DEVELOPMENT OF A DYNAMIC SIMULATION MODEL FOR PLANNING PHYSICAL DISTRIBUTION SYSTEMS: FORMULATION OF THE MATHEMATICAL MODEL

Thesis for the Degree of D. B. A.

MICHIGAN STATE UNIVERSITY

OMAR KEITH HELFERICH

1970

This is to certify that the

thesis entitled

DEVELOPMENT OF A DYNAMIC SIMULATION MODEL
FOR PLANNING PHYSICAL DISTRIBUTION SYSTEMS:
FORMULATION OF THE MATHEMATICAL MODEL

presented by

OMAR KEITH HELFERICH

**has been accepted towards fulfillment
of the requirements for**

D.B.A. **degree in** PRODUCTION

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Date November 10, 1970

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ABSTRACT

DEVELOPMENT OF A DYNAMIC SIMULATION MODEL FOR PLANNING PHYSICAL DISTRIBUTION SYSTEMS: FORMULATION OF THE MATHEMATICAL MODEL

By

Omar Keith Helferich

In the past decade the recognition of the importance of cost and service implications has increased the interest in the development and application of management science techniques to decision making associated with the design and administration of systems to control raw materials and finished goods flow. In general, however, the majority of the problems considered in the past have been defined such that the basic components or subsystems of the total physical distribution system have been modeled independently rather than considering the interaction and tradeoffs within the total system. In this context the PD system includes the facility component, the communications component, the inventory component, the transportation component, and the warehousing (unitization) component. The problems have also been stated in terms of a short term or tactical planning horizon while neglecting the strategic planning horizon. Finally, the problem definitions have in general not included the sequential or staged decision problem which

assumes that current decisions have an effect on the problem-solution decision process in future time periods or stages.

The overall objective of an ongoing research project at the Graduate School of Business at Michigan State University has been to develop a viable long-range planning model for physical distribution systems design. The goal has been to develop a model, referred to as the Long Range Environmental Planning Simulator (LREPS), that includes (1) all of the basic components of the physical distribution system, (2) a strategic planning horizon, and (3) the sequential decision problem. Two additional general research criteria established were that the model be modular in construction and universal in application for a broad class of manufacturing firms.

In formulating the mathematical model an overall systems approach was required. This approach is discussed in the Literature Review, Chapter II and the Approach to Mathematical Design, Chapter III. The general design approach consisted of performing activity analyses for each subsystem of the model using the following procedure: (1) State the objective of the activity, (2) Develop the conceptual approach using several alternatives for each activity, (3) Select the best alternative(s) for each activity, (4) Develop the specifications, input, output, and transformations for the selected alternative(s), (5) Collect, perform analysis and prepare data for the selected alternative(s), and finally (6) Program the selected alternative(s). The above procedure although listed as a sequence was in fact an iterative process.

Several special design concepts were used in the development of the mathematical model including work flow structure (strong-link analysis), enrichment and simplification and robustness-flexibility. Mathematical transformations included such techniques as statistical sampling, correlation, and regression analysis, Monte Carlo procedures, exponential smoothing, inventory control theory, linear, first-order difference equations and first-order information feedback control loops.

The general problem statement that the model consider the total physical distribution system essentially required that the general solution approach be heuristic rather than an analytical or optimal technique. The combination of the inventory allocation and location decision in a single model required that the service target variable be developed in terms of temporal measures such as the average and standard deviation of the customer order cycle rather than spatial measures such as distance or transit time.

The strategic planning horizon by definition usually includes a sufficient time interval to consider the effect of significant change in the system environment. Therefore, the solution approach for a strategic model must include the capability to introduce change in the marketing environmental factors throughout the time periods simulated. This aspect of model dynamics is frequently neglected by mathematical model builders. The sequential decision problem essentially required that the model be dynamic to provide the capability for locate, inventory, expansion and sales modification algorithms to consider aspects of the staged decision problem.

The result of the research associated with this dissertation was the LREPS mathematical model. The LREPS model was developed as three major systems; (1) The Supporting Data System, (2) The Operating System, and (3) The Report Generator System.

The purpose of the Supporting Data System is to analyze, prepare, and reduce the exogenous inputs for a set of simulation runs or experiments. In addition, changes in the experimental factors are introduced through this system to test the dynamics of change in the environment. The second stage, the Operating System, consists of four overlapping subsystems which form an integrated physical distribution system. The four subsystems are the (1) Demand and Environment Subsystem, (2) Operations Subsystem, (3) Measurement Subsystem, and (4) Monitor and Control Subsystem. The primary function of the Demand and Environment Subsystem is to generate information for the Operations Subsystem related to forecasting and allocating sales, customer order generation and the assignment of customer orders to agglomerated demand units. The Operations Subsystem processes the simulated customer orders through the major components of the physical distribution system. Each order processed is assigned a communications delay, order processing and preparation delay, an average delay due to stockouts, and finally a transit time delay for shipment from the distribution center to the demand unit. These four delay times provide the temporal measure--the

total customer order cycle. The Measurement Subsystem is concerned with developing the cost, sales, service, and flexibility measures for the activities processed in the Operations Subsystem. The Monitor and Control Subsystem via information feedback control loops compares desired levels of sales, cost and service against the levels generated by the Measurement Subsystem.

The Monitor and Control Subsystem includes algorithms for (1) sales modification, (2) inventory management, (3) facility addition and deletion, and (4) facility expansion. These algorithms are dynamic in the sense that each is a first-order feedback loop, with a sensor to detect the existing system state, a comparator to measure the difference between actual and desired system state, and an effector to cause the system change required. The third and final stage is the Report Generator Subsystem. This state has been designed to take the output data from the simulation model and print one or more optional or special reports.

Preliminary validation of the LREPS model results for one year's sales history indicates that the model is valid. Experimental runs for two, five, and ten year planning horizons indicate that the model is stable and that output is reasonable.

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF BUSINESS ADMINISTRATION

Department of Management

1970

ACKNOWLEDGMENTS

It is difficult to name all those who aided in this research effort or to state precisely what each individual contributed to the total thesis research effort.

First, I would like to express my sincere appreciation to Johnson and Johnson Domestic Operating Company who provided the support for the LREPS project.

I am indebted to the members of my thesis committee composed of Dr. Donald J. Bowersox, Professor of Marketing and Transportation Administration, Co-Chairman of the Committee; Dr. Richard F. Gonzalez, Professor of Management, Co-Chairman of the Committee; and Dr. Harold M. Sollenberger, Professor of Accounting and Financial Administration.

To Professor Bowersox, Faculty Director of the LREPS project, by whose efforts and professional reputation the LREPS project was conceived, obtained, organized, and completed I owe a special debt of gratitude far beyond the words that can be stated here. Professor Bowersox's insight and abilities in both the application and theory of the physical distribution concept in general and the LREPS project in particular have already had a significant positive effect on my career objectives and potential.

Professor Gonzalez's guidance as my major professor in production management began the day I entered the doctoral program and continued throughout the thesis stage. I am especially grateful to Professor Gonzalez for his guidance in planning my doctoral program which provided me with the additional academic background and interest in computer simulation to accept the challenge of modeling a complex planning model such as LREPS.

Professor Sollenberger provided comments and suggestions which were of great value in organizing the presentation of the thesis material. Even more important to me and to my career interests were Professor Sollenberger's insight and suggestions related to the information systems aspects of models such as LREPS.

I am deeply indebted to the doctoral candidate members of the research team without whom the completion of the project and this thesis would have been difficult at best and more likely impractical. It is impossible to delineate the specific areas of contribution of each individual since the team was truly interdisciplinary with each member performing any task assignment necessary to accomplish the project within the time and resources allocated. I do wish, however, to take this opportunity to express my thanks to the team members who were P. Gilmour, doctoral candidate in management; M. L. Lawrence, doctoral candidate in finance; E. J. Marien, doctoral candidate in marketing and transportation;

F. W. Morgan, Jr., doctoral candidate in marketing and transportation; K. Prasad, now assistant professor of marketing at University of Wisconsin; and R. T. Rogers, doctoral candidate in marketing and transportation. Each of these colleagues made a significant contribution to the total LREPS project and thus has also indirectly had a major influence on this thesis.

Working with each of these individuals, sharing their ideas, problems, and successes as we moved through the completion of each step of the doctoral program and the LREPS project has been a rewarding experience which will be difficult to equal throughout the remainder of my career.

I would also like to thank four great gals: Theo, Helen, Kathy, and Flo who always remained calm and cheerful under the pressures of preparing the many drafts and numerous figures for this thesis.

Finally, I wish to show my appreciation to my wife--Joan, children--Karrie, Kathy, Kimberly, and newest arrival, Kirk, and to my parents for your patience, understanding, and moral support throughout the duration of my doctoral program.

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CHAPTER I

INTRODUCTION

Statement of Purpose

The purpose of this dissertation is to develop the general mathematical model for a simulation model that is to be utilized for long-range planning of physical distribution systems. The planning model, developed under a Michigan State University industrial research grant, provides the capabilities for physical distribution system design given cost, service, or flexibility as target variables, or testing the effect on these performance variables due to changes in any or all of the basic components of a total physical distribution system.

The research monograph written by the research team at Michigan State University provides a detailed discussion of the following areas:

1. Purpose of the model
2. General class of problem to be modeled
3. Conceptual model
4. The capabilities of the model.[1]

The summary statements related to these areas are presented as background to introduce the research problem of this thesis.

The Long-Range Environmental Planning Simulator (LREPS) was developed to be dynamic in terms of information-feedback control loops and changes in the operating environment, modular in construction, and universal in terms of application to a general class of firms. The sequential decision problem has also received emphasis in the LREPS model. The sequential problem has the characteristic that current decisions in the model have an influence on future decisions.[2]

General Class of Problem

The general class of problem considered in this thesis research is that of long-range planning of physical distribution systems.

The physical distribution activity in broadest terms includes the design and administration of systems to control raw material and finished goods flow.[3] From an analytical viewpoint, a physical distribution system consists of several interrelated activity centers or subsystems between which tradeoffs in cost, service, and flexibility exist. These subsystems are often referred to as the components of a physical distribution system.

In this research physical distribution included the interrelated activity centers or components from the production line to the point of ownership transfer. These components are: the distribution facility network, inventory allocations, transportation, communications, and unitization.

The distribution facility network includes the network of distribution warehouses or centers that hold and handle finished goods inventories. This component involves the location of facilities including addition, deletion, and modification of distribution centers.

Inventory allocation refers to the holding and controlling of the level of finished goods inventories necessary to meet customer service requirements.

The transportation component involves the movement of finished goods inbound from the manufacturing control center or supply point to the distribution centers and outbound from the distribution center to the customer or point of ownership transfer.

Communications includes the functions of order transmittal and customer order processing.

Unitization in a broad sense involves materials handling, packaging, and containerization. In this research unitization includes the physical picking and preparation of the customer order.

Long-range planning deals with the futurity of present decisions and is concerned with: Where are we going? (Strategic Planning); and, How do we get there? (Operational or Implementational Planning). Drucker defines long-range planning as follows:

> It is the continuous process of making PRESENT ENTREPRENEURIAL (RISK TAKING) DECISIONS systematically and with the best possible knowledge of their futurity, organizing systematically THE

> EFFORTS needed to carry out these decisions, and measuring the results of these decisions against the expectations through ORGANIZED, SYSTEMATIC FEEDBACK.[4]

Planning is thus a continuous recycling process where it is necessary to constantly review the desired objectives and goals, the current position, and the means to obtain the goals. The sequence of steps in business planning usually includes:[5,6,7,8]

1. (Re) Establish objectives and goals
2. Establish planning premises
3. Search for alternative courses of action
4. Evaluate alternative courses of action
5. Select a course(s) of action
6. Formulate necessary operational plans
7. Implement operational plans
8. Observe and evaluate results.

Long-range planning in physical distribution thus involves continuous (or periodic) review, selection, and implementation of a "best" combination of tradeoffs among the components of the physical distribution system. The selection should be based on a continuously (or periodically) revised set of objectives and goals related to cost and/or customer service.

In general, the emphasis in physical distribution planning, as in most other aspects of business, has been on the immediate or short-term operational planning and problems with insufficient thought and effort directed toward long-range objectives.

Drucker points out that there are several things which are relatively new that have created the need for the organized, systematic, and above all, specific process that we call long-range planning. These reasons can be summarized as follows:[9]

1. The time span of entrepreneurial and managerial decision has been lengthening at a rapid rate

2. The speed and risk of innovation

3. The growing complexity of both the business enterprise itself, and of the economy and society in which it exists

4. The process of entrepreneurial decision making cannot be handled by the built-in experience reaction of a good manager due to the amount, diversity, and ambiguity of information which he must consider in making decisions.

There have been several reasons for the lack of emphasis in long-range planning of physical distribution systems. First, long-range planning for the firm in general has only recently become one of the primary areas of concern of top management. Second, there has been a lack of understanding and/or consideration of the interaction among activity centers of the physical distribution system. This has been due to a great extent to the fact that the concept of physical distribution as previously referred to in this thesis has only been accepted during the past decade. Third, there has been insufficient relevant data available to most firms to perform the total physical distribution cost, service, and flexibility analysis required to develop valid long-range planning models. Finally, the complexity of the total physical distribution system did not lend itself to analysis by the analytical optimization techniques.

The long-range planning models have thus in most cases been designed to optimize only one of the activity centers or subsystems of the physical distribution system without consideration for interactions among the remaining activity centers. If the subsystems are highly interdependent, as is the case in physical distribution systems, it is likely that sub-optimization of the total system as an entity will produce superior results to those derived from the sum of a set of subsystem optimals where each subsystem has been studied independently.[10]

Situation Analysis

Development of a long-range planning model for physical distribution systems that will advance the "State of the Art" has been the general objective of an on-going industrial research project at Michigan State University. The goal of the Michigan State University faculty-doctoral candidate research team has been to develop a dynamic simulation model for evaluating alternative physical distribution system configurations over a long-range planning horizon.

Figure 1.1 and Figure 1.2 present the general structure of the physical distribution system modeled. The graphical view presents the five basic physical distribution components in terms of three stages of activities. These three stages are:

1. The manufacturing control center (MCC) which produces a partial line of products and inventories these products in the adjoining replenishment center (RC)

2. The distribution center (DC) which provides inventory replenishment and product delivery to meet customer service requirements

3. The individual customer's demand and/or the agglomeration of customer demands represented by the demand unit (DU) stage.

The MCC stage includes the manufacturing control centers each of which produces only a partial line of products. Each MCC location also includes an adjacent RC where the products manufactured are held for distribution as required to the distribution centers.

Four different types of distribution centers are defined in the DC stage. A primary distribution center (PDC) handles a full line of products and has the potential of serving all of the DU's in the region served by the PDC. A remote distribution center full line (RDC-F) also handles a full line of products, but serves only a limited

PHYSICAL DISTRIBUTION SYSTEM

MANUFACTURING CONTROL CENTERS (MCC)
MULTI-LOCATION
EACH PRODUCES LESS THAN FULL LINE
EACH PRODUCT IS PRODUCED AT MORE THAN ONE MCC

REPLENISHMENT CENTERS (RC)
MULTI-LOCATION
EACH STOCKS ALL PRODUCTS MANUFACTURED AT MCC

DISTRIBUTION CENTERS (PDC) (RDC)
MULTI-LOCATION
FULL LINE - PRIMARY DC (PDC)
FULL OR PARTIAL LINE - REMOTE DC (RDC)

CONSOLIDATED SHIPPING POINT (CSP)

TRANSPORTATION
COMMON CARRIER - TRUCK, RAIL, AIR

INVENTORY
STOCKS AT RC, PDC, RDC

COMMUNICATIONS
COMPUTER, TELETYPE, MAIL, TELEPHONE

UNITIZATION
AUTOMATED OR MANUAL

PRODUCT PROFILE

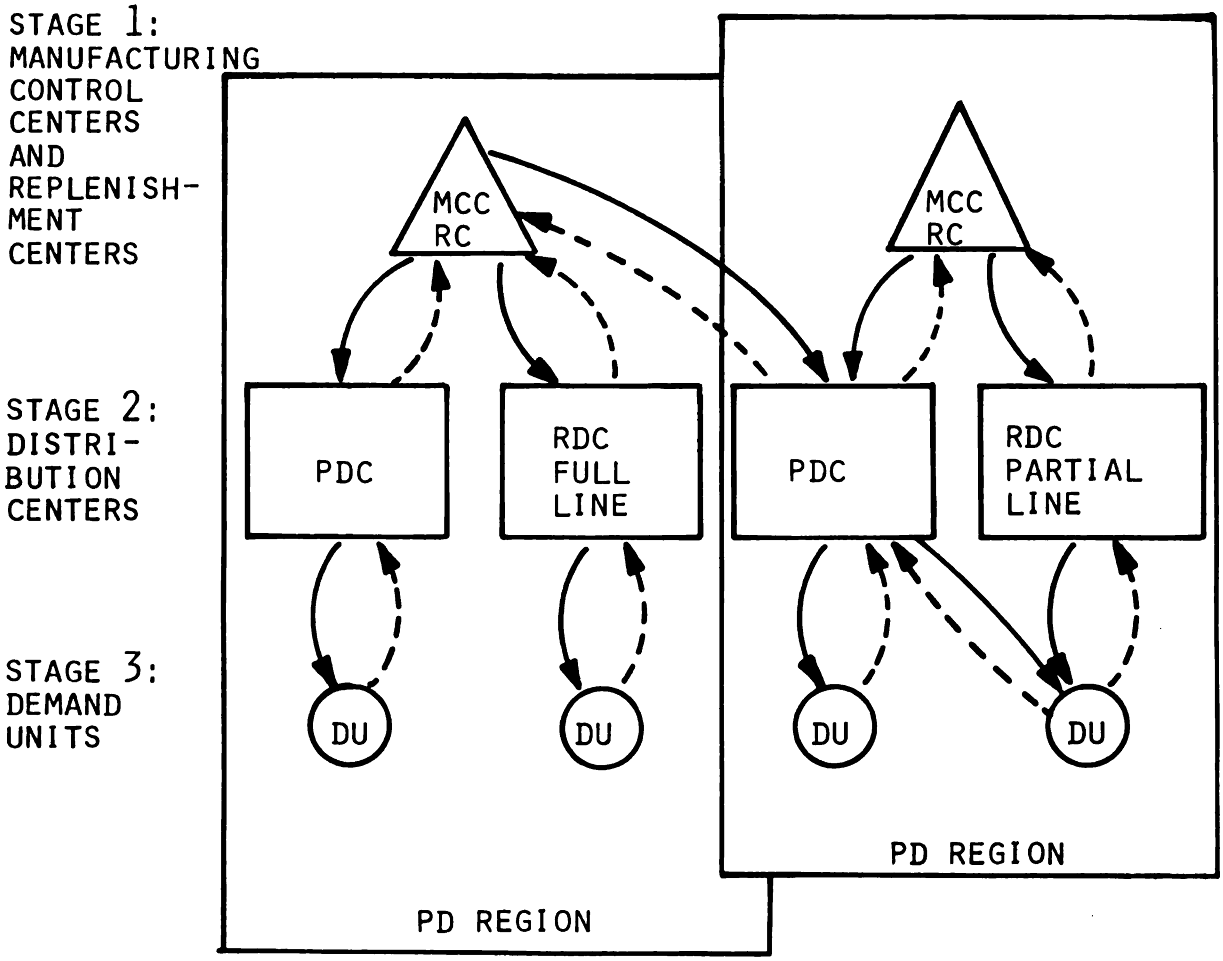
MULTI-PRODUCT LINE
KEY PRODUCT GROUPS FOR EACH CUSTOMER CLASS OF TRADE

MARKET PROFILE
MULTI-CUSTOMER CLASSES OF TRADE
TOTAL U.S. MARKET

COMPETITIVE PROFILE
MULTI-COMPETITORS

Figure 1.1--General Description of Firm-Distribution Audit[1]

[1]D. J. Bowersox, et al., Dynamic Simulation of Physical Distribution Systems, Monograph (East Lansing, Michigan: Division of Research, Michigan State University, Forthcoming).



------INFORMATION FLOW ——————PRODUCT FLOW

REGION..THE REGION IS DEFINED BY THE ASSIGNMENT OF RDCS AND DUS TO A PDC.
MCC.....EACH MANUFACTURING CENTER PRODUCES A PARTIAL LINE.
RC......REPLENISHMENT CENTERS STOCK ONLY PRODUCTS MANUFACTURED AT COINCIDENT MCC.
RDC.....REMOTE DISTRIBUTION CENTER, FULL OR PARTIAL LINE.
PDC.....PRIMARY DISTRIBUTION CENTER, EACH PDC IS FULL LINE AND SUPPLIES ALL PRODUCTS TO DUS ASSIGNED TO THE PDC REGION; PRODUCT CATEGORIES NOT STOCKED AT THE PARTIAL LINE RDCS IN THE REGION ARE ALSO SHIPPED BY THE PDC.
DU......THE DEMAND UNIT CONSISTS OF ZIP SECTIONAL CENTER(S).
CSP.....CONSOLIDATED SHIPPING POINT.

Figure 1.2--Stages of the Physical Distribution Network[1]

[1]D. J. Bowersox, et al., Dynamic Simulation of Physical Distribution Systems, Monograph (East Lansing, Michigan: Division of Research, Michigan State University, Forthcoming).

preassigned number of DU's in a PDC market region. A distribution center that supplies only a partial line of products to its assigned DU's is referred to as a remote distribution center partial line (RDC-P). The products not supplied by the RDC-P's in the region are supplied to the customer DU's by the PDC of the region.

The fourth and final type of distribution center, the consolidated shipping point (CSP), is similar to the RDC-P, but the CSP does not stock or physically handle any products. The CSP's serve as the geographical point where the demand of several DU's is consolidated or agglomerated to be shipped on break bulk basis to the individual DU's.

The research team developed a conceptual model that is universal in application to the many firms in both industrial and consumer goods industries that fit the above system definition.

Figure 1.3 presents the concept of the dynamic simulation model which includes an input system, a set of operating subsystems, and an output system. The input subsystem, the Supporting Data System, is run off-line from the main computer simulation model. The purpose of this system is to perform supporting design analysis and to prepare and reduce data that remains constant, the exogenous inputs, for stated operating periods of the simulation runs.

The Operating System, the main portion of the model, simulates the operation of the physical distribution network

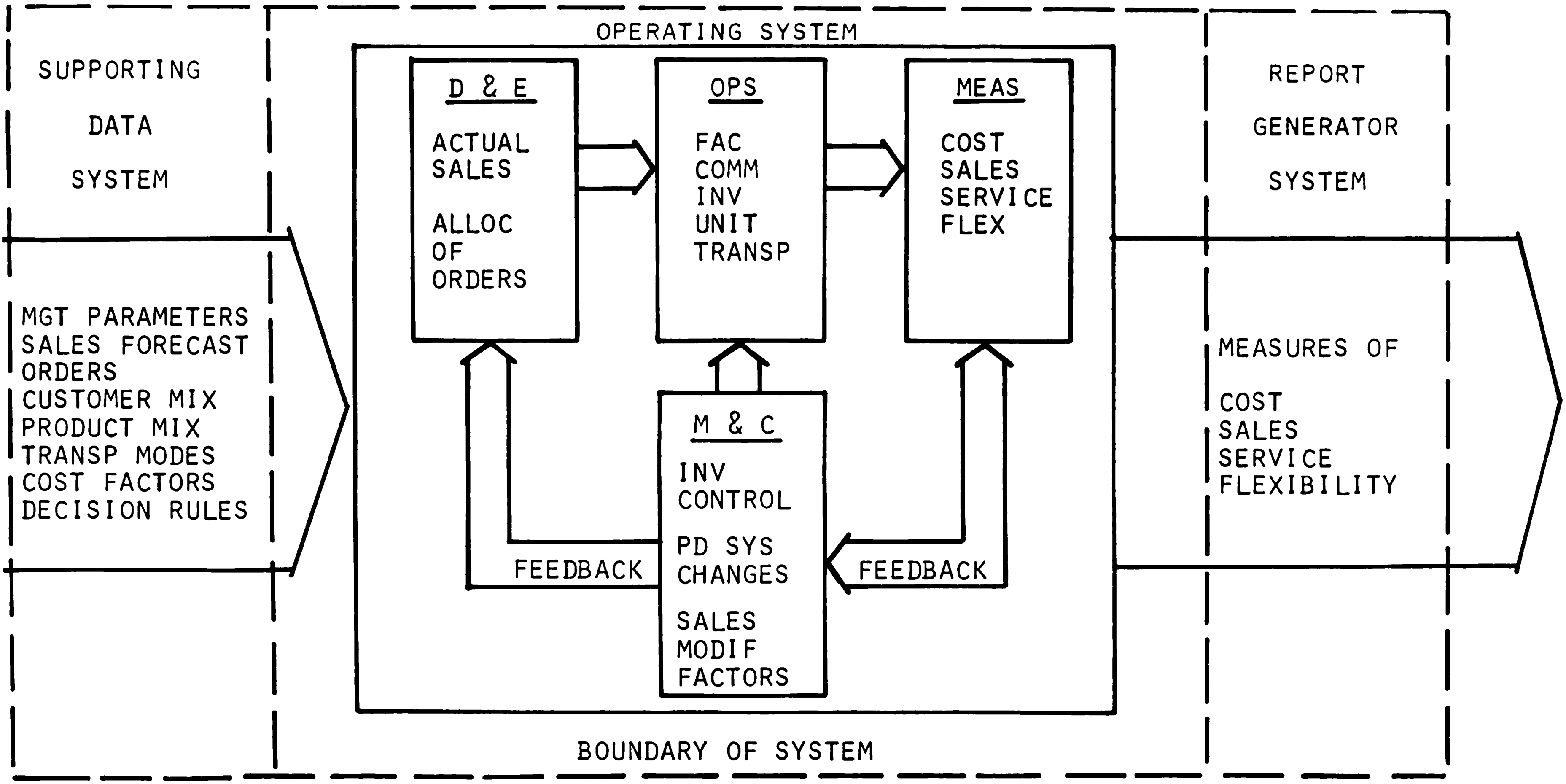


Figure 1.3--LREPS Systems Model Concept[1]

[1]D. J. Bowersox, et al., Dynamic Simulation of Physical Distribution Systems, Monograph (East Lansing, Michigan: Division of Research, Michigan State University, Forthcoming).

previously defined in general by Figure 1.1 and Figure 1.2. This portion of the model consists of four overlapping subsystems which include the mathematical relationships or transformations for demand generation, transportation, inventory control, facility location, unitization, and communications. These transformations form an integrated physical distribution model.

The four subsystems are the Demand and Environment Subsystem (D&E), the Operations Subsystem (OPS), the Measurement Subsystem (MEAS), and the Monitor and Control Subsystem (M&C).

The primary function of the Demand and Environment Subsystem is to generate information for the Operations Subsystem related to forecasting and allocating sales, customer order generation, and the assignment of customer orders to demand units.

The orders allocated to each customer demand unit are assigned to remote distribution centers on the basis of a pre-determined selection criteria such as minimum distance, minimum transit time, minimum transportation cost, or a combination of the above. The output of the Demand and Environment Subsystem, the sales dollars (orders) allocated to each remote distribution center, serves as the input to the Operations Subsystem.

The Operations Subsystem processes the flow of products and information through the physical distribution system as the orders arrive at the distribution centers. The orders are processed to determine if sufficient inventory for each of the products is available. If a product is in stock the order will be prepared and a shipment dispatched to the demand unit. If the inventory reorder points or periods are triggered, replenishment orders are dispatched to the firm's replenishment centers. The shipments (replenishments) are scheduled to arrive at the distribution center after a time delay due to order transmittal to, order processing and preparation at, shipping schedules at, and transit time from the replenishment center.

The effect of the communications network, the information flow, is tested by using various time delays, values of and functions for order transmittal and order processing throughout the Operations Subsystem. Time delays, both due to information and materials flow are used to develop measures of the total order cycle of the physical distribution network.

The Measurement Subsystem is concerned with examining the cost, service, and flexibility of the activity levels for each distribution center in-solution for the operating period. The volume of activity for each distribution center and transportation and information link coupled with cost factors and transformations related to order transmission and processing, inventory control, throughput or unitization, transportation, and fixed investment, enable the computation of total distribution costs for the simulated period of operation.

Service characteristics such as measures of the total order cycle, product stockouts, and percent of the market covered within a specified transit time are also calculated for each distribution center for each operating period based upon the output of the Operations Subsystem.

Measures of flexibility are related to the risk associated with actually implementing a specific recommended change in the physical distribution system structure.

The Monitor and Control Subsystem through information feedback compares desired levels of cost, service, and flexibility against the levels generated by the Measurement Subsystem. Modifications to the physical distribution system can be automatically activated in the simulation model or read in as exogenous periodic inputs for future periods to close the gap between desired and actual. These modified system inputs are incorporated in an attempt to evaluate their effect on the target variables, cost, service, and flexibility during simulated future periods of distribution system operation.

The third and final stage is the Report Generator System. This stage has been designed to take the output, raw data, from the simulation model and print one or more of several optional management reports and/or analyses.

The simulator runs on the Control Data 6500 computer system at Michigan State University. The model is programmed using the main subroutines of an event oriented simulation language called GASP-IIA and FORTRAN IV.[11,12]

Research Problem

The design procedures for the simulation model are presented in Figure 1.4. In general this figure shows the logical progression and evolution in developing the simulation model.

First, the research goals were reviewed and finalized after preliminary collection and analysis of sample data. This step, the Problem Definition and Feasibility Study, produced the detailed research problem statement, the mathematical model specifications, the design criteria for the operational model, and the boundary conditions on a defined set of feasible alternative solutions.

The outputs of the initial step provided the input necessary to accomplish the second step, which is the Mathematical Model Development. The formulation of the mathematical model for the conceptual model previously discussed in the Situation Analysis is the objective of this thesis. The emphasis of this thesis research is therefore the formulation of the mathematical model via systems design analyses, specification of the input-output variables, and transformations for each activity to meet the model capabilities listed in Figure 1.5.

Preliminary analysis and research design resulted in three categories of design criteria for the mathematical model. These categories were:

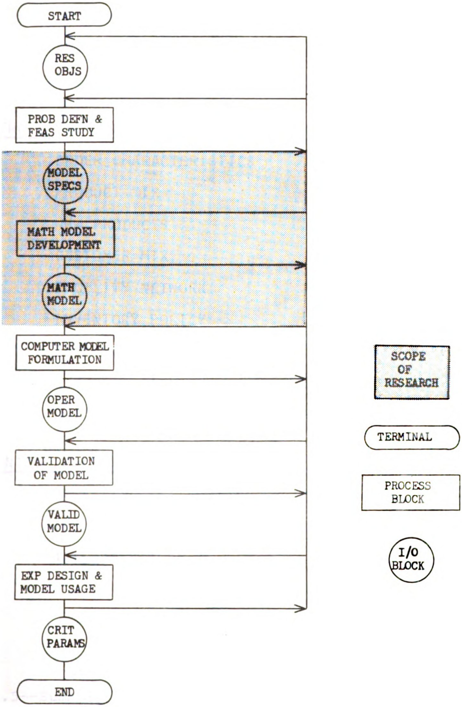


Figure 1.4--LREPS System Design Procedure[1]

[1]D. J. Bowersox, et al., Dynamic Simulation of Physical Distribution Systems, Monograph (East Lansing, Michigan: Division of Research, Michigan State University, Forthcoming).

TARGET VARIABLES

SALES

CUSTOMER SERVICE

PHYSICAL DISTRIBUTION SYSTEM COSTS

PHYSICAL DISTRIBUTION SYSTEM FLEXIBILITY

CONTROLLABLE VARIABLES

ORDER CHARACTERISTICS

PRODUCT MIX

NEW PRODUCTS

CUSTOMER MIX

FACILITY NETWORK

INVENTORY POLICY

TRANSPORTATION

COMMUNICATIONS

UNITIZATION

UNCONTROLLABLE VARIABLES

MARKETING ENVIRONMENT

TECHNOLOGY

ACTS OF NATURE

Figure 1.5--Summary of Experimental Factor Categories[1]

[1]D. J. Bowersox, et al., Dynamic Simulation of Physical Distribution Systems, Monograph (East Lansing, Michigan: Division of Research, Michigan State University, Forthcoming).

1. General research criteria
    a. Modular construction
    b. Universal model application
2. Physical distribution problem criteria
    a. Total physical distribution system
    b. Long-Range planning horizon
    c. Sequential decision problem
3. Model operating criteria
    a. Operating time
    b. Operating capabilities
    c. Operating realism
    d. Operating input requirements.

Each of the above criteria was considered in performing the value judgment required to evaluate the adequacy of the mathematical model.[13] At the end of this step in the research the assumptions made in developing the mathematical model were re-evaluated until found acceptable as the basis for the computer model.

The output of the mathematical model provided the specific transformations for developing the computerized model. Computer Model Formulation, the next step, must satisfy the needs and specifications of the abstract mathematical model, the validity of the model, the model's data base requirements, and the operational design criteria.

The Validation of the Model is the subject of the fourth major step of the design evolution. During this step test runs are made to validate the model against actual and/or expected results from the real world physical distribution system and environment. This step results in the use of model simplification and/or sophistication techniques on the activities of the model to develop a compromise between marginal improvement in validity versus required additional redesign and reprogramming effort.

The "valid" model serves as the input for the fifth and final step of the design procedure, which is to develop the Experimental Design and Model Usage. During this step sufficient runs of the model are run to perform the sensitivity analysis necessary to define the critical parameters. These critical parameters are then used as an aid to finding the subset of "satisfactory" or desirable solutions from among the many possible feasible solutions.

Order of Presentation

Chapter II presents in two sections a review of the literature on models for planning and decision making in physical distribution, and a review of the definition and description of mathematical models. The primary purpose of this chapter is to develop a classification scheme for presenting the "State of the Art" of physical distribution planning models. Chapter II is intended to be a summary of the literature relevant to the problem of developing the total approach to modeling the physical distribution system with all of its components; facility network, inventory allocation, communications, unitization, and transportation. A review of specific analytical modeling techniques that are applicable to a particular component of physical distribution are presented as required in the chapters which develop the mathematical model.

Chapter III presents the design procedures used in developing the mathematical model, and the approach that was used in reporting the design evolution of the LREPS model in Chapters IV, V, and VI.

The supporting analyses and data input requirements for the model are discussed in Chapter IV, the Supporting Data System. The emphasis in Chapter IV is to indicate the universal and modular characteristics of the model.

The specifications for the activities of the Operating System; the Demand and Environment Subsystem, the Operations Subsystem, the Measurement Subsystem, and the Monitor and Control Subsystem are presented in Chapter V.

The output of the model is presented in general form in Chapter VI. The emphasis in this chapter is the Report Generator System and the content of output information possible and probable types of management reports that would be an aid in long-range planning of physical distribution systems.

The final subject area, Chapter VII, presents the results of this thesis research, and implications for further research and development.

CHAPTER I--FOOTNOTE REFERENCES

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[12]A. A. B. Pritsker and P. J. Kiviat, _Simulation with GASP II, A FORTRAN-Based Simulation Language_ (Englewood Cliffs, N. J.: Prentice-Hall, 1969).

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CHAPTER II

REVIEW OF LITERATURE

Introduction

This chapter consists of two major sections. First, the "State of the Art" of long-range planning models in physical distribution is reviewed. The objective of this section is to gain insight related to component interrelationships that are critical in modeling a physical distribution system. The second major section reviews the approaches to mathematical model formulation. This section provides the framework for the design procedures used in formulating the LREPS mathematical model.

The research monograph provides additional background information related to this chapter in the following subject areas:[1]

1. Corporate long-range models
2. Physical distribution planning models
3. Computer simulation
4. Classification of physical distribution problems and models.

Physical Distribution Planning Models

Introduction

Initially this section introduces a classification scheme for problem definition of physical distribution planning problems and models. The section next presents the literature support for the relationship between problem definition and the suggested "best" solution approach for the stated problem. Third and finally the initial section reviews selected multi-component physical distribution planning models.

