability of filling all demand during lead time" is developed from a simple formula which takes into account the item unit cost, inventory holding cost, loss in gross profit if sales are not met, and number of order cycles per year. What is actually being calculated is the optimum "probability of filling all demand during lead time" which produces the minimum total of the "cost of understock" plus the "cost of overstock." Once this optimum probability percentage has been determined, the cumulative normal probability distribution is used to determine the factor to be used as a multiplier of the smoothed "mean absolute deviation of forecast error."

The foregoing has been a brief description of the manner in which both order quantities and safety stocks have been established in a manner to minimize the objective function of <u>total</u> inventory costs, with this total including the imputed interest on money invested in inventory. What is of particular interest is that the inventory holding cost was established to keep the aggregate inventory investment at a given number of dollars. In the classic EOQ formula the order quantity varies inversely with the square root of the inventory holding costs. Also, the use of a safety stock calculation intended to minimize the total of "understock" and "overstock" costs will produce lower safety

stocks the higher the inventory holding costs. Thus, increasing or decreasing this inventory holding cost will bring about gross inventory decreases of increases, respectively.

Experience with the System

This system had been in use over a period of several years, with apparently no major shortcomings. Several comments of the president of this company were of particular interest. During a discussion of turnover rates he pointed out that for control purposes the "turnover is a function of other factors." That is, with any given demand, turnover is governed by the size of order quantities and the level of safety stocks. Order quantities and safety stocks, in turn, are (in this case) a function of holding costs, ordering costs, stockout costs, material cost schedules, and number of order cycles per year. Another interesting comment was made about the forecasting system which was built into their program. He indicated that there were occasions when purchasing would attempt to "outguess" the statistical forecast, and "more often than not they don't do as well as if they'd stayed with the programed forecast."

Two Companies Using Intuitive Decision-Making

In contrast to the previously described company, there were two single-service-center companies where decisions regarding "when" and "how much" to buy were largely based on intuition--as commonly found among the smallest companies visited. Here, as previously, the use of the word "intuition" is not meant to imply any value judgment of the practices involved. Rather, it is being used as a means of describing the manner in which decisions are being reached.

In the first of the two companies the president of the company had a comfortable well-furnished office, but pointed out that he spent a large amount of his time at his other desk located in the order department. He pointed this out to add emphasis to his feeling about the extreme importance of ordering practices. In dealing with the high-cost-per-pound specialty items distributed by this firm he expressed the belief that "The biggest risk is getting stuck with material of improper specifications." To insure that the right material was ordered he believed it necessary to have information regarding customers, specifications, etc., "all right there in front of you," and for this reason he was throwing out the system which a well-known public accounting firm had installed as an ostensible improvement but which he said was made "without having a knowledge of the business."

The second company characterized by "intuitive" decision-making was likewise dealing in specialty steel. Late each afternoon the president and the secretary-treasurer of the company sit down and go through the orders received that day. This provides an opportunity to: 1) See what has been ordered and who has ordered it, 2) note any large demands which could be reason for expediting replenishment of stock and 3) submit orders for regular replenishment of stock. Thus, each day orders are submitted to the mills. They have five suppliers, and they order <u>in turn</u> from each supplier. Thus, orders are submitted each day to a given mill, and this is continued until that given mill has received a carload quantity, at which time they start submitting orders to the next mill in line. The mills, of course, accumulate these orders, and the sooner a given mill ships its carload of steel to the company the <u>sooner</u> it gets back in line to start receiving orders for another carload.

In addition to the above procedure, the president of the company goes through the Kardex once per month. It was indicated that the

company was in a highly liquid position at present, and hence, "put the money in inventory."

Remaining Companies in Medium-Size Category

Of the three remaining companies, one is somewhat closer to the previous in terms of having few formalized rules for purposes of guiding ordering decisions. The other two companies, as will be pointed out, exhibited varying degrees of control through ordering rules, use of inventory holding costs, etc.

In the first company referred to above, the executive vice-president takes care of the ordering, making use of a report which summarizes sales rate per month, amount of stock on hand, and amount on order. Upon review of this report the vice-president makes a notation concerning the amount to purchase, and from which mill. In reaching these decisions certain rules and guides were being followed. For example, it was stated that a ten percent inventory holding cost was being used to determine whether to invest in larger quantities. Other practices which were described would indicate that some attention was given to watching safety stock levels, although as was mentioned, the rules seemed quite informal. For example, in response to a question about "when" an order would be submitted, the example was given: "Assume sales of fifty tons per month, and lead time of approximately three weeks. We would order when down to a month's supply." This, of course, would imply a safety stock of only about one week's supply, and considering the number of order cycles per year, with this item being ordered in twenty-ton quantities, this would seem to be an extremely low safety stock.

While the order quantities were said to be based upon the use of a ten percent figure for inventory holding cost, no tables or EOQ formulae were in regular use. Because of the numerous times that

turnover was mentioned it appeared that order quantities were based more upon this goal than on any other. As was apparent from the inventory information used by the vice-president when he decided upon purchase quantities, he was guided primarily by the historical averages of sales, and in letting this be his guide in terms of order quantities he made the comment: "Turnover is the result."

One of the remaining two companies had a number of small branches, with the purchasing and transferring of material between branches being taken care of at the company's main location. In this particular company the chief operating executive did not get involved in the detail of inventory. Instead, he relied on control reports which included gross investment by branches, the pounds of material at each branch in terms of months supply at current demand levels, etc. A further report indicated "buyouts," broken down into categories to indicate whether the material bought was: 1) items which should have been in stock, 2) those items <u>not</u> normally carried in stock, or 3) direct mill shipments. This latter report was of interest because it ostensibly provided the detail to arrive at some broad conclusions as to whether safety stocks were too low <u>or</u> too high.

Of further interest in this company was a set of calculations showing the total cost comparisons of buying in various quantity brackets. These calculations included inventory holding costs, differences in material costs, and unit material costs. While these calculations had not been carried out in a manner such that tables could be developed to guide day-to-day purchasing decisions, the calculations did indicate recognition of the costs of holding inventory.

Re-order points are used along with a Kardex visible index system. Each time the inventory clerks adjust the perpetual inventory balance they move the slide to correspond to the new stock level. When the slide gets to a given point, this is a signal that it is time to

re-order, and once the material is re-ordered a colored tab is placed on the inventory card to indicate that the material is on order. The re-order point is not a calculated one, however, since it was stated that the re-order point was roughly "One month's average sales plus one 'reasonable' order."

The remaining company in this group, like the preceding one, had a president who did not get deeply involved in the day-to-day details of inventory. He did, however, know the details of the ordering rules and basic approaches being followed by those who did handle the determination of ordering quantities and safety stocks. In the relatively recent past, inventory levels had been reduced to what was believed to be a better operating level, and the president ascribed this improvement to: "a well established return-on-investment goal plus the organization's acceptance of an idea and the will to make it work." The "idea" referred to here was that to attain the return on investment it was necessary to purchase in the right quantities and to watch safety stocks, etc. Although nothing specific was shown in terms of order quantity calculations, it was stated that cost of possession was balanced against quantity extras costs. It was further pointed out that re-order points were based upon the average lead time multiplied by a ten-month moving average sales figure, plus (usually) the amount of the largest order. Thus, the safety stock is approximately the amount of the largest order, although it was mentioned that sometimes an additional margin is put in as well.

Summary of Medium-Size Company Practices

Within this size group there are sharp differences in approach, with one company in which there is a highly developed inventory control system, and two other companies in which either the president or the top operating executive personally establishes when and how much of

each item to order. In the latter two cases the specialty nature of the items carried may partially explain why the top executives have not relinquished these tasks.

In comparison to the smaller companies, the companies in this size group showed more evidence of developing controls for use in guiding ordering policies. One company had a well-defined inventory control program, as described. Two other companies had made some use of calculations to determine economic order quantities.

Large Metal Service Center Companies

Visits were made to a total of fourteen companies with sales of ten million dollars or more per year. Included in these companies were some of the largest companies in the industry, both in ferrous and non-ferrous metals. Only one of the companies visited was a single-service-center company, with the remaining ones having two or more branches in addition to the company headquarters plant. In some of these companies the branch plants were geographically close enough to the location of central headquarters that a large part, if not all, of the branch plant requirements were met from the central warehouse stocks. In other cases, the branches were so widely scattered geographically that each plant was more or less an independent stocking center, largely taking care of its own purchasing of material.

Similarity of Basic Problems

One could point out many other differences among these companies, but in terms of the focal point of this research the differences are not as great as one might imagine. In the case of the branch warehouses that draw most or all of their requirements from the "mother" warehouse, the major inventory problem is found at the primary warehouse

center. In this case the problem of "when" and in what "quantity" stock-keeping units will be replenished must take into account the branch warehouse "customers" along with other regular customers of the major warehouse. While there still remains the problem of determining stock levels to be maintained at the branch service centers, this problem is somewhat minimized because of the short lead time when they must re-order from the central headquarters warehouse. Frequently this amounts to overnight delivery.

The metal service center companies that have widely scattered branch plants present a different problem. At this time the most common approach under these circumstances is to have the major amount of stock replenishment taken care of at the branch plant locations. Thus, the branch plant manager is conceptually in much the same management role as if he were managing his own company. While usually operating under a constraint on total inventory investment, or possibly operating under a budget limiting how much may be spent for material during a given time period, the branch management must arrive at decisions concerning when to order and in what quantities to order. A variation on this is to go one step further and set up some basic ordering rules which are to be followed by the branch plant management. A further variation is to go yet another step and have the decisions concerning stock levels, replenishment of stock, etc., taken care of through a central headquarters information processing unit. While this latter method is not widely practiced as yet, a number of companies are establishing the basic groundwork for such a system, and one large company is reportedly making use of such a system at the present time.

Evidence of Transitional Stage

Both the questionnaire returns and the visitations to these fourteen companies indicate that many companies in this size group are either presently introducing changes in inventory record-keeping and/or data-processing equipment or are at least actively considering such changes. For example, twelve of the fourteen companies either are planning changes in their basic inventory record-keeping systems or are planning the introduction of a computer or other data-processing equipment. Five of the fourteen companies presently have computers, and another six have indicated that they are actively considering appropriate computing equipment. However, at this time, for metals at least, thirteen of the fourteen companies are using record-keeping systems of the Kardex or loose-leaf type, and one company is using a unit-record system. At the present time two of the fourteen companies are in the process of changing their inventory records to magnetic tape, and accompanying this move will be programing to provide for item-by-item calculations for the determination of optimum order quantities and safety stocks.

Varying Computer Uses

One of the larger companies visited has a large number of branch plants scattered over a wide geographical area. This company has a well-developed EDP program, but has not made direct use of its computer for inventory control in terms of establishing order quantities or re-order points. In the central data-processing department each plant has its stock represented by an inventory deck. During the month each plant sends in copies of its filled orders, and from these the punched cards are prepared. These cards serve not only for the monthly updating of the inventory deck, but also for a variety of purposes such

as getting gross sales by branches, sales by commodity groups, sales by salesmen, sales by account and profitability by account. At the end of the month, following the updating of the inventory deck for each branch, an inventory report is prepared for each division. This report provides data on an item-by-item basis, not only for the past month, but for previous months as well, thus providing a basis for watching the development of trends in such factors as the number of months' supply on hand, cost per pound, total inventory cost, shipments cost, intra-company transfers, and "buyouts" from competitors. A great deal of essential information is provided here, and even without any formal calculations of re-order points, for example, it would be possible to use such information to adjust operating policies. Making use of such reports the central corporate management sets up "maximum" inventories by branches, with these maximums being revised each quarter or so. Then, at the end of each month each branch is furnished a budgeted amount of money which it may spend for stock during the ensuing month. Thus, there is this much money "open to buy." Within these restrictions each branch carries out its own purchasing. In summary, the inventory control in this company is based upon the use of budgeted inventory, and inventory analysis based on EDP carried out at corporate headquarters. The branches, in turn, must stay within budgeted gross inventory investment and "open to buy" budgets, but are free to determine "when" and "how much" to buy within these constraints. A cost-of-possession figure has been calculated, and is used to arrive at a balance between inventory holding costs and quantity extras costs. In addition, re-order points are used, but are based on "a given number of days or weeks of demand for all items."

Inventory Records on Magnetic Tape

Somewhat in contrast, another large company, likewise with a large number of widely dispersed branches, is presently developing a computer program for inventory control. Many of the features of the programs of these two companies will be similar. For example, for many years this company has controlled branch plant inventories by means of bogey inventories for each branch. This company, however, in contrast to the former, is working toward the ultimate development of a "real time" system of inventory control. The present transitional step is to get their inventory on magnetic tape and to develop computer programs to calculate optimum order quantities and re-order points. For these latter calculations cost-of-possession figures have been developed, and are presently being used to determine economic order quantities.

Inventory Reduction in Advance of Computer Installation

The third company with a computer is likewise in a transitional stage. This company, with widely dispersed branches, is in the process of installing a large-scale information transmission system for use in conjunction with their central headquarters computer. At the present time the computer is being programmed and research is being conducted to develop re-order points, etc. What is of particular interest, from an inventory control standpoint, is this company's experience leading up to this particular point.

Several years ago the gross inventory investment at all branches appeared to be getting too high in relation to sales. In an effort to get at the root cause of this growth in inventories, each branch was asked to submit such information as weekly sales, lead time in weeks, and buffer stock <u>for each stock-keeping unit</u>. Analysis of this information

indicated that slack was being introduced both in the estimation of lead times as well as in the estimation of the average weekly usages. During this initial period, and in an effort to reduce inventory reasonably quickly, a policy directive was sent to all branches that "buffer stocks are to be eliminated." What this really amounted to was that the submitted estimates of average demand during lead time already had enough slack in them to serve both as demand during lead time and safety stock. At about this time calculations were carried out to develop order quantity tables, which were based upon a balance between inventory holding cost and quantity extras costs. These tables were distributed and were to be followed in determining order quantities. As a follow-up, periodic audits were made at branch plants to make certain that the ordering rules were being followed.

Several factors would account for the results obtained. First of all, the president of the company was taking a personal interest in inventory levels. Secondly, ordering rules were disseminated to guide both order quantities and re-order points. In addition, periodic in-plant audits were carried out by high-level corporate staff people. Two interesting results were reported. First, there was no increase in stockouts, although the purchasing department found its job somewhat more difficult. Secondly, inventory levels were reduced by approximately twenty-five percent.

There are two important reasons for relating this particular case study. First, it is of interest to note that better control was attained along with substantial inventory reduction in advance of the use of the computer. Secondly, the control of inventories at the widely dispersed branches was affected not by the establishment of gross inventory investment maximums, but by establishing the basic guides which determine, or are the root cause of, inventory levels.

Partially Computerized System

One of the large metal service center companies visited had what might be termed two systems in use. For the bulk of their items, including their specialty items, they were using a computer program to control inventory. This program included the use of inventory records on magnetic tape and the use of programs to determine re-order points and to signal when these points had been reached, etc. Because of limited computer capacity, however, inventory records for some commodity groups, including regular carbon steel items, were kept on Kardex inventory records. This second system included the establishment of order quantities and re-order points, as will be explained.

Management in this company had established a basic cost of possession figure, and then had developed an additional figure to reflect the opportunity cost of capital. The reason given for separating the opportunity cost from the regular cost-of-possession figure was not entirely clear. The <u>use</u> of these cost figures was clearly explained as follows: "Buy in the minimum mill quantities <u>unless</u> the material savings from buying in larger quantities is sufficient to cover both the regular cost of possession <u>and</u> the opportunity cost of the extra investment." Tables had been prepared to show what the demand must be before purchases should be made in the higher purchase quantity brackets.

Re-order points were also calculated for the carbon steel items, and these re-order points were recorded on the Kardex inventory records, along with the date that the re-order point had been established. These re-order points were established to "provide 95% service." The basic formula was as follows:

$$\text{Re-order point} = K \times \bar{X}_{2\ \text{months}} + \sigma_{2\ \text{monthe}}$$

Where: K = a factor for lead time.

$\bar{X}_{2\ \text{months}}$ = average demand for a two-month period.

$\sigma_{2\ \text{months}}$ = standard deviation of demand for the two-month period.

The interesting feature of the above formula is the manner in which the lead time is handled. For a given class or group of items the inventory records were examined to determine how long the lead times had actually been. These lead times were arranged in an array in order to select the length of lead time which would be exceeded only five percent of the time. For example, if sixty-seven days was the lead time length that was exceeded by only five percent of the lead time periods, then the factor, K, would be 1.1, i.e., sixty-seven days divided by the 60.8 days in a two-month period for which the average sales were calculated. By this means the problem of determining the lead time distribution was avoided, and consequently it was not necessary to deal with the difficult determination of the joint distribution of the demand and lead time distributions.