Classification Scheme

There are many schemes that could have been used to classify physical distribution planning problems and models. The purpose of developing a classification scheme is to aid in the selection of models presented in the literature that are applicable to the problem statement of this thesis. Figures 2.1 and 2.2 present the problem definition (independent variables) and the solution approach (dependent variables) that were used as the basis for the classification scheme. The physical distribution planning problems reviewed are defined in terms of the independent variables physical distribution component structure both number and type, the planning horizon, and the influence of current decisions on future decisions in the model. The dependent variables used to define the solution approach for the model are the general solution technique, the unifying

PROBLEM DEFINITION
THE
INDEPENDENT VARIABLES

1. TYPE AND NUMBER OF PHYSICAL DISTRIBUTION COMPONENTS

    Single Component

    Multi-Component

    All Components

2. PLANNING HORIZON

    Short Range (Operational)

    Long Range (Strategic)

3. INFLUENCE BY PREVIOUS DECISIONS

    Non-Sequential

    Sequential

Figure 2.1--Physical Distribution Problem Classification Scheme

APPROACH TO SOLUTION
THE
DEPENDENT VARIABLES

1. TYPE OF GENERAL SOLUTION TECHNIQUE

   Analytical (Optimization)

   Heuristic (Simulation)

2. UNIFYING DIMENSION

   Spatial (Distance or Location)

   Temporal (Time)

3. BEHAVIOR OF SYSTEM MODEL

   Static

   Dynamic

4. ENVIRONMENTAL INPUTS

   Fixed Over Planning Period

   Variable Over Planning Period

Figure 2.2--Physical Distribution Model Classification Scheme

dimension, the behavior of the system, and the environmental inputs.

The independent variables selected to define the physical distribution planning problem were presented and defined in the Introduction of the thesis. Using the independent variables each physical distribution model presented in this literature review is first classified according to the problem solved in terms of the number of physical distribution components and the type of components included in the problem statement. Each problem is classified as either a single component, multi-component, or total physical distribution system (all components).

The independent variable, planning horizon, refers to the period of time usually 5 to 10 years over the period of problem consideration. For this variable the problem is classified as either a short term (operational) planning model with considerations for 1-2 years or a long-range (strategic) planning horizon where consideration is frequently 5-10 years.[2]

The dichotomy non-sequential versus sequential is used to classify a physical distribution planning model relative to the influence of current decisions on future decisions made in the model. Hadley describes a sequential decision problem as:

> a problem which involves making two or more decisions at different points in time, and which has the property that the later decision(s) may be influenced not only by the previous decisions, but also by some stochastic parameters whose values will actually have been observed before later decisions are made.[3]

The key difference between sequential and non-sequential decision problems is that future decisions in sequential problems may be based partially on information known in the future but unknown at present. One of the frequent approaches to solution of sequential decision problems uses the functional equation technique of dynamic programming.[4]

The dependent variable, type of solution technique, refers to the general technique, either analytical or heuristic that is the primary solution technique for the planning model. In this thesis analytical includes any one of the mathematical techniques such as linear programming, least squares, dynamic programming, and inventory theory. Heuristic techniques are non-optimizing including such modeling techniques as simulation, which may or may not incorporate analytical (optimization) techniques for solution of subsets of activites or components within the total model.

The unifying dimension refers to the orientation of the model in developing measures of cost and/or service. The unifying dimension of a model is classified as spatial if the cost and/or service are developed based on location or transit time. If the model uses order-cycle time as the measure of physical distribution system performance, the model is classified as temporal or time oriented.[5]

The behavior of the model refers to classification of static versus dynamic. A dynamic model is defined as one where information feedback control loops provide time-varying interactions within the model.[6]

The environmental inputs are one of the operating forces that influence physical distribution policy and are external to the firm. The environmental forces are summarized by Bowersox as:[7]

1. Industry Competitive Structure
2. Market Differentials
3. Network of Service Industries
4. Legal Structure
5. Economic Forces

It is not the purpose of this thesis to establish and/or attempt to prove the hypothesis that "A given physical distribution planning problem defined in terms of the independent variables component structure, planning horizon, and influence by previous decisions would dictate a 'suggested best' solution approach in terms of the dependent variables type of solution technique, unifying dimension, behavior of system model, and environmental inputs." There is, however, evidence in the literature that lends support to the relationship of physical distribution problem to solution approach as defined above.

<u>Literature Support</u>

<u>Solution Approach</u>.--In terms of the solution approach there is support in the literature that suggests that complex problems frequently encountered in business must be solved with heuristic models, such as simulation, since mathematical analysis has not been capable of yielding

general analytical solutions. The alternative, an experimental approach with the real system is frequently too costly in time and money.[8,9,10]

The paper by Geisler and Steger considers alternative techniques in logistics systems analysis.[11] The authors, after classifying logistics systems by a set of characteristics, present a classification of systems analysis techniques and their attributes as illustrated in Table 2.1. The objectives of systems analysis as stated by Geisler and Steger are to:

1. Determine their operating characteristics
2. Study their completeness, and consistency
3. Evaluate new policies and procedures
4. Do sensitivity testing.

The object of selection from among these systems-analysis techniques, according to the authors, is to find the one technique that best deals with system characteristics in achieving the purpose of the analysis. The authors further state:

> . . . simulation plays a very important and central role in the spectrum of techniques used, particularly in dealing with those facets of a system that are not now or may never be subject to a high enough degree of abstraction to lend themselves to analytical treatment.[12]

The conditions affecting choice between heuristic and optimizing models are discussed by Kuehn.[13] The value of optimizing models according to Kuehn is that the computational method leads to the best possible solution or set of

TABLE 2.1.--A Classification of Systems Analysis Techniques and Their Attributes.[1]

Attribute	Technique				
	Real World	Observations from the Real World	Field Tests	Simulation: Gaming, Computer Simulation, Game Simulation, Training Simulation	Analytic Models
Degree of abstraction					→
Simplicity					→
Flexibility.					→
Realism.	←				
Cost	←				
Face Validity. . . .	←				
Ease of Implementation	←				
Experimentation. . .					→

NOTE: Attribute gathers intensity in direction the arrow points

[1] M. A. Geisler and W. A. Steger, "The Combination of Alternative Research Techniques in Logistics Systems Analysis," Operations Management Selected Readings, edited by G. K. Groff and J. F. Muth (Homewood, Illinois: Richard D. Irwin, Inc., 1969).

solutions of the problem statement. This is in contrast to heuristic methods which as a general rule do not guarantee reaching the optimal solution or solution set. Furthermore, heuristic methods do not provide an indication as to whether or not the optimal solution has been obtained. According to Kuehn, the value of heuristic method can be stated in terms of complexity, size, and cost. Heuristic methods can be used to solve much more complex problems than can be treated by existing optimizing models. Heuristic methods can be used to solve problems which are much larger than those which can currently be solved on existing computing equipment with the available optimizing models. Finally, heuristic methods can solve problems economically which could only be solved at prohibitive cost by available optimizing models.

Kuehn also stated that he believes that heuristic and optimizing models will be integrated into individual programs. For example, heuristic methods might be used to develop advance starting points for subsequent analysis by optimizing models, or the latter might be used merely to determine when an optimal solution has been reached. An important point made by Kuehn is that:

> Even greater integration is likely insofar as optimizing algorithms are incorporated as subroutines within heuristic programs.[14]

Bowersox discusses the degree of optimization that a firm should seek in physical distribution systems design stating that:[15]

> The design of an optimal system is a noteworthy objective, but one that is never achieved. Even if an optimum system could be conceived, it is doubtful that construction and overall implementation could be completed in sufficient time to enjoy the perfect arrangement.

Thus according to Bowersox, the system study should serve as a guide to evaluate and modify specific segments of existing physical distribution systems, to serve as a blueprint. A successful systems analysis thus requires a flexible model that produces "satisficing" solutions after consideration of changing patterns of customer demand, corporate objectives, technological developments, and competitive actions.

Starr, who was previously referred to in the Introduction, states that there is:

> . . . a definite relationship between the concept of long-range planning (where the sub-systems are time sequentially interdependent) and the acceptability of sub-optimation. Similarly, for master planning (where the sub-systems are interacting units of an extensive organization) sub-optimizing methods must be accepted in order to achieve the highest possible level of systems analysis.[16]

The above literature supports the relationship that the solution to total physical distribution systems design problem for long-range planning requires the use of heuristic, sub-optimizing solution techniques.

Unifying Dimension.--The second dependent variable is referred to when Heskett, expressing concern about the over emphasis on the use of spatial aspects, states:

> Undue, misplaced emphasis on spatial matters in physical distribution has prevented effective measurement of physical distribution activity and the development of truly valid system planning methods.[17]

The unifying dimension must be "time" according to Heskett:

> Time rather than distance will be the unifying dimension of an integrated model for helping plan and control a logistics system. This model-adapted to each company's special needs-will combine elements of a temporately oriented location model with an inventory model to produce information for planning purposes and a set of devices for the control of various elements of a company's logistics system.[18]

The two major cost areas, transportation and inventory according to Heskett, have served as a basis for location models based on transportation costs in combination with goods movement and inventory directly concerned with inventory costs. Heskett states:

> 1. Location models have been spatially oriented to date, while inventory models have and will always be temporally oriented.
> 2. A physical distribution system can be described completely for analytical purposes only in terms of its inventories, but not in terms only of its transportation elements.[19]

According to Heskett the majority of models for location analysis such as center-of-gravity, linear programming, and heuristic have been spatial rather than temporal.[20,21] One exception he noted was Bowersox's use of transit time in location and analysis.[22]

In contrast, according to Heskett, inventory models do not have spatial orientation. The relevant time is not transit time between inventory locations, but rather is the order-cycle time from point of order transmittal to, and through the distribution supply point and back to the point of delivery. According to Heskett the reasons for "time" as the unifying dimension can be summarized as follows:

1. Neither time nor cost necessarily bear close relationship to distance
2. There is low relationship between order-cycle time and distance
3. Spatially oriented models lack relevance because their primary objective has been cost minimization based on weighted distance, which has little to do with profit maximization.

Time-oriented models allow consideration of the order-cycle time and dependability. As stated by Heskett, these two determinants of demand (revenue) plus cost relationships incorporated in a model allow the capability for profit maximization objectives.

In summary as stated by Heskett:

> If an integrated, accurate method of analyzing and controlling physical distribution systems is to be developed, time instead of space will be the relevant unifying dimension to be used.[23]
>
> A system can be viewed most productively as a set of actual or potential inventory cells linked and partially determined by time-transit time for those inventory cells in network links, order cycle time for those cells at network nodes.[24]

The above literature review indicates that a planning model for the total physical distribution system should include inventory control and the development of measures of the total order-cycle time.

Behavior of the Model.--The third dependent variable to be reviewed, refers to the static versus dynamic nature of the model. The review previously presented in this chapter suggests the use of a heuristic solution technique and temporal orientation for complex problems such as integrated physical distribution systems. Therefore, the literature review here concentrates on the sequential versus nonsequential requirements of the problem.

Howard discusses the use of the optimizing technique, dynamic programming, for solving certain types of sequential decision problems. He characterizes a sequential problem as:

> . . . a problem in which a sequence of decisions must be made with each decision affecting future decisions.[25]

Howard further states that:

> . . . we need to consider such problems because we rarely encounter an optimal situation where the implications of any decision do not extend far into the future.[26]

Ballou discusses this problem in the context of a warehouse location model.[27] The shifting of market demand patterns and changing economic conditions, according to Ballou, can create many static, maximum profit distribution centers over time. Ballou states that in considering the possible multiple optimal distribution center location alternatives, the question is:

> What combination of these alternatives should be chosen to maximize cumulative profits from location for a given planning period?[28]

According to Ballou the decision problem is to determine the distribution center location plan, including the initial locations and all subsequent locations and/or relocations so that cumulative profits from the decision stages are maximized for the entire period in which the distribution centers are needed, the planning period. In summarizing his ideas on the importance of considering the sequential problem he says:

> The point is that existing models, although sophisticated, lack a certain amount of scope, especially for providing solutions that indicate the optimum location pattern over time.[29]

Forrester treats the time-varying (dynamic) behavior of organizations which he defines as industrial dynamics.[30] The foundation for his industrial dynamics is the concept of information--feedback systems, which he defines broadly as:

> An information-feedback system exists whenever the environment leads to a decision that results in action which affects the environment and thereby influence future decisions.[31]

Various other authors also have used dynamic programming and other techniques to solve what have been referred to as dynamic planning problems, optimal time-staged decisions, sequential decision problems, or time varying-interaction systems.[32.33]

The above brief review suggests that the sequential decision problem or time-optimal staging problem requires a dynamic approach.

Environmental Inputs.--The fourth and final dependent variable is concerned with the operating forces that influence physical distribution policy.[34] The factors which represent environmental inputs are subject to change over the period of interest, the planning horizon. The magnitude of the change is thus a function of the rate of change and the length of the planning horizon.

As reported by Bowersox, there are a number of factors that have had an impact upon effective physical distribution management. These, he states, include:

1. Geographic shifts
2. New product development
3. Transport and unit-loading
4. International marketing
5. Competition
6. Channel pressures[35]

Kotler and Schultz refer to this problem also:

> The American Marketing system is a huge, complex network of marketing firms and facilities. . . . It operates within an economic system characterized by a high rate of product innovation, multiple instruments and channels of marketing communication and persuasion, and constantly evolving patterns of buyer wants, attitudes, and behavior.[36]

These two authors present a review of the various marketing simulation models for studying complex marketing problems related to environmental changes in advertising, price, new products, and market share.

As previously discussed in the Introduction of this thesis, the time dimension of long-range planning varies considerably, but as discussed by Steiner it is not at all unusual to find in industry today long-range projections of economic environment, customer demand for products, or new technology extending 10 to 20 years in the future.[37]

Forrester in referring to the challenge to top management in long-range planning states that:

> The challenge lies in how today's decisions will affect the time interval between five and twenty years hence.[38]

Magee points out that it is reasonable to consider using a static model, not allowing for change of the environmental inputs, if the anticipated rate of change of the market is low enough and the flexibility of the physical distribution system great enough that a static model is useful.[39] For many other circumstances, however, he states:

> We must take a dynamic view of the distribution system:
> 1. Because change in the system may be expensive and laborious
> 2. Because anticipated future needs may be inconsistent with present needs
> 3. Because we may not be able to see the future too clearly.[40]

There is little argument that today's market is dynamic and subject to continuous change. In fact, various authors have stated that the only thing constant is change itself. The physical distribution system operates within the environment of, and functions to serve the demands of, the marketing system. The inputs to a physical distribution long-range planning model must therefore be able to reflect the continuous change in the marketing environment and other external operating forces which determine the operating boundaries for the distribution system. It is thus apparent from the literature that long-range planning models for physical distribution must be dynamic in terms of providing for modification of environmental inputs.

The literature reviewed above suggests that for the physical distribution problem defined in this thesis, which is a multi-level, total physical distribution system (all components) with sequentially staged decisions over a long-range planning horizon, the types of models that would be of greatest assistance are heuristic models with optimization techniques incorporated within. The model should in addition be dynamic rather than static, with time as the unifying dimension rather than distance, and with capacity for changing the environmental inputs of the model.

However, as was evident during the literature review, there have not been any models reported in literature or developed in industry that have considered this complexity of physical distribution problem. Thus the literature review in this chapter was selected to help form the framework for the general solution to the overall research problem and to report in summary form the state of the art of physical distribution planning models.

Problem statements and resulting models that were basically single component models are referenced in the Chapters IV, V, and VI, where the solution techniques for that particular component are developed.

Review of Selected Models

A recent review of applications of quantitative methods to physical distribution is presented by Ballou in which he discusses transportation models, inventory models, location models, warehousing analyses, merchandise layout, and dock requirements.[41] Ballou also reviews briefly in this article the use of computer simulation in physical distribution design. General reviews of quantitative techniques to physical distribution are also presented by Magee,[42] and by Bowersox, Smykay, and LaLonde.[43]

Many other books, monographs, etc. are also available in the literature that review the total range of possible quantitative techniques applicable to total physical distribution system and/or component analysis and design.[44]

Kuehn and Hamburger.--Several models have been developed that involve transportation and location but not inventory control. Kuehn and Hamburger developed a planning model to determine the geographical pattern of warehouse locations which would be most profitable to a company.[45] Figure 2.3 defines the model in terms of a general flow diagram. In the model marginal cost of warehouse operation is

1. Read in:
   a) The factory locations.
   b) The M potential warehouse sites.
   c) The number of warehouse sites (N) evaluated in detail on each cycle, i.e., the size of the buffer.
   d) Shipping costs between factories, potential warehouses and customers.
   e) Expected sales volume for each customer.
   f) Cost functions associated with the operation of each warehouse.
   g) Opportunity costs associated with shipping delays, or alternatively, the effect of such delays on demand.

2. Determine and place in the buffer the N potential warehouse sites which, considering only their local demand, would produce the greatest cost savings if supplied by local warehouses rather than by the warehouses currently servicing them.

3. Evaluate the cost savings that would result for the total system for each of the distribution patterns resulting from the addition of the next warehouse at each of the N locations in the buffer.

4. Eliminate from further consideration any of the N sites which do not offer cost savings in excess of fixed costs.

5. Do any of the N sites offer cost savings in excess of fixed costs?

   Yes → 6. Locate a warehouse at that site which offers the largest savings.

   No → 7. Have all M potential warehouse sites been either activated or eliminated? No

   Yes

8. Bump-Shift Routine
   a) Eliminate those warehouses which have become uneconomical as a result of the placement of subsequent warehouses. Each customer formerly serviced by such a warehouse will now be supplied by that remaining warehouse which can perform the service at the lowest cost.
   b) Evaluate the economics of shifting each warehouse located above to other potential sites whose local concentrations of demand are now serviced by that warehouse.

9. Stop

Figure 2.3--A Heuristic Program for Locating Warehouses[1]

[1]A. A. Huehn and M. J. Hamburger, "A Heuristic Program for Locating Warehouses," Management Science, Vol. 9 (July, 1963).

equated with transportation cost savings and incremental profits resulting from more rapid delivery. The problem includes screening and evaluation of alternative warehouse locations for a fixed set of exogenous inputs which define transportation costs as proportional to distance. Warehouse operating costs and opportunity costs associated with shipping delays are then used to estimate cost savings for addition of warehouses. The primary physical distribution components not considered are inventory and communications.

The planning horizon as developed in the problem is short range since the exogenous input is fixed. However, long-range considerations could be introduced via different exogenous input levels.

The problem as defined is non-sequential since only one set of decisions is made at a point in time. The problem does not involve time-varying interactions or decision stages over time. The general approach to developing a model for the problem selected was simulation rather than analytical. The authors state:

> . . . the linear programming algorithms available for optimizing the routing of shipments in multi-plant, multi-destination systems cannot in the current state of knowledge, be applied directly to the more general problem of determining the number and location of regional warehouses in large-scale distribution networks.[46]

The model is spatially oriented rather than time-oriented, since it does not allow the development of the total order-cycle and a measure of the dependability of service.

The system behavior is static rather than dynamic according to the previously stated definition of dynamic models. In this model there are no situations that change over time, and no information feedback control systems. The model simulates at a point in time the activity that has occurred during a total previous operating period. There is no simulated calendar or passage of time within the model and therefore no feedback control loops can be developed.

The environmental or exogenous inputs are fixed for each simulated year. These inputs could be modified to simulate a different point in calendar time, for example a future year. Thus the model could also be helpful as a long-range planning tool.

In summary, the Kuehn and Hamburger planning model does not consider the inventory component, is non-sequential, and is primarily a short-range planning model. It, therefore, does not provide an answer to the problem defined in this thesis. The Kuehn and Hamburger model, however, does serve as an excellent guide for the development of the location algorithm in the Monitor and Control Subsystem of the LREPS mathematical model being developed in this thesis.

Shycon and Maffei.--In the multi-component model developed by Shycon and Maffei, the problem is to combine the best features of direct plant-to-customer distribution with those of a national warehousing network.[47] Analysis is made to determine the number, size, location of warehouses and processing locations which would properly serve customers at a minimum cost nationally. The flow of the Shycon and Maffei model is illustrated in Figure 2.4.

As in the Kuehn and Hamburger model, this model includes elements of the transportation, warehouse operations, and location components. The authors state:

> It takes into account each of the important factors involved in the operation of a distribution system: transportation rate structures, warehouse operating costs, the characteristics of customers, demand for products, buying patterns of customers, costs of labor and construction, factory locations, product mix and production capacities, and all other significant elements. These factors, taken together, make up the distribution system.[48]

The model, however, does not include the inventory control or communications components of the physical distribution system.

The model, according to the authors, was designed to represent a complex, high-volume national distribution system with thousands of customers. Thus, according to the authors, the model makes provision for:

1. Each customer's order sizes, his ordering patterns, the various types of shipments he receives, and his product mix
2. Handling the costs of the various kinds of shipments made such as: carload, less-than-carload, truckload, less-than-truckload, and various shipment sizes within the lower classifications
3. Variation in warehouse operating costs such as: labor costs, rentals, taxes for different geographic areas
4. The many different classifications of products which Heinz manufactures, the alternative factory source points for each of these products, and the factory capacity limitations on each

PREPROCESSING RUN
(To eliminate the volume of shipments that go directly from factories to customers and hence will not effect the warehouse distribution system).

1. The computer is programed for the preprocessing run. It is given detailed instruction as to what it should do with the customer information that it will receive.

2. Information on every customer in the national Heinz distribution system is fed into the computer.

3. The computer tests each customer to determine whether his volume of purchase is sufficient to justify direct shipments from factories.

4. A. If a customer's volume justifies shipments directly from the factory, the computer lists each such customer separately, according to the type of product he orders and the volume of his orders.

TEST RUN
(To determine the costs of distribution under various warehouse location configurations).

   B. At this point the computer retains the volume of customer orders which are not shipped directly and must go through the warehousing system.

5. First, the computer has fed into it a new program which tells how to compute costs on the basis of the information which it will receive in step no. 6.

6. Next, the following information is processed by the programed computer.
   A. The results from the preprocessing run (i.e., the customer volume that flows through the warehousing system) which were retained in the computer in step no. 4.
   B. The particular warehouse location configuration that is to be tested.
   C. The freight rates, warehouse operating costs, taxes, etc. that make up the costs of the particular geographical areas in which the proposed warehouses are located.

7. THE COMPUTER ISSUES THE RESULTS:
   The costs of distribution for the Heinz company under the tested warehouse location configuration.

Figure 2.4--Simulation Test of a Particular Warehouse

[1]H. H. Shycon and R. B. Maffaei, "Simulation--Tool for Better Distribution," Readings in Physical Distribution Management, edited by D. J. Bowersox, B. J. LaLonde, and E. W. Smykay (New York: The Macmillan Company, 1969), pp. 243-260.

5. The knowledge of where these relationships differ, so that adjustments to cost and volume estimates might be made.[49]

Initially the model was developed for short-range planning, but as the authors stated the customer demand data, product data, cost data, etc. could be changed to reflect long-range effects in the environment. Some of the possible uses of the model for long-range planning are given by the authors. These include: (1) distribution cost studies for different combinations of customer classification schemes, (2) locational studies to determine the effect of shifts in customer type or location, factory relocation, etc., (3) studies related to changes in product mix, customer consumption patterns, product capacity at factory locations, etc., and (4) studies related to changes over time in annual volume, product line, etc.

The final independent variable to consider is non-sequential versus sequential. The model is non-sequential in that only a single set of decisions are simulated. Decision stages over time are not considered.

The general solution approach selected by Shycon and Maffei provides further support for the relationship previously suggested that total physical distribution problems require "heuristic" solution techniques. The Shycon and Maffei model does not develop a measure of the total order cycle and service dependability and thus is spatially oriented rather than time oriented according to the definition previously presented in this thesis. The behavior of their model is static rather than dynamic since there is no simulated passage of time in the model. Recursive equations or information feedback control loops are therefore not possible. The environmental inputs are fixed for a given simulation run for one year. The major emphasis of the model is thus not to test the effects of a changing environment over a long-range planning horizon. However, as previously stated, various changes in environmental inputs do make the model suitable for testing the effect of any assumptions for a given future year.

In summary, the Shycon and Maffei planning model does not consider the inventory or communications component, is non-sequential, and is primarily a short range planning model. It cannot, therefore, provide the answer to the problem statement of this thesis. The model, however, does include the essential parts which influence warehouse location. It thus provides background information for development of the location algorithm for the LREPS mathematical model.

Ballou.--Ballou considers the question of what combination of multiple optimal warehouse location alternatives should be chosen to maximize cumulative profits from location for a given planning period.[50] In this model the mathematical technique dynamic programming is used to find the optimal solution to the multi-period location problem. Ballou states that:

> A physical distribution system can be conceptualized as several inventory storage points (nodal points) interconnected by a transportation network (links). Location of inventories or location of warehouse facilities, transportation service choices, and inventory-level alternatives are the three major decision areas that concern the physical distribution manager about the design of a distribution system.[51]

In treating only the location problem independently of other alternatives, Ballou states that an upper limit is established on the profits that the distribution system can generate, due to the fact that one degree of freedom in overall system design is lost.

The concern in this model is to determine the location plan that describes when and where relocation should take place throughout the planning period. This plan is established at present time (time zero) for the entire planning horizon and is the optimum plan based on the problem statement and the forecasted revenue and cost levels. The model provides an example of a multi-component model that considers the sequential decision problem. Ballou states in this regard that:

> . . . existing models, although sophisticated lack a certain amount of scope, especially for providing solutions that indicate the optimum location pattern over time.[52]

The basic elements of transportation and location are considered in the model developed by Ballou. Inventory, warehouse operation, and communications are not, however, included in the problem definition. The planning horizon is primarily short-range for the model as presented in the literature. As in the two previous models, however, the inputs could be modified to reflect long-range estimates of environmental factors. The problem is defined by Ballou states that future decisions are to be influenced by previous decisions. Thus the problem does investigate the multi-period or sequential decision problem.

The solution technique found to be appropriate by Ballou was dynamic programming:

> . . . the best location plan is found by recasting the problem into a sequence of single-decision events. Then, according to Bellman's Principle of Optimality: in a sequence of decisions, whatever the initial decision, the remaining decisions must constitute an optimum policy for the state resulting from the initial decision.[53,54]

The dynamic programming technique is an analytical technique for finding a warehouse location-relocation plan that will yield maximum cumulative profits for a given planning horizon.

The unifying dimension for this dynamic programming model is spatial even though delivery time is used as a basis for measuring service. As indicated previously by Heskett, transit time alone does not make a model time-oriented. The model must also develop a measure of the total cycle time, and a measure of service dependability.

In summary, the model developed by Ballou is basically a location model with transportation costs and transit time used as the basis for measuring system performance. A key component, inventory control, however, is not considered. The model considers the sequential decision problem and thus provides a useful framework for developing this aspect of the LREPS mathematical model. The model is dynamic in the sense that it uses a completely recursive system of equations to solve the multi-period problem. It solves the multi-stage decision problem.

Forrester.--The model of the industrial system developed by Forrester attempts to match production rate to rate of final consumer sales.[55] The process of production and distribution according to Forrester is the central core of many industrial companies. A recurring problem is to match the production rate to the rate of final consumer sales. Forrester states that:

> It has often been observed that a distribution system of cascaded inventories and ordering procedures seems to amplify small disturbances that occur at the retail level.[56]

The model developed by Forrester as shown in Figure 2.5, deals with the structure and policies within a multi-stage distribution system. Flows of information, order, and materials are required to define the model. Three types of information are required according to Forrester: (1) the organizational structure, (2) delays in decisions and actions, and (3) the policies governing purchases and inventories.

The organizational structure includes the nodes or stages at which inventory exists; the factory, distributor, and retailer. Delays in flow of orders (information) and flow of goods are necessary to determine the dynamic

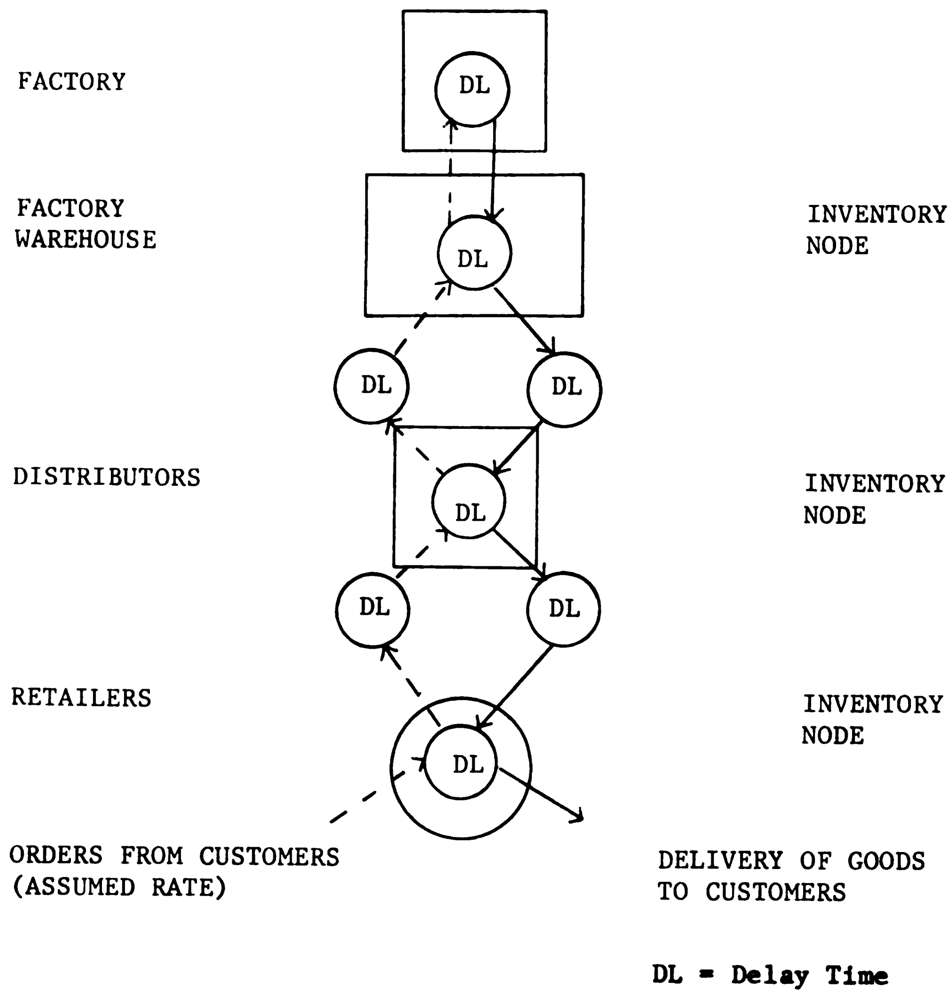


Figure 2.5--Organization of Production-Distribution System[1]

[1] J. W. Forrester, Industrial Dynamics (Cambridge, Massachusetts: The M.I.T. Press, Massachusetts Institute of Technology, 1961), p. 22.

characteristics of the system. Three principal components are defined by Forrester: (1) orders to replace goods sold, (2) orders to adjust inventories upward or downward as the level of business activity changes, and (3) orders to fill the supply pipelines with in-process order and shipments.

The physical distribution components included in the industrial dynamics production-distribution simulator are: (1) transportation, (2) inventory, (3) communications delays, (4) a fixed set of locations, and (5) warehouse or unitization.

The organization structure is a single factory, and single factory warehouse, multi-distributors and multi-retailers. The distributors and retailers are each represented by single location in the model. Aggregate increases and decreases in sales are assumed. Therefore, this model should be considered a single product type model. The problem as stated is thus one of total physical distribution system components for a single channel, single supply source, with multi-stage inventory nodes.

The model as developed is a "closed" system. Inputs are initialized as rate equations. Since the model is not presented as a decision making tool there is no reference to a planning period horizon for decision making. The response of simulation runs to various changes in inputs is measured for dynamic effects on system variables in terms of 1-3 years. The period of influence could therefore be considered short-range or long-range. The problem as stated is sequential since the objective is to examine possible fluctuating or unstable behavior arising from the principal structural relationships and policies over time.

The general solution approach used by Forrester is heuristic. He makes the point that mathematical analysis is not powerful enough to yield general analytical solutions to situations as complex as the total physical distribution system. Forrester constructs a mathematical model of the industrial system that tells how the conditions at one point in time lead to subsequent conditions at future points in time. The behavior of the model is observed and experiments are conducted to answer specific questions about the system that is represented by the mathematical model. The name "simulation" is often applied to this process of conducting experiments on a model rather than attempting the experiments with the real system. Forrester states that simulation consists of:

> . . . tracing through, step by step, the actual flows of orders, goods, and information, and observing the series of new decisions that take place.[57]

The unifying dimension in the model is "time" as previously stated by Forrester:

> . . . to be able to determine the dynamic characteristics of this system, we must know the delays in the flows of orders and goods.[58]

The behavior of the model is dynamic in the sense that it consists of information-control loops and deals with time-varying interaction.

The model developed by Forrester presents observations and results of experimentations related to the dynamics of the total physical distribution system. It, thus, provided valuable insight in developing the dynamic aspects of the LREPS mathematical model.

Carrier Air Conditioning Company.--The model developed by Carrier Air Conditioning Company uses a combination of simulation and linear programming for a physical distribution system.[59] The problem as defined includes elements of transportation, inventory, warehousing, communications, and location and thus is a total physical distribution model as defined in this thesis.

The planning horizon is not stated, but it appears that the model is run using activity levels for one operating year. It could be considered short-range or long-range, since the model inputs could and apparently have been modified to simulate different markets, customer demand, production schedules, freight rates, shipping modes, delivery times, inventory costs, warehouse rates and handling rates.

The problem as discussed in the article and illustrated in the input/output forms appears to be non-sequential. The decision maker requests the proposed physical distribution system he wishes to measure. The combination simulation and linear programming model then is used to develop the costs and a customer service level for the requested inputs.

The general solution approach as previously stated is heuristic with the optimization technique, linear programming incorporated in the model. The unifying dimension appears to be spatial rather than time oriented. The model incorporates a measure of the time of order processing and transit time, and the percentage of market within a number of days. However, as defined in this thesis the time dimension refers to the use of unit inventory control, transit time, order processing times, delays due to stockouts, etc. to develop the only true "temporal" measure--the total order cycle. Merely reporting a transit time and/or order processing time does not make the model time-oriented.

The model could be dynamic within the simulation of a given year. However, it does not appear to be dynamic in the sense of the definition stated in this thesis, which requires information-feedback loops or recursive equations. The model is short-range in the sense that it simulates one year at a time. The effect of changes in environmental inputs could, however, be tested for any given future year which would provide long-range capabilities.

In summary the Carrier Air Conditioning Company model includes elements of all of the components of the physical distribution system. The problem, however, does not consider the sequential decision problem, the unifying dimension is spatial rather than temporal, and the model is primarily oriented toward short-range planning. The model does present an illustration of the integration of a heuristic technique for general overall solution with analytical techniques incorporated for analysis of individual components. In this case, linear programming is used to solve the location problem within the constraints of the general solution provided by the simulation model.

Packer.--The next two models which are reviewed in this section emphasize the inventory component. The first by Packer is basically a single component model since it considers basically only the inventory component.[60] The problem as Packer defines it concerns a company that manufactures two classes of inventory. One is subject to deterministic demand, and the second includes overhead inventories such as components which are probablistic demand. The objectives are to determine the most effective parametric values for use in exponential smoothing formulas and to quantify the benefits resulting from the application of proposed inventory decision rules. The general program is outlined in Figure 2.6.

The program generally functions as follows:

1. The values, switches, etc., are initialized.

2. The demand for the month is read.

3. A new forecast is made.

4. If any previous orders are due (lead time has expired since last order), incoming stock is added to the quantity on hand.

5. Any back orders unfilled from last month are filled.

6. The stock available is compared with a newly calculated order point.

7. If the order point equals or exceeds the stock available, an order quantity is calculated and the order is placed.

8. Sufficient stock is 'issued' to meet current demand; a back order is established if current demand exceeds the stock available.

9. Under one option, detail relative to each month's activity is written. Under the second option, only summary totals are produced. For either option, program returns, reads the next month's demand, and repeats the loop from Step 2.

10. When the end of the simulated period (2 years) is reached, summary totals are written listing: (a) the average inventory in units and dollars; (b) the number of stockouts, demands, and orders; (c) the service percentage (in terms of both demands made/demands filled and quantity demanded/quantity filled); (d) safety and alpha factors; and (c) the average forecast error.

11. When all the items in the sample have gone through the above program, a summary report is run listing the following for each inventory class for the simulated period: (a) average inventory investment, (b) total and average orders placed per item, (c) total and average stockouts per item, (d) the number of sample items in the group.

12. If any more 'knob' cards are present, the parameters are changed according to those cards and the entire process begins again.

Figure 2.6--Simulation and Adapted Forecasting Applied to Inventory Control[1]

[1]A. H. Packer, "Simulation and Adaptive Forecasting as Applied to Inventory Control," <u>Operations Research</u>, Vol. 15 (August, 1967), p. 670.

The problem as defined is a multi-item, single stage stochastic demand inventory problem. It is thus a single component problem. As implied by Packer the planning horizon of the problem could be considered either long-range or short-range. The emphasis as written is, however, short-range. The problem is sequential in that future decisions of when to order and the amount to order are a function of previous decisions.

The solution approach selected by Packer was that of adaptive forecasting and statistical determination of safety stock. This is a technique suggested by Brown.[61] These techniques consist of using the exponential smoothing method for estimating demand, and establishing the level of safety stock based on the past success in estimating demand. A heuristic-simulation solution technique is used to seek numerical solution to the two problems defined. Packer states that:

> . . . considering the large number of items involved it appeared unrealistic to attempt to achieve an optimal policy for any of the individual items.[62]

Packer's decision to some extent was based on a statement by Hannssmann:

> From the operations research viewpoint, the theory has been carried to a degree of mathematical sophistication in some areas which is not fruitful in light of the fact that the inventory problem is only one aspect of a complex system.[63]

In essence there is no unifying dimension in this model in terms of time or space. It is a single stage, single location model and order cycle effects or delays are not considered. Stockouts are considered, but in terms of cost, not order cycle considerations. Packer states that his model is a static model. The model is dynamic, however, according to the definition in this thesis. The current deficiency (surpluses) of the inventory effect future decisions via information feedback-control loops. The environmental inputs are established to implement the model for short-range by assuming that cost parameters are constant. For longer range Packer develops a set of curves relating cost parameters between items and over time. The model can therefore be classified as both short-range and long-range.

Packer's model includes only the inventory component, thus it cannot be considered as the basis for the general solution approach to the LREPS mathematical model. However, it provided the basis for development of the inventory component which is presented in the Operations Subsystem activities of Chapters IV and V.

Ballou.--The second model, Ballou's dissertation, is a multi-component model with primary emphasis on the inventory component.[64] Ballou describes the problem as one of a multi-stage inventory situation involving three firms. The objective stated by Ballou is to test the effect of various inventory policies throughout a simulation period on cost and profit levels. Transportation costs are also altered to achieve sensitivity analysis. Decision rules are selected which yield the lowest total system cost under varying conditions.

The problem as stated includes elements of the inventory, transportation, and communications components. It is a multi-stage inventory problem for a single, finished-goods inventory of several firms. The problem does not consider the location problem or distribution center operation. The planning horizon is primarily short term and the assumption is that the facility network does not change. The problem is sequential in that current decisions in the model influence future decisions. For example, when demand is in excess of inventory level backorders are incurred. These backorders are eventually filled with reorders after a generated lead time.

The general solution approach is simulation with analytical subroutines such as computation of the EOQ incorporated as appropriate. The unifying dimension is time with a measure of service, backorder level, being partially dependent on the expected lead time, itself is an element of the total order cycle. The system behavior is dynamic in the sense defined previously in this thesis. Information feedback-control loops are developed for such variables as inventory level. Finally, the environmental inputs such as; cost lead times, product price, etc. are modified via exogenous input to the model.

In summary, Ballou's inventory model does not consider all of the physical distribution components and thus cannot be used as a basis for the LREPS general solution approach. The model does, however, provide important insight relative to the selection of the "best" inventory policy for stated assumptions and decision rules for managerial action.

Mathematical Models

Introduction

Initially this section presents the definition and description of mathematical models, including the variables of simulation models. This is followed by a review of literature concerning approaches suggested for model formulation.

Definition and Description

A mathematical model consists of four well defined elements: (1) components, (2) variables, (3) parameters, and (4) functional relationships.[65] The primary components in the LREPS model are related to the entities or objects of the three primary systems. A mathematical model can also be defined as a set of equations whose solution explains or predicts changes in the state of the system.[66] The variables are used to relate one component or entity to another and may be conveniently classified as exogenous, status, and endogenous variables.

Exogenous variables are the independent or input variables of the model and are assumed to have been predetermined and given independently of the system being modeled. These variables may be regarded as acting upon the system but not being acted on by the system. Exogenous variables can be classified as either controllable or non-controllable. Controllable (or instrumental) variables are those variables or parameters that can be manipulated or controlled by the decision makers or policy makers of the system. Non-controllable variables are generated by the environment of the system modeled and not by the system itself or its decision makers.

Status variables or entities describe the state of the system or one of its components at any point in time. The attributes, or characteristics of the entity, may change in value through time. The set of attribute values at any point in time define the "state of the system." Thus the status variables are also referred to as state variables. Attributes are properties of entities and an entity is described by listing its attributes.[67]

Endogenous variables are the dependent or output variables of the system and are generated from the interaction of the system's exogenous and status variables according to the system's operating characteristics. The system state, status, and endogenous variables can be used interchangeably to define variables whose value is generated within the model.

The exogenous variables or parameters are classifed as "factors." A simulation experiment consists of a series of computer runs in which tests are empirically made of the effects of alternative factor levels on the values of the endogenous levels. Parameters are considered to be those attribute values that do not change during simulation experiment(s).

Functional relationships or transformations describe the interaction of the variables and components. The terms functional relationships, transformations, and algorithm are used interchangeably. Each refers to the mathematical function, logical operation, or process operation that relates predictively an activity's output to its input.

An activity is a quantitative or logical relation of an input set of variables (or attributes) to an output set of variables (or attributes) by a mathematical function. Accomplishment of an activity usually results in a change of the system state. A general method of developing transformations is presented by Van Court Hare.[68]

Approaches to Mathematical Modeling

The general procedures for development of the LREPS model were previously referred to in the Introduction, Figure 1.4. This chapter is concerned with the approach(es) suggested for the formulation of the mathematical model.

Morris, in discussing the "art of modeling," states that the process of development of a model by a management scientist can best be described as intuitive.[69] The term "intuitive" as used by Morris refers to ". . . thinking which the subject is unable or unwilling to verbalize."

According to Morris, three basic hypotheses exist relative to model building. First, the process of model building can be viewed as a process of "enrichment" or "elaboration." The model designer begins with a simple model and after obtaining a "tractable" model attempts to move in an evolutionary manner toward a more sophisticated model that more nearly reflects the complex management situation.

"Analogy" or association with previously well developed logical structure is the second major requirement for development of a successful model.

Third and finally, the process of elaboration and enrichment involves several types of "looping" or "alteration" procedures. For example, as each version of the model is tested a new version is developed which leads in turn to subsequent tests. A second type of alteration is determining if a model version permits achievement of the designer's objectives. If it does the designer may seek further enrichment or complication of assumptions. If, however, the model is not tractable (well-behaved) or cannot be solved the designer has to modify and/or simplify the assumptions.

Before a simulation model is designed, two important questions must be asked and answered: (1) What use will be made of the model (what questions will be asked)?; and (2) What are the requirements of accuracy and precision? Answers to these questions determine the structure of a model.

The model's structure, as stated by Kiviat is affected by such factors as:

1. The purpose of the model.
2. The accuracy and precision required of the output.
3. The detail required in the model to achieve the required precision.
4. The assumptions required at the system boundaries.
5. The assumptions required within the system boundaries for
   - status representation
   - decision parameters
   - decision rules
6. The availability of necessary data.[70]

The model design is thus complicated by a combination of theoretical and practical factors. The theoretical factors determine such things as the system boundary interactions and decision rules, whereas the practical factors modify the theoretical decision, such as the level of detail incorporated within the model. Kiviat states this as the reason for feedback loops in the modeling process itself.

The model is thus an iterative process which must take into consideration the criteria of the model designer and the constraints of the environment. The final model reflects in both structure and implementation the influences of the real world system being studied, the questions that are of interest to the decision maker about the system, and the environment in which the model is to perform.

Modeling is therefore a continuous balancing of the costs of data collection and analysis against the costs (benefits) of precision, and program execution costs against the costs of model reprogramming. A five-stage iterative sequence describing the modeling process is presented in Figure 2.7.[71]

Naylor states that:

> . . . the formulation of mathematical models consists of three steps:
> 1. Specification of components
> 2. Specification of variables and parameters
> 3. Specification of functional relationships[72]

He states further that although a complete knowledge of the system being modeled as well as proficiency in mathematics are necessary prerequisites for the formulation of a valid model, they are in no sense sufficient conditions. A successful mathematical model depends also on:

1. The experience of the model designer or analyst
2. Trial-and-error procedures
3. A considerable amount of luck.

Naylor discusses a number of suggestions relative to the development of mathematical models which can be summarized below.

First, the question of how many variables to include in the model must be answered. Naylor indicates that the selection of endogenous or output variables is usually determined at the beginning of the study and thus do not cause much difficulty. The choice of exogenous variables

ITERATIVE MODELING PROCESS

Stage 1: Statement of a problem in general system terms. Definition of gross system boundaries. Statement of output(s) needed to solve the problem.

Stage 2: Statement of (initial) assumptions. Definition of static and dynamic system structure. Construction of minimal system model. Assessment of assumptions in light of Stage 1 goals.

Stage 3: Determination of input data requirements and availability. If input data required are not available, modify assumptions and model structure by returning to Stage 2.

Stage 4: Determination of output possibilities. If output is insufficient, modify assumptions and model structure by returning to Stage 2.

Stage 5: Prepare precise specifications for final model. Select a modeling and programming language. Reassess the implications of all assumptions for the future. Prepare a detailed plan for use of the model.

Figure 2.7--A Five-Stage Iterative Modeling Process[1]

[1]P. J. Kiviat, Digital Computer Simulation Modeling Concepts (Santa Monica, California: The Rand Corporation, 1967).

is more difficult, since too few exogenous variables may lead to invalid models whereas too many may render computer simulation impractical due to the computer and programming requirements.

The second major consideration is the complexity of the model. The number of variables in a model and its complexity are directly related to the programming time, computation time, and validity. A change in any one of these characteristics results in changes in all of the other characteristics.

A third area of consideration is the computational efficiency of the model. In this model for example, the objective is to keep the total computer model processing time for a simulation run below a pre-determined elapsed time. This objective has a direct influence on the development of the algorithms of the model.

Computer programming time represents a fourth area of consideration. Thus the amount of sophistication in the algorithms must be balanced against the increased programming efforts. The development of requirements such that one of the existing simulation languages can be used must also be evaluated.[73,74]

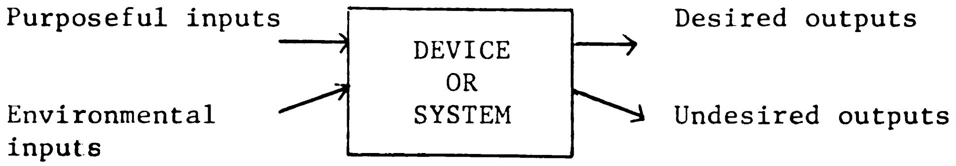
The fifth area of interest is the validity of the model or the amount of realism incorporated in the model. The model must adequately describe the real world system and use of the model should give reasonably good predictions of the behavior of the system for future time periods.

The final consideration that Naylor presents is the compatibility of the model with the type of experiments that are going to be conducted with the model. Thus the basic experimental design must be formalized prior to development of the mathematical model.

At each level of model formulation Asimow recommends the use of an activity analysis approach similar to that illustrated in Figure 2.8 to specify the design problem. For each level the procedure suggested by Asimow would be as follows:[75]

1. Derive the desired outputs of the system
2. Determine the undesired outputs of the system
3. Determine the inputs, which the system will transform into outputs
4. Determine the constraints for input and output variables
5. Consider the system constraints along with the design parameters
6. Establish the appropriate measures of value for the output and input variables and design parameters
7. Use the appropriate relationships among the variable to develop the criteria for measuring the goodness of the proposed systems.

A few of the potential difficulties encountered in mathematical model building are also presented in the literature.[76,77] These can be summarized as follows:



Constraints on inputs	Constraints on system	Constraints on outputs

Units of measure of inputs, outputs, and constraints (independent and dependent variables) and associated measures of value where needed

Overall objectives and the design criterion

Figure 2.8--Format for Activity Analysis--General Plan[1]

[1]M. Asimow, Introduction to Design (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1962), p. 54.

1. Those variables which affect the behavior of the system but are in a practical sense impossible to quantify or measure

2. The number of required variables may exceed the capacity of the computer capabilities available

3. All of the exogenous variables that affect the output variables may not be known

4. Not all of the functional relationships between exogenous and endogenous variables may be known or possible to develop

5. In many cases the relationships between variables may be too complex to express in a set of mathematical equations.

Summary

The literature review suggests that a long-range planning model for total physical distribution operations should consist of the following attributes:

1. A heuristic solution algorithm

2. Dynamic time varying interactions

3. Time as the unifying dimension

4. A procedure for changing environmental input factors.

The review also indicates that such a model has not been developed or at least has not been reported in the literature. The models surveyed did consider various combinations of the above attributes, but none of the models combined the two essential components, the location problem and the selection of inventory policy into a dynamic long-range planning model that uses total order cycle as the key measure of service. These models, however, did provide the basis for formulating the transformations for the activities of the LREPS mathematical model.

The review related to model building procedures also provided background information that was essential for establishing the design procedures for formulating the LREPS model. The first step of the development of the LREPS mathetical model, the design approach, is presented in Chapter III. The steps of the design process and the LREPS mathematical model itself are presented in Chapters IV, V and VI.

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CHAPTER III

APPROACH TO MATHEMATICAL MODEL DESIGN

Introduction

The conceptual model, required model capabilities, and general methodology for development of the LREPS model were discussed in the Introduction, Chapter I. This chapter in successive sections reviews the design criteria, presents the general approach used in formulating the mathematical model, and discusses several special design considerations. In the summary of this chapter, the method chosen for reporting the design evolution process for the LREPS math model is reviewed.

Design Criteria

The research problem of this thesis has previously been defined in terms of a set of independent variables as one of formulating the mathematical model to assist in making sequential decisions for total physical distribution responsibility over a long-range planning horizon. The design criteria established to achieve this were defined in terms of four general categories, which were to:

1. Solve the specific physical distribution problem statement

2. Meet the general research requirements

3. Remain within the established model operating limits

4. Achieve the desired model capabilities.

The problem statement required that the general solution approach be heuristic. Simulation, the heuristic technique selected, is according to the literature essentially the only modeling technique practical for analysis and design of a problem as complex as a total physical distribution system. Since the problem considered the total physical distribution system, it was also essentially required that the unifying dimension be temporal rather than spatial. The fact that the problem included sequential or staged decisions suggested that the model be dynamic, incorporating feedback control loops and recursive relationships. The requirement that the problem consider a long-range planning period made it important that a second element of dynamics, the ability to modify over time the environmental factor inputs to the model over the planning horizon, be incorporated in the LREPS operating model.

One of the general research design criteria was that the model must be of modular construction.[1] Using a modular or "building block" approach means that formulation begins with a single module of the system of interest, and by adding modules the total system can be developed as a total integrated system or in terms of its separate components. There are many benefits offered by the modular approach.

A modular approach is appealing from a pedagogical point of view. Designing a model upward from identifiable and observable process or analogies is also a logical procedure with examples of success documented in the literature. Finally, the modular approach provides the model designer with the possibility of considerable flexibility. Additional benefits of modular construction are also discussed in the literature.[2] An example of the modular construction in the LREPS model was the development of the inventory management module to operate with a "heuristic" inventory module with reorder quantity, reorder point, and safety stock set by management or with a theoretical inventory module incorporating the standard reorder point policy, the optional replenishment policy, and/or a hybrid combination of both the reorder point and optional replenishment policies. These two modules were interchanged in the LREPS model without reprogramming.

A second general criteria, which is not independent of modular construction, is the concept of universality. The concept of universality in the context of this thesis means that the model must be applicable, with little redesign, to a broad spectrum of industrial firms. This criteria required that variables, components, parameters, and transformations (algorithms) be defined in general terms. For example, the variable defined as the Demand Unit must be flexible enough to refer to a county, an

SMSA, an individual customer, Zip Sectional Center, etc., depending on which is selected in the supporting analysis for the particular application. A second example is the procedure for identifying the characteristics or attributes of the tracked products. The tracked products are identified by general characteristics that are common to all products such as the density, cube, weight, case units, and freight class.

The operating requirements such as the design constraints for the formulation of the mathematical model and the computer model, are related to the elapsed computer time requirement for each full run of the model, the cost of running the model, and the computer core requirements.

The final category of design criteria is the requirement that the LREPS model have the capabilities to test the effect on and/or effect by changes in the target variables, controllable variables, and uncontrollable variables previously presented in Figure 1.5.

Design Approach

The definitions, description, and steps used in formulating the LREPS mathematical model are similar to those reported in Chapter II. In this section, therefore, the primary emphasis is placed on the procedure for developing the transformations for the lowest system level in the model, the activity. Activities are combined to form a component such as the transportation component, inventory component, and demand component. Combinations of activities and components are formed and linked to develop the subsystems which in turn make up the total LREPS model.

The initial design effort consisted of developing a comprehensive list of the activities required for each level of the model. The design approach at the activity level then consisted of performing the following procedure:

1. State the objective of the activity
2. Develop conceptual approach to a set of alternatives for the activity
3. Evaluate each of the alternatives
4. Select the alternative(s) for each activity
5. Develop the specifications for the selected alternative
6. Collect, perform analysis, and prepare data for selected alternative(s)
7. Program the selected alternative(s).

In general this design approach is similar to that reported in the Literature Review, Chapter II. Therefore, only a brief statement is made in this chapter concerning the aspects that are possibly unique to the LREPS project. Multiple alternatives for each activity were developed to ensure that the full range of conceivable simplification to sophistication (or enrichment) of transformations would be covered. This approach also helped to ensure that the mathematical model would be modular and universal.

The decision was made to conceptualize four alternatives based on the fact that for many activities there appeared to be up to four methods of varying levels of sophistication which could be defined and that were both valid and practical. Each of the four alternatives was developed to the point that the outputs, inputs and general nature of the transformation requirements were documented.

Evaluation of the alternatives for each activity was performed not only in regard to the requirements of the activity itself relative to availability of input data, validity, modularity, and universality, but also relative to the effect on the total model in terms of computer processing time, and computer core requirements. In each case one alternative, referred to as Option 1, was selected as the primary alternative to be implemented in the initial version of the model. For a number of activities a second alternative, Option 2, was also selected either because the additional sophistication for Option 2 required very little marginal effort or both alternatives appeared to be equally acceptable.

The next step required the development of detailed specifications for the outputs, inputs, and mathematical transformations for Option 1 and if chosen, Option 2. Figure 3.1 illustrates the format used in recording the activity analysis. Flowcharts also are developed as needed to indicate the procedures for individual activities and

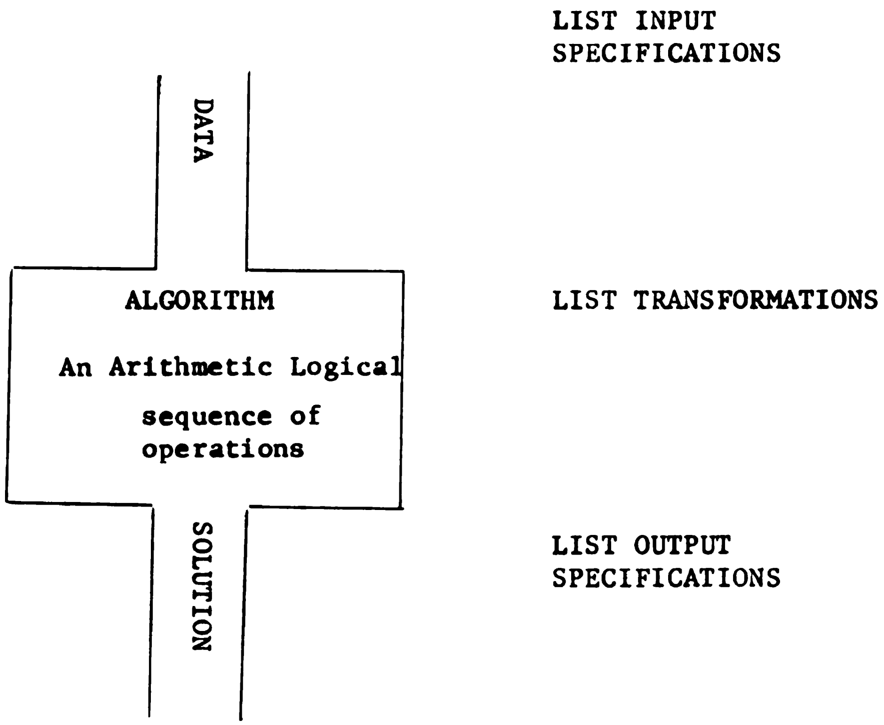


Figure 3.1--Format for Activity Analysis in LREPS

the connecting links for combinations of activities which form the systems hierarchy.

Special Design Considerations

In formulating the mathematical model several additional concepts not previously reviewed in this thesis were given consideration as they related to the objectives of the LREPS model. These three concepts were: (1) work flow structure, (2) model simplification methods, and (3) robustness or flexibility.

Work Flow Structure

Work flow structure is the first important special design consideration. Holstein and Berry define work flow structure as:

> . . . the pattern of aggregate work flow through the production system . . . and . . . the relationship or pattern of functional processing sequences in the shop.[3]

The work presented by these authors is specifically related to job-shop and manufacturing systems, but the general concept, nonetheless, appears to be applicable to the problem of formulating the system structure of the problem of this thesis, Figure 1.2. Essentially the authors develop a method for identifying the relative activity levels or importance of the links between individual work centers or nodes of the network. The activity levels or work flow structure in a physical distribution network for example are partially dependent on the source of manufacture for each product, product demand, inventory stocking policy, etc.

Holstein and Berry suggest the use of the important or strong links in job shop simulations rather than assuming that all links are possible. The neglect of the "weak" links, in terms of frequency of and amount of work flow, did not have a major effect on the results of simulations relative to the results achieved by previous authors who had considered all possible links of the job shops.

The above concept, which might be stated in terms similar to the ABC rule frequently used in inventory control--that 20 percent of the links account for over 80 percent of the activity, was used in the development of the structure of the physical distribution network for this model, Figure 1.2. For example, in the problem defined in this thesis the assumption was made that the closest manufacturing center, the MCC, always supplies the product to a particular distribution center when more than one MCC manufactures the product. Thus the assumption was that the "weak" link, the small amount of volume or activity from the remaining MCC's for the product, would not have significant effect on the design alternatives. A second example where the above concept was incorporated was the situation where a remote distribution center has a "stock out" for a particular product.

Using the above "strong link" concept the assumption was made that even though shipments of the product from a "second" best distribution center would actually be made occasionally these shipments would not have a significant effect on the design alternatives. These "strong link" assumptions will be investigated via sensitivity analysis to determine if the concept was valid for this physical distribution simulation model.

Model Simplification

The second special area for design consideration is "model simplification" methods. Simplification methods can be divided into two main categories: (1) first-order methods, which directly reduce complexity of the model, and (2) higher-order methods which simplify a system indirectly through a series of steps.

Direct attempts at system simplification usually involve the actions of "elimination" and "grouping." Either of these actions decreases the distinctions that need to be made in a system definition. Van Court Hare states that:

> We simplify by elimination when the system objective requires optimization, isolation, and search of detailed action. We simplify by grouping, classification, and consolidation of detail when the system objective requires estimation, comparison, and test between blocks of detail.[4]

The approaches to elimination that were considerd in this project were similar to the following three general methods:

1. Restricted ranges of measure, of interest,
2. Logically or statistically restricted combinations, or patterns of acceptance and
3. Threshold and discrimination methods.[5]

Higher-order simplification is accomplished by working with the system's control structure hierarchy--the system goals, objectives, values, and measures of effectiveness.[6] The higher-order approach is concerned with the system's potential for improvement, growth, change, and optimization. It is a strategic approach. The higher-order approach stresses relevance rather than the completeness or precision as stressed in the direct simplification methods.

In this model design the hierarchy was LREPS model, system, subsystems, components, and activities. A primary design problem related to higher-order simplification was thus to coordinate the subsystems into a model that would enhance the over-all purpose(s) of the total system. Van Court Hare states that:

> The most likely trouble-spot in the design of a complex system, or the operation of an existing complex system, is not that the individual blocks do not operate"efficiently" or even effectively regarding their own stated goals, but that the goals guiding these operations do not, when combined, result in either efficient or effective operation of the entire system.[7]

Just as conflicting subsystem goals may restrict the achievement of the full overall system objective, it is possible that there are conflicting multiple goals at the total system level. Consideration of constraints, risks, and commitments, are also important in the higher level definition. Modification of these makes possible higher-order simplification.

Morris also discusses simplification of models.[8] He states that if a model in its current version is "tractable" (well behaved) it can be enriched or sophisticated, otherwise it may have to be simplified by making variables into constants, eliminating variables, using linear relations, adding stronger assumptions and restrictions, and/or suppressing randomness. Enrichment involves just the opposite type of modification.

Robustness-Flexibility

The third area of special consideration previously not discussed is "robustness." This term is defined by Morris to mean:

> How sensitive is the model to changes in the assumptions which characterize it?[9]

Robustness also is defined as the measure of flexibility in a planned sequence of investment decisions by Gupta and Rosenhead.[10] The measure of robustness of a decision in the investment case is stated in terms of the numbers of "good" end-states for expected external conditions which remain as open options. An example of robustness reported by Gupta and Rosenhead is given for facility location in which the robustness-score is the ratio of the number of occurrences of a given potential location, among the set of good systems, to the number of good systems.

This was a useful concept for the LREPS model. One key problem in selecting the "best" set of staged decisions from among many good sets was the uncertainty of the environmental assumptions or inputs over time. An approach such as robustness aids in reducing the risk associated with decisions under uncertainty. For example, the location that appears most frequently in the final set of "good" systems facility network alternatives for various environmental and management inputs should be a lower risk (more flexible) decision than selecting a location that appears only in a few cases.

Summary

This chapter presented the basic design approach used in formulating the LREPS mathematical model. Before proceeding to the next three chapters, two points should be made concerning the method selected for reporting the model. The first point concerns the method of reporting the iterative design process which occurred during the actual development of the mathematical model.

Two extremes were possible for reporting this process. One extreme would be to present the model in its final form with specifications for output, input, and the transformations without reporting the alternatives and design efforts that were judged unacceptable for the final model. The second extreme would be to emphasize the iterative process by reporting all of the alternatives considered, including those rejected for the initial version of the LREPS model.

For this point a compromise position was taken. In the chapters that present the model the iterative process of design evolution is discussed for those activities and combinations of activities that are most critical to the model, appear to be of more general interest, and/or represent a possible contribution to the state of the art. For most activities, however, only the final selected alternative(s) are reported.

The second point is related to the order of presentation of the mathematical model. The activities could be reported generally either in the order in which the design process occurred or in the sequence of operation of the model. In the former case, the order of presentation at each level of the systems hierarchy would be outputs, inputs, and transformations. Thus, the order of presentation at the systems level would be Report Generator System, Supporting Data System, and Operating System.

In the latter case, reporting by sequence of operation, the order would be inputs, transformations, and outputs. The author made the decision to report the higher level systems, subsystems, etc., in the general order of model operation. Therefore, the order of presentation for the systems is Supporting Data System (Input), Operating System (Transformations), and Report Generator System (Output).

CHAPTER III--FOOTNOTE REFERENCES

[1]T. H. Naylor, *et al.*, *Computer Simulation Techniques* (New York: John Wiley & Sons, 1966).

[2]J. W. Forrester, *Industrial Dynamics* (Cambridge, Mass.: The M.I.T. Press, Massachusetts Institute of Technology, 1961).

[3]Holstein & Berry, "Work Flow Structure; An Analysis For Planning and Control," *Management Science*, XVI (February, 1970), 324-337.

[4]Van Court Hare, Jr., *Systems Analysis: A Diagnostic Approach* (New York: Harcourt, Brace & World, Inc., 1967), p. 157.

[5]*Ibid.*, p. 160.

[6]*Ibid.*, p. 200.

[7]*Ibid.*, p. 210.

[8]W. T. Morris, "On the Art of Modeling," *Management Science*, XIII (August, 1967), 715.

[9]*Ibid.*, p. 716.

[10]S. K. Gupta, and J. Rosenhead, "Robustness in Sequential Investment Decisions," *Management Science*, XV (October, 1968), 18-29.

CHAPTER IV

SUPPORTING DATA SYSTEM

Introduction

The Supporting Data System is the first stage of the three stage LREPS model. The primary functions of this system are to generate the supporting data analyses and the data input required for the Operating System. The supporting data analyses and data input are presented via a subset of activities for each of the operating subsystems of the model. Each activity analysis is defined in terms of the desired outputs, input requirements, and selected mathematical transformations. The major sections of this chapter and order of presentation within the chapter are:

1. The Demand and Environment Subsystem
2. The Operations Subsystem
3. The Measurement Subsystem
4. The Monitor and Control Subsystem

An important point to keep in mind is that the model was designed to be universal for any firm that fits the description of Figures 1.1, 1.2, and 1.3. The supporting data analyses become very critical in applying the model since it is via the supporting analyses that the input data and decision rules are prepared for the application of LREPS to different situations.

The subset of activities for each subsystem consisted of analyses and preparation of data that remain constant throughout the planning horizon and the introduction of exogenous change in the experimental factors. In addition, special subsets of activities were required for the Demand and Environment Subsystem to develop the demand input. In the first section of this chapter the outputs, inputs, and system transformations for each of the data support activities of the Demand and Environment Subsystem are developed in detail.

Demand and Environment

The Supporting Data System--Demand and Environment provided analysis of company data and environmental or external data. The output of the subset of support activities for the Demand and Environment Subsystem consisted of two major streams of data; the Order File (or demand) Generator and the input data for the Demand and Environment Subsystem. The subset of activities used to develop the desired outputs are presented in the Demand and Environment section in the following order:

1. Invoice Analysis
2. Customer Type Analysis
3. Product Item Analysis
4. Regional Analysis

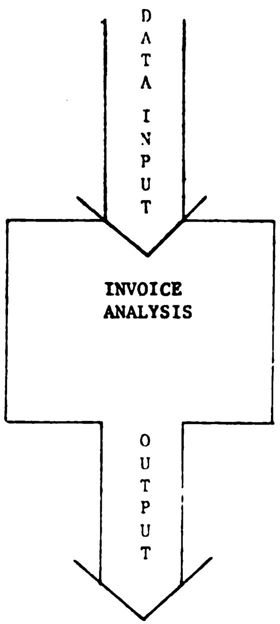
5. Customer Demand Generation
6. Basis for Demand Generation and Processing
7. Demand Unit Analysis
8. Order File Generator
9. Demand Allocation to Customers
10. Customer Sales Quota

Invoice Analysis

An analysis of the invoice file of the research subject firm being modeled was performed to study the relationship between the category or independent variables such as distribution center, class of customer, month of year, etc. versus dependent variables such as dollar per order, weight per order, sales per pound per order, invoice lines per order, cubic feet per order, and cases per order. Figure 4.1 presents the activity analysis diagram in terms of the outputs, inputs, and the transformations used to perform the Invoice Analysis. A flowchart of the Invoice Analysis is illustrated in Figure 4.2.

This analysis in some cases could be performed on the total invoice file, but for most firms that would utilize this model, the large number of invoices per year, for example over a hundred thousand, would make it impractical to perform analysis of all invoices for one year. Therefore, a sampling procedure was used to select the invoices to be analyzed.

Statistical inference was used to determine the number of invoices to be "pulled" from the invoice file



INPUTS

1. Invoice file
2. Independent variables
3. Dependent variables
4. Sampling error

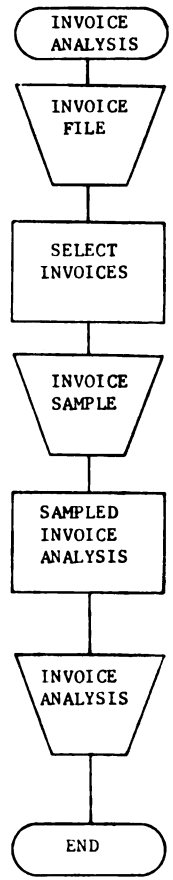
TRANSFORMATIONS

1. Design sampling procedure
2. Draw sample from invoice file
3. Use computer statistics routines

OUTPUTS

1. Average values for all dependent - independent variable relationships
2. Percentage breakdown by month for the dependent variables
3. Variances for all dependent - independent variable relationships

Figure 4.1--Activity Analysis: Invoice Analysis



Total Domestic Annual Invoice File from the firm for one year

Select a sample of invoices using stratified random sampling procedure

The invoice sample could be 100% of the file if total file is small

Perform invoice analysis to compute independent variable (DC, customer class, month, etc.) Statistics for each dependent variable ($/order, lbs./order, lines/order, cubic ft/ order, cases/order, etc.)

Invoice analysis used for several activities in the Data Support Subsystem

Figure 4.2—Flowchart: Invoice Analysis

of the firm. The sample size drawn was established based on Type I and Type II errors of 5 percent. The specified number of invoices, which approximated several thousand, were "pulled" using a random selection procedure within distribution center by month of the year for a 12 month period.

The statistics computed from the invoice data, using a set of computer statistic routines available at Michigan State University, were:

1. Average values for all dependent variables for all single and two way combinations of the independent variables

2. Percentage breakdown by month for the dependent variables

3. Variances for all dependent variables for all single and two way combinations of the independent variables.

Customer Type Analysis

This analysis was performed to select the classes of trade or types of customers to be included in the simulation model, for example retailers, wholesalers, and government. The annual sales data in conjunction with the firm's current list of customer classes, the total dollar sales volume, and the firm's invoice file was used to select the preliminary list of customer classes. Figure 4.3 presents the activity analysis diagram in terms of the outputs, inputs, and transformations required for the Customer Type Analysis.

The basis for the selection of the preliminary list was:

1. Select the customer classes desired or selected by the management of the firm

2. Select the customer type according to the amount of dollar sales or percent of total sales for each class

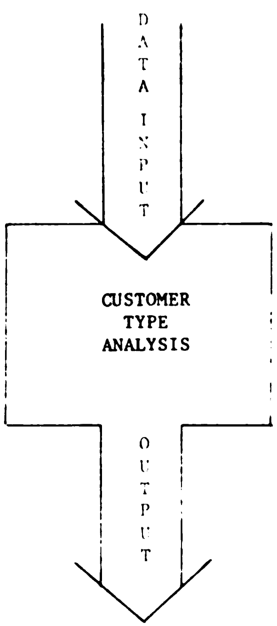
3. Select the customer type according to the number of orders or percent of total orders for each class of customer.

The final selection of classes of trade or customer types was made after evaluation of the sampled Invoice Analysis. A flowchart of the Customer Type Analysis as performed is illustrated in Figure 4.4.

For some applications, for example, firms which have a relatively small number of customer classes of trade or types, the above analysis will not be required. In these instances, all of the classes of trade could be included in the model.

Product Item Analysis

The purpose of this analysis was to select the products to be included in the simulation model. Most customer product companies have too large a number of products and/or stock keeping units (SKU) to include the entire product range in the model. On the other hand, including only a single or an average product could produce unreliable results and would limit testing of new products, different inventory policies, and different demand patterns for various products. Arbitrary or haphazard selection of



INPUTS

1. Annual sales data
2. List of customers
3. Number of invoices
4. Results of invoice analysis
5. Number of customer types to be selected and/or other criteria for selection

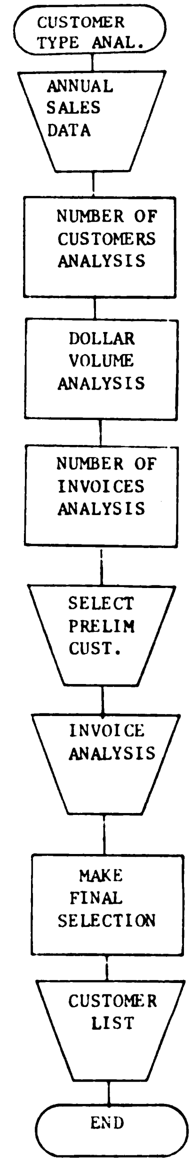
TRANSFORMATIONS

1. Determine different types customers
2. Determine rank based on volume each customer type
3. Determine rank based on number orders each customer type

OUTPUTS

1. Ranking of customer types
2. Selection of customer types

Figure 4.3--Activity Analysis: Customer Type Analysis



Annual sales data from the firm for one year

Perform analysis of the sales data to determine the number and classification of different customer types currently served

Perform analysis of the sales data to obtain the rank within the customer types by dollar and by percent of sales.