The addition of one standard deviation of demand for the two-month forecast period was apparently a trial-and-error approach. One reason given for the addition of this standard deviation was that as stock levels approached the re-order point it was common that a given sale would deplete the stock well below the re-order point. Of more importance, perhaps, is that through a period of experience it had been found that the use of one standard deviation of sales plus the product of the lead time factor times the average sales for a two-month period, had provided the desired service level.

Since one of the frequent criticisms registered against the use of re-order points is that they get out of date, it is of interest to note the mechanism by means of which these re-order points are revised. At the end of each month the total monthly sales is posted to the Kardex inventory records. At this time the posting clerk looks at the total for the preceding month (assuming this is a "two-month" item as described above) and adds these two together to note if their sum is greater than the amount protected for, i.e., the re-order point. If so, then a "recheck" of the re-order point is requested. Also, when the purchasing department re-orders an item they check the demand rate, in pounds per year, to determine what order quantity bracket the material should be ordered in. If the indicated purchase quantity is less than the previous order quantity, then a "recheck" of the re-order quantity is requested. The industrial engineer responsible for recalculating these re-order points suggested that: "These two features catch both upward and downward trends in demand." Revision of the lead time factor, K, was also used as a means of making further adjustments in inventory levels, and it was reported that experience had provided them with the means to predict the response of the system to such changes. While these adjustments could be made to keep the re-order points and order quantities up to date, it was noted that: "Only approximately ninety percent of the items are adaptable to controls such as have been described."

Non-Computer-Using Companies

Of the fourteen large companies visited, the only ones reporting the calculation of cost-of-possession figures were those companies who have a computer and some controls making use of cost-of-possession figures for such purposes as determining order quantities, re-order points, etc. And yet, as has been pointed out, there were a number of applications of cost-of-possession figures and re-order points which did not necessitate the use of the computer. It can be speculated that as additional companies in this size group install computers they will give more and more attention to similar types of controls and aids to inventory decision-making. In the following pages will be presented some brief descriptions of the basic inventory decision-making in some of these large companies which are not presently using a computer.

As has been previously discussed, some difficulty was experienced in determining exactly what rules, policies, procedures, programs, etc. were being followed in many of these companies. This difficulty can be better understood through a description of the commonly found organizational arrangement in these larger companies.

Division of Inventory Responsibility by Commodity Groups

It is not surprising that the larger companies, particularly those handling a wide line of metal items, have assigned inventory responsibilities by commodity groups. For example, in its central headquarters one company had eight men among whom were distributed responsibility for the various commodities carried by the company. Another large company had three men among whom were distributed the commodities or classes of metal items carried. In this way one man might be responsible for the aluminum items carried, another might take care of hot-rolled bars and plates, another the cold-rolled and cold-finished items, etc. These men, usually working immediately adjacent to the inventory records, were the "specialists" for these given commodities.

While titles varied, the most common title was "buyer," although the title "product manager" or "product specialist" were commonly encountered. Perhaps a typical description was this one: "Product managers are responsible for various commodity groups. These men, many of whom have twenty-five to thirty years experience, are responsible for the maintenance of inventory records, reviewing these records, and ordering stock."

Through interviews with many of these "product managers" it was possible to get some insights into the policies, or lack of policies, under which they typically operate. With the exceptions previously noted (i.e., those companies who have developed some fairly extensive ordering rules), these men largely determine their own day-to-day operating practices. While talking to these gentlemen it was interesting to note how they become the focal point of a number of organizational pressures. A number of times the inside or outside sales personnel would be checking with the product managers to determine why items were out of stock, when a new shipment was due in, etc. Pressure from sales personnel to maintain "safe" stock levels was clearly a source of pressure on the product managers. At the same time, if stock levels get too high there is organizational pressure from two other sources. First, the plant personnel become quite unhappy when new shipments arrive before the stock racks have been sufficiently depleted to accommodate the new shipment, since this requires additional handling in moving the stock to overflow storage areas. Secondly, if inventory investment appears to be growing disproportionately to sales, there is pressure brought to "cut down on inventory investment" or to "increase turnover."

Considering these antagonistic organizational pressures, along with other variables such as increasing or decreasing demand for various items, changing lead times, etc., it is not surprising that the product managers determine their own day-to-day operating practices. Neither is it surprising that these operating practices are changing over time, depending in large part on the "mix" of organizational pressures brought to bear on the product manager.

Description of Practices in Non-Computer-Using Companies

One company in this group had several branches reasonably close to the central headquarters service center. While the branches were operated on a decentralized basis, the central management had several means of maintaining control of inventories. To encourage minimum stock levels, the branches could get material from the headquarters warehouse in (say) 1000 pound quantities, but only be charged at the material cost at which the central warehouse had purchased the material. Thus, a branch could "transfer" 1000 pounds at the same price per pound as if they had gone to the mill for a minimum 6000 pound order. Secondly, the gross inventory investment at the branches was controlled. Barring a pick-up in sales, or any unusual or planned buildup, the inventory was kept within this gross inventory investment.

The president of the company commented that there was a widespread awareness of the need to keep inventories down, and that one of the reasons for this was that the company was basically a debt company, with borrowing from the banks required for inventory buildups.

No cost-of-possession figures had been developed nor were there any order tables or re-order point policies in use. The responsibility for inventories was divided by commodity groups, and within the constrains of total inventory investment, each commodity group manager exercised judgment in terms of "when" and "how much" to order.

One company, a single-service-center company carrying a general line of metals, placed great stress on inventory turnover. In fact, it was stated that: "An item won't be added unless it will turn from three to four times per year." This strong emphasis on turnover was carried into the ordering decisions in terms of established minimums and maximums recorded on the inventory records. The goal was an "inventory in dollars" of around ninety days business, thus providing four times turnover per year. The "maximum" recorded on each inventory card was based on the sales during the past ninety days. The minimum was set in relation to lead time, but in each case observed it was one-half the maximum, thus implying an average lead time of approximately 45 days. At the time the "minimum" on the inventory record card is reached, the inventory clerk checks to see what the demand was during the preceding ninety days, and if this usage varied substantially from the previous maximum, then a new maximum and minimum would be placed on the inventory card.

Another company, with several branch plants within overnight trucking distance of the central headquarters plant, takes care of all purchasing through its central headquarters. Three men, under a director of purchasing, spend full time reviewing records and purchasing the various commodities stocked. Most of the material purchased comes directly to the central headquarters plant and is transshipped from there to the branch operations.

Each of the three purchasing agents has commodity groups for which he is responsible. On a one to three week review cycle, depending upon the commodity and the individual purchasing agent, all inventory record cards are reviewed and orders are entered. These inventory records are complete, including not only detailed item-by-item records for the central plant but for the branch plants as well. The review procedure for a given item was observed as follows: first, a check was made of the amounts on hand and the usage rates at the central plant as well as at each of the branch plants carrying this item in their own stock. Then, with knowledge of the current lead time (plus a knowledge of how long it would be until the next review), it was decided whether or not it was time to order. If it was decided to order, then the usage rate was once again checked to determine what order quantity to buy.

No cost-of-possession, order quantity guides, or re-order points were used. In terms of order quantities each of the purchasing agents had his own rules. In response to a question concerning how it is decided whether to order 6000 pounds or 10,000 pounds, one purchasing agent answered that a rough guide was: "Order 10,000 pounds if ten months usage is 10,000 pounds." This was reportedly based upon a "breakeven at five percent interest." In a discussion with another purchasing agent, he mentioned that he was aware that: "The decisions concerning whether and how much to buy depends somewhat on whether I'm an optimist or a pessimist on a given day."

In two additional companies the basic inventory management was likewise centered around "commodity" or "product" managers. In neither case was there any explicit use of inventory holding costs for purposes of deciding on order quantities. In one of these companies the president of the company frankly expressed his lack of understanding of inventory holding costs, alternative or opportunity cost concepts, etc., and the manner in which these concepts are used in guiding order quantity decisions. In this same company an interview with a "buyer" revealed that he was largely guided by intuition in determining when and in what quantities stock should be replenished.

In the second of these two companies the officer responsible for purchasing expressed the view that: "Our business is inventory--this we have to have. The cost-of-possession concept has particular applications for users of steel, but doesn't have much relevance for steel distributors."

One of the large companies visited had a particularly troublesome problem because of the manner in which quantity extras were applied by the mills. Unlike the "all units" discounts which apply to most metal items, their specialty item had percentage quantity extras. The difficulty in applying these was that the quantity extra percentages were not added after all other extras had been applied. Thus the quantity extra applied to only a part of the total cost of a given item. Quite clearly these extras were never intended to help the purchaser evaluate the relative economy of buying in one quantity bracket versus another.

In this company one man spends essentially full time setting up re-order points. These are based primarily upon "a given number of days of usage plus demand during lead time." Then, when the stock is depleted to this re-order point this man reviews the usage and determines whether to order and in what quantity. The guide used in determining this quantity seems to be a turnover criterion, since no inventory holding costs or return on invested capital guides are available for guidance. Also, as was pointed out, each item would require a separate calculation because of the peculiar manner in which quantity extras are applied.

The top management of this company was fully aware of what was referred to as "seat-of-the-pants methods" as presently followed, and they were actively searching for appropriate data-processing and computer equipment.

Summary of Large-Company Practices

The preceding descriptions of inventory management practices indicate a diversity of approaches. Some of these differences can be attributed to variations in company size, degree of geographical dispersion of branch plants, type of metal items carried, etc., while others must be attributed to differences in management philosophy in relation to inventory management.

Interestingly, each of the four companies explicitly calculating cost-of-possession figures also have a computer. It is of further interest that, while five of the fourteen companies presently have

computers, only three of these five are either presently using or are preparing to use a computerized item-by-item inventory control system. Twelve of the fourteen companies visited are either presently using or are considering the adoption of a computer or other data-processing equipment which would have a direct bearing on inventory management practices. There is thus much evidence of the widespread concern for attaining improved data-processing and inventory management practices.

Among this size company there is not only the problem of basic ordering rules, in terms of the establishment of order quantities and re-order points, but there is the problem of maintaining control of branch-plant inventory levels. To maintain control of these branch-plant inventory levels three principal approaches are being followed. One approach is to specify the rules by means of which re-order points and order quantities are to be established. Thus, inventory levels are a function of these basic rules. A second approach is to have central headquarters staff manage the levels of stock at the branch plants. This is more commonly the practice when the branch plants are not widely dispersed geographically. The third approach, and by far the most common practice at this time, is to establish bogey or target inventory investment levels for the branch plants. Thus, while the branch plants are largely free to determine their own re-order points and order quantities, they must stay within a given gross investment level.

CHAPTER VI

NORMATIVE MODEL DEVELOPMENT

Introduction

The previous two chapters have presented descriptions and summaries of the inventory control methods currently being used by the companies studied. These methods varied from what has been described as "intuitive," to the use of rather highly developed inventory controls to guide ordering policies in a small number of companies. With this data as background it will be the purpose of this chapter to present and discuss some decision models which would seem to have wide applicability in the metal service center industry. The latter part of the chapter will deal with model sensitivity.

The models to be presented have as a primary application the determination of order quantities and re-order points. As will be shown, these same basic models, and the calculations necessary for their solution, offer guidance in a number of other decision areas. For example, it will be shown that the models offer a means of keeping aggregate inventories within constraints on capital investment or space and provide guidance in terms of when it is advisable to buy stock requirements from another service center rather than in minimum mill quantities.

There will be no attempt to show the use of "some" models for small service centers, others for large service centers, etc. However, there will be some discussion of the manner in which the models can be adapted for use in different size companies. In this regard, of course, each company which attempts to use any given inventory model must adapt this model to its own particular situation, if for no other reason than that their own parameter estimates must be developed for use in a given model.

The first model presented will deal with the determination of optimum order quantities. The optimum order quantity model is basic because the order quantity determines the number of order cycles per year, which is then used in several other models, most importantly, the re-order point model.

Order Quantity Model

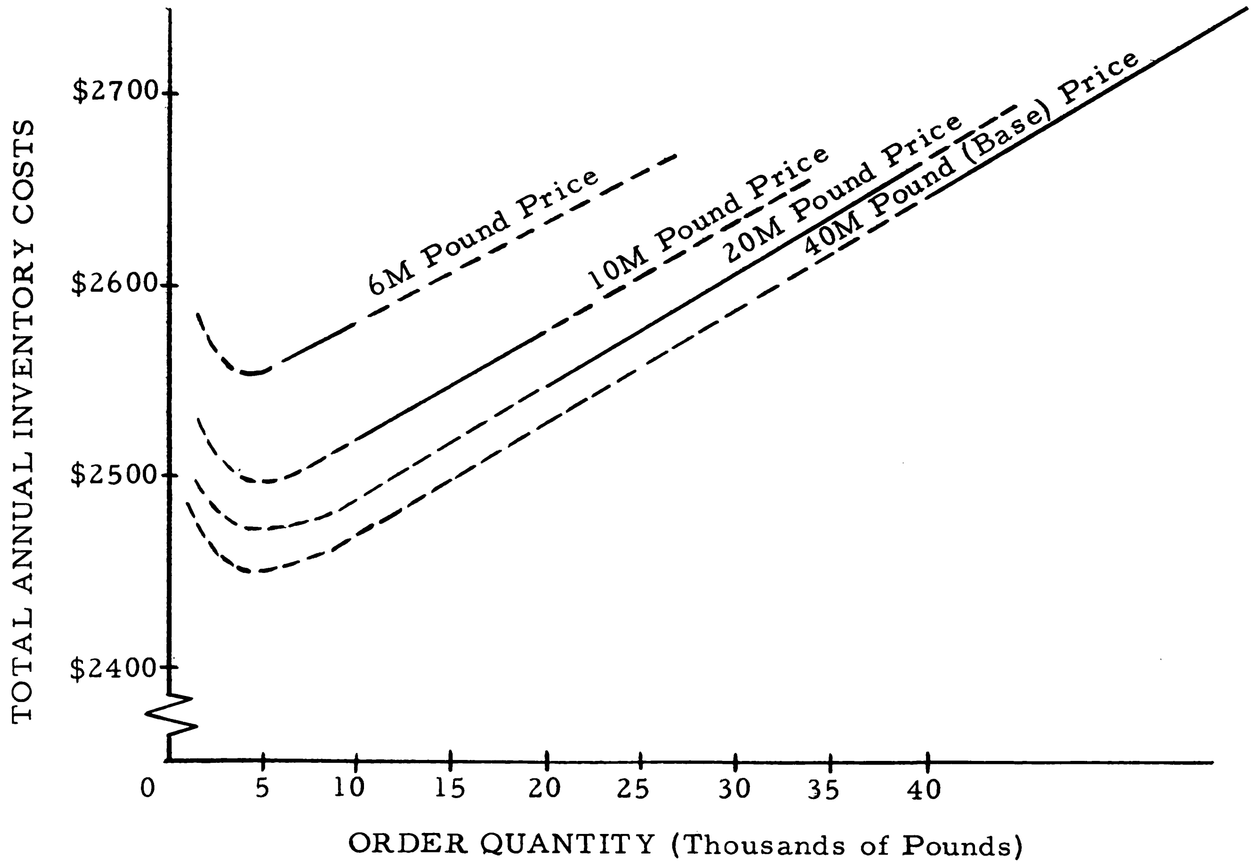
The determination of the "best" or "optimum" order quantity is a problem that all metal service centers face. While those metals service centers which get the bulk of their metals on consignment do not have quite the same type of problem as those which purchase their metals outright, it is still a problem to be dealt with. As was pointed out in chapter two, the direct material cost of most metal items depends upon the order quantity in which the item is purchased. Thus, there is a base price plus a "quantity extra." For example, a regular-size hot rolled bar may have a base price of $7.32 per hundred weight. If it is purchased in 40,000 pound quantities the base price applies. However, if the order quantity is from 20,000 to 39,999 pounds, then a quantity extra of $.05 per hundred pounds applies; if from 10,000 to 19,000 pounds, the extra is $.15 per hundred pounds; and if from 6000 to 9999 pounds the extra is $.35 per hundred pounds. Also, the mills will not accept less than 6000 pound item quantities of hot-rolled bars. Similar types of quantity extras schedules and minimum mill quantities apply for many classes of metal items, such as sheets, stainless, hot-rolled bars and strip, and cold finished bars.

Difficulty in Use of Classic EOQ Model

Two difficulties arise in the use of the classic EOQ model. Using hot-rolled bars as an example, the minimum item quantity of 6000 pounds is higher than the EOQ formula will produce for the normal limits of demand for most items. Thus, with an item having a base cost of $.08 per pound, a demand per year of 30,000 pounds, an inventory holding cost of 12%, and an order cost of $4.00, the optimum order quantity produced by the classic EOQ formula is approximately 4500 pounds, considerably less than the minimum order which a mill will accept. Secondly, even if the order quantity from the formula should be a quantity greater than the 6000 pound minimum, the question is: "Would not the total annual inventory cost be less if the material was purchased in a higher order quantity bracket carrying a lower quantity extra?" Thus, it would be necessary to calculate the total inventory costs using the unit costs associated with the various order quantity brackets. Graph 6-1 (not drawn to scale) illustrates these essential relationships.