Perform analysis of the annual invoices to obtain the rank in terms of total units and/or number of invoices within each customer type

Based on the analyses select preliminary list of customer types and individual customers within each customer type

Use invoice analysis to obtain customer type ranking of sampled invoices.

Compare preliminary selection and Invoice Analysis to make final selection of customers.

Final list of customer types and major customers

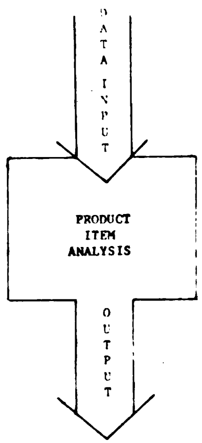
Figure 4.4—Flowchart: Customer Type Analysis

a few items could also produce unreliable results and would make it extremely difficult if not impossible to generalize regarding the total product range.

A logical criteria was, therefore, established for selection of a sample of products that could be used to represent the entire product range. The criteria considered for this model were based on a probability selection design which contributes to the adequacy of the sampled item to represent all the major system cost components.

The purpose of the Product Item Analysis was therefore to select the products to be tracked in the model. This was accomplished by using procedures referred to as Product Item Analysis-1, Product Item Analysis-2, and New Product Order Characteristics. Figure 4.5 presents the activity analysis diagram in terms of the outputs, inputs, and transformations of the Product Item Analysis. The flowchart for this set of activities is presented in Figure 4.6.

Product Item Analysis-1 was developed based on the selected customer types and the annual product sales data from the firm. This data was used to develop a list of the product items ranked according to sales. Product Item Analysis-2 was developed based on the sampled invoices. In this analysis the products were ranked according to the sales by product obtained from the summary data of the sampled invoices. New Product Order Characteristics were



INPUTS

1. Annual product sales data
2. Selected customer types
3. Sampled invoices analysis
4. New product order characteristics

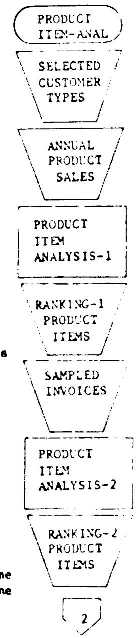
TRANSFORMATIONS

1. Product item analysis - 1 based on all products
2. Product item analysis - 2 based on sampled invoices
3. Analysis to select tracked products
4. Develop product detail

OUTPUTS

1. Product ranking-1 by sales volume
2. Product ranking-2 by sales volume
3. Tracked product list
4. Tracked product information

Figure 4.5--Activity Analysis: Product Item Analysis



Use the selected classes or types of customers from the Customer Types Analysis

Use the annual product sales data from the firm

Perform analysis to obtain the rank of items by sales dollar and/or other variables

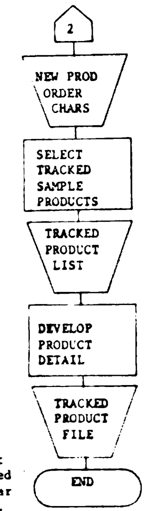
The ranking of product items by sales volume based on annual product sales

Use sampled invoices from the invoice analysis

Perform analysis of sampled invoices to obtain rank of product item sales for items on the sampled invoices. Not all items will appear unless sample is 100% of invoices.

The ranking of product items by sales volume based on the products in the sampled invoices

Figure 4.6--Flowchart: Product Item Analysis



Use new product or pseudo product order characteristics to test effect on system

Perform analysis of Product Ranking-1, Product Ranking-2, and new products to select preliminary list of products to be tracked

A list of tracked products.Other lists could be prepared to test significance of sample size, product characteristics, etc.

For selected tracked products develop product detail; i.e. average and standard deviation of cases/order, $/case, weight/case,cube/case,etc.

The tracked product information file

Figure 4.6—Continued

added based on information supplied from the management of the firm. A fixed number of new products can be added to the tracked product list.

The total number of tracked products for inventory control were selected considering the Product Item Analysis-1 and 2 and the new products that management desired to test in the model. The number of products selected was based on obtaining a statistically representative sample for each of several categories of products, such as the ABC categories and/or special products desired to be tracked by the management. For each of the products selected a product detail file was developed for use in the model.

In the procedure consideration was given to two major cost components--inventory and movement. The procedure was for a stratified random sample to be obtained from the designated product categories which would be representative of both the inventory costs and the movement costs for the category. A stratified sampling procedure was necessary since the distribution of descriptive parameters such as cost per item, dollar usage, and dollar density that are critical determinants of physical distribution cost components do not typically follow normal distribution curves. The distribution of dollar usage for example, is more likely to be 20 percent of the items accounting for 80 percent of the total dollar usage as is typical for ABC inventory analysis. The basis selected, therefore for the stratification design was dollar usage and weight density. Since inventory costs are sensitive to dollar usage and movement costs are likely to be sensitive to both measures this design should be representative of inventory and movement costs.

In the initial version of the model only dollar usage analysis was used, however, to develop the stratification categories. This approach was referred to as Option 1 for Product Item Analysis. The list of products from the sampled invoices of the firm were grouped into ABC categories based on dollar sales volume. A random sample of products was selected from each of the categories with the number of products selected in each being proportional to the strata size or variance in dollar usage. A fourth category, A1 consisted of products that were considered "Big Movers," for example the ten highest dollar volume products. The A1 category also could have included products which the management desired to be included as a tracked product such as relatively new products, and/or products that have low volume but high distribution costs.

The same procedure was applied to the ranking of product items obtained from the Product Item Analysis-2 which included all of the products of the firm, and was not limited to just the products on the sampled invoices. The list of products in the ABC categories obtained from this total list were checked against the same categories obtained from the product usage ranking of the sampled invoices. Discrepancies such as products with high usage in the total ranking which did not appear in the sampled invoices product list categories were reviewed and evaluated. A final selection of the tracked products was made after the discrepancies were resolved.

It is important to state at this point that different sets of tracked products could and should be tested to evaluate the sensitivity of the model to the particular sample of products used in the model. This sensitivity analysis should consider the importance of the size, categories, and specific products selected for the samples.[1] Additional samples could be obtained using the same general sampling procedure which, as presented above, was developed to obtain the initial list of tracked products.

In Option 2, the product list from the sampled invoices was grouped according to high, medium, and low weight density categories. After grouping the products into the two way classification scheme--dollar usage and density, random samples of products were drawn from each of the nine subgroups. For example, tracked products were selected randomly from each of the ABC categories for each of the density categories high, medium, and low. A separate A1 category is still included with products specifically selected by the management. The desirability of utilizing Option 2 will be determined via validation and calibration runs.

New products, as desired, can be entered up to the predetermined limit set in the model to reflect new or "pseudo" tracked products.

The result of the above analysis procedure was a list of selected "tracked" products which were used in the model to test inventory policies and to extrapolate up to the total product activity in each category.

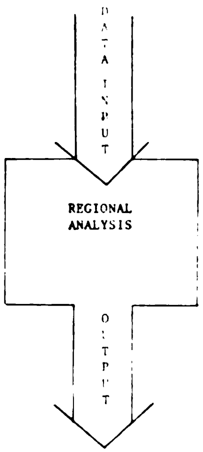
The next step in Product Item Analysis was to develop the product detail for each of the selected products. This included such information as the average and standard deviation of cases per order, dollars per case, weight per case, and cube per case. The result of the Product Item Analysis was the "tracked" product list, including possible new or "pseudo" products, and the information which was required input to the model.

The above discussion is also relevant for applications where the number of products is small enough to allow selection of all products as "tracked" products. For example, a company that has less than fifty significant products could include all of the products in the LREPS model.

<u>Regional Analysis</u>

The continental United States served as the geographical limit or system boundary of the model. As one aspect of modular construction, the decision was made to develop the multi-regional model presented in Figure 1.2, the system structure diagram. Figure 4.7 presents the activity analysis diagram in terms of the outputs, inputs, and transformations required for the Regional Analysis. The flowchart for this analysis is presented in Figure 4.8.

There were several reasons for developing a model with somewhat independent sections or regions. First, a multi-regional model allowed flexibility in testing different environmental inputs for each region such as different customer split percentages, different transportation rates, different "tracked" products, and use of different inventory policies. A second reason was that a multi-regional model could be developed such that one or more regions could be run essentially independent of the remaining regions to reduce the time and cost of computer processing. Thirdly, the option of running only one region would, in the future, allow the development of a higher level of enrichment or sophistication for a single region for a fixed constraining computer core and processing time limit. Fourth, a multi-regional model conceptually was logical for most national firms since they usually have manufacturing, distribution, and markets located throughout the continental United States. Frequently management control is centralized at the regional level.



INPUTS

1. Basis and purpose of regions
2. Sampled invoices
3. Selected customer types
4. Annual sales data

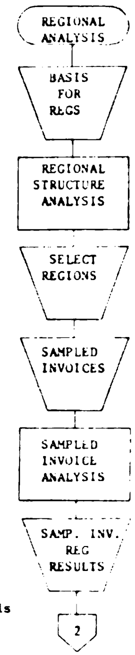
TRANSFORMATIONS

1. Analysis of regional structure
2. Regional invoice analysis
3. Annual invoice analysis
4. Develop all results by region

OUTPUTS

1. Selected regions
2. Sampled invoice regional analysis results
3. Annual invoice regional results
4. Information by region

Figure 4.7--Activity Analysis: Regional Analysis



Designate the basis and purpose of regional structure.

Perform analysis to determine structure of regions, i.e. ICC Rate Territories, service/cost territories, market areas, etc.

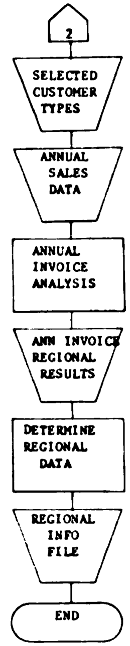
Select structure & number of regions.

Use the invoices from Invoice Analysis, Customer Type Analysis.

Perform invoice analysis by region.

Invoice analysis results by region.

Figure 4.8--Flowchart: Regional Analysis



Use the selected list of customer types from the Customer Types Analysis.

Use the annual sales data from the firm.

Perform analysis of all invoices of the firm for one year by region.

Regional invoice results.

Obtain all results by region.

Regional information file.

Figure 4.8 Continued

The purpose of the regions determined the basis for selection of the number of and boundaries of the regions. For example, if the purpose of regions is to enable more accurate and/or ease in updating of transportation rates the ICC rate territories could be used as regions. If the marketing information or introduction of new products in a market area is the primary purpose, the use of groups of Zip Codes, counties, states, or SMSA's, may be more logical. Finally, if the regions are to represent the level of operating control such as regional order processing, regional warehouses, or regional manufacturing locations, these locations should logically serve as the regions in the model for reporting and evaluating performance of the physical distribution system.

The primary basis for selecting the regions for the initial version of the LREPS model was management control. A region was defined as including the primary distribution center (PDC), a fixed list of potential remote distribution centers (RDC) assigned to the primary distribution center, and the demand units served by all of the distribution centers within the control of (assigned to) the primary distribution center. The exact boundary of each region shifts throughout the simulated planning horizon of the model as distribution centers are added and/or deleted to/from a region.

Given the basis for selection of the regions, the Regional Analysis developed the regional information and statistics similar to the domestic information. The annual sales data, sampled invoices and selected customer types were analyzed based on regional boundaries such as groups of Zip Sectional Centers, states, or counties. This model used groups of Zip Sectional Centers to define the four regional boundaries, which were established as the Eastern, Midwestern, Southwestern, and Western regions. The information from the sampled invoices was sorted and accumulated for each region.

The purpose of the Regional Analysis was to determine the number of and description of the regions for the model, both current and maximum number. The regional data was developed using annual sales data in conjunction with the annual Invoice Analysis to obtain annual regional results. The sampled Invoices Analysis was used to develop regional results based on sampled invoices. The selected customer types were also merged to determine number and rank of selected customer types for each region.

Customer Demand Generation

In a model that simulates physical distribution operations a specific demand function or set of demand activities was necessary to generate and allocate to the individual or group customer the demand for goods and services. The demand function expressed the demand in dollars or sales units for a stated period of time or by transaction for each demand unit. The quota or relative amount of the total demand to be allocated to each customer or demand unit and each distribution center also must be defined.

The development of the demand function thus required consideration of the following sets of activities:

1. Basis for Demand and Generation Processing
2. Demand Unit Analysis
3. Order File Generator
4. Demand Allocation to Customers
5. Customer Sales Quota.

The sections of the Demand and Environment section of the Supporting Data System develop the demand function activities in the order listed above.

Basis for Demand Generation & Processing

The alternatives considered to define the basic demand transaction included:

1. The individual order
2. Blocks of orders
3. Groups of order blocks
4. Demand for a fixed time interval

Preliminary analysis of the requirements of the LREPS model indicated that to test the effect of inventory policies the detail and variability of individual orders was essential. Defining the demand transaction as the aggregate demand for a fixed time interval such as a day or week did not appear to be suitable since the variability of individual orders would be lost.

Practical considerations, however, had to be evaluated in establishing the demand transaction and the batch processing time. The number of orders processed by a firm with consumer products is frequently in the range of hundreds of thousands per year or several million over a ten year planning horizon. Estimates indicated that generation by either a series of monte carlo techniques or direct input of all of the actual invoices for one year from a firm on a random selection basis would be impractical due to the computer input/output time required to run the model over the planning horizon. A compromise was therefore necessary to preserve the concept of individual orders, but to reduce input/output time and computer memory requirements.

The compromise based on preliminary test runs of LREPS involved establishing a matrix or file of randomly selected blocks of invoices from which a block of orders was "randomly pulled" to generate the demand for each time period. The number of orders summarized in each block was defined as the "Blocking Factor." The use of a Blocking Factor, of ten for example, directly reduced the data input time by approximately the same factor since each input of a block of orders contained a summary of ten orders. This concept is presented later in this chapter in more detail in the Order File Generator activity.

The ideal time period for demand generation and processing to obtain the details for inventory control is to generate individual orders and process each transaction as generated. Processing by transaction is impractical, however, when the number of orders reaches the magnitude previously stated as being possible in a consumer products firm. The problem of setting the interval for batch processing of the demand transactions is also considered briefly in the Supporting Data System-Operations. Based on preliminary test runs, the analysis indicated that a daily batch processing time should be used.

The requirements of the LREPS model also indicated that the demand transactions should contain product detail for each of the tracked products such as dollar per product, sales in weight per product, cases per product, lines per product, and cube per product.

Demand Unit Analysis

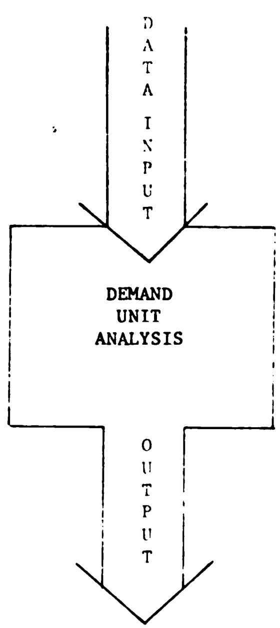
The Demand Unit Analysis defined the basis and structure of the customer and "Pseudo" customer for the LREPS model. The customer or demand unit generates the market demand for the goods and services provided by the physical distribution system.

In a large scale simulation model, the use of individual customers as the basic demand unit presents a problem if the number of customers becomes prohibitively large; for example, several thousand or greater, because of the data input and analysis, computer memory, and computer processing requirements. To be universal in terms of demand generation the model must therefore, be able to easily adapt to the use of an agglomerated demand unit. An analysis must therefore, be performed for each application of the model to determine the "best" or "most acceptable" demand unit structure. The selection and design of the demand unit structure is essential to generate simulated sales in each market area in the model. Figure 4.9 presents the activity analysis for the Demand Unit Analysis in terms of outputs, inputs, and transformations. The flowchart for this analysis is presented in Figure 4.10. The analysis to evaluate and select the alternative basic demand units was necessary prior to the design of the Demand and Environment Subsystem. The six different demand units considered ensure that the model could accept a wide range of demand unit structures. The demand units evaluated were:

1. Individual customers
2. County
3. Standard Metropolitan Statistical Area (SMSA)
4. Economic Trading Areas (ETA)
5. Zip Code
6. Grid (REA-Modified).

The above alternatives represent a cross-section of the possible demand unit structures that various firms might wish to consider. The model design allows the use of any one of these structures without major modification.

For the initial version of the model these alternative demand units were evaluated based on two categories



INPUTS

1. Demand units to be evaluated
2. Demand unit attributes (criteria)
3. Project considerations (criteria)
4. County structure
5. Zip code structure
6. ETA structure
7. SMSA structure
8. REA grid structure

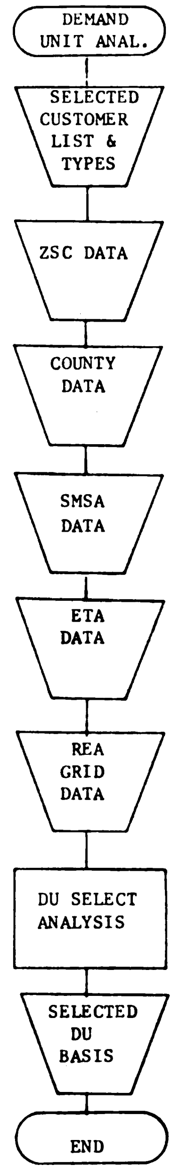
TRANSFORMATIONS

1. Evaluate county
2. Evaluate individual customer
3. Evaluate zip code
4. Evaluate ETA
5. Evaluate SMSA
6. Evaluate REA grid

OUTPUTS

1. Demand unit selection, option 1
2. Flexibility for selection for all others

Figure 4.9--Activity Analysis: Demand Unit Analysis



Use the selected list of customers and customer types from the Customer Types Analysis

Use Zip Section Center and Zip Code data

Use county data to evaluate county demand unit structure

Use Standard Metropolitan Statistical Area data

Use Economic Trading Area data

Use REA modified grid reference system data

Perform analysis of the alternative demand unit structures. Select the most appropriate for universal and existing application

The demand unit structure to be used in the initial model is the Zip Sectional Center

Figure 4.10--Flowchart: Demand Unit Analysis

of criteria: (1) demand unit attributes, and (2) specific project considerations. The demand unit attributes that were considered included:

1. Size of unit
2. Homogeneity
3. Stability
4. Flexibility
5. Geographic continuity
6. Availability of periodically updated data.

The specific project considerations included:

1. Availability of relevant data at the demand unit stage such as population and income
2. Appropriateness of demand unit for the markets served by the firm
3. Ability to determine distances from distribution center to demand unit
4. Compatibility of demand structure with management information system.

Each of the alternative demand unit structures was evaluated in terms of the advantages and disadvantages for its universal application in general and the existing application in particular.

Individual Customer.--The individual customer shipped to location is the most detailed demand unit considered in this project. One disadvantage of developing a demand unit structure based on individual customers is that for most applications the number of customers would be so large that it would be impractical to implement in the model. This factor alone eliminated further consideration of the individual customer demand unit structure. The individual customer could, however, be implemented for a reasonable number of customers ($\leq$400) with very little modification to the model.

County.--The county, which is an area established primarily with political considerations as basis, has the advantage that the information available, the census track, in the larger demand unit structures such as states, SMSA's, is also available at the county level. This provides a greater degree of control for the county structure. A county demand unit structure is sufficiently homogenous for many types of products, is mutually exclusive, fairly stable, and provides geographical continuity. A majority of firms could utilize the county as the basic demand unit. Thus, it is also a flexible demand unit structure. The county demand structure meets the majority of the specific project requirements relative to availability of relevant data, appropriateness, and compatibility with management information systems. Distances from the distribution center to the demand unit could be developed for a hub or key city in the county.

The primary disadvantage of the county demand unit structure is that it was developed on a political basis and thus, a county does not really represent a true trading area. The number of counties, approximately 3000, is also a disadvantage in terms of the practical problem of data collection, analysis, input preparation, computer memory, and processing time.

Standard Metropolitan Statistical Area.--The SMSA is defined as a county or group of continuous counties that contains at least one city of 50,000 inhabitants or more, or twin cities with a combined population of at least 50,000. The primary advantages of Standard Metropolitan Statistical Area (SMSA) as a demant unit structure is that it tends to be more self-contained than the individual county. The number of demand units required using SMSA's is only about 300 which is approximately 1/10 of the total number of counties that would have to be used in the county demand structure. The SMSA structure still accounts for 70 percent of the consumer sales and other independent variables that can be used to estimate future product demand. Thus, the SMSA demand unit structure requires less data collection, preparation, and computer processing than the county demand unit structure with little reduction in representation of the total domestic market. In addition, a large amount of the SMSA data is available on magnetic tape and in card decks for immediate use.

The major limitations of the SMSA demand unit structure is that in large metropolitan areas the information is too aggregative to facilitate control within each of the units. The total set of SMSA units also does not result in a control structure that is geographically continuous. In addition, SMSA's are not stable as evidenced by the fact that over a 10-year period the area covered changed as a result of growth patterns. The SMSA demand unit structure did meet the majority of specific project requirements relative to availability of relevant data, appropriateness, and compatibility with management information systems. Distance is determined from the distribution center to the hub city or key city as for the county demand unit structure.

Economic Trading Area.--An Economic Trading Area (ETA) was also considered for use in this project. An ETA was defined as a county or group of counties as follows:

1. Each SMSA is an ETA
2. Each county where annual sales of the firm exceed a minimum amount (M1) which is not a part of an SMSA and is an ETA.

The total ETA demand unit structure also included the assignment of each of the remaining counties with greater than a minimum sales level (M2) set less than sales level (M1) above to an ETA.

The major advantage of the ETA demand unit structure is that it can be developed specifically to suit a firm or division of a firm. The primary limitations are that units are relatively large in area. The ETA demand unit structure is also relatively inflexible which therefore reduces the universality of the structure as far as use by firms in general or different divisions of the same firm.

Zip Code.--The Zip Code demand unit structure is based on the Post Office Department Zip Code Sectional

Center system which divides the country into 552 areas with about 314 multicoded cities. The Post Office Department describes each area as including:

1. A hub city that is the national center for local transportation

2. About 40 to 75 post offices in the area

3. The most remote post office to be no more than two to three hours away by normal driving time.

The Zip Code as a demand unit structure has the key advantage of flexibility. Initially, this unit could be employed on a sectional center basis (561 units) and later could be expanded to up to 20,000 units by employing the entire Zip Code where desired. The Zip Code demand unit structure combines the advantages of the SMSA and county demand unit structures. In addition, present plans of the U. S. Government are to switch from SMSA to Zip Codes for collection and analysis of data beginning with the 1970 census. The Internal Revenue Service currently provides income data only on a Zip Code basis. The information potential therefore appears to be a definite advantage for using Zip Code demand unit structure. Other important attributes of the Zip Code demand unit structure included the fact that it is relatively homogenous and stable. The Zip Code, especially the Zip Sectional Center, is also generally representative of existing trading areas for many firms. Since most if not all companies have customer Zip Codes in their data file the use of this demand unit structure should not require major modification of management information systems.

The primary limitations of the Zip Code Sectional Center are similar to those of the SMSA in that the large size of the units results in aggregative information. However, this problem can be overcome by use of the total zip code areas or numbers contained within Zip Sectional Center areas. This ability to increase the number of units cannot be easily accomplished with the SMSA unit structure. A second disadvantage, which is only temporary, is that less data is available currently by Zip Code than by county and/or SMSA.

REA Grid.--Under the grid system, REA modified, the United States is divided into blocks one degree square. Each block is further divided into 256 smaller squares, each containing an area of approximately 41 square miles. The grid system has more advantages than the previously discussed demand unit structures relative to the attributes. The grid unit is the smallest, most homogenous, completely stable, most flexible, mutually exclusive, and geographically continuous. Further, under this system grid blocks may be aggregated to conform closely to state boundaries, counties, or SMSA. Even with this aggregation all traditionally defined marketing and production information is still available in the records, while homogeneity through the block system is maintained.

The primary limitation with the use of a grid system is that it cannot in most cases be utilized effectively because much of the relevant information is not available for the small grid units. Thus it could not be considered a feasible alternative without major developmental effort and expense.

After the six alternative demand unit structures were considered and evaluated, the first choice was Zip Code and second choice SMSA. The Zip Code was selected because of the feasible alternatives considered, it is: (1) the most flexible, (2) geographically continuous whereas SMSA is not, and (3) conversion to Zip Code is planned for the 1970 census track information collected by the U. S. Government which will provide much more detail at the Zip Code than is currently available even at the county level.

Although the model uses Zip Code, the activities developed throughout the model are sufficiently universal and modular to enable use of any one of the six demand unit structures considered with the same LREPS model.

Order File Generator

The basic purpose of this set of activities, the Order File Generator, was to prepare a routine to generate the stream of daily orders that simulate the demand allocated to each distribution center in-solution and each demand unit by the Demand and Environment Subsystem.

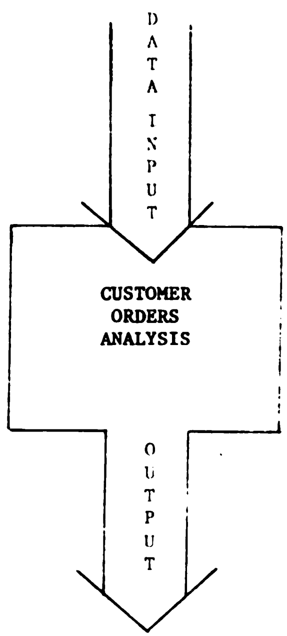
Development of the Order File Generator is presented as two analyses.

First, the Customers Orders Analysis develops the subset of activities required to construct an Order File Generator that has the capability of generating a separate stream of orders for up to three major customer types. In the initial LREPS version this included two existing and one "Pseudo" or potential new customer type. The assumption made in presenting the first analysis is that the pseudo orders were available and thus were treated as customer type three.

The second analysis, Pseudo Order File, presents the procedure used to develop the artificial or pseudo orders used in the Customer Orders Analysis.

Customer Orders Analysis.--The purpose of the Customers Order's Analysis was to develop the subset of activities that would generate demand based on existing customer order characteristics. Figure 4.11 illustrates the activity analysis diagram in terms of the outputs, inputs, and transformations necessary to construct the Order File Generator. The flowchart is presented in Figure 4.12.

Although the demand unit structure selected for the initial version of LREPS was the Zip Sectional Center the Customer Order's Analysis is general enough that any one of the demand unit structures previously reviewed would be readily adaptable to the Order File Generator. The tracked product information consists of the list of



INPUTS

1. Sampled invoices
2. Tracked product information, both existing and pseudo
3. Number of orders processed per year and by distribution center
4. Pseudo order file

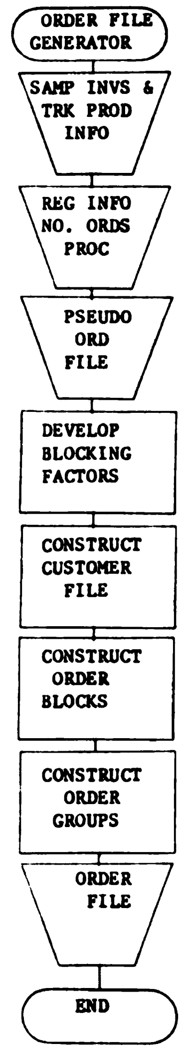
TRANSFORMATIONS

1. Develop customer and group block factors
2. Develop customer order files
3. Construct order blocks
4. Construct order groups

OUTPUTS

1. Order file generator, for actual and pseudo orders

Figure 4.11--Activity Analysis: Order File Generator



Sample of Existing Invoices. Tracked product information such as; average and standard deviation per order of cases, lines, dollars, etc.

Regional information such as; percentage of sales for each customer type. Number of orders processed per year per DC.

File of Pseudo orders prepared using the Pseudo Order File Analysis.

Develop Blocking Factors based on computer I/O constraints and maintaining variability in order stream.

Construct order file or matrix for each customer type.

Construct order blocks for each customer type by randomly selecting orders from customer's file. Develop line item information from tracked products and generalize for total order information.

Construct order groups by randomly selecting order blocks.

Order File Generator with groups of blocks of orders for three customer types.

Figure 4.12--Flowchart: Order File Generator

products selected in the Product Item Analysis and product information for each selected product such as the average and standard deviation of the cases per order, the dollars sales per case, the weight in pounds per case, and the cube per case. This input information is required for the existing products and the "pseudo" or new products that are to be included in the model.

The regional information required for the Customer Order's Analysis is primarily related to the percentage of sales assumed for each customer type for each region. In the LREPS model three customer types were selected, two existing and a potential or new type customer type referred to as the "pseudo" customers. The customer split percentage of sales per customer type per region can be modified in the model over the planning horizon. Thus, the effect of shifts between existing customer types and/or "pseudo" customers can be tested.

The initial procedure for developing the Order File Generator included the construction of an order matrix of individual orders which was then stored in the computer. The first step in constructing the order matrix consisted of pulling an order from the sampled invoices for the customer type order being developed. Each line entry on the randomly selected invoice was compared to the tracked product list. The line items or products that matched the tracked product list were placed as line item entries on a newly created order-the tracked product single-order summary. The line entry for the tracked product included dollars, weight, cube, and cases for the product. In addition to creating a line entry for the tracked product the above information was accumulated in the order summary totals such as total order dollars, total order weight, total order cube, total order cases, and total order lines.

Each line item from the sampled invoice that is not a tracked product is placed on the newly created order only in the order summary totals to reflect the totals of the original order. This process is continued until each line item on the selected sampled invoice has been processed. The process is continued by selecting randomly the next additional sampled invoice to create the next tracked product single-order summary until all of the invoices obtained via the Invoice Analysis have been processed for each customer type. The results of the above procedure was an order matrix for each customer type with each order in the given customer matrix consisting of a series of tracked product single-order summaries.

As stated previously the purpose of the order matrix is to enable the generation of the daily sales or demand for each distribution center and demand unit assigned to the distribution center. Two major constraints greatly influenced the design of the procedure for generating the daily demand: (1) the limit of computer core available, and (2) the limit set by the model design team for total processing time of the operational LREPS model.

Based on preliminary computer test runs the total number of sample invoices was too large to consider storage in the computer of all of the tracked product single-order summaries as a feasible alternative for the initial version.

Likewise, based on initial test runs, the input time required to read in all of the tracked product single-order summaries appeared to be impractical. The input time for several million orders could require several hours, which definitely exceeds the initial design criteria set by the design team.

At this point in the design evolution process it became apparent that some form of simplification would be required to reduce the computer input time and/or the computer core requirements for introducing tracked order information while still retaining the ability of the input to reflect the level of detail and variability of individual orders. After additional tests of several approaches two simplification techniques were selected to reduce core requirements and input processing time.

First, customer blocking factors were developed to accumulate individual orders into blocks of orders or summary orders to reduce the number of input operations. The customer blocking factor is defined as the number of tracked product single-orders accumulated into one tracked product multi-order summary. The use of a blocking factor, for example of ten, means that in the procedure for developing the tracked product single-order summary additional invoices are selected randomly and the line items are accumulated as tracked products and/or as summary totals until the number of invoices accumulated is equal to the customer type blocking factor. The result is a tracked product multi-order summary that contains ten summarized single orders.

The development of summary orders using customer blocking factors for each customer type represented a compromise, since the computer core requirements are greater than reading in each invoice individually, but less than storing all of the sampled invoices. Likewise, the input processing time for generating demand via blocks of orders is less than reading in each invoice, but greater than storing all of the sampled invoices.

Domestic and/or regional information provided the basis to develop the value of the blocking factors for the customer types. The considerations made in establishing the factors included:

1. Set the maximum blocking factor to obtain the maximum reduction in input time by reducing the number of input operations
2. Set the minimum blocking factor to maintain the maximum detail and variability of the individual orders
3. A review of the average number of orders processed by each distribution center
4. A review of the average order size based on the actual data.

The second simplification became necessary when further test runs of the input processing time indicated that the model would still exceed the desired processing time limit set as the design criteria.

Further reduction in input processing time could have been obtained by increasing the magnitude of the customer blocking factor. Since this resulted in further loss of variability of individual order detail through greater aggregation this alternative was rejected.

The second method chosen for simplification was to allocate additional core for storage of several blocks of customer tracked product multi-order summaries, referred to as a group of blocks of orders. These groups, constructed off-line from the main computer model, have the effect of reducing the input time by reading into the model a larger number of orders via the groups of order blocks with each input operation. Fewer input operations are required to read in the demand for a fixed sales quota per distribution center.

The procedure in general consisted of randomly selecting subsets of blocks of tracked product multi-order summaries for a given customer type. One subset of blocks for each customer together form a group of blocks. Thus a group consists of orders for each customer type.

The compromise between the additional reduction factor achieved in input processing time versus the additional amount of computer core required to store the group information provided the basis for selection of the total number of blocks per group, the group blocking factor. Analysis indicated that a group factor of approximately ten would be a reasonable compromise. Thus each group would be constructed with a total of ten blocks of tracked product multi-order summaries.

The relative average demand or customer split percentage by customer type determined the basis for selecting the percentage of the ten blocks which would be selected from each customer type order matrix. Assume that the sales split by customer type over a planning horizon of ten years will be as shown in Table 4.1.

Based on the data the groups should logically be constructed with the relative number of blocks changing over the period of the planning horizon. For practical reasons, however, related to computer processing the initial version maintained a fixed number of customer blocks per customer type for each group at or near the average percentage of sales per customer type over the planning horizon. Thus, under the above assumption that customer type 1 accounts for an average of 40 percent of the sales, customer type 2 accounts for an average of 50 percent and the "pseudo" customer accounts for the remaining 10 percent of sales over the planning horizon with a group blocking factor of ten the group would contain four blocks of orders in the customer type 1 section, five blocks of orders in the customer type 2 section, and one block in the "pseudo" section.

The logic of selecting the relative number of blocks for each customer section based on the relative sales volume of each customer type was to keep the probability

TABLE 4.1.--Customer Split for the Planning Horizon.

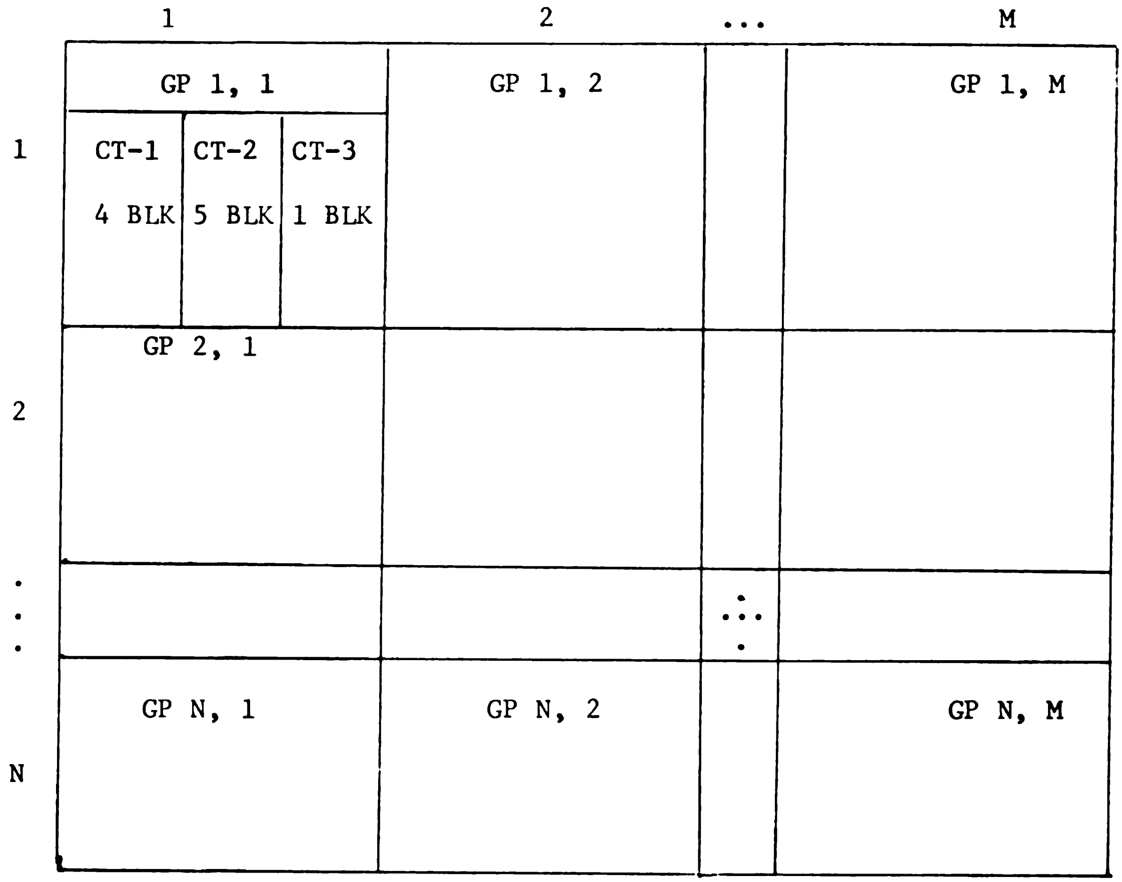
Year of Planning Horizon	Customer Type 1	Customer Type 2	(Pseudo) Customer Type 3
Year 1	50	50	0
Year 2	50	50	0
Year 3	50	50	0
Year 4	45	50	5
Year 5	45	50	5
Year 6	40	50	10
Year 7	40	50	10
Year 8	30	50	20
Year 9	30	50	20
Year 10	30	50	20
Approximate Average	40%	50%	10%

of multiple selection of the same block of orders for generating daily demand as low as practical.