As will be noted from graph 6-1, the order quantities associated with the minimum cost points of the four total cost curves is less than the minimum acceptable order quantity of 6000 pounds. It will also be noted that the relevant total cost curve, shown in solid lines, is discontinuous. Thus, in the case illustrated, the minimum total annual inventory cost will be obtained when material is purchased at $.0815 per pound, the unit price applicable in the order quantity bracket 10,000 to 19,999 pounds. The minimum point on this portion of the total cost curve is with an order quantity of 10,000 pounds. No other order quantity will produce a lower total annual inventory cost. An important point of this discussion is to note that the optimum order quantity is at a price break. The problem in this case, then, is whether to buy in 6M, 10M, 20M, or 40M pound quantities.

Graph 6-1. Order Quantity and Annual Inventory Cost



Total Annual Inventory Cost Formula

Continuing with the hot-rolled bars example, it is possible to determine the optimum order quantity by calculating the total annual inventory costs associated with order quantities of 6M, 10M, 20M, and 40M pounds, and then choosing the minimum of these total costs. Considering only direct material, ordering, and inventory holding costs, the total cost formula would be:

$$\text{Annual inventory cost} = DPY\ (C_i) + S\ \frac{DPY}{Q_i} + \frac{Q}{2}\ (C_i)\ I$$

Where:
- DPY = demand per year.
- C_i = cost per pound, i = 6M, 10M, 20M, or 40M quantity prices.
- S = order cost.
- Q_i = order quantity corresponding to 6M, etc.
- I = inventory holding cost, in decimal fraction.

To make these calculations on an item-by-item basis is computationally burdensome unless one has a computer. Fortunately there is a means of developing tables for order quantity determination.

Points of Indifference

As will be observed in the above annual inventory cost formula, if material is purchased in larger quantities the annual ordering cost decreases, the annual direct material cost decreases because of the lower unit cost, and the annual inventory holding cost increases. The two costs that decrease are a function of the demand per year, while the cost that increases is a function of the order quantity. Conceptually, one might start off with this rule: "Buy in the minimum mill quantity unless the demand per year is high enough so that the savings in direct material cost and ordering cost are at least equal to the increase in inventory holding cost when buying a larger quantity."

For example, in moving from 6000 pound to 10,000 pound ordering quantities, the increased costs are:

$$\frac{Q_{10}}{2}\,(C_{10})\,(I) \;-\; \frac{Q_6}{2}\,(C_6)\,(I)$$

The decreased costs are:

$$DPY\left[\frac{S}{Q_6} + C_6\right] - DPY\left[\frac{S}{Q_{10}} + C_{10}\right]$$

Where: C_{10} = cost per lb. in 10,000 pound quantity.
C_6 = cost per lb. in 6000 pound quantity.
I = inventory holding cost.
S = order cost.
DPY = demand per year.

The question, then, is this: At what demand per year will the savings equal the increased costs? Solving for DPY, we have:

$$DPY = \frac{\frac{Q_{10}}{2}\,(C_{10})\,(I) - \frac{Q_6}{2}\,(C_6)\,(I)}{\left(\frac{S}{Q_6} + C_6 - \frac{S}{Q_{10}} - C_{10}\right)}$$

In the example being given, the value for DPY may be called a "point of indifference," since at this demand per year the total inventory costs are the same whether the material is purchased in 6000 pound quantities or in 10,000 pound quantities. In addition, of course, it is necessary to calculate indifference points between each of the remaining quantity brackets. Following is a portion of a table of such indifference points for regular-size hot-rolled bars. In this case the inventory holding cost was 12%, and the order cost was set at four dollars. The quantities shown in the body of the table are pounds demanded per year.

Table 6-1. Indifference Points for Regular-Size Hot Rolled Bars

Base Cost Per Pound	Buy 6000 lbs. Up To:	Buy 10,000 lbs. Up To:	Buy 20,000 lbs. Up To:
$.07	7250	34,750	139,000
.08	8310	39,750	159,000
.09	9370	44,750	179,000
.10	10430	49,750	199,000
.11	11490	54,750	219,000

If the base cost of the material is $.07 per pound, and the expected demand per year is up to 7250 pounds, then the material should be purchased in 6000 pound quantities. If expected demand is from 7251 pounds to 34,750 pounds, then the material should be purchased in 10,000 pound quantities, etc. Note that the material would not be purchased in 40,000 pound quantities unless the expected demand was in excess of 139,000 pounds per year.

As will be noted, the indifference points increase rapidly as the base cost per pound increases. This is because holding costs go up in direct proportion to unit costs, while unit material savings are the same whether the unit base cost is $.07 per pound or $.11 per pound. This would indicate a need for caution in applying such rules as, e.g., "Buy 10M quantities if the demand is 1000 pounds per month."

Return on Invested Capital Formula

In the indifference table just shown, it was noted that at $.07 per pound base price, the point of indifference between 6M and 10M pound purchase quantities was 7250 pounds per year. Also, the inventory holding cost was 12%. Another way of explaining the meaning of this DPY of 7250 is this: At a DPY of 7250 pounds one may buy in 10,000 pound quantities and receive a return of 12% on the additional capital required to buy in 10M pound vs. 6M pound quantities. The formula is:

$$\text{Gross Percent return on extra invested capital} = \frac{\text{Savings}}{\text{Extra Investment}} \times \frac{\text{DPY}}{\text{Q}}$$

As an example: Assume that the DPY is 7250 pounds. What would be the return on the additional investment if this material were purchased in 10,000 pound quantities? Each time 10,000 pounds are purchased the direct material savings are \$.20 per hundred pounds, with the total material savings being \$20.00. In addition, each time 10,000 pounds is ordered there is a saving in ordering cost. While it costs \$4.00 each time 10,000 pounds is ordered, it would cost \$6.67 if this same amount of material were ordered 6000 pounds at a time. Thus, the order cost savings is \$2.67, resulting in a total savings of \$22.67 each time 10,000 pounds is ordered in preference to 6000 pounds. The additional investment in buying 10,000 pounds over 6000 pounds, at \$.0715 and \$.0735 per pound respectively, and basing the average investment on one-half the order quantity, is \$137. Thus, each time 10,000 pounds is sold we gain a return of \$22.67/\$137.00, or 16.6%. This is a meaningless figure, of course, until a calculation is made to determine how long a time it takes to gain this return of 16.6%. The factor, DPY/Q, provides the number of times per year that the \$22.67 is saved. In the particular example being used, DPY/Q = 7250/10,000, or a fraction of .7250. In the original formula:

$$\text{Gross Percent return on additional investment} = \frac{\$22.67}{\$137.} \times \frac{7250}{10,000} = 12\%$$

It is particularly important to note that this is a "gross" percent return on the additional invested capital. Obviously, if the total of the cost of possession factors added up to 15% per year, then it would have been a poor decision to invest the additional \$137 dollars required for the 10,000 pound quantity. Or, if a company has other investment opportunities which could be expected to return (say) 20% or 25%, then receiving only 12% for additional inventory investment is unwise.

Preparation of Indifference Tables

For research purposes some computer programs were used to develop a series of indifference point tables for various classes of metals. A desk calculator is adequate, however, particularly if the tables only reflect differences in material cost, ordering cost, and inventory holding cost, as discussed in the preceding section. Only a relatively small number of calculations need to be made, and then the tables may be completed by extrapolation. The reason this is possible, of course, is because as the base cost increases the holding costs increase in direct proportion, while the value of the denominator of the indifference point formulae remains unchanged. Thus, once the incremental difference between the indifference points for base costs of (say) $.07 and $.08 has been determined, then this incremental value may be added to the indifference value for $.08 base cost material to get the indifference point for $.09 base cost material, etc. These relationships will be noted in Table 6-1.

The purpose of going into this degree of detail is to demonstrate that here is a tool which is available to even the smallest metal service center which is looking for a technique to use for determining optimum order quantities. Once such tables are prepared it is simple to determine the optimum order quantity. All that is required is to know the base cost of the material and to have an estimate of the expected demand per year.

Computer Programs for Order Quantity Determination

With the availability of a computer programed to deal with individual items, it is computationally practical to include more elements in the determination of the optimum order quantity. For example, the differences in safety stocks required when ordering in 10M vs. 6M pounds. As will be discussed later in this chapter, such a program has been developed for one class of metal items. This program uses as input the following: demand per year, smoothed value of monthly forecast error, base cost per pound, inventory holding cost, and gross profit margin. Then, using this data, the total annual inventory costs were calculated for 6M, 10M, 20M, and 40M pound purchase quantities. The program then selected the order quantity producing the minimum total annual inventory cost. These calculations were made for a sample of twenty-five items. For twenty-three of the twenty-five items the recommended order quantities from this computer program were the same as the quantities that would have been obtained from the table. In the other two cases the order quantities were very close to a "point of indifference," so that the difference in annual inventory costs was negligible.

Stock Purchases from Other Service Centers

The questionnaire responses indicated that 92% of the service centers "pick up" from competitors, while only 21% replied that they "periodically review stock records and for 'slow moving' items purchase a quantity of stock of those items for which an inventory is to be maintained." One might have expected a larger percentage of smaller service centers to periodically review their stock records, accumulate (say) a 20,000 pound order of a number of slow-moving items, and order these from a larger service center. It is believed that the calculation of indifference points will provide some guidance in determining when such a policy would be economical. The specific question is: "At what DPY is there a point of indifference between purchasing in minimum mill quantities and purchasing from other service centers?"

In order to make such a determination it was necessary to make some assumptions. For illustrative purposes, the following assumptions were made.

1. The cost of material purchased from a service center is estimated to be 25% greater than the cost of the material if purchased in minimum mill quantities. To get this price it is assumed necessary to order a number of items, perhaps totaling 20,000 pounds, from another service center.

2. The inventory records would be checked twice per year, although each item would only be ordered on the average of once per year.

Using hot-rolled bars as an example, where the minimum mill quantity is 6000 pounds, the total cost formulae are as follows.

When ordered from other service centers:

$$TC_0 = S + \frac{DPY}{2} \text{ (I) } (C_0) + DPY\ (C_0)$$

When ordered from the mills:

$$TC_1 = \frac{DPY}{6000} \text{ (S) } + DPY\ (C_1) + \frac{6000}{2} \text{ (I) } C_1$$

Where: TC_0 = total annual inventory cost when ordering material from another service center, at C_0 price/pound.

TC_1 = total annual inventory cost when ordering material from the mill, at C_1 price/pound.

S = order cost.

I = inventory holding cost percentage.

At what DPY does $TC_0 = TC_1$? The answer, in terms of DPY, is given by the following equation:

$$DPY = \frac{3000\ I\ (C_1) - S}{C_0 + \frac{IC_0}{2} - \frac{S}{6000} - C_1}$$

A number of calculations were carried out to determine the points of indifference resulting from the use of the above formula. Table 6-2 shows some representative results.

Table 6-2. Service Center vs. Mill Indifference Points

Regular-Size Hot rolled Bars.
Quantities in Table are DPY in pounds.
Order cost = $4.00.

Base Cost Per Pound	Inventory Holding Cost Percentage .12	.16	.20
$.07	967	1248	1491
.08	984	1263	1504
.09	998	1275	1515
.10	1009	1285	1523
.11	1018	1292	1530

As will be noted, the points of indifference are not sensitive to changes in the base cost per pound. This is largely because material purchased from other service centers carries a percentage increase over the mill price. It is of further interest that with an inventory holding cost percentage of twenty percent the points of indifference are at a DPY of approximately 1500 pounds. During company visitations several executives mentioned that they would purchase from other service centers rather than making a minimum mill quantity purchase and have the material around for three years. This statement would imply that a 6000 pound mill purchase would not be made unless the expected DPY was in excess of 2000 pounds.

Construction of Indifferent Point Graphs

It may be anticipated that there will be two major areas of resistance to the development and use of indifference point tables. Each of these objections is conceptual in nature, and each has been encountered in discussions with metal service center executives. One area of resistance centers around the need to calculate or estimate inventory holding costs. As shown by the questionnaire results, cost-of-possession figures are explicitly used by a relatively small percentage of metal service center companies. Turnover is by the far the major criterion in determining order quantities. Secondly, it may be suggested that a single value cost-of-possession figure is unrealistic, and that even within classes of items there are significant differences in the inventory holding cost percentages. For example, 2 x 2 x 1/4 angle certainly has a negligible obsolescence factor, whereas another item in this same class of metal might call for a fairly high obsolescence cost factor as part of the inventory holding cost.

The use of indifference point graphs are useful for each of these two types of objections to indifference point tables. Use of such a graph will be a partial answer to the first objection, in the sense that its use will provide a means of determining the imputed return on invested capital as reflected in present ordering practices. For the second problem, the use of such a graph provides a ready means for determining optimum order quantities when using any one of a number of different inventory holding cost percentages.

Graph 6-2 shows such an indifference point graph. Here, instead of points of indifference, are what might be called "lines of indifference,"

Explanatory Remarks for Graph 6-2

The cost per pound is the base cost before item quantity extras, and an order cost of four dollars per order was used. Reading across the graph, the first set of lines is the "lines of indifference" between 6M and 10M pound quantities. The second set of lines is the 10M vs. 20M pound lines of indifference.

Example:

Assume a holding cost estimate of 12% per year, with a material base cost of \$.07 per pound.

1. Locate the holding cost percentage on the vertical axis.
2. Move horizontally to the right to the first line marked \$.07/lb.
3. Drop a vertical line, and where it intersects the X-axis will be the number of pounds, in demand per year, where it is economical to start purchasing in 10M pound quantities. In the example shown at DPY = 7250 pounds.
4. Extend the horizontal line from step "2" till it intersects the second line marked \$ .07/lb. Beneath this intersection is the point where it is economical to start purchasing in 20M pound quantities. In the example shown this is at DPY = 34,500 pounds.

In summary: If DPY is less than 7250, buy in 6000 pound quantities.
If DPY from 7250 to 34,500, buy in 10,000 pound quantities.

with these lines sloping upward to the right as the holding percentage increases. It will be seen that the lines of indifference reflect a linear relationship between the inventory holding cost and the demand per year, just as was true in the tables. Because of this linear relationship it is relatively easy to construct such graphs. By accurately calculating points of indifference for the percentage values at each end of the range of inventory holding costs, the line connecting these points becomes the line of indifference.

Use of Indifference Point Graphs

Such graphs should prove useful for a number of purposes. First, of course, they may be used to determine the optimum ordering quantity, being particularly helpful when it is desired to make use of different holding cost percentages within a given class of items. Secondly, for a company presently using other criteria for determining order quantities, the use of the graph will provide a means of estimating the imputed return on investment from whatever criterion is presently being used. For example, assume an inventory record reveals the following:

> Regular-size hot-rolled bar.
> Base cost of $.08 per pound.
> DPY at rate of 10,000 pounds.
> Being purchased in 6M pound quantities.

Referring to graph 6-2, it will be noted that the intersection of the $.08 line and the vertical line above 10,000 pounds DPY reveals a holding cost percentage of 14.5%. All that can be said in this case is that the imputed holding cost percentage is 14.5% <u>or greater</u>. Otherwise, the material would be purchased in the 10,000 pound quantity instead of the 6000 pound quantity. Assume that another inventory record shows the following:

Base cost of $.08 per pound.
DPY at rate of 30,000 pounds.
Being purchased in 20,000 pound quantities.

Referring to graph 6-2, it will be noted that the intersection of the 30M DPY vertical and the $.08/lb. line is opposite the nine percent holding cost percentage. Thus, this ordering policy imputes a holding percent of nine percent <u>or less</u>. Otherwise the material would be purchased in 10,000 pound quantities instead of 20M pound quantities.

In the examples given, the first indicated an imputed holding cost percentage of 14.5% or greater, and the second an imputed holding cost percentage of 9.0% or less. By auditing a number of such ordering decisions it should be possible to determine the approximate imputed inventory holding cost accompanying the present ordering policies.

<u>Importance of Consistent Ordering Policies</u>

The need for consistency becomes of particular importance when there are a number of commodity or product managers responsible for the various classes of items. With any given total investment in inventory it is of importance that the <u>overall</u> inventory cost be minimized. Perhaps an audit, making use of indifference graphs, will indicate that one product manager is following ordering practices which impute an inventory holding cost of six or eight percent, while another product manager is following practices which impute a cost as high as twelve or fourteen percent. Because of the decreasing quantity extras savings as ordering quantities increase, the first manager is investing money in inventory to gain a relatively low marginal reduction in direct material cost. The second manager, using ordering practices imputing a higher inventory holding cost, is foregoing investment opportunities. In effect, the first manager may be investing capital to gain a return of 6%, while the second manager is foregoing investment opportunities which would return (say) 9%.

Use of Inventory Holding Cost as a Management Control Variable

In the questionnaire responses one company reported the use of a 23% cost-of-possession figure, but then mentioned that this figure was only used for EOQ. In addition, another company is known to be using 20% for similar calculations, and in this latter case it is known that this 20% is being used for what might be described as a "management control" variable. For example, when there are constraints on total available capital, or on total available space, it is necessary to make appropriate adjustments in ordering policies. Frequently the literature will illustrate the use of the Lagrange multiplier technique[1] for handling these types of constraints. Aside from the computational difficulties in using this technique, there are further difficulties for the same reasons that there are difficulties in using the classic EOQ formulae.

There are two methods which may be suggested for dealing with constraints on capital and/or space. One method makes use of the indifference point graphs. Assume, for example, that it is desired to reduce aggregate inventory by ten percent. Conceptually, this is equivalent to raising the inventory holding cost percentage. The question, of course, is: "How much should the holding cost be raised in order to decrease aggregate inventory by ten percent?" A random selection of stock-keeping units may be chosen from each class of items. As will be indicated shortly, perhaps as few as twenty-five items will provide sufficient accuracy. Then, using the indifference point graph, determine the order quantities which would result _if_ a given (higher) inventory holding cost is used. For example, the present

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[1]G. Hadley and T. M. Whitin, _Analysis of Inventory Systems_ (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1963), pp. 213-219.

holding cost may be twelve percent. Perhaps sixteen percent could be used to test the effect in terms of lower order quantities. With this increased holding cost there will be some items that were formerly purchased in 20M pound quantities that will now be purchased in 10M pound quantities, and some that formerly were 10M quantities will now move down to 6M pound quantities, etc. After having checked a sample of items it will be possible to note the percentage decrease in average cycle stock. Perhaps raising the inventory holding cost to sixteen percent produced more than a 10 percent drop, so the procedure could be repeated at 14% or 15%.

The second method is greatly simplified if a computer is available. In this case a computer program may be developed to calculate the changes in inventory, both in pounds and in dollars, as the holding cost percentage is varied. By this means a graph can be prepared which will show the expected change in inventory as the inventory holding cost is adjusted. Such a program was used to derive the relationships shown in graph 6-3. A random sample of twenty-five hot-rolled items was used. The computer program calculated the average pounds and dollars in inventory when the inventory holding cost was 6%, 9%, 12%, 15%, and 20%. In addition to these holding cost percentages, the input information for each item included the expected demand per year, the standard deviation of monthly forecast error, a two-month lead time, the base cost per pound, and the gross profit margin. With this input the program calculated the order quantity which would produce the minimum total annual inventory cost, including the material costs, stockout costs, ordering costs, and inventory holding costs.

Even though only twenty-five items were used in the analysis, the plotted totals fitted reasonably close to the curve drawn in graph 6-3.

Graph 6-3. Inventory Levels at Various Holding Cost Percentages

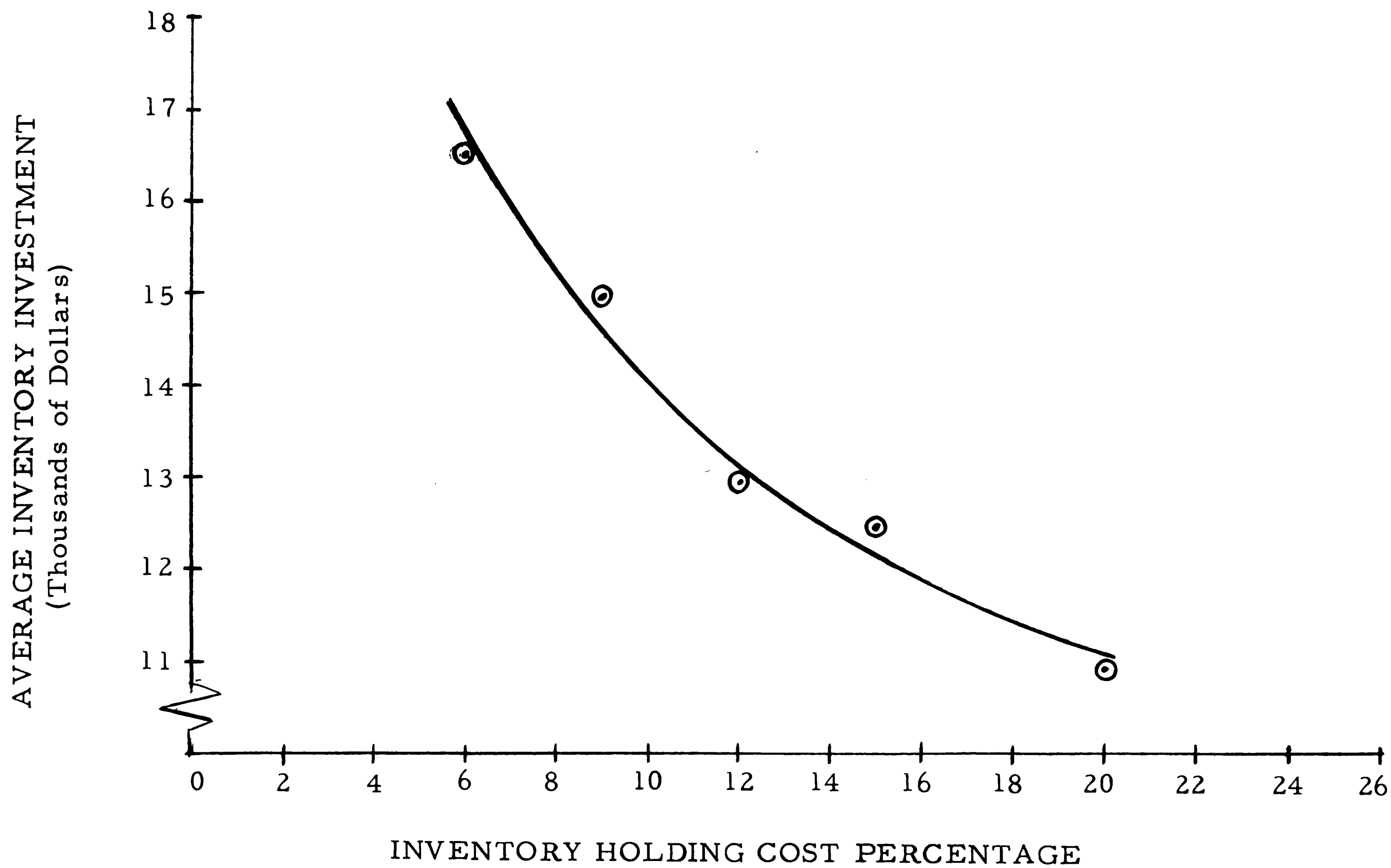

Table 6-3. Relationship of Average Inventory Level to Holding Cost Percentage

Inventory Holding Cost Percentage	Average Inventory in Dollars	Percentage of Incremental Reduction
6	$16,800.	
8	15,400.	8.3
10	14,300.	7.1
12	13,300.	7.0
14	12,600.	5.3
16	12,000.	4.8
18	11,500.	4.2
20	11,100.	3.5

It will be noted that, as the inventory holding cost percentage gets larger, each succeeding increase produces a smaller incremental reduction in the average inventory investment. For this reason, the percentage change in inventory investment which can be expected from the use of a given holding cost percentage will depend upon what percentage is reflected in the present ordering practices. Thus, if present ordering practices are based upon the use of a six to eight percent holding cost percentage, then a 15% to 20% reduction in inventory could be expected from increasing the holding cost percentage to the ten to twelve percent range. However, if ordering practices already reflect (say) a ten percent holding cost percentage, then increasing this percentage another two or four percent may decrease the inventory investment by only ten percent.

Safety Stock Model

It might be said that each decision to order stock reflects an explicit or implicit safety stock calculation. In those cases where re-order points are posted on a stock, record, the safety stock is explicitly dealt with. Where no re-order points, as such, are in use, the person making the periodic review makes at least an implicit estimate of safety stock requirements in the very process of deciding whether or not to replenish stock. From the experience during company visitations it was observed that a great variety of "rules of thumb" were being followed. Some of these were mentioned in the chapter summarizing the practices followed in the various companies visited. It was of interest that many of these rules of thumb could have been formally defended through the use of one or another of the models available for determining safety stocks. For example, several purchasing agents mentioned that they were _never_ going to be caught short of 2 x 2 x 1/4 inch angle. Thus, they made certain of high safety stocks for this item. In other discussions about safety stocks it was mentioned that high safety stocks would be kept for items that were high-profit-margin items and which could not easily be picked up from competitors. In each of these remarks one may note that there is a justifiable reason for having high safety stocks. Thus, _other things equal_, the larger the number of order cycles (as would be true with 2 x 2 x 1/4 inch angle), and the higher the margin, the larger should be safety stocks.

One of the models which would seem to have wide applicability in the metals service center industry is the "general single period model with time independent costs"[2] (perhaps better known as the "newsboy" model or the "Christmas tree" model). There are several reasons why this model seems appropriate for determining levels of safety stock. First, it is known that at least one metal service company is using such a model, with apparent satisfaction. Secondly, the model provides a clear representation of the relationships between the variables which

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[2] _Ibid._, p. 297.

should be taken into account when deciding upon item-by-item safety stock levels. Third, and perhaps most important, the assumptions underlying the model seem reasonable in terms of the nature of the metal service center industry. This latter point will be explained as the model is described.

One of the requirements for the use of the "newsboy" model is that there be estimates of the losses from "overstock" and "understock." In a metal service center, "overstock" is the average amount of stock on hand when replenishment stock is received, and "understock" is the average amount of material which must be "picked up" from a competitor to meet demand during a replenishment cycle. What is of particular interest is that the cost of "understock" can, in most cases, be quite closely estimated. It will be recalled that the questionnaire indicated that 92% of the responding companies make "pickups" from competitors. Also, fifty-five companies said that they had calculated the cost of being out of stock. Loss of gross profit and expense to get the material from a competitor were listed as the two major components in the determination of this "cost."

As a means of both deriving and describing the model, the incremental or marginal principle is useful.[3] Using this principle one may reason that units of safety stock would be added until safety stock is of such size that the last unit added will decrease understock cost by as much as it increases overstock cost. Thus, the following relationship exists:

$$P(DDLT \geq R) \times U = P(DDLT < R) \times 0$$

Where: R = re-order point = $\overline{DDLT}$ plus safety stock.

$\overline{DDLT}$ = average demand during lead time.
$DDLT$ = demand which actually occurs during lead time, i.e., a random variable with $\overline{DDLT}$

[3]Robert Schlaifer, Probability and Statistics for Business Decisions (New York: McGraw-Hill Book Company, Inc., 1959), p. 130.

$P(DDLT \geq R)$ = probability that the demand during the lead time is greater than or equal to the stock reflected by the re-order point.

$P(DDLT < R)$ = probability that the demand during lead time is less than the stock reflected by the re-order point.

U = understock cost, i.e., the loss if a unit is demanded and there is no stock to fill this demand.

0 = overstock cost, i.e., the cost of carrying a unit in stock for which there is no demand.

Replacing $P(DDLT \geq R)$ by $1 - P(DDLT < R)$, we then have:

$$U \quad [1 - P(DDLT < R)] = 0 \times P(DDLT < R)$$

$$P(DDLT < R) = \frac{U}{U + 0}$$

$$= \frac{1}{1 + \frac{0}{U}}$$

The ratio, $U/(U + 0)$, defines the optimum probability that the demand during lead time should be less than the level allowed for by the re-order point, R. Thus, if the value of the ratio is .90, the safety stock would be set at a level such that the probability of filling all demand during lead time would be .90. The nature of this "critical ratio"[4] is such that the costs of understock and overstock must be for the same time period. The "understock" cost occurs because of the lost sales during <u>each</u> order cycle, and in order to state the overstock costs for a comparable period it is necessary to divide the cost of holding a unit of overstock for a year by the number of order cycles, of which there are DPY/Q per year.

Thus, per order cycle:

$$U = \text{understock cost} = C \times m$$

$$0 = \text{overstock cost} = \frac{C \times I}{DPY/Q}$$

Where: C = unit cost per pound of material.

m = gross profit margin.

I = inventory holding cost percentage.

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[4] *Ibid.*, p. 74.

One further step[5] to simplify computation is to define the ratio, 0/U, which is the cost of overstock divided by the cost of understock. A simple table can then be developed which shows, for a range of such ratios, the optimum probability of filling all demand and the corresponding safety factors required to attain this probability. Table 6-4 is an example of such a table.

Table 6-4. Safety Factors to Minimize Overstock and Understock Costs

$\frac{0}{U} = \frac{\text{Cost of Overstock}}{\text{Cost of Understock}}$	Probability of filling all demand. $P(DDLT < R) = \frac{U}{U + 0}$	Safety Factor* k
.01	.99	2.39
.02	.98	2.05
.03	.97	1.90
.04	.96	1.80
.05	.95	1.65
.06	.94	1.55
.07	.93	1.48
.08	.93	1.48
.09	.92	1.40
.10	.91	1.34
.15	.87	1.12
.20	.83	.96
.25	.80	.85
.30	.77	.74
.40	.71	.56
.50	.67	.44
.60	.62	.30
.70	.59	.23
.80	.56	.17
.90	.53	.08
1.00	.50	.00
1.1	.48	-.05
1.2	.46	-.15
1.3	.44	-.17

*These safety factors are the number of standard deviations of DDLT to be added to DDLT to attain the calculated probability of filling all demand during lead time.

[5]Robert G. Brown, Smoothing, Forecasting and Prediction of Discrete Time Series (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1963), p. 374.

The first two columns of Table 6-4 are of great value in terms of understanding the relationship of the variables involved in answering the question: "What should a goal be in terms of meeting demand during lead time?" As will be noted, by calculating the ratio of overstock cost to understock cost, it is possible to determine the optimum probability of filling the total demand during lead time. This ratio, 0/U, equals (C x I x Q) divided by (C x m x DPY), and this may be simplified to the ratio, $\frac{I \times Q}{m \times DPY}$. Remembering that the lower this ratio the higher is the optimum probability of filling all demand during lead time, it is possible to note the justification for some of the rules of thumb mentioned earlier. For example, other things remaining the same, the higher the gross profit margin, m, the lower the ratio. Also, with a high DPY relative to Q, as is frequently found with 2 x 2 x 1/4 inch angle, the lower the ratio. With a low inventory holding cost percentage, I, there will be a low ratio, and hence a high optimum probability of filling all demand during lead time. For even greater ease in application, the relationships may be expressed in a simple table. With a given inventory holding cost percentage, as would apply to at least the great majority of items in a given class of items, such a table would show how the safety factor, k, changes as a function of the gross profit margin and the number of stock turns per year. Table 6-5 represents the type of table which could be prepared. This particular table was built with the use of an inventory holding cost of 12% per year.

Tables 6-4 and 6-5 are suggestive of the manner in which the reorder point model could be simplified for application. The number of order cycles for given items is readily available from existing records, and the gross profit margin is commonly a part of the sales analysis data presently used by many metal service centers.

Table 6-5. Safety Factors Related to Profit Margin and Turnover

Gross Profit Margin	Number of Order Cycles = $\frac{DPY}{Q}$							
	.33	.67	1.	2.	3.	4.	6.	8.
.20	-.4	.1	.3	.7	1.0	1.1	1.3	1.5
.25	-.2	.2	.5	.9	1.1	1.2	1.5	1.6
.30	-.2	.3	.6	1.0	1.2	1.3	1.5	1.7
.35	0	.4	.7	1.1	1.3	1.4	1.6	1.8
.40	.1	.5	.7	1.1	1.3	1.5	1.7	1.8
.45	.2	.6	.8	1.2	1.4	1.5	1.7	1.9
.50	.2	.7	.9	1.3	1.5	1.6	1.8	1.9

Factors in the above table are in multiples of standard deviations of DDLT to fulfill the optimum probability of filling all demand during lead time.

<u>Problems of Parameter Estimation</u>

Tables 6-4 and 6-5 included "k" factors obtained by reference to cumulative normal probability tables. This value of "k" is then used in a re-order point formula of the following type:

$$\text{Re-order point} = \overline{DDLT} + k\ \sigma_{DDLT}$$

As used here, the factor "k" has meaning in relation to a normal distribution with an average, $\overline{DDLT}$, and a standard deviation, σ. A number of problems, not the least of which is the computational burden, present themselves at this point. As will be noted from the re-order point formula, it is necessary to determine the demand during lead time. This requires both forecasting of the lead time interval as well as the rate of demand during this interval. Once this is developed, it is then necessary to develop the standard deviation of demand during this lead time. Great complexities are involved in dealing with these variables in a statistically <u>precise</u> manner. While it is a fundamental

requirement to use precision in dealing with inventory theory development, the problem of implementing this theory in practice frequently requires ingenuity and resourcefulness in developing suitable approximations of the various parameters. This point is brought out for two reasons. First, some of the ideas and discussion which follow are in the nature of rules of thumb for the approximation of certain parameters. Thus, their usefulness may be discussed, even though statistical precision is not attained. Secondly, a number of exceptions may be noted for almost any rule one may offer. There will be no attempt to discuss all these exceptions. What can be said, however, is that in the metal service center industry, as perhaps in most industries, there are peculiarities which must be dealt with. These "exceptions" and peculiarities must be recognized and dealt with as such. Perhaps the best illustration of this point comes from a metal service center company that is presently using a statistical inventory control program. In this case it was stated that approximately ninety percent of their items could be covered by the controls which they had established. The remaining ten percent were "exceptions," for a large number of reasons.