Figure 4.13 presents the Order File Generator to illustrate the group and block of orders concept, and the level of product information contained in a tracked product multi-order summary.

Pseudo Order File.--The purpose of the pseudo customer analysis was to provide a way for the model to generate orders with different characteristics from the existing customer sample of orders. Figure 4.14 presents the activity analysis in terms of the outputs, inputs, and transformations used in developing the Pseudo Order File. The pseudo orders used to construct the file were developed by a series of random processes. The flowchart for the development of the Pseudo Order File is presented in Figure 4.15.

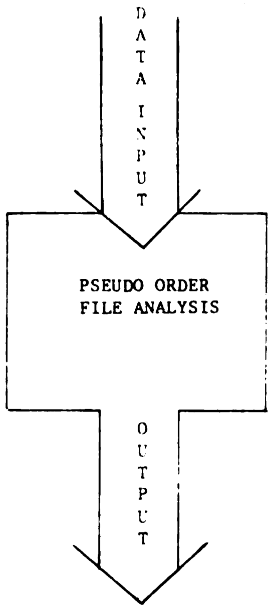
First the number of lines for the pseudo order being constructed was generated using a normal distribution with average and standard deviation based on the sampled invoice results. A new assumed average could also be set by management to test the effect of various order characteristics. Next, for each line a product was selected on a random basis from the list of tracked products which included existing and pseudo products. The probability distribution was developed by establishing the percent of orders on which the tracked product appeared in the invoice sample. For the pseudo products the percentage must be set by management.



ORDER FILE GENERATOR(1)

This Order File Generator was developed for average customer type (CT) split of CT 1=40%; CT2=50% and CT3=10%. Each group, GP, has 10 blocks, and each block 10 invoices. Therefore, in GP (1,1) there would be the equivalent of 40 invoices from CT 1, 50 from CT 2, and 10 from CT 3 (the pseudo).

Figure 4.13--Order File Generator



INPUTS

1. Product detail
2. Order statistics for each tracked product
3. Tracked product list
4. Number of time each tracked product appeared on sample invoices

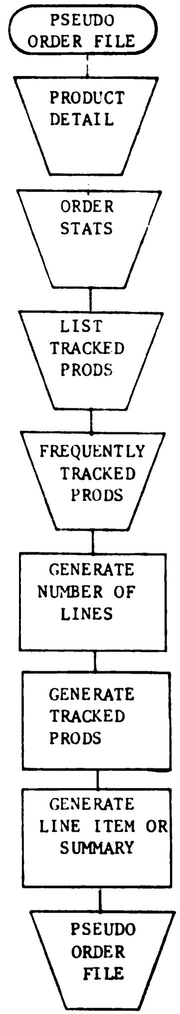
TRANSFORMATIONS

1. Determine number of lines for pseudo order
2. Generate tracked products for pseudo order
3. Generate selected products as line item or summary
4. Develop line item and summary information

OUTPUTS

1. Pseudo orders for pseudo order portion of order file generator

Figure 4.14--Activity Analysis: Pseudo Order File



Tracked product detail per order such as; cases, lines, dollars, weight, etc.

Pseudo order statistics from invoice analysis or set by management such as;' the average number of lines per order

List of tracked products existing and/ or pseudo

Percent of orders on which each tracked product appeared

Generate random number to determine the number of lines for each Pseudo order

Generate a random number to select the tracked product for each line

Generate a random number to determine if tracked product is line item or only summary

Pseudo Order File for customer order's analysis

Figure 4.15--Flowchart: Pseudo Order File

The third step required a random process to determine whether the product information was to be stored only as summary information or as both summary information and as line item information on the pseudo order. The discrete distribution used was based on the percent of total products in the category of the selected product included in that category for the tracked products. The conditional probability was developed as follows:

PBLNTM(ITP,IC) = n(IC)/N(IC)

where:

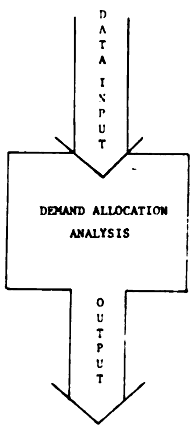
PBLNTM(ITP,IC)	= Conditional probability that given product, ITP, is selected it will appear as a line item entry on the pseudo order being constructed
n(IC)	= The number of tracked products in the product category, IC
N(IC)	= The number of products in the category, IC
IC	= The product category: A1, A, B, or C of product, ITP.

The final step required the development of the summary and line item information for the pseudo orders. For the summary this included total dollars, total weight, total cube, total cases, and total lines for pseudo order. For the line entry the dollars, weight, cube, cases, etc. were entered for the product based on averages developed and/or assumed for each tracked product, both existing and pseudo.

Demand Allocation to Customers

This set of activities developed the transformations for allocation of demand to the customer demand units. The analysis required (1) development of relative demand for each demand unit, and (2) development of relative demand for each distribution center. Figure 4.16 presents the activity analysis in terms of outputs, inputs, and transformations established for demand allocation. The flowchart is presented in Figure 4.17.

Relative Demand Per DU.--The relative demand for each demand unit required an analysis of independent variables that appeared to have a high correlation with annual demand. The list of independent variables tested via correlation analysis included but was not limited to effective buying power, personal income, retail sales, population, and number of households. Using the annual sales data for a sample of the demand units a multiple correlation across space was performed to select the three independent variables with the highest correlation against sales. The next step was to determine the growth rates or projections of the selected independent variables for each demand unit. An attempt was made to develop regression equations to determine the projections of the independent variables, but this was impractical since sufficient time series data did not exist for the independent variables selected. Therefore, forecasts were developed based on compound rates of growth for each independent variable.



INPUTS

1. List independent variables
2. Annual sales data from firm
3. Data for each independent variable by zip code

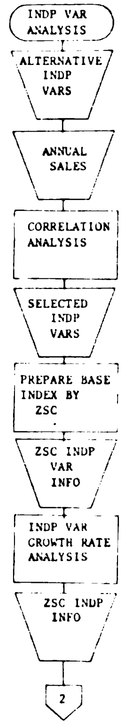
TRANSFORMATIONS

1. Correlation analysis of variables against sales
2. Prepare base index by ZSC
3. Project each independent variable
4. Construct ZSC data generator
5. Select the list of ZSC's to be used
6. Agglomerate ZSC's

OUTPUTS

1. List of independent variables selected for the model
2. Independent variable information for each ZSC for the base year
3. List of selected ZSC's
4. Bases for demand for each DU for the planning horizon

Figure 4.16--Activity Analysis: Demand Allocation



List of independent variables for evaluation.

Annual sales data from the firm.

Perform correlation analysis of independent variables;i.e. population, personal income, effective buying power, retail sales, etc. against firm sales.

A list of the independent variables selected for the model.

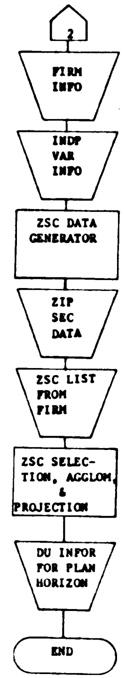
Prepare the base year data for the selected independent variables by the DU's, the ZSC's. For example: estimate population for the year 1969.

The independent variable information for each ZSC for the base year.

Obtain the projection of each of the independent variables selected using weighted average growth rates for states and/or groups of states.

The appropriate growth rate for each selected independent variable.

Figure 4.17--Flowchart: Demand Allocation



Information from firm; i.e. total sales and sales by customer type.

Independent variable information by Zip Code; i.e. population, retail sales, buying power, etc.

Generate data by Zip Sectional Center based on aggregating the Zip Codes

Data by Zip Code converted to data by Zip Sectional Center

Select the list of final ZSC's to be used from the firm.

Select the ZSC that are to remain as individual demand units. Agglomerate the remaining ZSC's to the selected ZSC's. Project the independent variables using the selected growth rates.

The final result is the basis for demand to be allocated to each demand unit for each year of the planning horizon.

Figure 4.17--continued

Using forecasts made by the Bureau of Census and supplied by the firm, growth rates for each independent variable were developed according to various geographical breakdowns. Three regional approaches were considered to develop the average compound growth rates:

1. The firm's existing service areas
2. Grouping of Zip Sectional Centers
3. Individual or groups of states.

A comparison of the state growth rates with the rates of growth for the firm's service areas indicated that the service areas encompassed states of widely varying compound growth rates. Such service area classification would result in a distortion of the independent variable over a ten year planning horizon. Similarly, the zip groupings combined states of widely varying rates of growth. The approach chosen was that of grouping states with similar rates of independent variable growth rate. Four groupings of states were selected and a weighted average growth rate was computed for each grouping.

The selection of Zip Sectional Center as the demand unit structure presented the problem of developing the projections by demand unit of the independent variables over the 10 year planning horizon. Growth rate information was not available by Zip Sectional Center at this time. Therefore, growth rates developed based on the states were applied to Zip Sectional Centers within the geographical limits of the states. As additional census data is collected the growth rates can be developed directly by Zip Code. The data does exist now by Zip Code from commercial sources, but the cost to purchase each year of data by Zip Code was prohibitive for this project. The appropriate growth rate was then applied to the base level (1969) of each independent variable to develop the estimated projection for each demand unit for each future year of the planning horizon.

The equation for calculating the future values of the independent variables is of the form:

$$X(IDU,Y) = X(IDU,O) * (1+R(IDU))^{Y-1}$$

where:

$X(IDU,Y)$ = The independent variable level for the Yth year for demand unit, IDU

Y = Year of the planning horizon (1, ..., 10)

$X(IDU,O)$ = The base value (1969) for the demand unit that was read in

$R(IDU)$ = The rate of change for the demand unit, IDC.

The projection of the independent variables used in conjunction with the list of ZSC's, the data by Zip Code from the firm, and the independent variable information by Zip Code provided the necessary input to develop the total ZSC data file. An activity titled the ZSC Data Generator accomplished this by merging and accumulating the Zip Code area data into the ZSC areas.

The ZSC Data Generator merged the following inputs:

1. Total firm sales and sales by each customer type

2. A data deck containing Zip Sectional Center number (or range of numbers), Zip Code agglomeration, Zip Code independent variable information, identification of domestic or non-domestic Zip Codes, number of customers in the Zip Code area, and the number of competitors in the Zip Code area

3. A deck containing Zip Sectional Center number, the firm's annual sales in dollars and pounds by Zip Code.

The analysis included a merge run in which the data by Zip Code was accumulated into all Zip Sectional Centers. The percent dollar sales for each ZSC and the percent for each customer type was calculated relative to the total firm sales. This analysis produced the data file for each Zip Sectional Center.

There were certain problems associated with using the ZSC's in the large metropolitan areas such as; Chicago, New York, Los Angeles. For example, ZSC 600-606 inclusive comprises the Chicago 3-digit Zip Code Sectional Center area.

The southern half is not meaningful because post offices in each half are assigned codes in alphabetical order, so that there is no geographic line dividing the two groups of offices. There are also difficulties in gathering accurate marketing data for Evanston (602), Oak Park (603), and Chicago proper (606) since the areas served by these post offices do not necessarily correspond with the limits of these cities.

Hence, most users of zip marketing data will find it more convenient to consider the entire Chicago area (600-606) as a unit, and treat other major metropolitan areas similarly. An agglomeration of the 561 ZSC's was then necessary to merge the ZSC's in major metropolitan areas into one ZSC. The basis of the agglomeration was taken from Rand McNally ratings on ZSC's in terms of how well they actually represent true trading areas.[2] The codes used allowed the 560 sectional areas to be reduced to just under 400 agglomerated Zip Sectional Center demand units.

The ZSC data, the selected independent variable growth rates and the basis for selection of the desired number and list of ZSC's provided the information necessary to select the ZSC's, agglomerate other ZSC's to the selected ZSC list, and project the independent variables for the agglomerated ZSC's. The output of this analysis provided the basis to develop the relative demand for each demand unit for each year of the total planning horizon.

Relative Demand to DC.--The relative demand to the distribution centers was determined using a weighted index. This weighted index based on the independent variables was determined as follows:

$$\text{WTDINDX}(Y,\text{IDU}) = \sum_{I}^{n} \frac{r^2(I)}{\sum_{\text{IDU}}^{m} r^2(I)} * \frac{X(Y,I,\text{IDU})}{\sum_{\text{IDU}}^{m} X(Y,I,\text{IDU})} * 100$$

where:

WTDINDX(Y,IDU)	=	Percent of total sales for period, ITP allocated to DU,IDU
r^2(I)	=	Correlation analysis coefficient of independent variable, I against sales for the year
X(I,IDU,Y)	=	Value of independent variable, I for demand unit, IDU for time period, Y
I	=	Independent variable identification number
IDU	=	Identification number of the DU
Y	=	Time period in years.

The demand allocated to a demand unit was thus a function of the level of the Ith independent variable within the demand unit and the correlation coefficient of the Ith variable against sales. The relative demand to a DC was determined by summing the weighted indices for all DU's assigned to the in-solution DC.

Customer Sales Quota

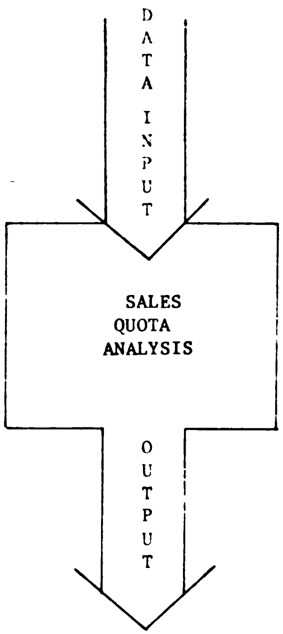
The purpose of domestic forecast analysis was to develop the daily forecast basis which was used in the D&E to generate daily sales quota for each distribution center. The options considered in developing forecast data for the model included:

1. Developing a forecast method for the firm such as exponential smoothing
2. Using the existing forecasting model already in existence in the firm incorporating it in the simulation model
3. Using output of the firms existing forecast model to establish the annual forecast exogenous to the LREPS model.

The decision was made to use the research subject firm's existing forecasting model. The reason was that most large firms, already have an existing sophisticated computer forecasting model and/or "grass roots" forecasting model where salesmen forecast for each territory then summarize and modify at region, district, domestic, etc. Therefore, the model was designed to accept, exogenously, the total annual forecasts in dollars for each of the years of the planning horizon. The M&C Subsystem presents a method of modifying this forecast to indicate the effect of high service (or low service) by increasing (decreasing) the forecast.

This analysis developed the daily forecast factor used in conjunction with the Weighted Indices to establish the daily sales level for each in-solution DC. Figure 4.18 presents the activity analysis in terms of the outputs, inputs, and transformations required for development of the sales quota. Figure 4.19 presents the sequence of development in flowchart format.

The firms daily sales history is analyzed to determine the variability of sales for the days of the week. This is accomplished in the Analysis of Daily Sales/Week Activity. A Monthly Sales Analysis is also conducted using the sampled invoices to determine the variability of sales by month. Option 1 for this activity involved the assumption that the variability within the days of the week and by month is not critical for a long range



INPUTS

1. Annual forecasts over planning horizon
2. Sampled invoice analysis results
3. Daily & monthly sales history

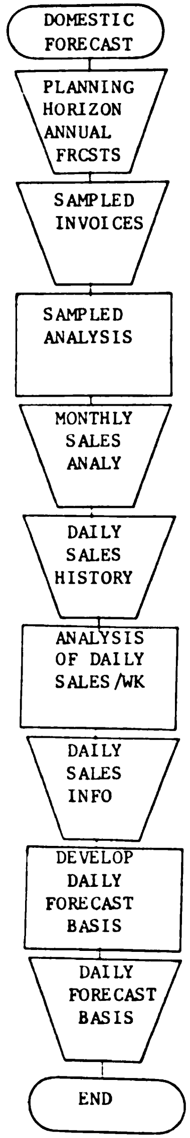
TRANSFORMATIONS

1. Monthly sales analysis
2. Daily sales analysis
3. Development of daily forecast basis

OUTPUTS

1. Daily sales forecast factor
2. Monthly sales forecast factor

Figure 4.18--Activity Analysis: Customer Sales Quota



Annual forecasts for past years

Sampled invoices from firm's invoice file

From Sampled Invoice Analysis generate the monthly and daily sales statistics

Monthly sales statistics

Daily sales history

Comparison of relative sales by day of week, average and standard deviation

Daily sales statistics

Develop Daily Forecast Basis

Daily Forecast Basis

Figure 4.19—Flowchart: Customer Sales Quota

planning model such as LREPS. For the firm used in this project the variability was low and therefore the assumptions presented no problem. Option 2, for the sales quota which would not require any major revisions would include an activity to generate a day of the week factor and monthly variability factor to correct for seasonal and weekly buying pattern variability. The daily factor is used in conjunction with the Weighted Index in the D&E to determine the daily sales by DC.

Summary

The completion of the above activities was required to provide the supporting data analysis and to prepare the data for the Operating System--Demand and Environment Subsystem. The next major section of the Supporting Data System presents the Operations Subsystem analysis and data preparation activities.

Operations

The Supporting Data System-Operations provided the analysis and data preparation for the basic components of the physical distribution system, which as previously stated, are transportation, unitization, communications, inventory, and location. In addition special supporting analyses were required for the manufacturing control center to distribution center (MCC-DC).

Transportation Component

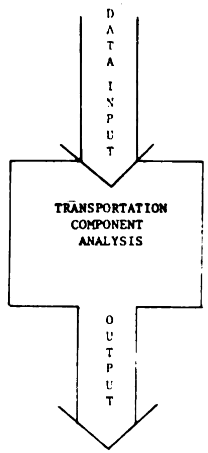
For the inbound and outbound transportation components in the Supporting Data System--Operations the following analyses were required:

1. Development of transit times
2. Establishment of shipping policies
3. Development of shipment statistics
4. Development weight break

Transit Times.--The development of transit times for the outbound and inbound transportation links required consideration of the modes of transportation, and reliability or consistence of the transportation. The location and number of demand units relative to the distribution center was considered for outbound transit times and the relative location of manufacturing control centers for inbound. Figure 4.20 illustrates the activity analysis in terms of the outputs, inputs, and transformations required for the transportation activities. Figure 4.21 presents the flowchart for the transportation component analysis.

The shipment modes considered for each DC-DU link of the outbound transportation network were primarily truck and rail. In some cases air freight was also evaluated for the universality aspect of the model.

Preliminary analysis indicated that truck should be the normal mode for outbound transportation, whereas rail should be the normal mode for inbound shipments. Air cargo was included as a possible mode for direct consolidated



INPUTS

1. Distance between DU-DC and MCC-DC
2. Conversion for spherical to road miles
3. Feasible modes of transportation
4. List of possible shipping policies
5. Shipment data
6. Carrier data
7. Number of DU-DC and MCC-DC links

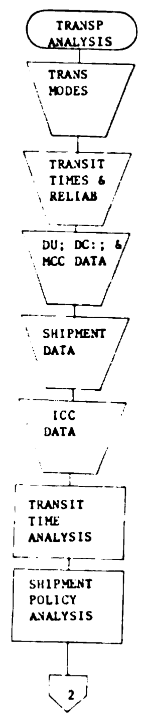
TRANSFORMATIONS

1. Transit time analysis
2. Shipping policy analysis
3. Shipment statistical analysis

OUTPUTS

1. Average and variability of transit times outbound
2. Average and variability of transit times inbound
3. Shipping policy(s) outbound
4. Shipping policy(s) inbound
5. Shipment statistics outbound
6. Shipment statistics inbound

Figure 4.20—Activity Analysis: Transportation Component



Transportation modes; truck, rail, air

Transit times and reliability from carrier and firm operating reports

Number of Dus, DCs, MCCs, DU-DC links; DC-MCC links. Identification and distances

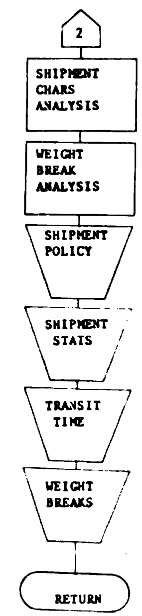
Shipment statistics from firm such as; average and standard deviation of shipment size, shipment policy

ICC data to determine the weight breaks

Transit time analysis to develop average and variability of transit times outbound and inbound

Shipment policy analysis to determine outbound and inbound transportation policies

Figure 4.21--Flowchart: Transportation Component



Shipment characteristics analysis to develop shipment size statistics

Weight break analysis to determine the weight breaks for inbound and outbound transportation

Selected shipment policy(s) for inbound and outbound transportation

Shipment statistics for shipment size, average and deviation, i.e. cases, lines, weight, dollars, etc.

Transit times for inbound and outbound links

Weight breaks for inbound and outbound transportation

Figure 4.21—Continued

shipping points, CSP's. Differences in modes were accounted for by developing and inputing as exogenous variables different transit times and cost functions.

The reliability or consistency of transit time and of transportation service was evaluated considering the availability of transportation equipment, performance of the mode in route, and historical performance by the carrier(s) in each existing service area. The approach used to generate the transit times and reliability adjustment for outbound and inbound transportation times is developed within Order Cycle Analysis in the Supporting Data System-Measurement.

The location of the demand units and the distributions centers was considered because of the differences in transit time and reliability due to topographical, carrier, and/or directional differences. Differences in the transportation networks of regions also accounted for differences in transit times between regions.

The number of demand units and distribution centers was also a factor in developing the transit times because of the practical problem of developing the transit times for each of the feasible DC-DU links. The number of potential DCs was greater than 30 and the number of demand units greater than 400. Thus it became somewhat impractical to consider the development of point to point transit times for each possible outbound transportation DC-DU link.

Two methods of developing point-to-point times were evaluated. The first was the use of concentric circles where transit time within a given mileage circle would be established for each DC as shown in Figure 4.22. The distance between the DC-DU would determine which circle the DU was within and thus the average transit time. The distance between any DC and DU is obtained via a Distance activity that is presented in the Measurement Subsystem.

The second method for developing average transit times was to use a set of regression equations with the dependent variable being transit time and the independent variable being distance. The regressions equations were of the form:

OTBD=DCDUDIS* A + B

where:

OTBD = The outbound transit time

DCDUCIS = The DC-DU distance in spherical miles corrected by 1.17 to road miles

A,B = The regression coefficients

The regression method is more precise than the concentric circle since it can be made more exact and measurement can be developed and allowances for differentiation in border line transit times. Using the regression equation demand units A and B, Figure 4.22, would have different transit times, whereas using the concentric rings both would have the identical transit times, the average time of interval Number 2, which is two days.

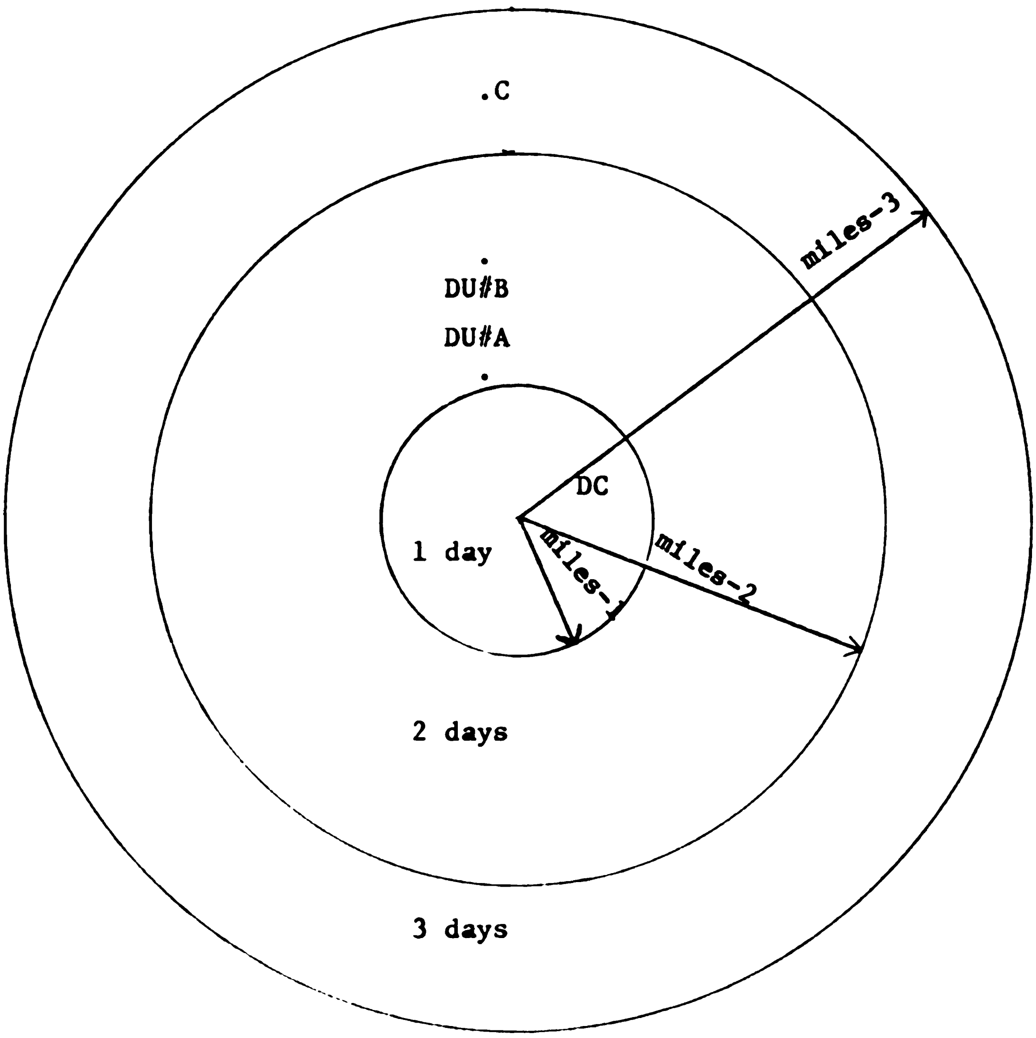


Figure 4.22--Concentric Circles for Transit Times

The regression equations, however, require more data than was initially available and much more analysis. Therefore, for the initial LREPS version the marginal sophistication to be gained by using the regression equations did not seem warranted for the effort required. The decision was therefore made to use concentric circles for Option 1 and to develop a variability function to generate variations around the average transit times of the concentric circles. The method used to generate the average transit time variability for each DC-DU link is presented in the discussion in the Order Cycle Analysis.

The error resulting from the use of concentric circles rather than regression equations should on the average be cancelled out over the period of the simulation due to the large number of possible DC-DU combinations from greater than 400 DUs and greater than 30 DCs.

Transit time data to develop the service rings for the outbound transportation was established based on service area information provided by actual distribution operations. Using this information the 1 day, 2 day, and 3 day transit time distances were established from each of the existing and potential distribution centers. Information on the performance or consistency of service was also obtained and used to develop reliability functions for each distribution center.

In Option 1 for the transportation time activity regional differences between distribution centers was taken into account by selecting various sets of concentric circles with different values of the variables miles 1, 2, and 3 to establish the transit time versus distance relationship. The directional differences were not, however, taken into account directly as is evident from the Order Cycle Time Analysis, since the assumption in Option 1 was that transit time for a specific distance is the same in any direction from a DC.

High variability around a DC due to any of the reasons previously mentioned such as carrier differences and roadway differences can be taken into account by selecting a higher probability variance function.

Inbound transit times were developed after consideration of the modes of transportation, and reliability or consistency of service using basically the same procedures used for outbound transportation. However, since inbound transportation involved only the MCC-DC links, which are much fewer in number than the DU-DC links for outbound transportation, the transit times were developed for point-to-point distances. Transit time values were developed based on historical operating data from the subject research firm and its carriers.

Shipment Statistics.--Shipment statistics such as the average and standard deviation of shipment size in cases, lines, weight, dollars, and orders were developed via data obtained from actual operating data. This data was necessary, for example, to develop weighted average freight rates based on the percent of weight moving in each weight break interval.

Shipment Policy.--Several shipping policies were considered that involve outbound transportation, such as scheduled or pooled shipments where customer orders are held until a scheduled date and then are combined for shipment to DU's with other orders ready for shipment. Typical shipping policies were analyzed and the universality preserved by developing the flexibility to include a range of policies in the model. For example, to simulate scheduled shipments a fixed percentage of the outbound orders were set to be shipped on fixed calendar days of the week rather than when the orders are ready for shipment. The percentage was established based on operating data.

One of the important policy areas was to set rules for shipment of reorders from the MCC supply point to DC's. The decision rules developed included for example; a fixed shipment interval, a fixed shipment quantity rule, or a combination of both the fixed interval and quantity. After analysis of typical shipping policies the combination rule was selected for the initial version of the model with the flexibility of implementing either of the other decision rules if desired. Thus, the replenishment shipments were made on an interval of a fixed number of days and/or when the volume of replenishment orders accumulated to the quantity shipment minimum. This interval by definition is the shipment dispatch policy delay time MCC-DC, RT3.

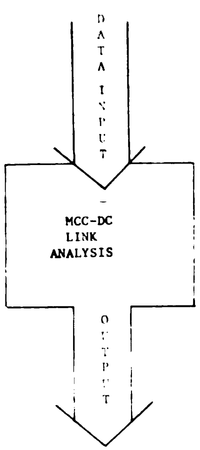
Weight Breaks.--Weight breaks were required to accumulate the shipments in the appropriate intervals for development of transportation costs. The weight intervals at the DC level were based on typical Parcel service and Common carrier weight break intervals. The finalized weight breaks were set at 50, 200, 1000, and greater than 1000 lbs.

The weight breaks established for the MCC were based on the ICC Tariff Bureau rate structure. The weight intervals finalized were set at 5,000, 24,000, and greater than 24,000 lbs.

MCC-DC Link Analysis

In addition to the above transportation analyses special analyses were required for the inbound transportation MCC-DC links. These analyses included the development of product assignment or product supply points, the weight percentage split for reorders, and the extrapolation ratio of tracked products to all products. All three of the above were related to the physical supply profile. Figure 4.23 presents the activity analyses in terms of the inputs, outputs, and transformations required for the MCC-DC links. The sequence of development is illustrated in Figure 4.24.

Product Assignment.--The product assignment activity was required to determine which replenishment center should serve as the supply point for a reorder if more than one



INPUTS

1. Number of MCC & DC
2. Location of MCC & DC
3. Distance MCC-DC
4. Feasible MCC sources of product
5. Tracked product weight shipped from each MCC & total weight
6. Number of products tracked total products

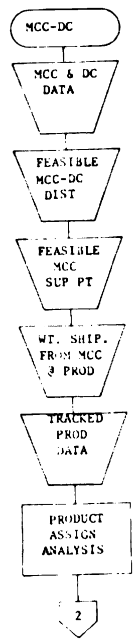
TRANSFORMATIONS

1. Product assignment analysis to each MCC
2. Percentage weight for each MCC
3. Shipment weight extrapolation to each MCC

OUTPUTS

1. Assignment of RC supply point for each tracked product for each DC
2. Percentage of total weight to each DC shipped from each MCC
3. Extrapolation-ratio to "generalize up" weight of tracked products

Figure 4.23--Activity Analysis: MCC-DC Link



Number of MCC's and DC's. Location of MCC and DC.

Distance for all feasible MCC-DC links.

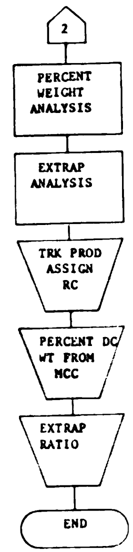
List of all MCC's that can supply each tracked product.

From operating data weight shipped from each MCC of each tracked product.

Number of tracked products. Tracked product weight shipped.

Product Assignment Analysis to determine which RC should serve as supply point for each tracked product for each DC.

Figure 4.24--Flowchart: MCC-DC Link



Percent Weight Analysis to develop the percentage of weight shipped to DC from each MCC.

Extrapolation Analysis to develop the EXTRAPOLATION-RATIO to generalize up the weight of tracked products to all products.

Assignment of RC supply point for each tracked product for each DC.

Percentage of total weight allocated to each DC shipped from each MCC.

EXTRAPOLATION-RATIO to generalize up weight of tracked products to all products.

Figure 4.24—Continued

MCC source manufactures the product. The various assumptions made regarding the selection included a Monte Carlo process with the probability weighted inversely to the distance from the MCC to the DC. The initial version of the model contained the assumption that the closest possible MCC would provide replenishment to a DC.

As discussed in Chapter III this assumption represents an example of both the simplification and the strong link concepts. Analysis of operating data indicated that most DC replenishment would be from the closest possible MCC. This relationship is the "strong link."

Analysis of operating data allowed the selection of the list of feasible MCC sources of supply for each tracked product. The feasible list and the MCC-DC distances determined the MCC to be assigned for each DC for each tracked product.

Percentage Weight Split.--Additional analyses were then required to establish the percentage of total weight of the accumulated replenishment shipments to a given DC that would be shipped from each MCC. It is important to note that this analysis was only necessary since the products tracked were less than the total product line. If all products are included in the tracked product list each replenishment order reflects actual total replenishment volume (weight, cases, cube, lines, and orders) from MCC to DC. However, in cases where only a sample of products are tracked, for example in the initial version of

LREPS where approximately 10-12 percent of the products are tracked, the replenishment orders for the tracked products must be extrapolated up to represent the volume for the additional 90 percent, the non-tracked products.

The method selected to determine the percentage weight supplied from each MCC was developed using a proximity ranking for each DC based on the closest MCC, second closest MCC, and so on until all MCC's were ranked for the DC. The number of rankings of MCC's possible for the various DC's equals the permutations of the number of MCC's taken all together which was:

$$nPn = n!$$

where:

nPn = Number of possible proximity rankings of the MCCs.

n = Number of MCCs

Therefore, for three Mcc's the number of possible proximity rankings for any given potential DC is six.

The proximity ranking for a particular DC was determined by selecting the appropriate ranking of closest MCC, next closest MCC, and so on. The percentage weight to each MCC in the ranking scheme was developed by developing the ratio of the total weight shipped for all products feasibly supplied by the closest MCC to the total for all MCCs, then all products supplied by the next MCC not already supplied by the closest MCC, and so on until the percentage was determined for both MCC.

Table 4.2 illustrates the hypothetical results of such an analysis. Assume that for the DC that MCC2 is closest, MCC1 next, and MCC3 furthest distant. Proximity ranking III would be the appropriate choice with 60 percent of the weight to the DC for the extrapolated replenishment shipments supplied from MCC2, 20 percent from MCC1, and 20 percent from MCC3.

Shipment Weight Extrapolation.--The next step in the MCC-DC link analysis was establishment of the extrapolation factor. In this final step the product activity of the tracked products is extrapolated to the total product line. Analysis of the weight of total products relative to the selected tracked products in the Product Item Analysis was performed using operating data. This ratio, Extrapolation-Ratio, is used to "generalize up" the transformations required for extrapolation which are presented in Chapter V, Operations Subsystem, the DC End-of-Day routine.

Unitization Component

The Unitization component of the Supporting Data System--Operations required:

1. Development of DC attributes related to the facility
2. Establishment of a procedure for implementing Full and/or Partial line DCs
3. Establishment of operating capacity limits for the DCs
4. Development of order processing and preparation time.

TABLE 4.2.--Proximity Rankings.

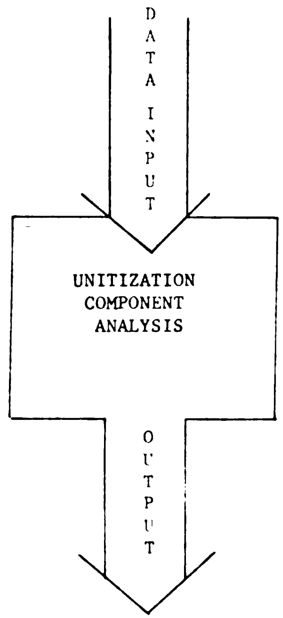
No.	Proximity Ranking	% of Total Weight
I.	1. MCCl	55
	2. MCC2	25
	3. MCC3	20
II.	1. MCCl	55
	2. MCC3	35
	3. MCC2	10
III.	1. MCC2	60
	2. MCCl	20
	3. MCC3	20
IV.	1. MCC2	60
	2. MCC3	20
	3. MCCl	20
V.	1. MCC3	55
	2. MCC2	25
	3. MCCl	20
VI.	1. MCC3	55
	2. MCCl	30
	3. MCC2	15

Figure 4.25 presents the activity analysis in terms of the outputs, inputs, and transformations. The flowchart for the unitization component is presented in Figure 4.26.

DC Attributes.--The definition of each of the four types of distribution centers; the remote full-line, remote partial-line, the primary distribution center, and the consolidated shipping point were presented in Chapter I. The major attributes of the DC facility can be defined as the location, ownership, type, size, and level of automation.

The location was defined as the city by longitude and latitude. A distance routine incorporated in the model was used to compute the spherical distances from point to point using the latitude-longitude coordinates. The implementation of new locations is presented in the supporting analysis for the Monitor and Control Subsystem.

The types of ownership considered were ownership and operation by the manufacturing firm--private distribution centers, leasing of the centers by the manufacturing firm, and public warehouses. The decision regarding ownership was made as exogenous input and was reflected via input of different values of such parameters as fixed and variable cost, average and variability of order processing and preparation time, and time required for implementation. The model can thus simulate any one or all of the above types of ownership.



INPUTS

1. DC space requirements
2. Operating data for order processing and preparation
3. Operating data for levels of efficiency
4. DC size intervals feasible
5. DC types feasible
6. DC ownership feasible

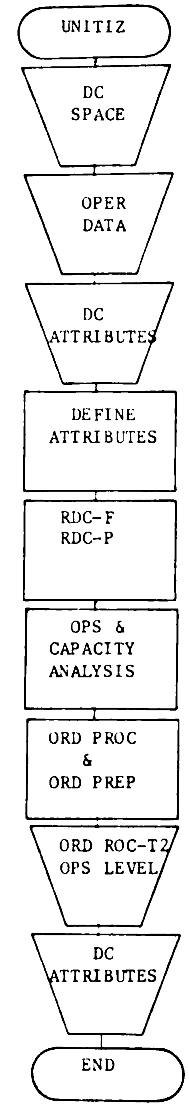
TRANSFORMATIONS

1. Development of DC attributes
2. Procedure for full- and partial-line
3. Operations and capacity analysis
4. Development of order processing and preparation time

OUTPUTS

1. Order processing and preparation time, T2
2. Peak level of operation by type and size
3. Definition of ownership, type, size, level of automation

Figure 4.25--Activity Analysis: Unitization Component



DC space requirements, "active" and "reserve"

Operating data for order processing and preparation, for levels of efficiency

DC attributes, i.e. size, type, ownership

Define the DC attributes

Develop procedure for full-line and partial-line DC

Perform operations and capacity analysis

Develop order processing and preparation time

Order processing and preparation time, T2, peak level of operation

DC attributes

Figure 4.26--Flowchart: Unitization Component

The type of DC refers to the level of automation of the distribution center. In the LREPS model the assumption was made that the level of automation would be directly related to the DC size intervals and expected throughput of the distribution center being implemented. Thus the minimum size interval was assumed to be essentially a manual operation whereas the maximum size interval fully automated. The degree of automation was reflected through the fixed dollar investment of the facility, the costs of throughput, and the capacity of the center.

The size of the DC refers to the capacity of the distribution center in terms of annual dollar volume processed. Five size intervals were developed from which the capacity of each DC coming in-solution or being expanded was reflected.

Full-Partial DC Product Line.--The criteria of universality required that the model be capable of simulating of partial-line and full-line distribution centers. This was accomplished by designating that a partial-line handles products by inventory categories such as the previously defined AI, A, B, and C. Thus, a full-line (RDC-F) handles all categories whereas a partial-line (RDC-P) handles only those categories tagged for the in-solution distribution center.

The system structure Figure 1.2 was established such that only one primary distribution center (PDC) and one partial-line remote distribution center (RDC-P) can serve a given demand unit. The tracked products not handled by the RDC-P are supplied to the DU by the PDC. A DU served by an RDC-F or a PDC, both of which are full-line, receives all tracked products from the assigned full-line center.

DC Operating Capacity Limits.--The capacity analysis established the level of throughput at which a reduction in efficiency would be expected to occur. This level, stated as a percentage of the design throughput capacity for the DC's, was established after considering both "active" and "reserve" space requirements.

Active space referred to the space required to move the case volume or dollar volume through the DC whereas; reserve space referred to the space requirements for support functions such as administration, docks, sidings, and shipping areas. The significance of the efficient operating level was that it served as the trigger for expanding the DC or location of a new DC. If the efficient level of operation is exceeded a penalty time is generated for the order processing and preparation time based on the percentage of actual operating level relative to the efficient level. DC throughput costs also are increased for this period. The supporting data activities of the M&C discuss this subject in more detail.

Order Processing and Preparation Time.--The average order processing and preparation time, customer order cycle time, CT_2 and reorder cycle time RT_2, which was defined as the time to process the order and produce or pick the order from the inventory stock of the DC or RC was determined by a review of operating data. A constant time was selected for the average value of CT_2 and RT_2 with a variability function included as described later in this chapter in the Order Cycle Analysis.

Communications Component

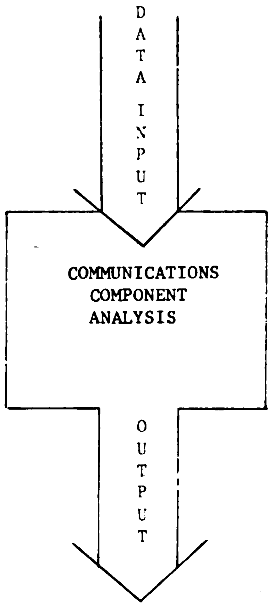
The communications component of the Supporting Data System--Operations required the following analyses:

1. Development of communications network
2. Time delays for communications links

Figure 4.27 presents the outputs, inputs, and transformations for the communications component. The flowchart for this component is presented in Figure 4.28.

Communications Network.--This component analysis considered the universal aspects of communications in that decentralized, regional, and centralized networks can be simulated.

A decentralized communications network is where orders are transmitted to remote distribution centers from the customer demand units with replenishment orders originating at the decision of the remote distribution center. Regional network referred to a communications network where customer orders are transmitted to regional distribution centers (order processing centers) such as the primary distribution centers. Reorders



INPUTS

1. Data on communication mode performance
2. Definition of type of communication networks

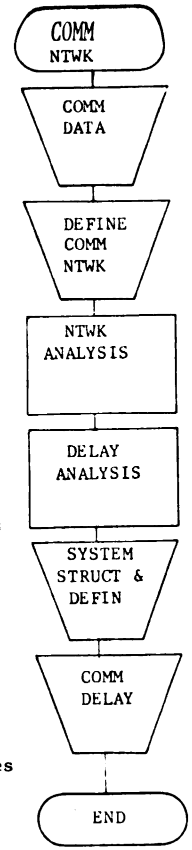
TRANSFORMATIONS

1. Type of network analysis
2. Communication time delay analysis

OUTPUTS

1. System structure and definition for decentralized, centralized and regional networks
2. Average communications delay times
3. Variability of delay times
4. Communication modes

Figure 4.27—Activity Analysis: Communications Component



Data on communication mode performance

Definition of communication networks

Analysis of communication network types

Communication delay time analysis

System structure and definition for decentralized, centralized, and regional networks

Average and variability of communication delay times for networks and modes

Figure 4.28--Flowchart: Comunications Component

originate for replenishment of remote distribution center inventories at the primary distribution center. Centralized network refers to control at one central order processing facility. Customer orders from the demand units are transmitted, for example by WATTS line or directly by telecommunication to one central location for order entry and processing. All reorders to replenish the remote distribution centers inventory levels originate at the central order processing location where all inventory update is processed.

The approaches considered enabled simulation of the three basic communications networks. The first approach required different communications structure for each of the three systems with different numbers and definition of communication links for each system. The second approach required only one basic communications structure with different values for the communications delays for each link of the system. The basic structure, Figure 1.2, represents the decentralized system by selecting appropriate communications delays for CT1 of the customer order cycle and RT1 for the replenishment cycle. The structure can be made to reflect a regional system by redefining CT1 of the customer order cycle to be the time required to transmit an order from the customer demand unit to the primary distribution center (regional order processing center). RT1 of the replenishment cycle can be redefined to reflect the time required to place a reorder at the decision of the primary distribution center to the replenishment center for inventory requirements at a remote distribution center in the region. The redefinition is accomplished by changing the communications delay times to values typical for a regional system. The system structure can be made to represent a centralized communications network by setting CT1 to a value to reflect the time for an order transmittal from customer demand unit direct to the central order processing facility. Likewise RT1 of the replenishment cycle can be set to reflect communications delay for reorder decisions initiated by the central inventory control location for replenishment shipments to a remote distribution center from the replenishment center.

Communication Time Delays.--It was necessary to evaluate operating data to obtain (1) statistics on the percentage use of each mode, such as mail and telephone within each region of the distribution system, (2) the average delay for each mode, and (3) variability around the average for each mode. Based on the data analysis the average communication delay times were developed for CT1 of the customer order cycle and RT1 of the replenishment cycle for each of the three types of communications systems. The function developed to introduce variability for the delay times is presented in the Order Cycle Analysis.

Inventory Component

The Supporting Data System--Operations included the following analyses related to the inventory component:

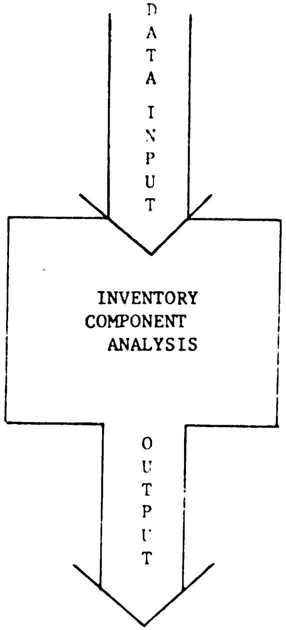
1. Definition of the inventory nodes
2. Development of approaches for inventory control
3. Development of procedures to handle backorders
4. Development of reorder lead time
5. Establishment of initial inventory levels.

Figure 4.29 presents the outputs, inputs, and transformations required for the inventory component. The flowchart for the inventory component is presented in Figure 4.30. The inventory management systems are presented in the Monitor and Control Subsystem.

Inventory Nodes.--The inventory nodes in the LREPS model were defined as the remote distribution centers, full-line and partial-line (RDC-F and RDC-P), primary distribution centers (PDC), and replenishment centers (RC) of the manufacturing control center (MCC). The assumption was made that inventory levels for tracked products would be monitored and controlled at the distribution centers. Inventories of tracked products at the MCC-replenishment center were assumed 100 percent available.

Inventory Control.--Four approaches to inventory control were considered:

1. Development of one average product



INPUTS

1. Definition of DC types
2. Approaches to inventory control
3. Approaches to backorder procedure
4. Definition of reorder lead time
5. Basis for initial inventories

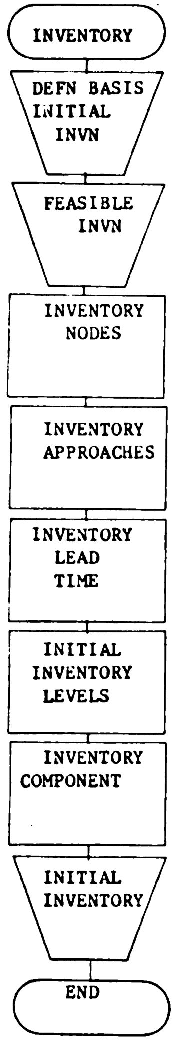
TRANSFORMATIONS

1. Analysis of inventory nodes
2. Development of approaches to inventory control
3. Development of backorder procedures
4. Establishment of reorder lead time
5. Establishment of initial inventories

OUTPUTS

1. Definition and location of inventory nodes
2. Inventory control approaches
3. Backorder procedures
4. Reorder lead time approach
5. Initial inventories

Figure 4.29—Activity Analysis: Inventory Component



Definition of DC types and reorder lead time. Basis for initial inventories.

Feasible inventory approaches to consider.

Analysis of inventory nodes.

Develop inventory approaches, and backorder procedures.

Develop reorder lead time.

Establish initial inventory levels each in-solution DC

Definition and location of inventory nodes, inventory control approach(es), reorder procedures, reorder lead time.

Initial inventory procedure for each new in-solution DC

Figure 4.30--Flowchart: Inventory Component

2. Development of product categories to group individual products
3. Use of all individual products
4. Development of list of tracked products.

Analysis indicated that to test the effect of different policies it would be necessary to track a representative number of individual products. The work by Packer indicated that the use of a statistical sample of products would enable testing of various inventory policies representative to the total product line.[3] The procedure for selection of the tracked products was presented in the Product Item Analysis of the supporting analysis for the Demand and Environment Subsystem. The selection of the inventory policies for the LREPS model is discussed as part of the supporting analysis of the Monitor and Control Subsystem.

Backorder Procedures.--Two basic approaches were considered for handling backorders. The first approach required generation of a new order with each backorder for the unfilled amount of each tracked product. The procedure required the generation of the backorder, holding the backorder until the replenishment shipment of all the tracked products arrived at the distribution center. The backorder then would be resubmitted into the order stream and processed. This appeared to be inefficient to implement because of the additional program complexity, core storage, and additional processing required. The second method completely filled each customer order allowing the inventory to go negative (or more negative). This negative inventory was relieved with receipt of the replenishment orders for each of the individual tracked products. The order processing and preparation time, CT2, is not increased as a result of stockouts using this approach. However, an average delay due to stockouts (backorders) of tracked products CT_3 is calculated as part of the total customer order cycle. As previously stated, the Order Cycle Analysis is presented in the Supporting Data System-Measurement.

Reorder Lead Time.--The reorder lead time analysis developed the replenishment order cycle in terms of the reorder transmittal time from DC-RC, RT_1, the reorder processing and preparation time at the RC, RT_2, and the shipment dispatch policy delay time at the RC, RT_3, and the transit time from RC-DC, RT_4. The procedure for development of the values for each of these order cycle time elements is presented in the Order Cycle Analysis.

Initial Inventories.--The initial inventory for each tracked product was established by stocking each distribution center based on six weeks of average demand.

Location Component

The analyses performed for the location component within the Supporting Data System--Operations included the calculation of the initial sizes for each existing facility in terms of the five size intervals established and designation of the initial DC location.

Summary

The completion of the above activities was required to provide the supporting data analyses and to prepare the data for the Operating System--Operations Subsystem. The next major section of the Supporting Data System presents the Measurement Subsystem analysis and data preparation activities.

Measurement

The Data Supporting System-Measurement provided the analysis and data preparation for the target variables of service and cost. Chapter VI, Report Generator System discusses the target variable flexibility. In addition a special supporting analysis was required for calculating the distance between point-to-point locations.

Measures of Service

Preliminary analyses indicated that the following measures of service to customers and distribution centers would provide a sufficient range of measurement criteria:

1. Customer Service
    a. Normal customer order cycle, NOCT
    b. Total customer order cycle, OCT
    c. Outbound transit time, CT4
    d. Percent of sales volume for various order cycle times
2. Distribution Center Service
    a. Reorder cycle time, ROCT
    b. Stockout delays
    c. Percentage of case units backordered

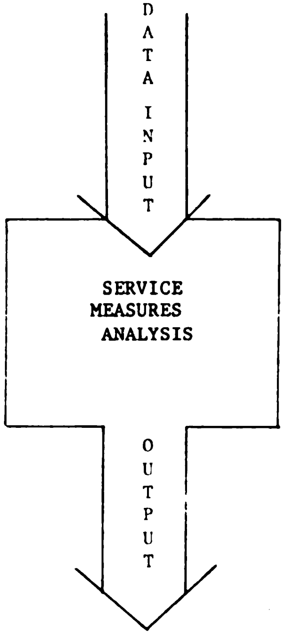
Figure 4.31 presents the activity analyses diagram in terms of the outputs, inputs, and transformations for the development of the measures of service. The flowchart for the service analyses are illustrated in Figure 4.32.

Customer Service.--The customer service analyses provided the approach used to calculate the average and variance values for elements of the normal and total customer order cycles. The main elements of the normal customer order cycle (NOCT) as defined included:

1. Customer order transmittal time (DU-DC), CT1
2. Customer order processing and preparation time (DC), CT2
3. Outbound transit time (DC-DU), CT4

As previously discussed the order transmission time, CT1 is composed of time from dispatch of the order from the customer demand unit to the arrival at the processing distribution center. The order processing and preparation time, CT2 consisted of the time for processing of written orders and the materials handling required to prepare the physical order for shipment. The CT4 element represented the transportation time for the DC-DU link. The NOCT thus does not include any delay due to stockouts at the DC. The procedure for developing a penalty order delay time due to stockouts is presented later in this section.

After consideration of several approaches the method selected for developing the element values for the NOCT involved the establishment of a fixed average



INPUTS

1. Definition of customer service in terms of NOCT and OCT
2. Definition of distribution center service in terms of ROCT
3. Input data for each T1, T2, and T4 element

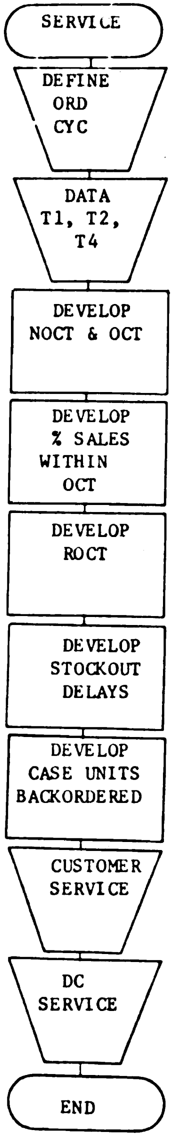
TRANSFORMATIONS

1. Develop procedures NOCT and OCT
2. Develop procedures for percent of sales volume for OCT
3. Develop procedures for ROCT
4. Develop procedures for stockout delays
5. Develop procedures for case units backordered

OUTPUTS

1. Procedure for calculating, NOCT and OCT
2. Procedure for calculating percent of sales volume for order cycle time
3. Procedure for calculating stockout delays
4. Procedure for calculating outbound transit time, CT4
5. Procedure for calculating ROCT
6. Procedure for calculating percent case units backordered

Figure 4.31—Activity Analysis: **Measures** of Service



Definition of customer service and distribution service order cycles

Data input for order cycle elements T1, T2, and T4

Develop approach(es) for normal customer order cycle, NOCT and total customer order cycle, OCT.

Develop approach(es) for percent sales dollars and orders within OCT

Develop approach(es) for reorder cycle time, ROCT

Develop approach(es) for stockout delays, CT3

Develop approach(es) for case units backordered

Output procedures for measuring customer service; NOCT, OCT, and percent sales within OCT output

Output procedures for measuring DC service, ROCT, stockout delays, and case units backordered

Figure 4.32**--Flowchart:** **Measures** of Service time for the element and a Monte Carlo function to develop a variance around the average. The variability function was incorporated to simulate random variation in each time component for such reasons as weather, unavailability of service, breakdowns in the communications network, and low reliability for carriers.

The development of the NOCT elements for Option 1 consisted of establishing sets of service time rings which then were applied to the appropriate DC's. Each set of rings contained three rings: a 1-day, 2-day, and 3-day ring. Any distances beyond the third ring were assumed to require an average of four days. As shown in Figure 4.33 each DC has two sets of rings designated for it, one for outbound transportation and one for inbound communications (order transmittal time). As illustrated a DU may be within the 2-day ring for communications, for example by mail; but in the 1-day ring for transportation. Analyses of service data provided the ring sets and variance values for the DC's.

The variance for each element was developed using Monte Carlo functions such as:

Probability	Additional Delay Time
10%	2-days
20%	1-days
70%	0-days

Assignment of 70 percent probability of no additional delay time thus implied that the component was 70 percent reliable

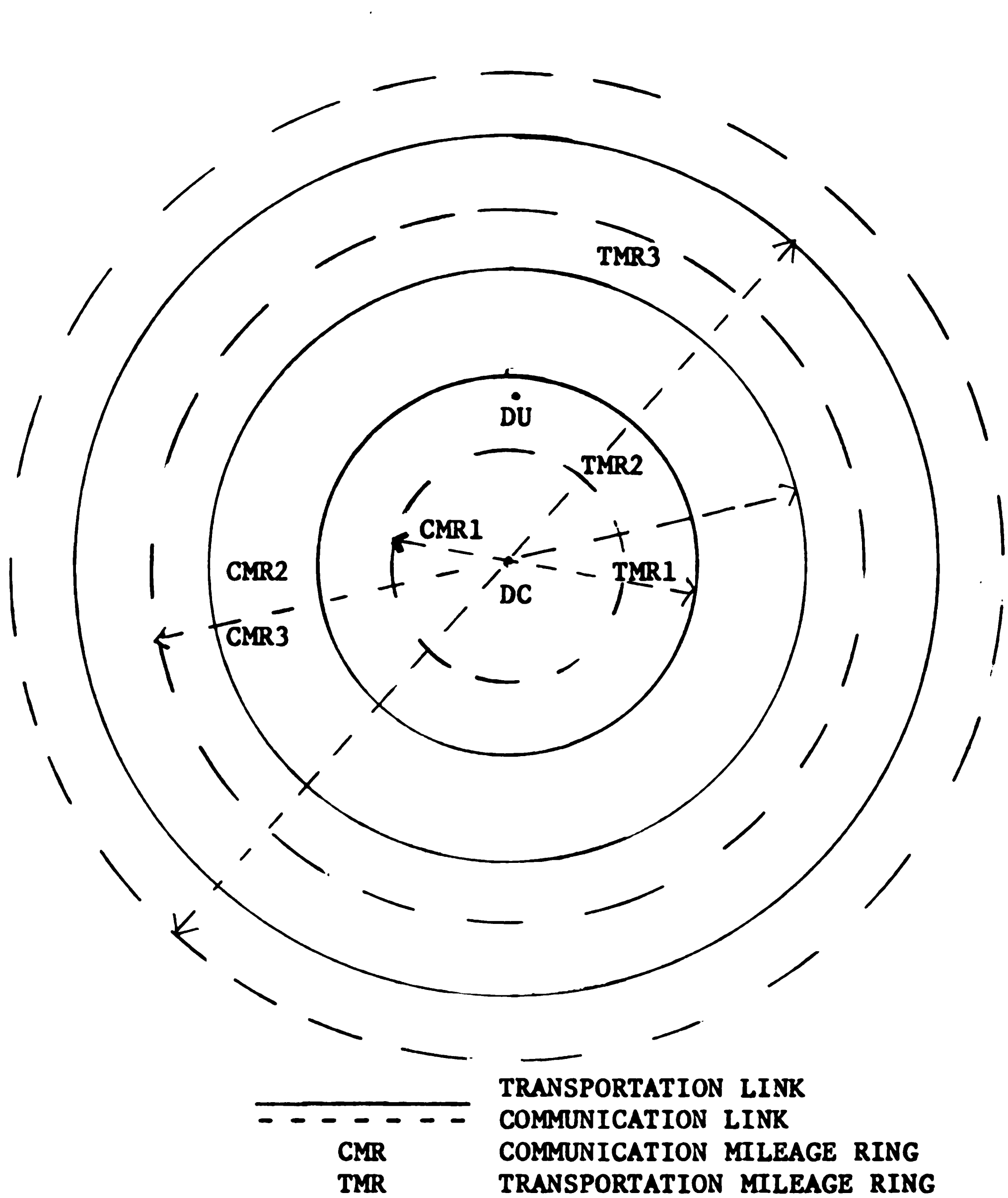


Figure 4.33—DC Ring Set for Communications and Transportation

in achieving the fixed average service times. Likewise the component with the above variance function and the 1-day fixed average time would require 2-days for 20 percent of the time, or within 2-days for 90 percent of the time. A different set of variance probability distributions were developed for use with outbound and inbound communications components. This also allowed a different distribution to be used for different distribution centers.

Initially each distribution center was designated for each component one of the M possible ring sets of the form illustrated in Table 4.3 and one variance function as illustrated in Table 4.4.

As an example a given distribution center might have the following ring set designations:

If DU WITHIN	Variance COMM:CT1	Functions TRANSP:CT4	Ring Set OPT	CT1	CT4
Ring #1	4	1	2	7	2
Ring #2	4	2			
Ring #3	3	3			

A ring set number 7 for CT4 indicated for example that if the demand unit was within 300 miles it would require on the average 1-day communication order transmittal time, within 600 miles would require 2-days, and within 1000 miles require 3 days. The designation of variance function number 4 for the demand unit within ring number 1 (300 miles) for CT1 indicates that 20 percent of the orders would be delayed an additional 1-day, since service

TABLE 4.3.--Average Service Time Functions.

Ring Set	Concentric Ring Interval		
No.	1-Day Ring	2-Day Ring	3-Day Ring
1	100 Miles	250 Miles	500 Miles
2	100	350	700
3	150	400	800
.	.	.	.
.	.	.	.
7	300	600	1000
8	1000		
.	.	.	.
M	m1	m2	m3

TABLE 4.4.--Service Time Variance Functions.

Variance	Probability of Delay			
Function No.	0-Day	1-Day	2-Day	3-Day
1	100%	0	0	0
2	90	10	0	0
3	60	30	10	0
4	80	20	0	0
.	.	.	.	.
.	.	.	.	.
N	n0	n1	n2	n3

is 80 percent reliable. For a demand unit within ring number 3 (1000 miles) service is 60 percent reliable which would mean that 60 percent of the orders would not be delayed, but 30 percent would require 1-day longer, and 10 percent would require 2-day additional days to be transmitted.

For outbound transportation using this same distribution center the demand units within 100 miles (ring number 1) would have 100 percent reliability for 1-day service. The demand units within the 400-800 miles (ring number 3) would have 60 percent shipments without additional delays, 30 percent with a delay of 1-day, and 10 percent with a penalty of 2 days. The values of the ring set number 8 and the variance function, number 1 for example are used to simulate WATTS communications times or other constant times.

Order processing and preparation time, CT_2 is determined by using sets of Monte Carlo random variate functions. For example, the discrete probability distributions were developed as follows:

Probability	OPT - CT2
10%	0 Days
60%	1 Days
30%	2 days

In addition, if the DC being processed is operating above an established level of throughput relative to the maximum capacity an additional 1-day delay was added to

CT_2 for a percentage of orders equal to the percentage of operation above the stated level. The procedure for establishing the throughput constraint is developed in the Monitor and Control Subsystem. The sum of the CT_1, CT_2, and CT_4 thus determined the normal order cycle time, NOCT for each customer order processed.

Since the NOCT as defined assumed no delay due to stockouts an additional time element CT3 was established to develop an average and standard deviation of stockout delay. The following relationship defines the CT3 element:

CT3 = SUMSOD/SUMUNT

where:

CT3 = Stockout Delay in Days

SUMSOD = Sum of Stock-Out-Days

SUMUNT = Sum of Stock-Out-Units

The sequence of calculations to develop the average and standard deviation of CT3 are presented in the Measurement Subsystem, Chapter V.

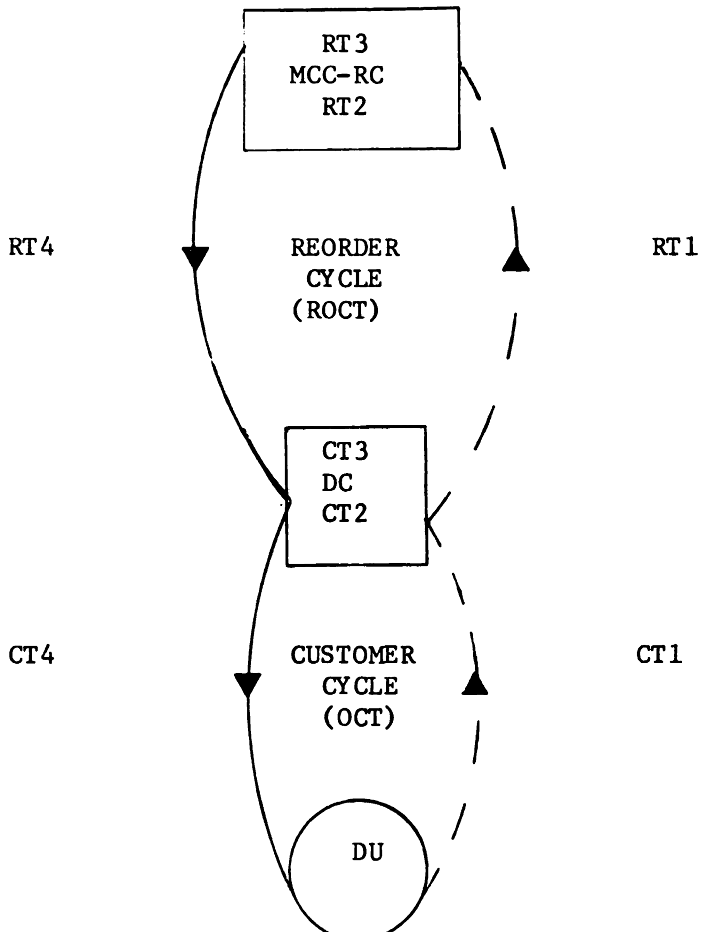
An additional measure of customer service, the percent of sales volume within various order cycle times for example within 1-day, 2-days, and so on was developed to have a measure of speed and consistency of service for existing customer volume. The two approaches considered involved (1) calculation of this measure of service per DU, and (2) calculation per DC. The second approach was selected for two basic reasons.

First, the computer core requirement for storing the required data per DU was impractical for the computer memory allocated for this function. Second, development at the DC level had the potential of providing an excellent overall measure of performance. This measure could serve as the criteria for DC addition to or deletion from the system. The approach developed to accomplish this is presented in the supporting analyses for the Monitor and Control Subsystem.

Distribution Center Service.--The distribution center service analyses developed the approach for calculating the elements of and the total reorder cycle, ROCT. The main elements of the ROCT, the average lead time, as defined include:

1. Reorder transmittal time (DC-MCC), RT1
2. Reorder processing and preparation time (MCC), RT2
3. Inbound transit time (MCC-DC), RT4

The values of the elements RT1, RT2, and RT4 were calculated by the appropriate assignment of ring sets and variance functions as illustrated for the respective CT1, CT2, and CT4 elements of the normal customer order cycle (NOCT). The RT3 element of the ROCT was defined as the shipment dispatch delay for various shipping policies simulated at the MCC's. Thus as the total order cycle time (OCT) the ROCT consisted of four elements. Figure 4.34 presents the order cycle elements for both the OCT and the ROCT.



<u>REORDER CYCLE</u>

RT1: REORDER TRANSMITTAL
RT2: REORDER PROCESSING & PREPARATION
RT3: SHIPPING POLICY DELAY
RT4: INBOUND TRANSIT

<u>CUSTOMER ORDER CYCLE</u>

CT1: ORDER TRANSMITTAL
CT2: ORDER PROCESSING & PREPARATION
CT3: STOCKOUT DELAYS
CT4: OUTBOUND TRANSIT

Figure 4.34--Order Cycle: Reorder and Customer

The measure of stockout delays, CT3 presented as an element of the customer order cycle also provides a measure of service by the system to the distribution centers. It indicates the average and standard deviation of delay in days for the distribution centers reorders placed against the MCC-RC complex. Additional measures of service developed related to inventory management and control included:

1. Number of reorders
2. Number of stockouts
3. Average inventory-on-hand.

The number of reorders was defined as the number of single product reorders placed by a DC against the MCC-DC quarter-to-date. The number of stockouts was defined as the number of single product units stocked out at a DC quarter-to-date. The average inventory-on-hand was defined as the cubic inventory. Based upon tracked products, results of each of these measures was generalized to all products. The transformations used to calculate these measures referred to as Inventory Extrapolation are presented in the Measurement Subsystem, Chapter V.

Measures of Cost

The supporting analyses and data preparation for the cost activities included development of approaches for:

1. Outbound transportation cost
2. Inbound transportation cost
3. Throughput cost
4. Communications cost

5. Inventory cost

6. Facilities investment cost.

Outbound Transportation Cost.--The supporting analyses for the outbound transportation cost developed the freight rates for the DC-DU links. The following approaches were considered:

1. DC-DU average cost/cwt by freight and weight class

2. DC-DU average cost/cwt by weight class

3. DC-DU average cost/cwt for all weight and freight classes

4. DC-location regression equations based on distance, with a modification factor for the PDC

5. DC-location regression equations without modification factor for the PDC

6. Regional regression equations for all DC's in the region.

The decision as to which one of the approaches to select was based to a great extent on the number of DC-DU links. If the number of possible combinations had been relatively small the development of point-to-point rates would have been practical. However, in this application of LREPS the number of DUs was greater than 400 and the potential DCs greater than 30. Therefore, the use of point-to-point rates even for only one freight class and weight interval becomes impractical because of the computer core and/or input/output time.

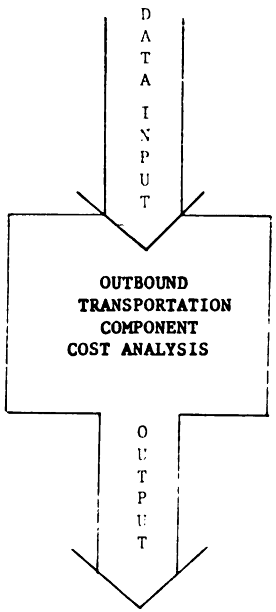
The approach of using regression equations was therefore selected as Option 1 for implementation in the

LREPS model. Figure 4.35 presents the activity analysis diagram in terms of the outputs, inputs, and transformations for the development of the regression equations. The flowchart for this analysis is presented in Figure 4.36. The initial step in development of the outbound transportation freight rates for the PDC locations required the selection of a sample of cities. The freight rates for these PDC-DU links and the road distances provided the input required to use a set of regression analyses where the freight rates were the dependent variable and the distances the independent variable. The freight rates used were based on operating reports. The distances were obtained from a subroutine which converted longitude and latitude into rectangular coordinates. These coordinates then were converted into miles. The best equation, using the index of determination, "r" as the criteria, determined the "a" and "b" coefficients for each existing PDC.

The approach used in developing the outbound freight rates for the RDC-DU links was in general similar to that used to develop the PDC rates. The four basic alternatives considered for developing the number of regression equations for the potential RDC's included:

1. Use five weight breaks, five freight classes, and four directions for each DC location or a total maximum number of 100 regression equations per DC

2. Use five weight breaks, five freight classes, and assume no directional difference. This required a maximum of 25 equations per DC



INPUTS

1. **Sample cities**
2. **Freight rates**
3. **Latitude-longitude**
4. **PDC&DC list and coordinates**
5. **Weight class factors**

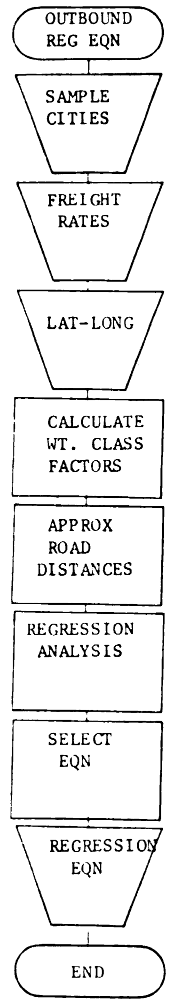
TRANSFORMATIONS

1. **Road distance program**
2. **Regression analysis**
3. **Weight class factor analysis**

OUTPUTS

1. **Regression equations for PDCs and DCs, with "A" and "B" coefficients**

Figure 4.35--Activity Analysis: Outbound Transportation



Select sample of cities around PDC & DC freight rates

Obtain freight rates for the sample cities

Obtain latitude-longitude of each point of the links, PDC-DU, and/or DC-DU

Calculate weight class factors using sampled invoices

Use computer routine to calculate road distances from latitude-longitude

Perform regression analysis on rates and distances using statistics program

Select best equation, using coefficient of determination "r"

Use coefficients "a" and "6" as input in LREPS model

Figure 4.36—Flowchart: **Outbound Transportation**

3. Use a weighted average freight rate and four directionals for each DC location, or a total maximum of 4 equations per DC

4. Use a weighted average freight rate and assume no directional differences, or a maximum of one equation per DC.

Preliminary analysis indicated that the amount of data collection, processing, analyses, and the computer core and processing requirements made the first two alternatives impractical for implementation for the initial LREPS version. Since the potential number of DC locations was greater than 30, the number of equations even for alternative three was greater than 100. The decision was made, therefore, to use alternative four. This alternative, referred to as Option 1, required the development of a frequency distribution of volume by weight intervals to develop a weighted average interval and a weighted average freight class. Actual data was used to develop the combined weighted average rate.