Lead Time Estimation

From inventory records it is possible to determine the historical lead times. The difficulty, of course, is that lead times are continuously changing with time, particularly for certain classes of items. In some instances these lead times may change quite rapidly. This is partly because lead time distributions and demand distributions are not independent, so that when demand starts picking up this is reflected in increased mill backlogs, which in turn causes mill customers to boost their order sizes, thus further increasing mill backlogs, etc.

In addition, it must be remembered that lead time includes the elapsed period from that time when it is observed that the stock requires replenishment until the stock has been received from the mill and is available to fill orders. For this reason, the lead time of interest is the sum of the "mill" lead time and the time between periodic reviews (or from the time that the re-order point is reached and purchasing is notified), plus the time for actually preparing the order, etc. Because of these many variables it is difficult to generalize. What can be said, however, is that it is dangerous to use a constant average lead time. One author has suggested:

> However, one can often get by quite well using a model which assumes that the lead time is constant, if instead of using the mean lead time in the model one uses something like the maximum lead time or the mean lead time plus one standard deviation.[6]

It is known that several companies are essentially following such a means of dealing with the lead time variable, with reportedly satisfactory results.

Estimation of Average Demand During Lead Time

The most obvious approximation of this parameter is obtained by multiplying the average demand rate per period by the number of periods in the lead time. Thus, if demand is running at the rate of 5000 pounds per month, and the lead time is two months, then $\overline{\text{DDLT}}$ would be 10,000 pounds. This, then, is a forecast of the average demand during the next two months. The problem, of course, centers around the determination of the item-by-item sales rate to be expected. With the use of a computer it is possible to develop these item-by-item

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[6]G. Hadley and T. M. Whitin, Analysis of Inventory Systems (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1963), p. 420.

forecasts by means of statistical formulae smoothing. In the absence of a computer it is necessary to reach approximations of these sales rates. The sales pattern over the past ten to twelve months may be used to determine the average sales rate per month. Usually these figures are posted as part of the inventory records, and examination of these same figures will often reveal whether there is enough evidence of a trend to warrant using something other than this historical average.

Determination of Standard Deviation of Demand Distribution

While there will be little difficulty in determining the average demand during lead time, since this is already being estimated by most companies, the determination of the standard deviation presents a computational problem. Also, from a control point this factor is often more important than the average. This point may be illustrated by listing a year's demand history for an item, in pounds per month: 982, 2734, 1057, 727, 287, 133, 83 2304, 760, 99, 273, and 479. While it is useful to know that the average of these demands is 844 pounds per month, it is also necessary to know something about the dispersion of demand around this mean. During two of these twelve months the demand was approximately three times the average monthly demand.

Use of Estimators for Standard Deviation

While it would be possible to calculate the variance of demand on an item-by-item basis, this would rarely be done even if a computer were available. Instead, various estimators would probably be used. For example, the mean absolute deviation is known to be approximately eight-tenths of the standard deviation for samples drawn from a

normal distribution.[7] In one well-known computer program the mean absolute deviation is used as the estimator of the standard deviation of forecast error, and this same approach is discussed in detail in a recent book on forecasting.[8]

Another estimator which should offer some usefulness is the use of the range. For samples of n from the normal distribution there is a known relationship between the standard deviation and the range. Manual inventory records usually include a usage record listing the demand by months, and thus it would be relatively easy to note the range of demand over a period of n months. Following are some representative ratios.[9]

n	Standard Deviation Divided by Range
10	.325
12	.307
14	.294
16	.283
18	.275
20	.268
30	.245

For example, for the twelve monthly demands previously listed, the range is 2651. Making use of the above ratio we would estimate the standard deviation by multiplying this range by .307, resulting in an estimated standard deviation of 814 pounds. The calculated standard deviation for this twelve month period is 864 pounds. To evaluate the usefulness of this estimator, a total of thirty items was checked.

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[7]Robert G. Brown, Smoothing, Forecasting and Prediction of Discrete Time Series (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1963), p. 282.

[8]Ibid.

[9]George W. Snedecor, Statistical Methods (Ames, Iowa: The Iowa State University Press, 1962), pp. 37-38.

For each item the range and standard deviation of twenty-four monthly demands were calculated. The resulting ratios of the standard deviation to the range varied from a low of .20 to a high of .33, with an overall average for the thirty items of .27. The preceding table shows that for a normal distribution of demand the ratio of the standard deviation to the range would be approximately .26, which is quite close to the .27 ratio obtained for the average of the thirty items analyzed. Some of the ratios which were higher or lower than the expected .26 ratio were what could be referred to as "exceptions." For example, in the case of the .20 ratio, the average monthly demand was 812 pounds per month, and yet because there was an "exceptional" demand of 11,000 pounds during one month, the ratio is lower than would be normally expected.

Problem with Differing Forecasting and Lead-Time Intervals

Within the metal service center industry it is almost a universal practice to make use of monthly reports of one sort or another. For example, the posting of usage records, sales analysis reports, and inventory deck updating are usually on a monthly basis. The use of these records provides the basic information for either calculating or estimating monthly sales forecasts, standard deviations of monthly sales, etc. A problem arises when the lead time period is different from the forecasting period. Assume, for example, that the forecasting interval and the estimation of the standard deviation of sales are on a monthly basis, while the lead time is two months. For determining the re-order point for this lead-time period of two months, it is necessary to forecast the average demand during this two-month period, and to develop the standard deviation of sales for a two-month period. The problem is this: Given an estimate of the average demand

and the standard deviation of demand for a one-month period, how does one use this information for estimating the average demand and the standard deviation of demand for a two-month period? In statistical terms the average and standard deviation are referred to as "moments" of the demand distribution, and the demand distribution for (say) a two-month period is a "convolution" of the demand distribution for the basic (one-month) period. Starr and Miller have described the problem as follows:

> Fortunately, the relationships between the moments of the convolutions and those of the basic distribution are quite simple, at least for the lower order moments which we will be using. Let us suppose that the demand distribution is known for some fixed time period. . . . Then it can be shown that the corresponding moments of the ith convolution will be [10]
>
> $$\bar{z}_i = i\,\bar{z}$$
> $$s_i^2 = i\,s^2$$
>
> Where: $\bar{z}$ = average demand for basic period
>
> s^2= variance of demand.

Thus, in the example being used, the average demand during the two-month lead time period is estimated to be twice the average demand forecast for a one-month lead time period. Also, as shown, the variance for the two-month period is twice the variance of the one-month period. Thus, given s^2, the variance for a one-month period, the variance for a two-month period (for $i = 2$) is $2s^2$. In terms of the standard deviation:

$$s_i = \sqrt{i\,s^2} = \sqrt{i} \times \sqrt{s^2}$$

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[10]Martin K. Starr, and David M. Miller, Inventory Control: Theory and Practice (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1963), p. 154.

In the example being given, "i" is equal to two, so the standard deviation for the two-month period is 1.41 (i.e., the square root of two) times the standard deviation for a one-month period. Thus, if it is standard practice to estimate standard deviations in terms of a one-month interval, it is a simple matter to derive the factor required to convert these standard deviations to cover other lead-time intervals. Assume, for example, that lead time is ten weeks, and that the average demand and standard deviation of demand have already been estimated for a one-month, or 4.33 weeks period. Then "i" becomes 10/4.33, or 2.3, and the square root of 2.3 is 1.52. The estimate of the standard deviation of demand for a ten-week period is thus 1.52 times the standard deviation for a one-month period.

Total Cost Model and Model Sensitivity

In the earlier discussion of order quantity determination it was pointed out that the order quantity and the re-order point calculations are interdependent. It was further pointed out that twenty-three out of twenty-five stock-keeping units analyzed had the same order quantity when using an "indifference point" order quantity table as when using a total cost formula which took into account the differences in safety stock costs in determining optimum order quantities. With so many metal items having their optimum order quantities at price breaks, it is not surprising that the order quantities are not particularly sensitive to the re-order point determination. Thus, it was suggested that the order quantity might be determined first, and then the optimum re-order point could be calculated, predicated upon use of this order quantity.

With a computer's calculating efficiency it is practical to develop total cost formulae to calculate both optimum order quantities and re-order points in the same program. Such a program was developed for

this purpose, and this same program provided a means of comparing the total inventory costs of various operating doctrines, of testing the sensitivity of the model to errors in parameter estimates, etc. The particular program developed was for regular-size hot-rolled carbon bars, although with slight modifications the same program could be used for many other classes of items. The "input" information for each stock-keeping unit included the expected demand per year, standard deviation of monthly forecast error, the base cost per pound, gross profit margin as a percentage of the base cost, and the appropriate inventory holding cost. Following is the total cost formula[11] used in the program.

$$TC = C_i \left[DPY - \frac{DPY}{Q_i} E(DDLT > R) \right] + \frac{DPY}{Q_i} \left[S + mC_i \, E(DDLT > R) \right]$$

$$+ \; IC_i \left[\frac{Q_i}{2} + (R - \overline{DDLT}) + E(DDLT > R) \right]$$

Where: C_i = cost per pound, i = 6M, 10M, 20M, or 40M quantities.

Q_i = order quantity, i = 6M, 10M, 20M, or 40M

DPY = demand per year.

$E(DDLT > R)$ = pounds of stock by which demand during lead time exceeds the re-order point during an order cycle.

S = order cost.

m = gross profit margin as a percentage of the base cost.

$\overline{DDLT}$ = average demand during lead time.

Incorporated in the object program was a cumulative normal probability table. The use of this table facilitates the calculation of $E(DDLT > R)$. The object program also included the lead time estimate,

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[11]With slightly different notation this is taken from: Robert B. Fetter and Winston C. Dalleck, Decision Models for Inventory Management (Homewood, Illinois: Richard D. Irwin, Inc., 1961), p. 14.

along with a factor to convert the monthly deviation of forecast error to the forecast error for this lead time interval, and an order cost of four dollars. This latter information could just as easily have been part of the data input for each stock-keeping unit.

Making use of the above total cost formula the program calculated the total cost for order quantities of 6M, 10M, 20M, and 40M pounds. For each order quantity the optimum probability of filling all demand during lead time was calculated. Once this probability was known it was used to enter the cumulative normal probability table to find the variate, k, to be used along with the cumulative probability value to calculate E(DDLT > R). The partial expectation formula[12] used is as follows:

$$E(t > k) = \int_{k}^{\infty} (t - k)\ p(t)\ dt \ = p(k) - k[1 - F(k)]$$

$$\text{Where: } p(k) = \frac{1}{\sqrt{2\pi}}\ e^{-k^2/2}$$

F(k) = Cumulative probability which in this case is the optimum probability of filling all demand during lead time.

In the program the value used for F(k) was the "optimum probability of filling all demand during lead time." Once the partial expectation was calculated, the value of E(DDLT > R) was:

$$E(DDLT > R) = \sigma_{DDLT}\ E(t > k)$$

This, then, is the pounds of stock by which demand during lead time exceeds the re-order point during an order cycle. For purposes of calculating the total costs, it was assumed that this was the amount of stock to be "picked up" from competitors. Thus, the total demand per

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[12]Robert G. Brown, Smoothing, Forecasting and Prediction of Discrete Time Series (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1963), p. 444.

year is filled, with the establishment of the re-order point determining the relative amounts of demand filled from "own" stock vs. "pickup" from competitors.

The remainder of the program is a straightforward application of the total cost formula. Once the total costs have been calculated for each different order quantity, the program selects the order quantity producing the minimum annual inventory costs. This order quantity, the re-order point, annual material cost, annual order cost, annual stockout cost, average inventory in dollars and pounds, inventory holding cost, and total inventory costs are printed out.

Test of Model Sensitivity

To test the model sensitivity it was necessary to gather some demand and cost data from a metals service center. The cooperating firm was using Kardex inventory records from which it was possible to obtain the cost of the material and the demand, both by transactions and by monthly and yearly totals. A total of twenty-five regular-size hot-rolled carbon bars and angles items were chosen at random. For each item the demand by months was recorded for the past twenty-four months. This demand data was analyzed to determine the average demand and the standard deviation of demand for the twenty-four month period, and the mean absolute deviation of monthly forecast error. This analysis produced an estimate of the standard deviation of monthly forecast error, which was one of the required inputs for the computer program used to test the model sensitivity.

For each of the twenty-five items the base cost, expected demand per year, standard deviation of forecast error, inventory holding cost percentage, and gross profit margin were key punched on an IBM card. The resulting deck of twenty-five cards provided the input for the

operation of the program. To test the sensitivity of the program, two basic types of analysis were carried out. First, the same basic set of twenty-five items was used, but inventory holding cost percentages of 6%, 9%, 12%, 15%, and 20% were used. In each case, of course, all other parameters were held the same. This provided a means of noting the changes in system behavior resulting from changes in this cost parameter. In addition, it provided a means of assessing the model sensitivity to errors in the estimation of the holding cost percentage. A second type of analysis involved the introduction of an arbitrary "probability of filling all demand during lead time." The original program was slightly modified to determine the system behavior when it was decided to fill 90%, 95%, 97%, 98%, and 99% of all demand during lead time. The resulting system levels of material cost, stockout cost, inventory investment, etc. were then analyzed.

Model Sensitivity to Holding Cost Percentage

The result of this analysis is partly explained in Table 6-3 and Graph 6-3, which show the relationships between aggregate inventory investment and inventory holding cost percentages. Following are the average dollar inventory investments accompanying each of the listed inventory holding cost percentages.

Holding Cost Percentage	Average Inventory Investment
6	$16,539.
9	14,962.
12	12,958.
15	12,495.
20	10,929.

For each holding cost percentage the various total annual inventory costs were developed, and these costs were used to determine the "costliness" of errors in estimating holding cost percentages.

For purposes of this analysis it was assumed that the "true" holding cost percentage was twelve percent. Under these circumstances, then, it is desirable to know the seriousness of the use of other holding costs in "ignorance" of this true holding cost percentage. Table 6-6 shows the resulting gross costs. The "total material cost" includes both the cost of the material purchased from the mill and that "picked up" from competitors. A separate total of these "pickups" is shown to indicate how this total increases as the holding cost percentage rises. In effect, the "total material cost" includes the stockout penalty, since approximately 23% of the dollar total of outside "pickups" represents foregone gross profit margin. The total cost figures in the right-hand column include the total material cost, the total ordering cost, and the "true" inventory holding cost based upon twelve percent of the average inventory investment.

With the holding cost percentages varying from 6% to 20%, or from .5 to 1.67 of the assumed "true" holding cost of 12%, it will be noted that total costs are essentially the same. Thus, with these twenty-five items the model shows a rather extreme insensitivity to errors in estimating the holding cost percentage.

An examination of Table 6-6 provides evidence to explain this lack of sensitivity. This table shows how outside pickups, total material cost, and total ordering cost vary with the inventory holding cost percentage. Not surprisingly, the outside "pickups" go up in nearly direct proportion to the holding cost percentage, since the higher the holding cost percentage the more expensive it is to have "overstocks." Total material cost goes up as the holding percent increases, partly because of smaller order quantities and partly because of the increased material picked up from competitors. Because of the smaller order quantities the total ordering cost increases as the inventory holding cost percentage increases. These costs vary in such a manner that, when

Table 6-6. Model Sensitivity to Errors in Holding Cost Percentage

Holding Cost	Outside "Pickups"	Total Material Costs (1)	Ordering Cost (2)	Average Inventory Pounds	Average Inventory Dollars	Inventory Holding Cost (3)	Total Inventory Cost (1, 2, 3)
.06	$ 502.	$30,937.	$ 98.	228,000	$16,539	$1985.	$33,020.
.09	720	31,040.	107.	205,548	14,962.	1795.	32,942.
.12	977.	31,269	141	176,922	12,958.	1555.	32,965.
.15	1196.	31,329.	142.	169,971	12,495.	1499.	32,970.
.20	1518.	31,583.	169.	148,194	10,929.	1311.	33,063.

added to the "true" inventory holding costs, the total costs resulting from the use of erroneous inventory holding cost percentages vary only slightly from the costs developed from using the true holding cost percentage of twelve percent.

Table 6-6 shows some interesting relationships among the variables included in the model, and serves as an example of the analytical benefits from the use of a model. Any one of the segments of costs, in itself, is extremely difficult to interpret. For example, "outside pickups" varies from \$502. to \$1518. and average inventory investment varies from a low of \$10,929. to a high of \$16,539. Yet, of course, the low figures are not necessarily "better" than the high figures. To properly interpret any one of these figures requires more complete information concerning the relationships among the set of relevant variables. This information is provided by an appropriate model.

One further comment could be made in regard to the lack of sensitivity to errors in estimating the inventory holding cost percentage. Starr and Miller[13] have developed a formula which indicates the increases in annual inventory cost resulting from errors in estimating the inventory holding cost. This formula is as follows:

$$TC_1 - TC_0 = TC_1 \left(1 - \frac{2\sqrt{k}}{k+1}\right)$$

Where: TC_1 = annual costs when using the erroneous holding cost.

TC_0 = annual costs when using the "true" holding cost.

$k = \dfrac{\text{erroneous holding cost percentage}}{\text{true holding cost percentage}}$

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[13]Martin K. Starr, and David W. Miller, Inventory Control: Theory and Practice (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1962), p. 177.

Applying this formula to the previous example, one would expect that the use of 6% and 20% inventory holding cost percentages would have produced approximately five percent increases in total costs over the total costs resulting from the use of the "true" holding cost of twelve percent. The above formula does not apply to the present model, however, because it does not take into consideration the savings in quantity extras costs or the differences in safety stock costs as the holding cost percentage varies. Thus, when erroneously using a six percent holding cost percentage, there are substantial material cost savings to help compensate for the increased holding costs because of the larger average inventories. Furthermore, the formula assumes that the order quantity may be a continuous variable, whereas in the present model the material is purchased in one or another of four discrete quantities. Thus, when the holding cost percentage moves from twelve percent to twenty percent, only nine of the twenty-five items used in the analysis were purchased in smaller purchase quantities.

Model Sensitivity to Safety Stock Levels

The computer program which was described included the determination of the optimum safety stock level for each item. An alternative means of establishing safety stock levels is to set safety stock levels to meet an arbitrary percentage of demand during lead time. It is quite common, for example, to find attempts to establish re-order points to fill 95% of demand during lead time. To test the total inventory cost of following such policies, the computer program was slightly modified. Instead of an item-by-item calculation to determine the optimum percentage of demand to be filled during lead time, a fixed percentage was used. All other aspects of the program remained unchanged. Thus, the total inventory costs for quantities of

6M, 10M, 20M, and 40M were calculated, and the order quantity producing the minimum total inventory costs was selected by the program. These calculations were made for .90, .95, .97, .98, and .99 probabilities of filling all demand during lead time. In order to provide comparability, the inventory holding cost was kept at a constant twelve percent, and the order cost was kept at four dollars. Table 6-7 is a summary of the resulting total values.

From Table 6-7 it will be noted that the average inventory increases rapidly with increases in the desired service level. At P(DDLT < R) of .99, the average inventory is nearly forty percent greater than the average inventory to meet the "calculated" percentage of demand to be filled during lead time. In addition, total inventory costs increase significantly. Below are listed these increased costs compared to the optimum total inventory cost.

P(DDLT < R)	Increase over Optimum
.90	$193.
.95	96.
.97	137.
.98	210.
.99	322.

The probability of .95 produces the least increase in cost over the optimum, while the .97, .98, and .99 probabilities produce increasingly larger cost increases. While these cost increases do not appear large in comparison to the total annual inventory costs, they may be better interpreted by noting that a five percent return on the annual sales represented by these twenty-five items is estimated to be $2000. The above figures loom somewhat larger in comparison to this figure.

Table 6-7. Sensitivity of Total Cost Model to Service Levels

P(DDLT < R)	Outside Pickups	Total Material Cost (1)	Ordering Cost (2)	Average Inventory Pounds	Average Inventory Dollars	Inventory Holding Cost (3)	Total Inventory Cost (1, 2, 3)
Optimum	$977	$31,299.	$141.	176,000	$12,958.	$1,555.	$32,965.
.90	945.	31,445.	180.	172,500	12,793.	1,535.	33,158.
.95	271.	31,146.	149.	200,800	14,715.	1,766.	33,061.
.97	100.	31,022.	132.	222,600	16,315.	1,958.	33,132.
.98	90.	31,020.	132.	230,000	16,858.	2,023.	33,175.
.99	20.	31,003.	132.	244,800	17,930.	2,152.	33,287.

Chapter Summary

This chapter was devoted to the development of some models which would seem to have a generally wide applicability in the metal service center industry. Indifference points, tables, and graphs were suggested as a means of determining order quantities, as well as offering guidance in terms of when to make mill purchases versus buying from another service center. The use of a return on invested capital formula was used to illustrate the basic meaning of an indifference point. The use of indifference graphs was suggested as a means of determining the imputed interest cost reflected in present ordering rules, and as a means of attaining consistent ordering policies when a number of individuals are responsible for purchasing various classes of metal items.

The use of the inventory holding cost as a "management control" variable was discussed. Through the use of indifference graphs and the development of appropriate cost-of-possession figures for various commodities and/or branch plants, this technique would seem to offer promise for management control when there are constraints on total capital and/or space.

A basic safety stock model was described, along with a discussion of some of the problems in estimating the parameters necessary for its use. Several tables were shown as being suggestive of the means by which such a model could be effectively used.

A program to test the sensitivity of these models was described. It was shown that, at least for the twenty-five items tested, the model was not sensitive to errors in estimating the holding cost percentage. Of interest, however, was that there were widely varying totals for average inventory investment and stockout costs, depending upon the

inventory holding cost percentage actually used. A further test was made of the sensitivity of the model to arbitrarily established levels of "demand to be filled during lead time." As was shown, deviation from the "optimum" percentage of demand to be filled during lead time can be costly.

CHAPTER VII

SUMMARY, CONCLUSIONS, AND NEEDS FOR FURTHER RESEARCH

The first part of this chapter is devoted to a brief summary of this study. This summary is followed by a discussion of some of the overall conclusions of the study, indicating how this study fits into perspective in terms of the historical development of inventory theory and practice. The latter part of the chapter is devoted to a discussion of some of the present trends in inventory practice in the metals service center industry, and some of the needs for further research.

Metals Service Centers

As a backdrop for the discussion of some of the overall conclusions of this study, a summary of the preceding chapters will be presented. Since this study was carried out in the Metals Service Center Industry, it was necessary to identify this industry and to point out some of its inventory management problems. There were shown to be a number of factors in this industry which would lead to an *a priori* expectation of highly sophisticated inventory management practices. Among these reasons were the nature of the "quantity extras" price schedules applying to so many metal items, and the cost-of-possession concept that has for years been widely discussed throughout the industry. The opportunity to "pickup" material from competitors suggested a basis for calculating a reasonably precise stockout penalty, thus providing a basis for calculating the "optimum

probability of filling all demand during lead time." While there were these reasons for expecting the widespread establishment and use of ordering rules to cover order quantities and re-order points, there was some preliminary research data which raised some doubts concerning whether there really was a widespread use of scientifically determined ordering rules.

Historical Background

From 1915, the date of the first published lot-size formula, until 1931, when Raymond published his full-length book dealing with the development and use of lot-size formulae, a large number of individuals had made contributions toward the development and use of such formulae. Among these contributor's was R. C. Davis, who presented an economic purchase quantity formula to the ASME in 1928. In succeeding years, right up to the present time, many further contributions had been made, particularly in recent years on the part of mathematicians, economists, and others who have developed more complete models, supported by mathematical existence proofs of their optimal solutions under given assumptions.

Evidence of the early resistance to the use of lot-size formulae was pointed out. One of the discussants of R. C. Davis's paper provides evidence of such resistance, and Raymond devoted a significant portion of his book to pointing out the irrational nature of many of the objections to the use of lot-size models. The source of this resistance centered around the problems brought about because of the use of mathematics, problems of determining the interest on invested capital, and overhead accounting problems. Raymond discussed each of these problems in an attempt to show how they could be dealt with, and presented some compelling arguments in favor of the use of such formulae.

It was further pointed out that, at least up to the relatively recent past, there is evidence of a rather wide gap between inventory theory and practice. The continuation of the early resistance to use of formulae was pointed out by one author who indicated that the use of EOQ went into eclipse in the thirties and forties, and was just coming back into practice with the use of the computer.

Inventory Management Survey

The results of the inventory management survey were presented in chapter four. Questionnaires were returned from 240 companies, representing a wide range of sizes and types of companies who are members of the Steel Service Center Institute. Data from each questionnaire was key punched on an IBM card, and through a computer program a number of contingency tables were prepared. These tables showed the distribution of answers in relation to: company size in gross sales, number of branch plants, inventory record-keeping system, and type of metals service center. Through this analysis it was possible to account for some of the differences and similarities of practices in relation to these variables.

The results of this survey presented a broad overall picture of the presently employed inventory management practices. Following are some of the key findings:

- Approximately 90% of the respondents are presently using manually posted inventory records, either of the "Kardex" or "loose-leaf" types.

- Only eighteen companies, or 8% of the respondents, indicated that they calculate a cost-of-possession figure.

- Thirty-nine percent responded that they make use of EOQ, cost-of-possession balanced against quantity extras cost, or tables or graphs for purposes of determining order quantities. A total of sixty-one percent determine order quantities with the primary use of either "historical records and averages" or "turnover goals."

- Fifty-four percent of the respondents make use of re-order points. Cross-relating the answers to this question to the answers to other questions shows that the majority of the re-order points are based upon "a given number of days or weeks of demand for all items."

- Only three companies responded that they make use of "k factors, special slide rules, or record of forecast errors" for purposes of determining reorder points.

- Turnover is by far the most common means of judging whether inventories are at a "correct" or "best" level, with seventy-eight percent of the respondents listing this answer. This may be compared to the twenty percent of the respondents who rely on "return on investment" for judging inventory levels.

- Forecasting is primarily by estimates from salesmen and sales and/or other executives, adjusted for current demand and latest sales information. Only three companies listed the use of statistical smoothing formulas.

- The inventory management problems mentioned by the various companies presented an interesting means of noting the diversity of problems in the industry. The largest companies (over ten million dollars gross sales) listed system design and the need for development of better methods of decision-making and control as the major problem areas. The companies with gross sales of up to two million dollars per year listed "product line" and "forecasting" as the dominant problems.

- As further evidence of the changes presently taking place, a total of thirty-four percent of the companies indicated that their present or forward planning included the lease or purchase of a computer or other data-processing equipment. It is of further interest that 71% of the largest companies were included in this group.

The summary of the questionnaire responses provided quantitative data concerning inventory management practices. Some difficulties of interpretation were encountered due to the imprecise nature of the meaning of terms. For example, EOQ, re-order points, and cost-of-possession are terms which can have different interpretations.

Thus, while 39% of those responding indicated the use of EOQ formulae or "cost of possession balanced against quantity extras costs" for purposes of determining order quantities, only 8% indicated that they calculated a cost-of-possession figure!

Company Visitations

The company visits provided a more reliable basis for determining the practices actually being followed in the sample of companies visited. The thirty companies visited were divided into three groups on the basis of gross sales, with the "small" companies comprising those companies with sales of up to four million dollars per year, the medium-sized companies with sales of from four million to ten million dollars per year, and the "large" companies with sales of over ten million dollars per year. During these company visitations an attempt was made to gain some insights into the means by which ordering practices were determined. For those companies which had explicitly determined ordering rules, it was not difficult to determine with reasonable precision the basis upon which the rules were established. In the great majority of cases, however, no precise rules had been established, and hence only the outward manifestations of the bases of the ordering rules could be established. The descriptions of the various company practices, along with the summaries of the similarities and diversities of practice within each group, could be characterized as making up the "positive" models of decision-making.

Normative Models

This chapter was devoted to the development and discussion of order quantity and re-order point models, and their interrelationships. These models served to demonstrate the principles underlying the

establishment of order quantities and re-order points, and to further serve as a means of showing their usefulness for inventory control of many classes of metal items. The use of the holding cost percentage as a "management control" variable was suggested as having potential application for purposes of keeping inventory within constraints on total capital and/or space requirements. The sensitivity of the model to errors in estimating holding costs was discussed, and the costliness of attempting to fill too high a "percentage of demand to be filled during lead time" was pointed out.

Present Practices in Perspective

The research design for this study briefly described both the economic and behavioral theories explanations of decision-making in the firm. One of the goals of this research was to reach some insights concerning which of these two theories would better serve to explain the manner of arriving at ordering decisions. Based upon the description of the industry, there was an implicit hypothesis that the metal service center industry would be largely characterized by rationally determined inventory management ordering rules. The results of this study offer insights into the applicability of these two theories of decision-making. The second type of question which will be touched upon has to do with how this study fits into the historical picture of the development of inventory theory and practice.

Economic Theory and Behavioral Theory Perspectives

"Economic theory" refers to the use of inventory theory in terms of EOQ models and re-order point models for arriving at the optimum economic balance among the conflicting costs which may be assigned to inventories. As was clearly shown in the descriptions of company visitations, there are a number of cases in which ordering rules are explicitly determined in an effort to minimize total inventory costs. For these firms, the economic theory of the firm better suffices for describing the nature of inventory management decision-making.

At the other extreme were a number of companies where a behavioral theory would be required in explaining the ordering rules being followed. Perhaps the best illustrations of this type of inventory management were found in the medium-size companies, which were big enough that top management did not take a direct hand in the day-to-day ordering practices, and where a number of different product managers or buyers were held responsible for given classes of items or commodities. Under these circumstances, and in the absence of any prescribed ordering rules which were to be followed as a matter of policy, these product managers were the focal point of a variety of organizational pressures. For example, there was pressure to: maintain enough inventory, but not too much; order in "good" quantities from the mills, but also to keep turnover up; minimize stockouts, but not have too much investment in safety stocks, etc. These pressures were freely discussed by a number of product managers. Thus, in cases such as this one, one could only explain the ordering rules at any given time as the result of the "mix" of organizational pressures brought to bear on the product managers. Here is where behavioral theory, in the Cyert and March[1] sense, would better serve to explain inventory decision-making.

Perhaps the two different types of decision-making just described could be considered the opposite poles of a continuum, with the great

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[1]Richard M. Cyert, and James G. March, A Behavioral Theory of the Firm (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1963).

majority of companies fitting somewhere in between. There is some evidence to indicate that many metal service center companies are moving along this continuum toward the inventory theory pole. There are several reasons for this belief. In the last six or seven years inventory management has apparently become a much more critical problem. On eight or ten different occasions metals service center executives reported that inventories had not been a problem until 1957 or 1958, and that prior to that time the only problem was to build inventories. This same idea was further repeated a number of times as part of the inventory questionnaire responses. For example, one questionnaire response was:

> Wider ranges of sizes and grades will require heavier investments and, hence, a closer scrutiny of turnovers and inventory levels.
>
> Inventory management will be raised to equal stature with sales departments as key to profit in the Steel Service Center Business.

Thus, there is this evidence of an industry awakening to the inventory problem in the relatively recent past. Other evidence of this awakening to the problems is suggested by the 34% of the respondents to the questionnaire who indicated that a computer was part of their present or forward planning. In nearly all cases one of the reasons for considering the computer was to improve their inventory record-keeping and purchasing management.

Inventory Practices in Historical Perspective

It is of interest to consider briefly the present status of inventory management in this industry in terms of the historical development of inventory theory and practice. Going back to the book by Raymond, it can be observed that one of the hindrances to the early practice of

inventory theory was due to what could be broadly described as a "conceptual" problem. Thus, problems of interest rate determination, and determination of the opportunity cost of capital, overhead accounting problems, etc. were discussed. Also, one of the discussants of R. C. Davis's paper in 1928 had pointed out that there were many factors that the EOQ formula didn't consider. Whitin's book, The Theory of Inventory Management, published in 1953, discussed the use of mathematical formulations, and presented some of the arguments (of others) against their use. His statement "Another argument against the use of mathematics in inventory control is that there are many intangibles involved in the problem that cannot be quantified with any degree of precision,"[2] is quite similar to what was being said and written a quarter of a century earlier. Similar statements still appear regularly in the literature. For example, in regard to the use of simple formulas or decision rules, a recent author stated:

> But although many of these techniques are widely used, a typical reaction of the manager with inventory problems when he examines an illustration in the literature is: "Very interesting, but it doesn't apply in my situation. My case is different!"[3]

During company visitations this "conceptualization" problem turned up many times, in a variety of ways. In some cases there was outright skepticism that formulated inventory controls would work. "Each item is different," for example, was stated on several occasions. Or, as stated in a questionnaire return, the problem was conceived as one of establishing proper inventory levels to get: "Maximum turnover,

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[2]Thomson M. Whiten, The Theory of Inventory Management (Princeton, New Jersey: Princeton University Press, 1953), p. 228.