First, the average freight class and average weight class were calculated as follows:

<u>Average Freight Class</u>

Freight Class	% Total Weight Shipped
FC(1)	PCFC(1)
FC(2)	PCFC(2)
⋮	⋮
FC(IFC)	PCFC(IFC)
•	•
FC(N)	PCFC(N)

$$XFC = \sum_{IFC}^{N} (PCFC(IFC) * FC(IFC)/N)$$

where:

XFC = The average freight class based on actual data

PCFC(IFC) = Percent shipped in freight class, IFC

FC(IFC) = The freight class, IFC

N = The number of freight classes

IFC = The freight class identification number.

Average Weight Class

Weight Category:Lbs.		% Total Weight Shipped
WTCAT(1)	0-50	PCWT(1)
WTCAT(2)	50-200	PCWT(2)
WTCAT(3)	200-1000	PCWT(3)
WTCAT(4)	1000-Up	PCWT(4)

$$XWTCAT = \sum_{IWC}^{4} (PCWT(IWC) * WTCAT(IWC)/4)$$

where:

XWTCAT = Average weight category based on actual data

PCWT(IWC) = Percent weight shipped in weight category, IWC

WTCAT(IWC) = Weight category, IWC

IWC = Weight category identification

The Parcel and Minimum Charge rates were stated in dollars per shipment rather than dollars per cwt, where cwt equals one hundred pounds. Since the average shipment size in Parcel was 20 pounds, and the average shipment on Minimum Charge was 120 pounds the Parcel percentage was multiplied by 5 and the minimum charge multiplied by 1/1.2 to convert to equivalent rates per cwt.

The percentage weight factors, PCWT(IWC) used in conjunction with the average freight class, XFC defined the freight rate for the regression equations. The procedure involved:

$$\text{FREQN(IRE)} = \sum_{\text{IWC}}^{4} (\text{PCWT(IWC)} * \text{FRXFC(IWC)})$$

where:

FREQN(IRE) = Freight rate for regression equation IRE for a point-to-point DC-DU

PCWT(IWC) = Percent weight in weight category, IWC

FRXFC = Freight rate for average freight class XFC for weight category, IWC for a specific DC-DU.

Given the weighted average freight rates the regression equations were developed as were the equations for the PDC's. The form of the equations is presented in the Measurement Subsystem, Chapter V.

Inbound Transportation.--The inbound transportation cost component also required analysis to obtain the freight rates to be used for the MCC-DC links. Figure 4.37 presents the activity analysis in terms of the outputs, inputs, and transformations for the inbound transportation component. The flowchart for this analysis is presented in Figure 4.38.

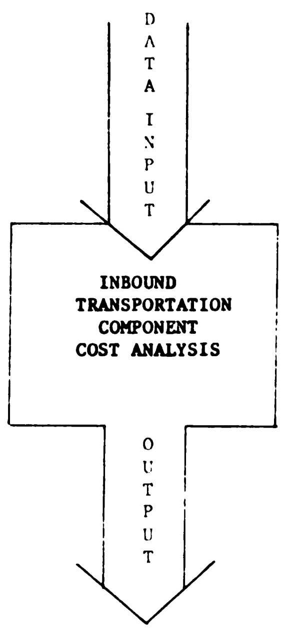
The number of potential MCC-DC combinations was relatively small compared to the number of potential DC-DU combinations for the outbound cost component. Therefore, the decision was made to use point-to-point freight rates for each MCC-DC link. The freight rates, based on mixed goods shipments, were obtained from an analysis of existing MCC locations to existing and potential DCs. The three weight breaks used included:

Weight Interval	Mode
2,000-5,000 pounds	Truck Load, TL
5,000-24,000 pounds	Truck Load, TL
24,000-Up	Rail, CL

Throughput Costs.--The supporting analyses required for development of the throughput costs included:

1. Evaluation of standard costs and operating reports
2. Definition of cost elements to be included in throughput cost component
3. Determination of any adjustment factors to modify existing or establish estimated costs for each size DC and type DC
4. Establishment of the fixed and variable cost for each size DC and type DC.

Figure 4.39 presents the activity analysis in terms of the outputs, inputs, and transformations for the throughput cost component. Figure 4.40 illustrates the flowchart developed for the throughput cost analysis.



INPUTS

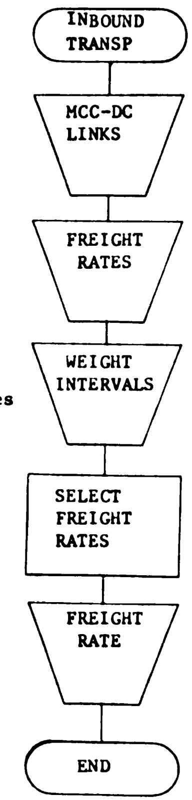
1. List and locations of MCCs
2. MCC-DC links
3. Freight rates for mixed goods
4. Weight intervals

TRANSFORMATIONS

1. Select appropriate freight rates

OUTPUTS

1. Freight rates for inbound transportation



List, location, number, and distance of MCC's, DC's, and MCC-DC Links.

Freight rates for mixed goods.

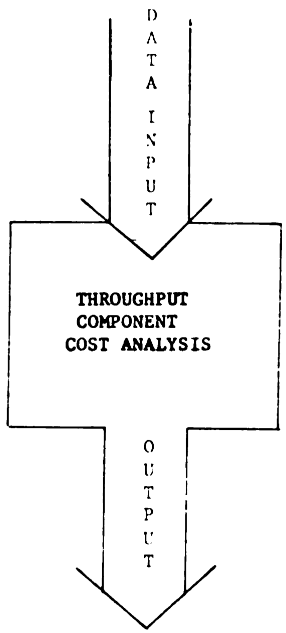
Weight intervals for TL & CL.

Select appropriate point-to-point freight rates.

Freight rates each MCC-DC Link.

Figure 4.37—Activity Analysis: Inbound Transportation

Figure 4.38--Flowchart: Inbound Transportation



INPUTS

1. Definition of throughput cost elements
2. Definition of fixed and variable elements
3. Fixed and variable cost data from standard cost and operation reports
4. Size and type of DC

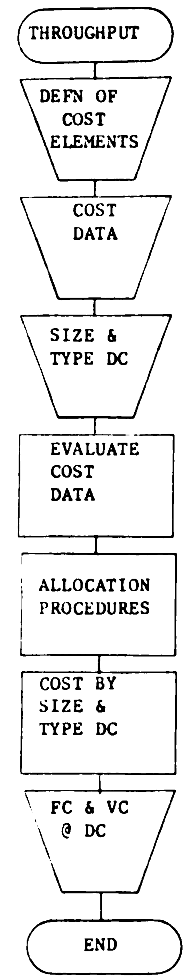
TRANSFORMATIONS

1. Evaluation standard costs and operating reports
2. Analysis of procedures for allocation of fixed and variable cost elements
3. Analysis of fixed and variable cost for each size DC and type DC
4. Analysis of work unit, cases or pounds of throughput

OUTPUTS

1. Fixed and variable cost for each size and type DC

Figure 4.39--Activity Analysis: Throughput Component



Definition of throughput cost elements, fixed and variable.

Fixed and variable cost data from standard cost and operating reports.

Size and type of DC's.

Evaluate standard cost and operating reports.

Analysis of procedures for allocation of fixed and variable costs.

Analysis of fixed and variable cost by size and type DC per work unit.

Fixed cost and variable cost for each size and type DC.

Figure 4.40--Flowchart: Throughput Component

After extensive review and analysis of the actual cost data the cost elements included cost centers frequently included in warehousing cost studies[4] such as:

1. Floor space
2. Traffic and purchasing
3. Payroll and salaries
4. Branch shipping and receiving
5. Plant receiving
6. Lift trucks
7. Customer shipping
8. Depreciation
9. Management
10. Warehouse reserve.

Communication Cost.--The communications network in LREPS was developed to simulate either decentralized, regional, or central order processing. The cost structure therefore was developed to include the flexibility to change from one type network to another. The supporting analyses required to develop the communications cost component included:

1. Evaluation of standard costs and operating records
2. Definition of cost elements for decentralized, regional, and central communications networks
3. Determination of adjustment factors
4. Establishment of fixed and variable costs for each size of DC and each type of network.

Figure 4.41 presents the activity analysis in terms of the outputs, inputs, and transformations for the communications cost component. The flowchart for this analysis is presented in Figure 4.42. The regional and centralized fixed and variable cost factors were relatively small for the decentralized network but became significant when centralized and regional networks were simulated. The variable cost was calculated in terms of dollars per order and dollars per line for each stage of DC and each size interval.

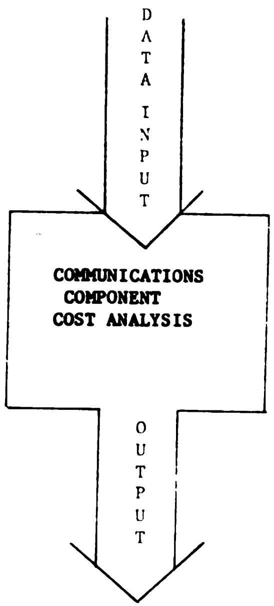
Inventory Cost.--The supporting analysis for the inventory cost component included:

1. Development of the carrying cost
2. Development of the reordering cost

Figure 4.43 presents the activity analysis in terms of the outputs, inputs, and transformations for the inventory cost component. The flowchart is presented in Figure 4.44. The development of the carrying cost required that a carrying charge in percent of inventory value per year be established and a measure for the value of inventory-on-hand be calculated. The inventory carrying charge was set as a management parameter. For the value of inventory several alternatives were evaluated:

1. Value per sales unit
2. Value per pound
3. Value per sales dollar.

The first alternative was selected as Option 1. Thus, the value was stated in terms of sales dollars per cube. Analysis of operating statistics developed the cost of



INPUTS

1. Definition of decentralized, regional and centralized network
2. Definition of fixed and variable cost elements
3. Fixed and variable cost data
4. Size and type DC

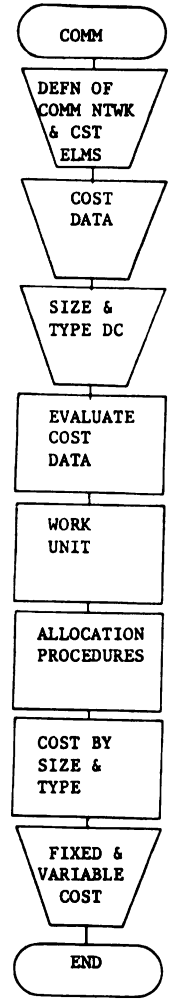
TRANSFORMATIONS

1. Evaluation of standard costs and operating records
2. Analysis of allocation procedures for fixed and variable cost elements
3. Analysis of fixed and variable costs for each size DC and each type network
4. Analysis of work unit lines and orders

OUTPUTS

1. Fixed and variable cost for each size and type DC for each network

Figure 4.41—Activity Analysis: Communications Component



Definition of communications networks, decentralized, regional and centralized; and fixed and variable cost elements.

Fixed and variable cost data from standard cost and operating reports.

Size and type of DC's.

Evaluate standard cost and operating reports.

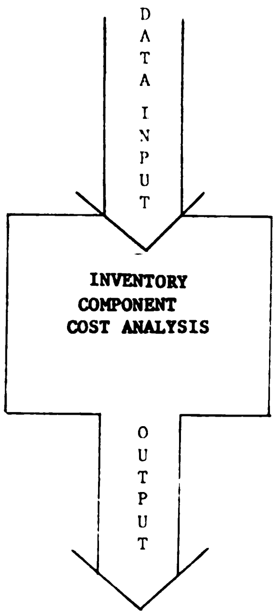
Analysis of work unit for communications network, i.e. lines and orders.

Analysis of procedures for allocation of fixed and variable costs.

Analysis of fixed and variable costs for each size and type DC by work unit.

Fixed and variable cost for each size and type DC for each network.

Figure 4.42—Flowchart: Communications Component



INPUTS

1. **Definition of carrying cost elements**
2. **Definition of reorder cost elements**
3. **Carrying charge per year**
4. **Definition of value of inventory**
5. **Definition of average cube of inventory**
6. **Tracked products**

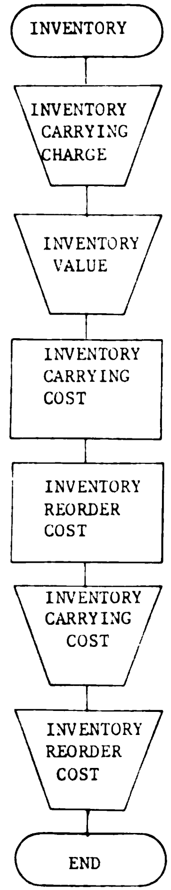
TRANSFORMATIONS

1. **Develop approach(es) to carrying cost**
2. **Develop approach(es) to reordering cost**

OUTPUTS

1. **Procedure for inventory carrying cost**
2. **Procedure for inventory reordering cost**

Figure 4.43—Activity Analysis: Inventory Component



Inventory carrying charge as a percent of inventory value per year.

Units of measure for value of inventory.

Develop approaches to inventory carrying cost.

Develop approaches to inventory reordering cost

Approach selected for inventory carrying cost.

Approach selected for inventory reordering cost.

Figure 4.44--Flowchart: Inventory Component

goods sold stated as a percentage of sales dollars per cube for the tracked products. The value of inventory-on-hand thus was determined as follows:

INVNVAL(ITP) = PCCGS(ITP) * SLDPCU(ITP)

where:

INVNVAL(ITP)	=	Value of the average cube inventory-on-hand for tracked product, ITP for QTD
PCCGS(ITP)	=	Percent of cost of goods sold relative to sales per cube unit
SLDPCU(ITP)	=	Sales per cube for tracked product, ITP
ITP	=	Tracked product identification.

The inventory value for the tracked products generalized up to represent all products provided the total inventory value from which the carrying cost was calculated each quarter. The procedures used are presented in the Measurement Subsystem, Chapter V.

The two basic approaches considered for inventory reordering costs were:

1. Development of reordering costs as separate from communications order processing cost
2. Development of reordering costs as part of the communications network order processing cost.

Initially the reorder processing costs both fixed and variable were included in the communications costs. A separate reorder cost is in the process of being developed based on the number of single and multiple product reorders placed by the DCs. The costs allocated to this will be reported separate from the communications network costs.

Facilities Investment Cost.--The supporting analyses and data preparation required for the facilities investment cost included:

1. An estimate of investment in land and facilities for each size interval

2. An estimate of investment of equipment for each size interval

3. Development of equivalent annual cost for the total of the investment in land, facilities and equipment.

Figure 4.45 presents the outputs, inputs, and transformations for the facilities investment costs. The flowchart for the development of these analyses is presented in Figure 4.46.

The first step involved developing a procedure for estimating the square footage for each size of DC. This was accomplished as follows:

SQFTSZ(ISI) = MAXSZ(ISI) * (1/DPLB) * 1/LBPC) * SQFTPAC

where:

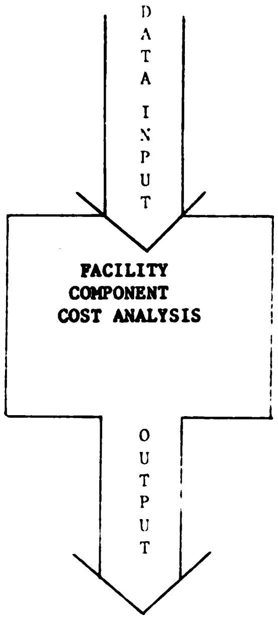
SQFTSZ(ISI) = Square footage for size ISI distribution center

MAXSZ(ISI) = Maximum limit (capacity) of the size interval, ISI

DPLB = Average dollars per pound for all products

LBPC = Average pounds per case for all products

SQFTPAC = Average square footage of floor space per 1000 annual cases.



INPUTS

1. Square footage for each size DC
2. Size intervals of DCs
3. Maximum capacity of each DC size
4. Average dollars per pound all products
5. Average pounds per case for all products
6. Average square footage per 1,000 annual cases
7. Depreciation procedures
8. Economic life of facilities

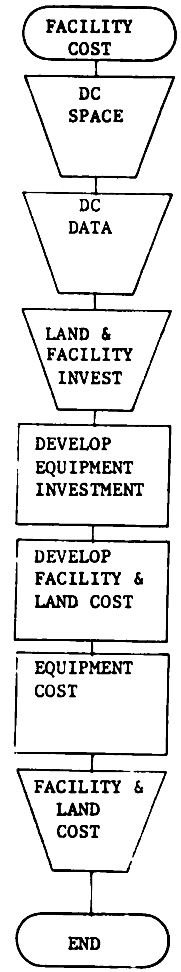
TRANSFORMATIONS

1. Develop estimate square footage required
2. Develop investment in land and facilities for each size interval
3. Develop investment in equipment for each size interval
4. Develop approach for annual cost and quarterly cost

OUTPUTS

1. Approach for DC size estimate
2. Approach for DC investment
3. Approach for DC annual cost

Figure 4.45--Activity Analysis: Facility Investment



Square footage space requirements and capacity requirements for each size interval.

Average dollars per pound for all products, average pounds per case for all products, and average square footage of floor space per 1,000 annual cases.

Develop land and facility investment for each size interval.

Develop equipment investment for each size interval.

Develop approach to annual and quarterly cost.

Approach to equipment cost.

Approach to facility and land cost.

Figure 4.46--Flowchart: Facility Investment

The investment in facilities was then calculated by an assumed dollars investment per square foot of floor space. Investment in land was set at a fixed dollar amount per acre of land, corrected for DC cost of living factors, for each size interval. The investment in equipment determined for such items as conveyor systems and lift trucks was also estimated based on operating data.

The approaches considered for calculating the annual and/or quarterly investment cost included:

1. Evaluation of the cost as a cash flow problem both before and after taxes
2. Evaluation of the equivalent annual or quarterly cost using the time value of money
3. Evaluation of the annual or quarterly cost using standard depreciation techniques such as straight line depreciation.

For the initial LREPS version alternative 3 was selected as Option 1. The time value of money and cash flow alternatives are in the process of being developed as Options 2 and 3 respectively.

Straight line depreciation determined the quarterly cost for Option 1, although other depreciation methods could have been implemented. The depreciation life of the investment was divided between N1 years and N2 years where N1 was for the facility; for example, for the building shell, walls, and railroad spur and N2 was established for conveyor systems, lift trucks, and air conditioners. In the initial version N1 equaled 50 years and N2 equaled 12 years.

Summary

The completion of the above activities was required to provide the supporting data analyses and to prepare the data for the Operating System--Measurement Subsystem. The next major section of the Supporting Data System presents the Monitor and Control Subsystem analysis and data preparation activities.

Monitor and Control

The Supporting Data System--Monitor and Control provided the analysis and data preparation for the two primary functions of the Monitor and Control Subsystem. The functions are (1) monitoring the activities of the simulation model, and (2) controlling the information feedback used for the decision stages within the model.

The required subfunctions of monitoring were:

1. Establish order and perform execution of the activities--THE EXECUTIVE
2. Execute all input and output of the model, except for input of The Order File Generator--THE GATEWAY
3. Schedule fixed events--THE SCHEDULER.

The subfunctions of control consisted of:

1. Review, compare, and decision via the information feedback loops--THE REVIEW
2. Revision or updating of the system state variables--THE UPDATE
3. Provide information required by all other levels of the system hierarchy--GENERATE.

The performance of these subfunctions is presented in Chapter V, Operating System and in greater detail by Marien in his dissertation.[5] The supporting analysis and data preparation for the Monitor and Control Subsystem primarily relate to:

1. The EXECUTIVE Subfunction
2. The GATEWAY Subfunction
3. The REVIEW Subfunction
4. The UPDATE Subfunction.

The Executive Subfunction

The supporting analysis required for the Monitor and Control Executive subfunction included:

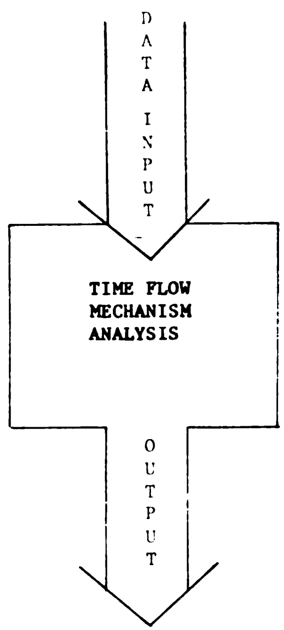
1. Selection of time flow mechanism
2. Selection of programming language.

Figure 4.47 presents the activity analysis in terms of the outputs, inputs, and transformations for evaluation and selection of the time flow mechanism. The flowchart for the analysis is presented in Figure 4.48.

Time Flow Mechanism.--The three approaches evaluated for the time flow mechanism were:

1. Fixed time flow
2. Variable time flow
3. A hybrid combination.

Fixed time mechanism was defined as recording each instant of compressed real time, where each discrete time unit is scanned to determine whether Events are to occur. In the variable time mechanism the clock is advanced until the next most



INPUTS

1. **Definition of time flow mechanism**
2. **Attributes of approaches to time flow mechanism**
3. **Nature of LREPS model-event orientation**

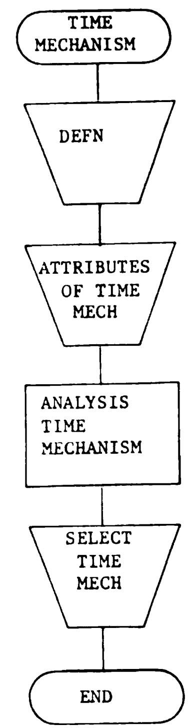
TRANSFORMATIONS

1. **Analysis of approaches to time flow mechanism**

OUTPUTS

1. **Time flow mechanism**

Figure 4.47—Activity Analysis: Time Flow Mechanism



Definition of time flow mechanism.

Attributes of time flow mechanism.

Select time flow mechanism.

Analysis of time flow mechanisms; fixed time, variable time, and hybrid.

Figure 4.48--Flowchart: Time Flow Mechanism

imminent Event is scheduled to occur. A hybrid design includes both a fixed time mechanism and a variable time mechanism.

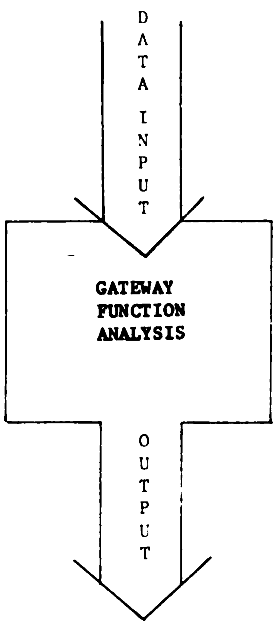
After a review and analysis of the advantages and disadvantages of the time flow mechanisms presented in the literature, the decision made for LREPS was to use a hybrid combination of both fixed and variable time to schedule events.

Selection of Computer Language.--The analysis and selection of the computer language GASP IIA, to perform the functions of the EXECUTIVE and the LREPS model in general was performed by Marien.[6]

The Gateway Subfunction.--The supporting analysis and data preparation related to the input/output requirements of the LREPS model. Figure 4.49 presents the activity analysis in terms of outputs, inputs, and transformations for the GATEWAY function. The flowchart for this analysis is presented in Figure 4.50. The analysis related to the input aspect involved the specification of the list of and frequency of modification of the exogenous variables.

The exogenous input variables are presented in Appendix 1. Analysis indicated that the input frequency of the exogenous variables should be quarterly to test the effect of changes of the factors. The procedure for implementation of the input changes is reported by Marien.[7]

The analyses related to the output of the GATEWAY subfunction required definition prior to the specification of inputs, or the development of the mathematical model, of the nature of the following:



INPUTS

1. Design criteria of LREPS
2. Conceptual model
3. Desired output variables content and frequency

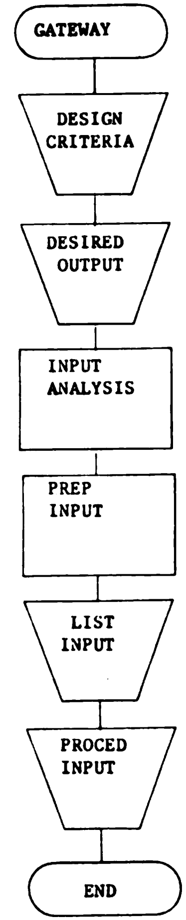
TRANSFORMATIONS

1. Analysis of the input requirements
2. Analysis of frequency of modification to input variables
3. Preparation of procedure for preparing input to LREPS

OUTPUTS

1. List of input requirements
2. Procedure for input changes

Figure 4.49—Activity Analysis: Gateway Function



Design criteria for LREPS for conceptual model.

Desired output variables, content and variability.

Analysis of input requirement, list of variables, content and frequency of change.

Procedures for preparation and read-in of input.

List of input requirements.

Procedures for input changes.

Figure 4.50--Flowchart: Gateway Function

1. Definition of endogenous and/or output
2. Information content of output
3. Frequency of output
4. Types of output reports
5. Formats of output reports
6. Procedure for generating output.

Chapter VI, REPORT GENERATOR SYSTEM discusses this aspect of the GATEWAY function, with major emphasis on the first four items. The specific formats and procedures for obtaining management and special reports are presented in Marien's dissertation.[8]

System Review

Supporting analyses of the REVIEW function were required to select the approach(s) for development of the system change during the simulation cycle for each of the PD components; location, unitization, inventory, communications, and transportation. Two basic approaches were considered. First, the system changes could be introduced via preprogrammed exogenous input at the end of each operating period. Second, information feedback control loops could be used to develop dynamic algorithms. The latter approach was preferred since it meets the design criteria that the model enable the evaluation of the sequential decision problem.

Preliminary analysis was performed to determine whether or not all PD components of the LREPS model should be formulated as information feedback loops thus allowing staged decisions for each component. The analysis indicated that the feedback loops with option for exogenous change for the location, unitization, and inventory components should be implemented in the first LREPS version with exogenous input used to modify the communications and transportation components. In addition the analysis indicated that a feedback loop to modify forecasted sales according to actual service relative to the desired service would be highly desirable in initial LREPS version. The use of modular construction provided the necessary flexibility so that a dynamic decision algorithm can easily be developed for transportation and/or communications components as desired in the future.

Sales Modification Factor.--The effect of a reduction (increase) in service measured by total customer order cycle time, outbound transit, and so on is not known for the majority of actual physical distribution systems. In general, however, it can be assumed that continuous or long periods of poor service probably would have an adverse effect on sales indirectly via "unhappy" customers switching either permanently or temporarily to new sources of supply.

The LREPS model thus incorporated a function to test the effect of reductions (increases in) simulated actual sales even for a general market demand or trend which was assumed to continue unchanged. This essentially allowed the testing of both reductions and increases in market share. The output of the analysis resulted in a concept referred to as the SMF, Sales Modification Factor. Figure 4.51 presents the activity analysis in terms of the outputs, inputs, and transformations for the SMF analysis. The flowchart is presented in Figure 4.52 for the analysis.

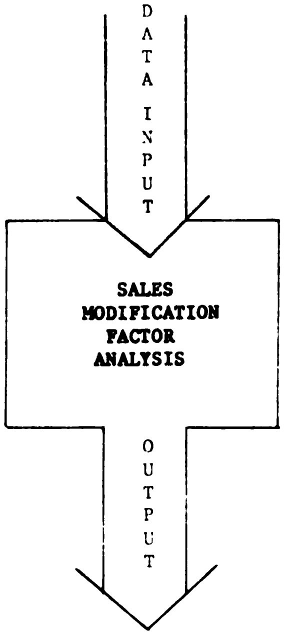
In general, the SMF was defined as the ratio of actual to desired service. The total order cycle time was used as the measure of actual service and the desired service was an exogenous input each quarter. The supporting data required thus included the level of desired service for each quarter of the planning horizon. The use of the SMF to reduce (or increase) sales as the result of the long term quality of service is presented in the Monitor and Control Subsystem, Chapter V.

Facility Location Algorithm.--The supporting analyses required for the location algorithm included:

1. Analysis of potential locations
2. Analysis of solution approaches.

Figure 4.53 presents the activity analysis in terms of the outputs, inputs, and transformations required for development of the facility location supporting analyses. The flowchart is presented in Figure 4.54.

Two basic approaches were considered relative to the potential locations for new distribution centers. First, a non-constrained approach that would allow any location to be selected based on cost, and/or service was evaluated. The location identification for this approach was the latitude-longitude. Therefore, an infinite number of potential locations existed for this approach. The second approach limited



INPUTS

1. Total customer order cycle OCT measure of service
2. Outbound transit time, CT4 as measure of service
3. General effect of quality of service on sales
4. Definition of desired service level and actual service

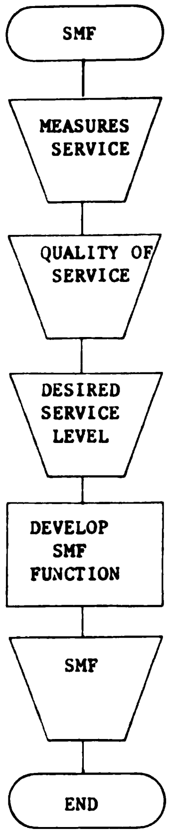
TRANSFORMATIONS

1. Develop function for modifying sales as function of service

OUTPUTS

1. Sales modification factor approach, SMF

Figure 4.51--Activity Analysis: Sales Modification Factor



The measures of service used; total customer order cycle OCT and/or outbound transit time, CT4.

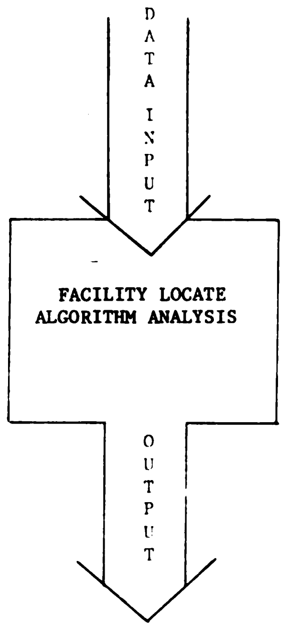
General effect of quality of service vs. sales over time.

Desired service level for the regions over time in terms of the OCT and/or CT4.

Develop function for showing the effect on sales resulting from quality of service.

The sales modification factor procedure or approach.

Figure 4.52--Flowchart: Sales Modification Factor



INPUTS

1. Existing location algorithms LP, dynamic programming, and heuristic
2. Management criteria for locate routine, add and/or delete:
   a. When - basis for need
   b. Where - basis for priority and
   c. Time for implementation

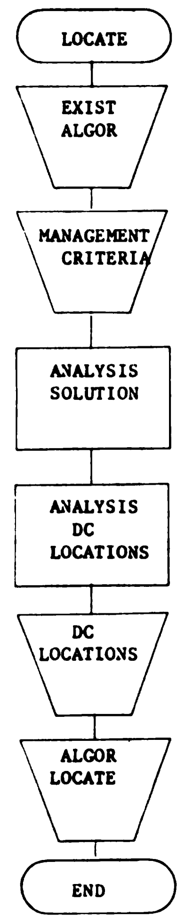
TRANSFORMATIONS

1. Analysis for potential locations
2. Analysis for solution approaches:
   a. Trigger
   b. Review
   c. Priority
   d. Select add and design
   e. Select delete
   f. Schedule and implement

OUTPUTS

1. Approach for potential DC locations
2. Approach for algorithm-LOCATE

Figure 4.53--Activity Analysis: Facility Locate Algorithm



Existing locate algorithms, LP, dynamic programming, and heuristic models.

Management criteria for locate routine, for add and/or delete, for when to process, for priority, and time required for implementation.

Analysis for solution approaches:
1. **Trigger**
2. **Review**
3. **Priority**
4. **Select Add location and Design**
5. **Select Delete**
6. **Schedule and implement**

Analysis for DC locations.

Approach for DC locations.

Approach for Algorithm LOCATE

Figure 4.54--Flowchart: Facility Locate

the potential locations to a fixed list of N sites or cities from which the new locations are selected.

Analysis of the various relevant factors such as adequate transportation networks, carrier availability, labor availability, general acceptability to management, etc. suggested that an approach closer to a fixed list approach was more realistic. A fixed list developed via heuristic rules was therefore incorporated in LREPS where the maximum list size N was set initially at 35 locations. Each potential site was identified by city name and in the model also by latitude-longitude.

The three basic location algorithm approaches evaluated were (1) linear programming algorithm, (2) a heuristic algorithm, (3) a dynamic programming algorithm.[9,10,11] All of these approaches were considered because they have been previously implemented for facility location problems. The heuristic algorithm approach was selected as Option 1, however, even though sufficient data appeared to be available within the model to use either of the remaining two alternative approaches. The dynamic programming approach was not selected because of the complexity of implementation in the model.

The LP model selected as Option 2 was not selected for initial implementation because:

1. LP models programmed to be compatible with LREPS did not appear to be readily available, thus implementation time rules out this alternative

2. Existing LP models were not flexible enough to allow the variety of management constraints desired

3. Analysis indicated computer core and processing time requirements would have been above acceptable limits.

Linear Programming is, however, being evaluated for implementation in the next version of LREPS. Various combinations of routines were considered to develop the LOCATE algorithm. The basic format of the algorithm implemented as Option 1 is presented in the Monitor and Control Subsystem, Chapter V. The algorithm consisted of:

1. TRIGGER to review deficiencies of the in-solution facility network
2. REVIEW of management constraints
3. PRIORITY of regions for network changes
4. If ADDITION, SELECT location and DESIGN new facility
5. If DELETION, SELECT location for deletion
6. SCHEDULE for implementation and after elapsed TIME bring into solution.

The TRIGGER determined when the LOCATE algorithm was to be processed or called by the Monitor and Control Subsystem. As programmed the Option 1 LOCATE was designed with a fixed time event TRIGGER set to function quarterly. The analysis for the REVIEW step considered various alternative management constraints. For the initial version of LREPS the constraint variables implemented included limits for investment dollars actual and committed, and facilities in-solution and in-process.

The analysis performed for the PRIORITY function required development of the approach(s) to select the region which was operating with:

1. The greatest deficiency (surplus) of service relative to the desired level of service
2. The highest level of cost relative to the desired cost

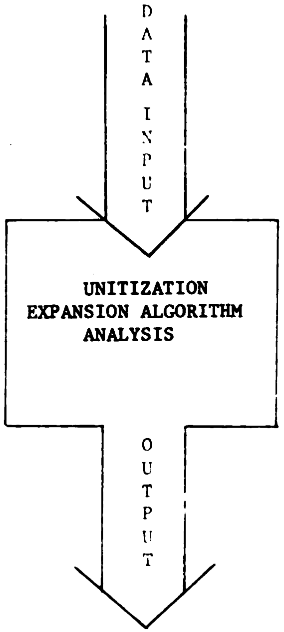
3. A combination of service and cost.

The next major step in the algorithm is SELECT the location for ADDITION if for example service is deficient or DELETION if service is surplus relative to the desired service. A new facility must be DESIGNED to establish the size and type. Both additions and deletions must be SCHEDULED for implementation of the decision after the elapsed TIME. The algorithm is presented in detail in the Monitor and Control Subsystem, Chapter V.

Unitization Expansion Algorithm.--The supporting analysis required for the unitization algorithm for the DC expansion involved primarily an analysis of solution approaches. Figure 4.55 presents the activity analysis in terms of the outputs, inputs, and transformations required for the development of the supporting analyses. The flowchart is presented in Figure 4.56.