[3]James I. Morgan, "Questions for Solving the Inventory Problem," Harvard Business Review, Vol. 42, No. 4, July-Aug., 1963, p. 96.

maximum return on dollars invested, and minimum occasions of being 'out of stock'."

In other cases the conceptualization problems concerned the manner of developing the appropriate costs to use in the models. Thus, even in estimating the costs required for use of a simple lot-size model, there can arise great problems of conceptualization. Following several discussions centered around the determination of cost parameters, a typical comment was, e.g., "Yes, but how do you know?" A representative answer from the literature is:

> Despite the difficulty in measuring costs--and indeed because of such difficulty--it is eminently worth while to look at the lot-size problem explicitly formulated. The value of an analytic solution does not rest solely on one's ability to plug in precise cost data to get an answer. An analytic solution often helps clarify questions of principle, even with only crude data available for use.[4]

One author, in a critical evaluation of the inventory theory periodical literature, has stated: "The literature tends to give the impression that the relative weights of conceptualization and solution are 5% and 95%, whereas just the reverse allocation of effort is experienced in actual operations research work."[5] The point of all this discussion is to note that one must look much farther than to the availability of proven inventory models in order to explain the status of inventory practice. Inventory models may be available, but their use begins with the conceptualization of a problem in such terms that a model may be used.

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[4]John F. Magee, Production Planning and Inventory Control (New York: McGraw-Hill Book Company, Inc., 1958), p. 45.

[5]Fred Hannsmann, Operations Research in Production and Inventory Control (New York: John Wiley and Sons, Inc., 1962), p. 4.

One further point is of interest in terms of historical perspective. Several references have been made to Franklin Moore's statement in regard to the use of EOQ having come back into use with the availability of computer computations. There is a good deal of evidence that this is a valid observation in the metal service center industry. As was noted in a number of company visitations, as well as being reflected in the questionnaire returns, a number of companies are estimating costs, determining optimum order quantities, and moving into statistical forecasting because of the motivating force of a computer. For example, of the fourteen companies visited who had sales of over ten million dollars per year, the only ones who had calculated cost-of-possession figures <u>also</u> had computers. It is of further interest that in a number of instances companies are moving from practically no inventory controls, i.e., in terms of optimal order quantities and re-order points, into the practice of quite highly sophisticated control systems. In these cases the computer served as the stimulus for renewed management attention to the determination of the cost parameters and organizational changes required for the use of such programs.

Present Trends and Needs for Further Research

In earlier discussions it was suggested that perhaps the present period would be looked back on as a transitional period in the development of inventory management in the Metals Service Center Industry. Both the problem statements listed on the questionnaire responses and the information gained during the company visitations provide evidence that a wide segment of companies in the industry are presently planning for changes, or at least have recognized the need for improvement in inventory management. The most pronounced trend toward change was

found among the large companies, i.e., those with sales of over ten million dollars per year, where 71% indicated that present or forward planning included the purchase of lease of a computer or other data-processing equipment. The least pronounced trend was evidenced on the part of the smallest companies, i.e., those in the "less than three million dollars per year" group. In this latter group it is much more common to find a "wait and see" attitude, with planning more often including accounting machines, perhaps intercoupled with a by-product punched card to provide basic sales analysis data as a function of the order processing operations. Then, too, in these smaller companies, inventory management problems frequently took on a somewhat different character, in that "control," ownership, and basic inventory management were often centered in the top operating executive. Under such circumstances it is perhaps not surprising that the establishment of economic order quantities, re-order points, and the problem of aggregate inventory investment, are not conceived of as being as troublesome as problems of "product line" and "forecasting."

As an indication of how rapidly data processing, including computers, is becoming a consideration for even relatively small companies, it is of interest to note that as recently as 1959 one author stated:

> A rough rule of thumb is that a business with annual sales of more than $10 million can probably show some advantage for the use of mechanical (punched cards) or electronic (computers) data processing.[6]

Five years later another author, in an article, "The Computer Enters Distribution," made a statement that provides an interesting contrast to the above statement, and would seem to have relevance to some metals service center firms which were visited. This author

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[6]Robert G. Brown, Statistical Forecasting for Inventory Control (New York: McGraw-Hill Book Company, Inc., 1959), p. 153.

suggested that companies with sales of three million dollars or greater were of a size where a computer could perhaps be considered feasible, and then stated:

> Many of today's large industrial distributors, with gross sales of three million dollars or more, have grown to their present size without much planning. Over the years these firms have forged ahead in an expanding market. They have broadened their market coverage, increased their inventories, expanded their sales staffs, and increased their inside personnel to handle the resulting increased work load. With notable exceptions, the office operations of many of these firms--inventory control, order processing or billing, payroll, purchasing, sales analysis and cost analysis--have developed on a piecemeal basis rather than as coordinated systems.[7]

At this particular time there are a few companies in the metals service center industry with sales of even less than three million dollars per year, who have a computer or are considering the lease or purchase of one. In general, however, the use of computers, of a size for inventory record-keeping, is at this time primarily being considered by metal service center firms with sales of in excess of five million dollars per year. If the present trend continues, however, it may be expected to become increasingly common for many of the smaller companies to justify a computer through the use of "coordinated systems" as mentioned in the preceding quotation.

Reduction in the Cost of Calculations

Throughout this study there have been a number of direct and indirect references to the cost of the computations required for item-by-item inventory control. In general, the greater the refinement of the decision-making process the greater is the expense in its use.

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[7]Charles H. Brownell, "The Computer Enters Distribution," Industrial Distribution, Feb., 1964, Vol. 54, No. 2, p. 44.

An economist recently referred to this in terms of what he called an "optimally imperfect decision,"--which: "Requires that the marginal cost of additional information gathering or more refined calculation be equal to its marginal (expected) gross yield."[8] This statement is of interest in the present context because of the greatly reduced cost of making these "more refined calculations." As Forrester has pointed out:

> In the last fifteen years the cost of arithmetic computation has fallen by a factor of 10,000 or more in the areas where the digital computers can be used in their most efficient modes of operation.[9]

He further stated:

> The technical performance of electronic computers increased by a factor of nearly 10 per year over the decade of the 1950's; in almost every year there was a ten-fold increase in speed, memory capacity, or reliability.[10]

These advances in computer technology account for the increased feasibility of the use of a computer by smaller companies. This is merely another way of stating that the cost of calculation has decreased. Because of this decrease in the cost of calculation it would seem to be a reasonable assumption that "optimally imperfect decisions" are going to be moving in the direction of more refined decision-making processes.

Economic Impact of Inventory Theory Application

This study in the Metals Service Center Industry has indicated the

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[8]William J. Baumol and Richard E. Quandt, "Rules of Thumb and Optimally Imperfect Decisions," The American Economic Review, Vol. LIV, No. 2, Part I, March, 1964, p. 23.

[9]Jay W. Forrester, Industrial Dynamics (New York: John Wiley and Sons, Inc., 1961), p. 18.

[10]Ibid., p. 19.

ferment in terms of the introduction of computers and other data-processing equipment. Thirty-four percent of the respondents to the questionnaire indicated that they were presently considering such equipment. This study has further provided some clues to enable prognostication concerning the potential economic impact of a widespread introduction of scientific inventory control.

There are several reasons for expecting an economic impact from the widespread use of scientific inventory theory. One could argue that an additional degree of economic stability would be one result. The fluctuations in inventories is one of the important factors accounting for cyclical movements in the economy. As more and more scientific inventory control is introduced, it is reasonable to assume that statistical formula smoothing and other forecasting techniques will become more widely used. One of the expected results from progress in this area would be to bring about an increased measure of stability. Instead of large numbers of "intuitive" managers creating a multiplier effect in inventory buildups and depletions, it may be anticipated that more emphasis will be placed upon trend and cycle analysis and other forecasting measures.

A closely related stabilizing effect may be anticipated because of a greater emphasis upon the understanding of the interrelationships between the industrial and economic systems. Through increased attention toward the understanding and implementation of scientific inventory management systems, it may be anticipated that there will evolve a better understanding of the factors influencing company success. One of the best-known exponents of this view is Jay Forrester, who has stated:

> Managing is the task of <u>designing</u> and <u>controlling</u> an industrial system. Management science, if it is to be useful, must evolve effective methods to analyze the principal

interactions among all the important components of a company and its external environment.[11]

Need for Intra-Company Research

Intra-company research is one type of research that would be suggested by this study. As pointed out in the chapters summarizing the questionnaire results and the company visitations, there are many companies who have not given any explicit attention to the formalization of inventory decision rules. As a consequence, there is a lack of relevant cost information upon which to evaluate present methods. Also, in many companies there seemed to be no one who had been assigned the responsibility of attaining a familiarity with inventory control methods. This is in sharp contrast to those companies where scientific inventory management rules had been adopted, in which cases there were individuals, usually staff in nature, who were familiar with the basis upon which ordering rules had been determined, and who had insights into the behavior of the system. There was some evidence that this experience was only developed over a period of time, and that a "gestation" period was required for the development and de-bugging of the system which had evolved.

One author has stated the case as follows:

> As long as ordering decisions involve judgment they cannot be made mechanically; but when mathematical decision rules are used, mechanization becomes possible. Thus, the optimal ordering rules provided by operations research may lead to a double payoff through better inventory decisions and higher potential for mechanization, provided that mechanization can be done economically.[12]

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[11]Jay W. Forrester, Industrial Dynamics (New York: John Wiley and Sons, Inc., 1961), p. 8.

[12]Fred Hannsmann, Operations Research in Production and Inventory Control (New York: John Wiley and Sons, Inc., 1962), p. 97.

This quotation is of interest for two reasons. First, it points out a sound reason for engaging in intra-company research to determine the relevant costs for evaluating inventory management practices and the extent to which they may be formalized in the form of ordering rules. A second part of the quotation which is of interest is the phrase, "provided that mechanization can be done economically." It would seem that in the absence of preliminary research concerning present practices it would be hazardous to consider mechanization. Mechanization should pay its own way through the marginal savings brought about by such mechanization, and marginal savings cannot be adequately ascertained without the study, audit, or analysis of present practices and the total annual inventory costs which they produce.

A closely related type of intra-company research has to do with the means of controlling branch-plant inventories. The company visitations summaries pointed out the alternative practices in this regard. One company, with widely dispersed plants, has what is largely a decentralized inventory responsibility. Here the company has made profit-center managers responsible for inventory management. An alternative approach is to centralize inventory management decisions, either in the form of rather precisely detailing the ordering rules by means of which stock-keeping units at branch plants will be replenished or by taking care of all replenishment decisions on a centralized basis.

This intra-company research effort begins with a top management awareness of the need for such research, as pointed out in a recent study by the National Industrial Conference Board:

> In many companies top management has placed greater emphasis on sound inventory management. This emphasis has had a number of manifestations, among them a reappraisal of inventory objectives, methods of achieving these objectives, and efforts to instill in company personnel an awareness of the need for good inventory controls. As the chairman of a metals

company put it, "We desire to make inventory control a continuing and mandatory demand from top management, rather than a horrified reaction annually."[13]

Other Research Needs

A number of other research needs were brought into focus by this study. For example, two of the most common problems listed in the questionnaire responses were the "forecasting" problem and the closely related "product line" problem. These problems are related in the sense that the determination of whether to add or drop items from a line is largely based upon an explicit or implicit "forecast" of the demand for such items. These problems were only lightly touched upon in this study, and yet they are of crucial importance in terms of making use of ordering rules. For example, even in the use of the simplest ordering tables it is necessary to estimate the rate of demand per year. With fluctuating demand rates this poses a difficulty.

Both demand distributions and lead-time distributions become part of this same "forecasting" problem. It will be recalled that the discussion of the re-order point model included assumptions about the length of lead time and the normality of the distribution of forecast errors. While these assumptions may be acceptable for illustration purposes and perhaps even for heuristic problem-solving purposes, it would seem to be a worth-while research effort to determine more precisely what types of statistical demand distributions are typically encountered, and how they may be identified.

Another research need, building upon the preceding one, is to make use of statistically determined distributions of lead time and

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[13]"Progress in Inventory Management," The Conference Board Record, National Industrial Conference Board, Inc., Vol. 1, No. 3, March, 1964, p. 14.

demand for purposes of simulation. Through the use of the simulation tool various combinations of forecasting and decision models could be tested to determine their interrelationships and to derive conclusions about the costliness of deviations from optimal solutions.

With the passage of time further research needs and opportunities should present themselves. With the number of companies presently engaged in installing scientific inventory management programs it may be anticipated that problems not presently considered may become important. As the executive of one company stated: "Our present problem is to implement our new inventory system. It's much more complex and more technical than our present system." The experience of this company and others who are presently installing control systems may very well provide fruitful fields of research for gaining insights into the implementation and verification of inventory models.

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APPENDICES

APPENDIX A

STEEL SERVICE CENTER INSTITUTE
540 TERMINAL TOWER · (216) 241-3468 · CLEVELAND, OHIO 44113

ROBERT G. WELCH, President

March 3, 1964

TO ACTIVE MEMBERS:

Enclosed is a questionnaire prepared by John Demaree, the Steel Service Center Institute Graduate Fellow who is working for his doctors degree as a research assistant at the Graduate School of Business Administration, Michigan State University. John has been making a study of inventory management practices and problems in the metal service center industry. While the research conducted thus far has included visits to a number of small, medium, and large size service centers over a wide geographic area, and covering most product lines, it is believed desirable to get the broadest possible sampling of inventory management practices and problems in our industry. This is the reason for the "Inventory Management Survey" which is enclosed.

Your assistance will be greatly appreciated since replies from a large number of member companies will provide more reliable data concerning what our members are presently doing in the area of inventory management. The survey also provides each member an opportunity to make any comments concerning particular problem areas. The analysis of the survey results will also help to guide the second part of this research study dealing with methods and approaches toward handling the problems revealed in the questionnaire answers.

All individual replies will remain confidential, but in anonymous summary, they will provide added meaning and significance to this research study.

In our opinion, and in the opinion of the business school professors supervising the study, John Demaree is making excellent progress. We are very hopeful that results of real value to our industry will be produced. Your cooperation in this project will make a substantial contribution to this purpose.

Sincerely yours,

Robert G. Welch

Robert G. Welch
President

RGW/la
ABECO

INVENTORY MANAGEMENT SURVEY
GRADUATE SCHOOL OF BUSINESS ADMINISTRATION
MICHIGAN STATE UNIVERSITY

INSTRUCTIONS:

ON THE FOLLOWING PAGES ARE A SERIES OF QUESTIONS. MOST ARE FOLLOWED BY A SERIES OF ALTERNATIVE ANSWERS, SO IT IS MERELY NECESSARY TO PLACE CHECK MARKS OPPOSITE THE ANSWERS WHICH APPLY IN YOUR PARTICULAR CASE. WHEN NONE OF THE LISTED ANSWERS APPLY, AND FOR A FEW OTHER QUESTIONS FOR WHICH IT WAS NOT PRACTICAL TO LIST A SERIES OF POSSIBLE ANSWERS, YOU ARE REQUESTED TO FILL IN THE REQUESTED INFORMATION. ALL ANSWERS WILL REMAIN CONFIDENTIAL, AND EVEN DURING THE STATISTICAL ANALYSIS OF THE REPLIES YOUR COMPANY WILL ONLY BE IDENTIFIED BY A SEQUENCE NUMBER ON AN IBM CARD.

<u>PLEASE ANSWER ALL QUESTIONS</u>. SOME QUESTIONS MAY NOT BE APPLICABLE TO YOUR TYPE OF SYSTEM, OR THERE MAY BE DOUBT ABOUT THE MEANING OF CERTAIN TERMS IN A QUESTION. IN EITHER CASE PLEASE PROVIDE THE ANSWER YOU BELIEVE BEST ANSWERS THE QUESTION, <u>OR</u> PUT A QUESTION MARK THROUGH THE QUESTION. IN THIS WAY IT WILL BE KNOWN THAT THE QUESTION WAS NOT MERELY OVERLOOKED.

<u>ALL REPLIES WILL BE VALUED.</u> IT IS RECOGNIZED THAT SOME COMPANIES HAVE QUITE SOPHISTICATED INVENTORY CONTROL SYSTEMS, WHILE OTHER FIRMS RELY ON THE MORE TRADITIONAL METHODS OF CONTROLLING INVENTORY. IT IS THIS VERY DIVERSITY OF PRACTICE WHICH IS ONE OF THE REASONS FOR THIS SURVEY. REGARDLESS OF WHAT TYPE OF SYSTEM YOU'RE USING, YOUR ANSWERS WILL BE RESPECTED AND VALUED.

<u>RETURN ENVELOPE IS ENCLOSED</u>. AN ADDRESSED RETURN ENVELOPE IS ENCLOSED FOR YOUR CONVENIENCE. A PROMPT REPLY WILL BE APPRECIATED, SINCE THE ANSWERS WILL BE KEY PUNCHED FOR IBM PROCESSING, AND THE FINAL TABULATION WILL BE HELD UP UNTIL ALL THE RETURNS ARE IN.

<u>HAVE A PENCIL IN HAND</u>. MAY I SUGGEST THAT YOU (OR THE EXECUTIVE TO WHOM YOU DELEGATE THIS TASK) HAVE A PENCIL IN HAND, SINCE MOST OF THE QUESTIONS CAN BE READ <u>AND</u> ANSWERED IN LITTLE MORE TIME THAN WOULD BE NECESSARY FOR READING ALONE.

YOUR COOPERATION IS GRATEFULLY APPRECIATED.

JOHN DEMAREE, SSCI DOCTORAL FELLOW
GRADUATE SCHOOL OF BUSINESS ADMINISTRATION
DEPARTMENT OF MANAGEMENT
MICHIGAN STATE UNIVERSITY
EAST LANSING, MICHIGAN

INVENTORY MANAGEMENT SURVEY
GRADUATE SCHOOL OF BUSINESS ADMINISTRATION
MICHIGAN STATE UNIVERSITY

(STRICTLY CONFIDENTIAL)

1-3. SEQUENCE NUMBER. ____________
(DO NOT FILL IN)

4,5. TYPE OF SERVICE CENTER: PLEASE PLACE A "1" IN BOX OPPOSITE MAJOR SOURCE OF INCOME (OVER 50%). PLACE A "2" OPPOSITE SECOND MOST IMPORTANT SOURCE OF INCOME.
- ☐1. STEEL 100%.
- ☐2. STEEL.
- ☐3. FABRICATING.
- ☐4. WHOLESALE HARDWARE AND MERCHANT PRODUCTS.
- ☐5. ALUMINUM.
- ☐6. BRASS, COPPER, AND MISCELLANEOUS.
- ☐7. NON-FERROUS METALS AND MISCELLANEOUS.

6,7. NUMBER OF BRANCH PLANTS, IF ANY. ____________

8. GROSS SALES: (PLEASE PLACE A CHECK MARK IN THE APPROPRIATE BOX.)
- ☐1. LESS THAN ONE MILLION DOLLARS.
- ☐2. ONE TO TWO MILLION DOLLARS.
- ☐3. TWO TO THREE MILLION DOLLARS.
- ☐4. THREE TO FOUR MILLION DOLLARS.
- ☐5. FOUR TO FIVE MILLION DOLLARS.
- ☐6. FIVE TO TEN MILLION DOLLARS.
- ☐7. OVER TEN MILLION DOLLARS.

9. BASIC INVENTORY RECORD-KEEPING SYSTEM: (PLEASE CHECK)
- ☐1. KARDEX, ACME VISIBLE, OR POST INDEX.
- ☐2. LOOSE-LEAF BOOKS.
- ☐3. PUNCHED CARDS.
- ☐4. MAGNETIC TAPE.
- ☐_. OTHER (PLEASE SPECIFY) ____________

10,11. ARE YOU PRESENTLY PLANNING ANY CHANGES IN YOUR BASIC INVENTORY RECORD-KEEPING SYSTEM?
- ☐1. YES.
- ☐2. NO.

PLEASE INDICATE THE PRINCIPAL REASON(S) FOR ANY PLANNED CHANGES.

____

____

12. DO YOU PRESENTLY MAKE USE OF PUNCHED CARDS FOR SALES ANALYSIS AND/OR OTHER PURPOSES?
- ☐1. YES.
- ☐2. NO.

13. ARE THESE CARDS PROCESSED THROUGH YOUR OWN EQUIPMENT OR THROUGH A SERVICE BUREAU?
- ☐1. PROCESSED WITH OWN EQUIPMENT.
- ☐2. SERVICE BUREAU.

(ANY FURTHER COMMENTS IN RESPONSE TO THE ABOVE QUESTIONS WILL BE APPRECIATED. USE MARGINS OR BACK OF THIS SHEET IF YOU DESIRE.)

14. Is the purchase or lease of a computer or other data-processing equipment part of your present or forward planning?
- ☐1. Yes.
- ☐2. No.

Type and Manufacturer of equipment being considered: ____________________

____

Anticipated installation date: ____________________

15-17. In deciding "when" to submit orders for items you stock, do you make use of: (check one or more)
- ☐15. Re-order point (i.e., minimum) listed on stock records.
- ☐16. Periodic review each _______ weeks. (During normal periods)
- ☐17. _ Other (please specify) ____________________

____

18-21. What do you make primary use of in determining "lead times" for the routine ordering of stock from the mills.
- ☐18. Average lead times based upon delivery information in your records?
- ☐19. Rolling schedules?
- ☐20. Telephone or other direct contact with mill personnel?
- ☐21. _ Other (please specify) ____________________

____

22-27. In deciding "how much" to buy, do you make use of: (check one or more)
- ☐22. Tables or graphs to show the quantity to buy?
- ☐23. Economic order quantity formulas?
- ☐24. Cost of possession balanced against quantity extras costs?
- ☐25. Turnover goals?
- ☐26. Historical records and averages?
- ☐27. _ Other (Please specify any rules or standard practices which you follow.) ____________________

____

28-30. Person(s) in company who actually decide when to submit orders and how much of an item to order. ____________ (title), who reports to ____________ (title).

Other: ____________________

31. Do you calculate a standard "cost of possession" figure?
- ☐1. Yes.
- ☐2. No.

32,33. If "yes" to previous question, ________% = total percentage figure.

34. Do you make direct use of this figure in your inventory management?
- ☐1. Yes. Please show detail of your total percentage figure.
- ☐2. No.

COST OF CAPITAL:	1. Inventory	______%
	2. Space	______%
OPERATING COSTS:	3. Material handling	______%
	4. Space	______%
OTHER COSTS:	5. Obsolescence	______%
	6. Insurance	______%
	7. Taxes	______%
	8. Accounting	______%

35. Please give your estimate of the cost to submit an order to the mills.

☐1. Less than $5.00?
☐2. $5.00 to $10.00?
☐3. Over $10.00?
☐_ Other (please specify) ______________________________

____

36,37. Please indicate the average number of items per order upon which the above estimate is based.

______ = Average number of items per order.

38. Have you calculated (or estimated) the financial loss or penalty resulting from being "out-of-stock" of an item you normally carry?

☐1. Yes.
☐2. No.

39-41. If "yes" to above question, what has this cost included?

☐39. Gross profit?
☐40. Expense required to get material from competitors?
☐41. _ Other (please specify) ______________________________

42-45. On what basis are your buffer or safety stocks determined?

☐42. A given number of days or weeks of normal demand for all items?
☐43. Service level? For example, to have sufficient inventory levels such that you will fill (say) 95% of the orders for an item normally carried in stock.
☐44. Use of "K" factors, special slide rules, or record of forecast errors?
☐45. _ Other (please specify) ______________________________

46-48. On what basis do you purchase from other service centers?

☐46. "Pickup" orders as needed?
☐47. Periodically review stock records and for "slow moving" items purchase a quantity of stock of those items for which an inventory is to be maintained?
☐48. _ Other (please specify) ______________________________

49-62. How are sales forecasts developed?

BY ESTIMATES FROM:

☐49. Customers.
☐50. Salesmen.
☐51. Sales Managers.
☐52. Other executives, e.g.,
☐53. Outside consultants.
☐54. _ Other (please specify) ______________________________

____

BY STATISTICAL METHODS:

☐55. Correlation with economic indicators.
☐56. Trend and cycle analysis.
☐57. Leading series.
☐59. _ Other (please specify) ______________________________

____

BY HISTORICAL AVERAGES:

☐60. Without adjustment.
☐61. Adjusted for current demand.
☐62. Adjusted for latest sales information.
☐63. Adjusted by statistical formula smoothing.

63-67. WHICH OF THE FOLLOWING DO YOU FIND THE <u>MOST</u> USEFUL IN JUDGING THE "CORRECT" OR "BEST" LEVEL OF INVENTORY FOR A CLASS OF ITEMS.

- ☐ 63. TURNOVER RATES?
- ☐ 64. GROSS INVENTORY INVESTMENT BY CLASSES OF ITEMS?
- ☐ 65. RETURN ON INVESTMENT?
- ☐ 66. INVENTORY INVESTMENT BASED UPON: (SUM OF EOQ'S/2) PLUS SAFETY STOCKS.
- ☐ 67. _ OTHER (PLEASE SPECIFY) ______________________________

68-71. WHICH DO YOU FIND THE <u>MOST</u> USEFUL IN DETERMINING THE "CORRECT" OR "BEST" TURNOVER FOR A CLASS OF ITEMS?

- ☐ 68. COMPARISON WITH OWN HISTORICAL TURNOVER RATES?
- ☐ 69. COMPARISON WITH OTHER CENTERS THROUGH USE OF SSCI STATISTICS?
- ☐ 70. GOAL OR TARGET OF A GIVEN NUMBER OF TIMES TURN PER YEAR.
- ☐ 71. _ OTHER (PLEASE SPECIFY) ______________________________

72-79. WHAT DO YOU CONSIDER AS THE MAJOR PRESENT (OR FORESEEABLE) PROBLEM(S) IN INVENTORY MANAGEMENT IN YOUR COMPANY AND/OR THE INDUSTRY?

80. COMPANY NAME: ______________________________

OTHER COMMENTS: ______________________________

(ANY FURTHER COMMENTS IN RESPONSE TO THE ABOVE QUESTIONS WILL BE APPRECIATED. USE MARGINS OR BACK OF THIS SHEET IF YOU DESIRE)

APPENDIX B

Exponential Smoothing

In the text a number of references have been made to such terms as: exponential smoothing, single smoothing, double smoothing, forecast error, and smoothed mean absolute deviation of forecast error. In the following pages these terms will be identified and their use briefly described. For a more complete treatment the references at the end of the appendix are suggested.

One of the requirements for the application of scientific inventory control is that there be forecasts of demand on an item basis. A number of computer programs, including the IBM IMPACT program, for example, make use of "exponential smoothing" for purposes of developing these item-by-item forecasts. Exponential smoothing is defined by

$$d_t^* = d_{t-1}^* + \alpha (d_t - d_{t-1}^*)$$

Where: d_t^* = the forecast for the next period.

d_{t-1}^* = forecast for current period.

d_t = actual demand which occurred during current period.

α = exponential smoothing constant $0 < \alpha < 1$

As noted in the above definition, the new forecast is the old forecast adjusted by a fraction of the difference between the old forecast and the demand which actually developed for the period covered by this forecast. If the demand which actually occurred is less than the forecast, then the new forecast will be lowered. Conversely, if the demand which actually occurred is greater than that which was forecast, then the new forecast will be increased. The amount of this increase or decrease depends upon the choice of the exponential smoothing constant. For example, if one assigned a value of one to α, the new forecast would be merely the demand which occurred during the present period. Conversely, if a low value such as .01 is used, there would be an extremely slow response to any change in demand. Brown (1) has suggested that $\alpha = .1$ is frequently a satisfactory smoothing value for a wide variety of applications.

Single Smoothing and Double Smoothing

The terms in the preceding exponential smoothing definition are frequently rearranged to facilitate computation. Thus:

$$\begin{aligned} d_t^* &= d_{t-1}^* + \alpha(d_t - d_{t-1}^*) \\ &= \alpha\, d_t + (1 - \alpha)\, d_{t-1}^* \\ &= \alpha\, d_t + \beta\, d_{t-1}^* \end{aligned}$$

Where: $\beta = (1 - \alpha)$

Up to this point the definition has been that of "single" smoothing, which is all that is required as long as there is no trend in demand. As will be shown in Table I, when there is a trend the single-smoothed value never catches up. For illustrative purposes the data in Table I shows a trend of 10 units per month. Also, a smoothing constant of .5 is being used.

At the end of December a forecast was made for January. Assume that this forecast was for sales of 100 units. As will be noted, the actual sales starting in January show a constant positive trend of ten units per month. At the end of January the sales for that month are known, and the fore cast for February is made. Using the formula

Table I.

Time t	Demand d_t	Forecast $d^*_t = \alpha d_t + \beta d^*_{t-1}$	Lag
Dec.	100	100.	
Jan.	110	105.	5.
Feb.	120	112.5	7.5
March	130	121.2	8.8
April	140	130.6	9.4
May	150	140.3	9.7
June	160	150.2	9.8
July	170	160.1	9.9
Aug.	180	170.0	10.0

shown, this forecast would be 105 units. At the end of February the record shows the sales were actually 120, so the forecast for March is 112.5 units, etc. It will be noted that the "lag," between the forecast and the sales which actually developed, fairly rapidly levels off at a lag of 10 units per forecast. Double smoothing is a means of correcting for this deficiency. Double exponential smoothing is defined

$$d^{*[2]}_t = d^{*[2]}_{t-1} + \alpha(d^*_t - d^{*[2]}_{t-1})$$

As shown, the new double smoothed value is equal to the previous double smoothed value adjusted by a fraction of the difference between the present single-smoothed value and the double-smoothed value from the preceding period. Rearranging the terms, we have:

$$d^{*[2]}_t = \alpha d^*_t + (1 - \alpha) d^{*[2]}_{t-1}$$

$$= \alpha d^*_t + \beta d^{*[2]}_{t-1}$$

Table II shows the double-smoothed values for the same data as in Table I.

Table II.

Time t	Demand d_t	Single Smoothed d^*_t	Double Smoothed $d^*_t[2] = \alpha d^*_t + \beta d^*_{t-1}[2]$
Dec.	100	100.	100.
Jan.	110	105.	102.5
Feb.	120	112.5	107.5
March	130	121.2	114.4
April	140	130.6	122.5
May	150	140.3	131.4
June	160	150.2	140.8
July	170	160.1	150.5
Aug.	180	170.0	160.2

An interesting relationship between the double-smoothed value and the single-smoothed value is shown in Table II. It will be noted that the double-smoothed value is lagging behind the single-smoothed value at the same rate as the single-smoothed value is lagging behind the actual demand rate. The amount of this lag depends upon both the trend in demand and the smoothing constant being used. This relationship is useful in determining both the current estimate of demand and the estimate of the demand for the forthcoming period.

$$\text{Current estimate of demand rate} = d^*_t + (d^*_t - d^*_t[2])$$
$$= 2\,d^*_t - d^*_t[2]$$

The larger the smoothing constant the lower will be the lag. As a correction for this, Brown (2) has pointed out that:

$$\text{Lag} = \frac{\alpha}{\beta}\,(d^*_t - d^*_t[2])$$

Making use of single and double exponential smoothing, as expressed in the above factors, the forecast of demand is the sum of the current estimate of the demand rate plus the lag, or

$$\text{Forecast} = 2\,d^*_t - d^*_t[2] + \frac{\alpha}{\beta}\,(d^*_t - d^*_t[2])$$

Using Table II, the forecast for the month of July will demonstrate the use of the above formula. This estimate would be made at the end of June, and the following values are applicable:

$$d_t^* = 150.2$$

$$d_t^{*[2]} = 140.8$$

Current estimate of demand rate = 2 (150.2) - 140.8 = 159.6

Lag = $\frac{.5}{.5}$ (150.2 - 140.8) = 9.4

Forecast = 159.6 + 9.4 = 169.0

Sales Forecast Error

The preceding discussion has pointed out the manner in which exponentially-weighted moving average forecasts are developed. The sales forecast error is the difference between the sales forecast and the sales which actually occur.

Mean Absolute Deviation as a Measure of Forecast Error

The "absolute deviation" is the difference (without regard to algebraic sign) between the forecast of sales for a period and the sales which actually developed. With the passage of each month a new absolute deviation results. By definition, the average of these deviations over a period of time is the "mean absolute deviation," or MAD. An exponentially-weighted moving average is an efficient means of updating the MAD. The formula is (3):

$$\text{New MAD} = \text{old MAD} + \alpha\,(\,|\text{current deviation}| - \text{old MAD})$$
$$= \alpha\,|\text{current deviation}| + (1 - \alpha)\,(\text{old MAD})$$

Where: $|\text{current deviation}|$ = difference between the sales forecast and the sales which actually occurred, without regard to algebraic sign.

The important feature of the mean absolute deviation is its relationship to the standard deviation. For the normal distribution, for example, the ratio of the MAD to the standard deviation is .8, i.e., MAD/σ = .8. Thus, it is merely necessary to multiply the MAD by a factor of 1.25 in order to determine the standard deviation.

REFERENCES

1. Robert G. Brown, Statistical Forecasting for Inventory Control (New York: McGraw-Hill Book Company, Inc., 1959), p. 54.

2. Robert G. Brown, Smoothing, Forecasting and Prediction of Discrete Time Series (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1963), p. 128.

3. Robert G. Brown, Statistical Forecasting for Inventory Control (New York: McGraw-Hill Book Company, Inc., 1959), p. 93.