The basic approaches taken for the EXPANSION routine involved analysis similar to the LOCATE routine. The format was generally developed as follows:

1. TRIGGER for when to expand a DC
2. REVIEW of management constraints to determine if expansion is possible
3. PRIORITY for selection of the region for which expansion is most critical
4. SELECTION of location to be expanded
5. Determine new SIZE of the expanded DC
6. SCHEDULE for implementation and after elapsed TIME bring new SIZE into solution.



INPUTS

1. Management criteria for expansion:
   a. When - basis for need
   b. Where - basis for priority
   c. New size
   d. Time for implementation

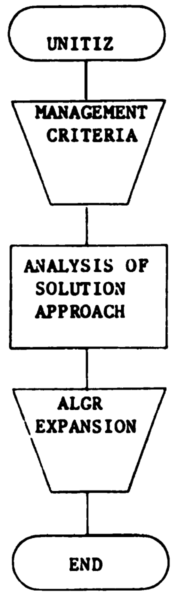
TRANSFORMATIONS

1. Analysis of solution approaches:
   a. Trigger
   b. Review
   c. Priority
   d. Selection
   e. Expansion to new size
   f. Schedule and implement

OUTPUTS

1. Approach to expansion of in-solution DC

Figure 4.55—Activity Analysis: Unitization Expansion Algorithm



Management criteria for expansion routine, for when to process, priority, new size and time for implementation.

Analysis of solution approaches:
1. **Trigger**
2. **Review**
3. **Priority**
4. **Select**
5. **Expansion to new size**
6. **Schedule and implementation**

Approach to expansion of in-solution DC.

Figure 4.56--Flowchart: Unitization Expansion

The detailed algorithm for EXPANSION is presented in the Monitor and Control Subsystem, Chapter V.

Inventory Management.--The inventory management required the supporting analyses for inventory policy and the partial-line inventory procedures. Figure 4.57 presents the activity analysis in terms of the outputs, inputs, and transformations for the inventory management support analyses. The flowchart is presented in Figure 4.58. Brown discusses three levels of inventory management systems:

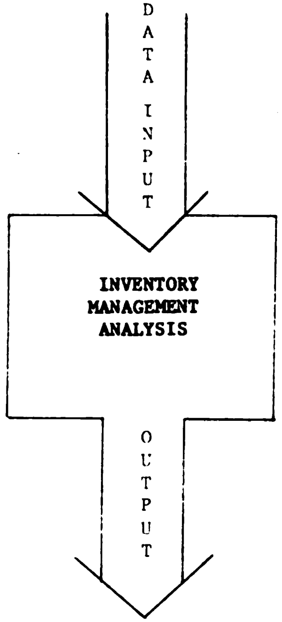
1. Level 1--order processing and reconciling book balances with periodic physical stock counts

2. Level 2--computation of order point and stock operating level via inventory management decision rules

3. Level 3--monitoring of actual performance resulting from Level 1 order processing, comparing it to performance intended by policy and reporting the differences.[12]

The Level 1 system in the LREPS model is the inventory control procedures in the Operations Subsystem. The Level 2 and Level 3 systems in LREPS are included in the Monitor and Control Subsystem. Simulation allows the evaluation of alternative decision rules for strategic selection among the rules and tactical decisions of policy.

The inventory component of the Monitor and Control Subsystem was analyzed as a Level 3 system. After extensive analysis and review of the literature the



INPUTS

1. Definition of levels of inventory management
2. Types of inventory control policy
3. Inventory tracked product categories
4. Definition of partial-line DCs

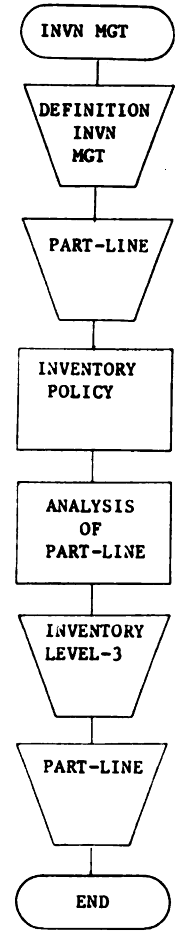
TRANSFORMATIONS

1. Inventory policy analysis:
   a. Approach for review period
   b. Inventory initialization procedure
   c. Safety stock procedure
   d. Reorder quantity procedure
2. Partial-line inventory procedure

OUTPUTS

1. Approach for inventory management level-3
2. Partial-line approach for PDC and RDC

Figure 4.57—Activity Analysis: Inventory Management



Definition of levels of inventory management, types of inventory control policy.

Inventory tracked products categories.
Definition of partial-line inventory.

Inventory policy analysis:
1. Theoretical inventory models
2. Approach for review period
3. Inventory initialization
4. Safety stock procedure
5. Reorder quantity procedure

Analysis of partial-line inventory for PDC and RDC.

Approaches for inventory management level-3.

Partial-line approach for PDC and RDC.

Figure 4.58--Flowchart: Inventory Management

policy options selected for testing the full range of the Level 3 system included:

1. Reorder point system
2. Review period system or optional replenishment system
3. Heuristic inventory management policy
4. A hybrid combination of the reorder point and replenishment system.

For the LREPS model, two inventory options accomplished this full range of inventory policies. First, Option 1 was developed as a heuristic inventory policy to enable management to set exogenously the safety stock, EOQ, reorder point, and so on. The second, Option 2, referred to as the inventory management module, was developed as a hybrid of the reorder point and optional replenishment systems. The detailed options are presented in the Monitor and Control Subsystem, Chapter V.

The use of the review period policy required that a review period be established for each tracked product. Based on initial analysis it appeared that development of a review period by each inventory category A1, A, B, and C would require less computer core, less analysis, and remain accurate and logical.

The initialization process required analysis of the reorder points, replenishment levels and initial inventories for all tracked products for each DC initially in-solution. The reorder points, replenishment levels and initial inventories were calculated using base year sales, 1969. The two major components used to develop the information were the lead time and average daily demand. The percentage of base year total sales volume moved through a particular DC was multiplied by the base year case unit sales of the tracked product being considered to develop the annual demand per product per DC. This divided by the number of working days assumed for the year (252) provided the average daily demand for the tracked product for the given DC.

Lead time was previously defined as the sum of the reorder transmission time, RT1, the reorder processing time, RT2, the time the order has to wait from the time at which it was ready to ship until the time at which the (scheduled) shipment was made, RT3, and finally the shipment transit time, RT4.

The safety stock requirements were developed for both the heuristic policy and the inventory management modules. The heuristic policy established the safety stock as a fixed number of days for each category A1, A, B, and C whereas for the inventory management module two standard deviations of demand was set as the safety stock.

Analysis of the reorder quantities was in general established based on the EOQ formulation. The detailed transformations are presented in Chapter V.

Update Function

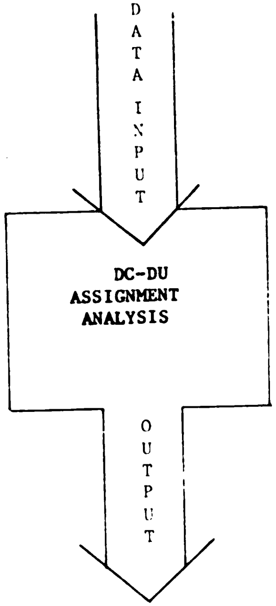
The supporting analysis related to the Update function was the DC-DU Assignment Analysis. This analysis was required for the LOCATE algorithm since addition or deletion of a DC caused a shift in the DC-DU assignments. Figure 4.59 presents the activity analysis in terms of the outputs, inputs, and transformations for the DC-DU Assignment Analysis. The flowchart is presented in Figure 4.60.

The approaches considered for assignment of the service areas of the DC network after an addition or deletion included:

1. Assign DUs to the closest DC in-solution
2. Assign DUs to the DC by the minimum estimated transportation cost
3. Assign DUs to the DC by geographical marketing area for example by state, county, or groups of ZSC's
4. Assign DUs to the DC by the net effect expected on total cost and/or service.

After preliminary analysis the approach that appeared to be logical and practical for the initial version of LREPS was a hybrid combination of the minimum mileage and minimum transportation cost, alternatives number 1 and 2. Option 1 established assignments based on both transportation cost and service time.

Initially as part of the data input each DU was assigned to a maximum of N different potential DCs with a relative ranking scheme indicating the preference in terms of the Option 1 criteria. The value of N for the initial version of LREPS was set at a maximum of seven and a minimum of one. Multiple assignment of DUs



INPUTS

1. DC-DU, PDC-DU mileage
2. DC-DU, PDC-DU outbound costs
3. DU assignment preferences by management

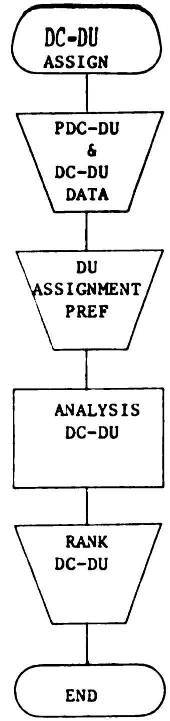
TRANSFORMATIONS

1. Analysis of DC-DU assignments

OUTPUTS

1. Ranking procedure for DC-DU for assignment of DU to "BEST" DC in-solution

Figure 4.59--Activity Analysis: DC-DU Assignment



PDC-DU and DC-DU mileage and costs.

DU assignment preferences by management.

Analysis of DC-DU assignment approaches.

Ranking procedure for DC-DU assignment based on assigning DU to the best DC in-solution.

Figure 4.60--Flowchart: DC-DU Assignment

was necessary since each DU was served by the highest ranking DC in-solution. Multiple rankings were developed for each DC until the PDC for the region was assigned to the DU. The PDC was automatically set as the seventh ranking DC if the Option 1 rules caused the PDC to be of lower preference than the seventh rank. The length of the multiple ranking was set at a fixed value so that the computer arrays would be of fixed size. The regional PDC was thus always the final assignment for each DU.

Summary

The above supporting activity analyses were required for the Monitor and Control Subsystem. At this point the Supporting Data System analyses and data input requirements have been presented for the Operating System--the Demand and Environment Subsystem, the Operations Subsystem, the Measurement Subsystem, and finally the Monitor and Control Subsystem. The next major area is the Operating System, Chapter V, in which the inputs, outputs, and transformations of the initial LREPS version are presented.

CHAPTER IV--FOOTNOTE REFERENCES

[1]Bowersox, *et al.*, Monograph.

[2]Rand McNally Commercial Atlas, 1969.

[3]Packer.

[4]Bowersox, LaLonde, and Smykay.

[5]Marien.

[6]*Ibid.*

[7]*Ibid.*

[8]*Ibid.*

[9]Wagner.

[10]Kuehn and Hamburger.

[11]Ballou, "Dynamic Warehouse . . ."

[12]R. C. Brown, *Statistical Forecasting for Inventory Control* (New York: McGraw-Hill, 1959).

CHAPTER V

THE OPERATING SYSTEM

Introduction

The Operating System includes the Demand and Environment Subsystem, the Operations Subsystem, the Measurement Subsystem, and the Monitor and Control Subsystem. The Operating System simulates the operation of the physical distribution system using input from the Supporting Data System and generating output for the Report Generator System.

The primary objective of this chapter is to present the model in a manner that demonstrates the modular and universal nature of the activities of the Operating System for firms of the general description of Figures 1.1, 1.2, and 1.3. The outputs, inputs, and transformations are presented for each activity in sufficient detail to illustrate the application of the model to a particular class of firm.

Each of the subsystems is discussed in the general sequence that a batch of customer orders are processed as follows:

1. The Demand and Environment Subsystem
2. The Operation Subsystem
3. The Measurement Subsystem
4. The Monitor and Control Subsystem.

In certain cases an activity of a subsystem is presented with the activities of a different subsystem to illustrate the linkages between the various subsystems.

Demand and Environment Subsystem

The primary function of the Demand and Environment Subsystem is to generate information for the Operations Subsystem related to forecasting and allocation of sales, customer order generation, and the assignment of customer orders to agglomerated demand units.

In order to eliminate the processing of individual customers, customer demands are summarized to the 560 Zip Sectional Centers for the domestic United States. These Zip Sectional Centers are the lowest level of demand control. A stratified sample of a firm's products based upon a defined ABC classification and of the firm's actual orders from its information system is selected at random and stored on magnetic tape. This sample of customer orders is used to create a matrix of blocks of orders that serves as the basis for generating orders for each day of simulation operation.

Order generation consists of randomly pulling sufficient blocks of orders from the order matrix to meet the daily sales forecast for each customer demand unit. The daily forecast is based upon a set of selected, correlated independent variables such as population, retail sales, personal income, and effective buying power.

During this order generation step pseudo orders, with different order characteristics can be added to the order matrix to test the effect of various levels of demand from different classes of customers. The pseudo orders are also used to test the effect of changing buying patterns of existing classes of customers. In addition, the pseudo orders serve as the method of measuring the dynamics of various unit inventory control policies contained within the model. Finally, the pseudo order matrix allows the introduction of new products on system performance and design. Finally, the pseudo order matrix allows the introduction of new products to test the effect on system performance and design.

Each demand control unit, with its allocated customer orders, is then assigned to an in-solution distribution center on the basis of a predetermined selection criteria such as minimum distance, minimum transit time, minimum transportation cost, or based on a heuristic rule combining all three criteria.

The output of the Demand and Environment Subsystem, the daily sales dollars (orders) allocated to each demand unit and assigned by demand unit to a distribution center, serves as the input to the Operations Subsystem.

The Demand and Environment functions are accomplished by the processing of the Fixed Daily Event, a Monitor and Control Subsystem Event, via the activities, Daily Domestic Sales Dollar Quota and Sales Processing. These activities, illustrated in Figure 5.1, are presented in the next two major sections.

Daily Domestic Sales Dollar Quota

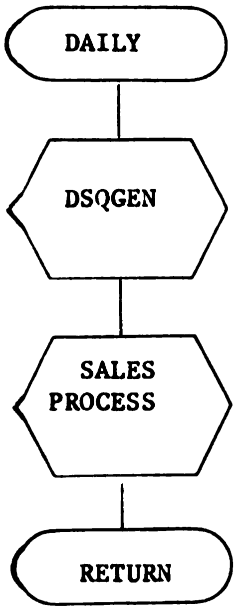
The Daily Domestic Sales Dollar Quota is used to generate the daily sales forecast for the total United States market excluding the states of Alaska and Hawaii. Figure 5.2 presents the activity analysis in terms of the outputs, inputs, and transformations developed for the Daily Domestic Sales Dollar Quota activity. The flowchart for this activity is presented in Figure 5.3.

The basis for calculation of the daily sales quota was developed in the Supporting Data System, Chapter IV. The transformations developed for this calculation are:

$$DSQ(ID) = (TDSF(IY)/NWKDYS) * MODIFAC$$

where:

- DSQ(ID) = The total domestic daily sales quota or forecast for day, ID
- TDSF(IY) = The annual domestic forecast in dollars for year, IY
- NWKDYS = The number of simulated workdays in a year
- MODIFAC = The Modifier function or factors for the combined effect of variability in sales by day, week, and/or month of the year.

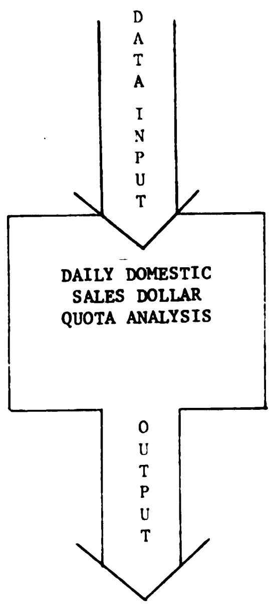


DAILY EVENT. The procedure to call this event is presented in the Monitor and Control Subsystem.

A routine to obtain Domestic Forecasted Daily Sales Quota.

A routine to process for one region; all RDCs, and the PDC. Then the next region until all regions processed.

Figure 5.1--Flowchart:
Daily Event



INPUTS

1. Annual domestic dollar forecast
2. No. of simulated workdays in calendar year

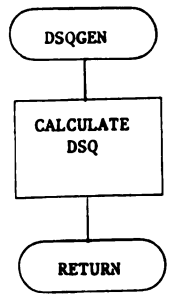
TRANSFORMATIONS

1. Calculate modifier
2. Calculate daily sales quota

OUTPUTS

1. Daily domestic sales quota

Figure 5.2--Activity Analysis:
Daily Domestic Sales Dollar Quota



Generate Daily Domestic Sales Dollar Quota.

Calculate DSQ as a constant; and/or as Monte Carlo function.

Return to Daily Event.

Figure 5.3--Flowchart:
Daily Domestic Sales Dollar Quota

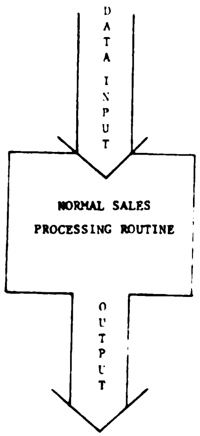
The daily sales quota via the modifier function thus can be generated as a constant per day, a random variate, a trend modified variate, a seasonal variate, or a combination of these.

Sales Processing

The Sales Processing Activity processes the normal daily sales of the demand units assigned to a distribution center, the DC-DU links. As shown in Figure 5.1 the Sales Processing Activity, as part of the Monitor and Control Fixed Daily Event, processed the sales after the Daily Domestic Sales Quota had been calculated. Figure 5.4 presents the activity analysis of the Sales Processing Activity in terms of the outputs, inputs, and transformations. The flowchart is presented in Figure 5.5.

DC Sales.--The first step in this activity was to determine the simulated sales for the in-solution distribution center being processed. The basis for the allocation of the sales quota to a DC in-solution was developed in the Supporting Data System, Chapter IV.

The percentage of the Domestic Daily Sales Quota allocated to DC in-solution being processed was established based on the Relative Demand to DC Activity presented in the Supporting Data System. This activity calculated the relative demand on the sum of the weighted indices. The sum of the weighted indices represented the percentage of sales of the daily domestic total allocated



INPUTS

1. In-solution DC being processed
2. Potential DC code being processed
3. Group of customer orders
4. Region being processed
5. Regional cust dollar split percentage
6. Orders blocks per cust type
7. Total number of DU's being processed
8. Special customer indicator
9. DC assigned DU
10. Cumulative weighted index
11. In-solution DC pointer
12. Number of DU's in DC
13. Sales modification factor
14. Sum of DU weighted indices
15. DC simulated sales
16. Cust type being processed
17. Cust sales dollar allocation
18. Cust sales dollar accumulator
19. Order block modifier
20. Number of order blocks per cust type
21. Number of past order blocks processed
22. Demand unit being processed
23. Daily domestic sales dollar quota

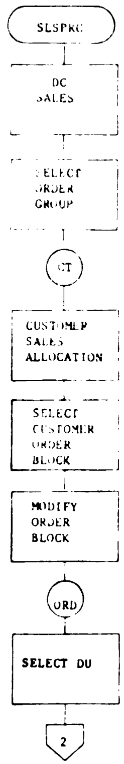
TRANSFORMATIONS

1. Calculate DC simulated actual sales
2. Select order group
3. Customer sales allocation
4. Select customer order block
5. Modify order block
6. Select DU
7. Process individual order
8. Process order summary
9. Select order group
10. Forecast sales by DC
11. Process sales and orders by cust type
12. Update inventory

OUTPUTS

1. Demand unit selected for order
2. Cust order being processed
3. Cust order block being processed
4. Group of customer orders

Figure 5.4--Activity Analysis:
Normal Sales Processing



Sales Processing Activity called by the Daily Event for the DC currently being processed.

Calculate DC simulated actual sales.

Select Order Group and pull in for Demand Generation.

Process sales by Customer Type or Class; Type 1, Type 2 and Pseudo (Type 3).

Calculate the amount of sales to be allocated to the Customer Type or Class.

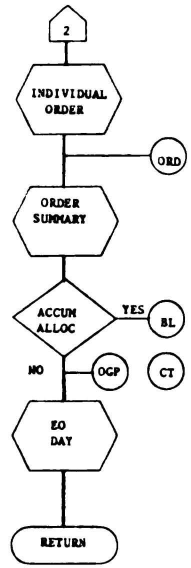
Randomly select an Order Block from the Customer Block Type set of blocks within the Order Group.

Modify Order Block information by the Order Block Modifier (OBM) which is 1.0. The OBM based on % sales of the Block required to reach the Quota for the day.

Process all the N Orders for the Order Block. N=10 in initial LREPS.

Randomly select DU for this Customer Type, (1,2 or Psuedo). If invalid DU i.e. DU does not contain the Customer Type being processed, select another DU.

Figure 5.5--Flowchart:
Sales Processing



Process Operations Routine - Individual Order for DC-DU Link.

Loop through all orders for the Order Block being processed.

Process Operations Routine - Order Block Summary for the DC.

IF ACCUMULATED SALES IS ALLOCATED AMOUNT go back to select another Order Block.

Loop through all selected Customer Types.
Loop through for next DC, Select new Order Group.

Process Operations End-of-Day Routine for in-solution DC's inventory levels.

Return to "DAILY" EVENT.

Figure 5.5--Continued

to each DC for the current quarter of simulated operations. The product of the sum of the weighted indices for the quarter times the domestic sales forecast established the sales forecast for the DC for the day.

The daily sales forecast for the DC was next adjusted by the Sales Modification Factor, SMF, to obtain the simulated actual sales or sales quota. The SMF, previously defined in the Supporting Data System--Demand and Environment, is an exponentially smoothed ratio of actual to desired service level calculated at the end of each quarter. The SMF factors were generated for each DC and region via a feedback-control loop within the Monitor and Control Subsystem. The transformations developed for calculating the simulated actual sales or sales quota by DC were of the form:

DCSALS(ID) = DSQ(ID) * WI(IQ) * NWSMF(IQ)

where:

DCSALS(ID,IDC)	=	The simulated actual daily sales dollars for the DC for the day, (ID)
DSQ(ID)	=	The daily sales quota (forecast) for day, (ID)
WI(IQ)	=	The sum of the weighted indices for all DUs assigned to the DC for quarter, IQ
NWSMF(IQ)	=	The current exponentially smoothed value of the ratio of actual to desired service.

The daily domestic sales quota or forecast was thus used to calculate the actual simulated sales for each DC in—solution on the particular day.

Select Order Group.--An order group containing the sets of customer order blocks was then read in to provide the total basis for demand generation for the DC for the current clock day. As stated in Chapter IV, Supporting Data System--Demand and Environment, the total number of equivalent orders within the order blocks of the order group was established to provide the larger size DC's with the average number of orders normally processed per day.

Process Customer Type.--The next major step involved processing of sales and orders by the customer types selected via the customer type analysis. The percentage sales allocated to the customer types for the region being processed was used to calculate the simulated sales allocated to each customer type for the DC. The transformation for this calculation was:

CSTSAL(ICT,IDC,ID) = DCSALS(ID,ICT) * CSPLTP(ICT)

where:

CSTSAL(IDC,ID) = Customer type ICT simulated sales dollar allocation for day, ID, for DC (IDC)

DCSALS(ID,ICT) = Simulated actual daily sales dollars for the DC(IDC) for day, ID

CSPLTP(ICT,IR)= Regional, IR customer, ICT dollar split percentage.

A random variate generator was then used to select an order block from the appropriate customer's order block file. The sales accumulated for the DC being processed was then compared against the sales quota or allocation of the DC for the current day to calculate the value of an order block modifier, OBM. The OBM, the percentage of the customer order block being processed, was required to generate the simulated sales allocated to the DC for the day. The transformation was of the form:

OBM(ICT,IDC,ID) = (CSTSAL(ICT,IDC,ID) -
CSTDAC(ICT,IDC,ID))/ORDBLK(ICT)

where:

OBM(ICT,IDC,ID)	= Order block modifier (OBM) for the customer types, ICT; DC,IDC and day, ID
CSTSAL(ICT,IDC,ID)	= Customer type, ICT sales dollar allocation for DC, IDC for day, ID
CSTSAC(ICT,IDC,ID)	= Accumulated customer type, ICT sales dollars for DC, IDC for day, ID
ORDBLK(ICT)	= Sales dollars for customer type, ICT order block ready to be processed.

Process Orders at DU.--The next major step initiated the processing of the N equivalent individual orders of the customer order block at the DC-DU level. In the initial version of LREPS each order block contained ten orders (N=10) for each of the three customer types. A random variate generator selected a DU from among the DU's assigned currently to the in-solution DC being processed.

The basis for the Monte Carlo procedure was the DU's weighted indices for sales allocation. The probability distribution for selection of the DU's within a DC service area was developed as shown below assuming hypothetically that only five DU's were currently assigned to the DC:

For Each DC-IDC Number

DU:ZSC No.	Code	WI	$\sum$WI	WI Prob.	Cust. Types
1	110	0.001	0.001	10%	1,2
2	101	0.003	0.004	30%	1,3
3	112	0.001	0.005	10%	1,2
4	100	0.004	0.009	40%	1,2,3
5	108	0.001	0.100	10%	1

Each DU selected was then checked to determine if the DU contained the special customer type being processed. If for example the customer type being processed was Type Number 2 and the initial DU selected was DU Number 2 the DU would be unacceptable since it does not contain the type of customer being processed. In this case another DU was selected until any one of DU's Number 1, 3, or 4 was selected. Once the appropriate DU was selected the individual order was processed for the DC-DU link.

At this point in the operating sequence the Operations Subsystem Activity-Individual Order (INDORD) processed the orders allocated to the DU by accumulating the dollars and weight at the DU level. This routine is presented in more detail in the Operations Subsystem. The above sequence was repeated until N orders of the order block had been processed. The Operations Subsystem Routine-Order Summary next developed the product detail and all the summarized sales information at the DC-level. This routine is presented in the next section of the Operating System.

The decision block next checked the amount of accumulated dollar sales for the customer type being processed against the allocated sales. An additional order block for the customer type was randomly selected unless the accumulated sales dollars were less than or equal to one half percent (0.5%) below the allocated sales. When the allocated sales were achieved a new order group was selected to process the next DC for the current day.

End-of-Day.--The final Operations Subsystem Routine, End-of-Day performed the end of day activities such as inventory update for the orders processed during the day. The Operations Subsystem presents this routine in more detail. Once all of the DC's have been processed for the day the control of the LREPS model was returned to the Monitor and Control Subsystem for scheduling and processing of the next event.

Summary

The Daily Sales Quota and Sales Processing events presented in this section develop the input necessary for the Operations Subsystem. The Operations Subsystem, the next section of this chapter, presents the events, routines, and activities developed to simulate the operation of the physical distribution system structured for the LREPS model.

Operations Subsystem

The Operations Subsystem deals with the flow of products and information through the physical distribution system. The orders allocated by the Demand and Environment Subsystem must be processed at the remote distribution centers. Thus, for each remote facility in the physical distribution network, orders will arrive each day from the customer demand units. The batch of orders from each demand unit is then assigned a communications delay referred to as the customer order transmittal time. This time delay is the first element of the total order cycle, CT1. The order transmittal times are selected from a discrete probability distribution based on the expected variation around the average time delay.

The orders are then processed to determine if sufficient inventory for each of the tracked products in the orders is available. If sufficient product units are in stock the order is prepared and a shipment dispatched to the demand unit. The order processing and preparation are assigned a combined time delay which is also based on a discrete probability distribution, CT2.

The transit time from shipment dispatch until shipment arrival at the demand unit is based on the reliability of achieving the average service time stated for the distance from the distribution center to demand unit, CT4. A discrete probability distribution formed the basis for developing the reliability function.

If the inventory for a particular product is insufficient, back orders are created. As inventory reorder points or periods are triggered, replenishment orders are dispatched to the firm's replenishment centers. The shipment (replenishment) is then scheduled to arrive at the distribution center after a time delay due to order transmittal to, order processing and preparation at, shipping schedules at, and transit time from, the replenishment center. The information from these time delays determines the replenishment reorder cycle statistics which are used to generate the mean and standard deviation of reorder cycle time. The average customer order cycle time is thus a function of the customer order transmittal time, the customer order processing and preparation time, the average stockout delay time, and the customer transit time.

The inventory policies tested in the model for the tracked products include a daily reorder point system, an optional replenishment system and a hybrid combination of the reorder point and replenishment systems. The information for the tracked products is extrapolated to the total line of products of the firm.

The effect of information flow for various communications networks can be tested using different values of, and functions for, the various order transmittal and order processing time delays in the Operations Subsystem.

The Operations Subsystem performed the above functions via a series of fixed and variable events. The fixed time activities included the following four areas:

1. The processing of individual orders which included the allocation of and accounting for sales information at the demand unit plus the generation of and accounting for customer service statistics at the distribution center level (INDIVIDUAL ORDER)

2. The processing of the tracked product-multi order summarys, the order block's, both sales and product detail information at the distribution center level (ORDSUM)

3. The distribution center End-of-Day Activities by which the distribution center's tracked product inventory levels are checked with the appropriate inventory management policy variables to determine if reorder for product replenishment should be dispatched from the distribution center to the supplying manufacturing control centers (DC-EODAY)

4. The End-of-Day Activities at the distribution center to determine if any shipments are ready to be dispatched to the distribution center from the supplying manufacturing control center's (DC-EODAY).

The variable time events, which do not occur every basic time unit, in this model the day, for the DC-MCC links were grouped under two major categories:

1. The arrival of a multiple-product reorder at a MCC which was placed by a DC, (MCORAR)

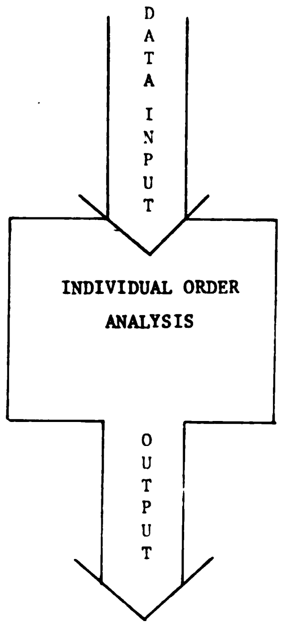
2. The arrival of a replenishment shipment at a DC for a supplying MCC, (DCSHPAR).

Fixed Event-Individual Order

The processing of the Individual Order Routine called by the Daily Event previously discussed in the Demand and Environment Subsystem, allocated the sales information to the demand units and generated the customer service statistics at the distribution center. Figure 5.6 presents the activity analysis in terms of the outputs, inputs, and transformations for the Individual Order Routine. The flowchart for this routine is presented in Figure 5.7.

Order Cycle Time CT1.--The first activity of the Individual Order Routine generated the CT1, customer order transmittal time for the DC-DU link. The generation of CT1 both constant and variable times as previously presented in the Supporting Data System--Measurement were developed using sets of concentric rings for the constant and Monte Carlo selection procedures with values of 0, 1, or 2 for the variable element.

The next step depended on the type of distribution center being processed. If the DC was a full-line, RDC-F, the entire individual order was allocated to the DC. If, however, the DC was a partial-line the percent of the individual order allocated to the RDC-P must be calculated. The basis for splitting the order between the RDC-P and its assigned PDC as presented in the Supporting Data System was the accumulated weight of the RDC-P's tracked products. The transformation required was of the form:



INPUTS

1. In-solution DC being processed
2. Potential DC code being processed
3. DU selected for the order
4. Customer order block being processed
5. Total no.of inventory categories
6. DC type and PDC assignment
7. Service time variance functions
8. T_2 maximum \$ daily shipment for PDC
9. Percent of PDC daily customer shipments
10. Capacity constraint by DC size
11. DC size indicator
12. Customer service time ring nos.
13. Average weight per case unit
14. Partial line inventory category
15. Order block from groups
16. % order for full-line DC
17. % order for partial-line DC

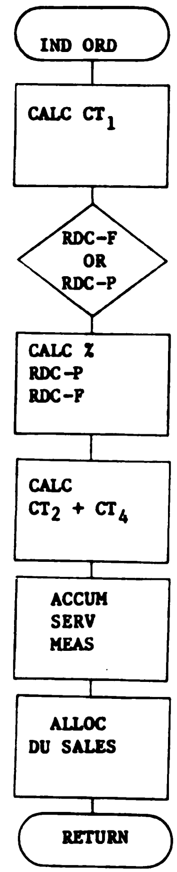
TRANSFORMATIONS

1. Calculate order transmitted time, CT1
2. Calculate percentage of the order to the RDC-P
3. Calculate order processing and preparation time, CT2
4. Calculate outbound transit time, CT4
5. Accumulate service measures
6. Allocate DU sales

OUTPUTS

1. QTD sales for full-line, and partial-line DC
2. QTD wt. sales for full-line, and partial-line DC
3. NOCT sales \$ and orders proportions
4. Average and std. deviation of NOCT accumulators
5. Average and std. deviation of outbound transportation

Figure 5.6--Activity Analysis: Individual Order



Calculate the order transmittal time, CT1

Determine whether the RDC is a full- or partial line

Calculate the percentage of the order to the RDC

Calculate the order processing and preparation time, CT2 and the outbound transit time, CT4

Accumulate information necessary to develop the measures of service for the DC-DU link

Allocate the sales information to the DU

Return to the D & E sales processing event

Figure 5.7--Flowchart: Individual Order Routine

$$\text{RDCPLPC(IDC)} = \sum_{\text{IPL}} \text{WTCU(IPL)} / \sum_{\text{ITP}} \text{WTCU(ITP)}$$

where:

RDCPLPC(IDC) = Percent of the weight of each order in this order block allocated to the RDC-P

WTCU = Average weight per case unit for the tracked product

ITP = Identification of tracked product

IPL = The identification of partial-line tracked products

IDC = The identification of the DC.

The percentage of the weight and sales of the order allocated to the PDC was then established by:

$$\text{RDCPC(IO)} = 100\% - \text{RDCPLPC(IO)}$$

where:

RDCPC(IO) = Percent of weight of each order in this order block allocated to the PDC for each split order

RDCPLPC(IO) = Percent allocated to RDC-P

IO = Identification of order.

Order Cycle Time CT2.--After allocation to the RDC-F or-P the next step calculated the customer order processing and preparation time at the DC, CT2 and the customer shipment time, DC-DU, CT4. The value of CT2 was developed using a Monte Carlo procedure that generated a time for order processing and preparation of 0, 1, or 2 days. This activity also added an additional one day delay to the randomly generated value for each individual order whenever throughput exceeded a set percentage of design capacity. The transformation for this aspect of the unitization component at the DC was:

CT2 = NCT2 + CAPDL

where:

CT2 = Total order processing and preparation time for customer order cycle time

NCT2 = Normal CT2 calculated from Monte Carlo function with values of 0, 1, or 2 days

CAPDL = The additional one day delay for each order when the volume at DC exceeds 70% of design capacity.

An additional test required prior to generating CT2 was made to see if the DC being processed was a PDC. Since the throughput volume of a PDC warranted pooled or consolidated shipments to the DU's a procedure was established for scheduled shipment dispatch of a percentage to the customer orders. If the maximum daily shipment (SDSM) to the PDC, was greater than the customer order being processed (IORD) a random number was generated to determine if the order being processed was one of a set percentage (CSDP) of orders that received daily shipment dispatch. All other orders less than SDSM plus all orders greater than SDSM were shipped on the next scheduled shipment day, for example Monday, Wednesday and Friday of simulated calendar time. The CT2 for the orders that were shipped on the day ready to ship was generated in the same manner as the CT2 for the PDC's, the RDC-F, and RDC-P. The CT2 designated for the scheduled distribution was based on the order processing and preparation time plus any additional delay resulting from the ready to ship date to the next scheduled shipment day. The transformation was:

IF(DCSLQD(IDC) is > ULOPC(IDC) * DCCAPC(IDC)

where:

DCSLQD(IDC) = Sales volume in dollars for the DC(IDC) quarter-to-date

ULOPC(IDC) = Upper limit on throughput, or sales volume as percent of design capacity before delay occurs in order processing and preparation

DCCAPC(IDC) = Design capacity of DC(IDC) in throughput dollar volume

then:

CT2 = PARM + 1

where:

PARM = A Monte Carlo function of the form:

Probability of Delay	Normal Order Processing and Preparation Time
70%	1-day
20%	2-day
10%	3-day

Order Cycle Time CT4.--The generation of the shipment time for outbound transit CT4 for the DC-DU link was next calculated based on the same procedure of concentric service rings for constant time element and the variance functions for the variability time element as used to generate the CT1 element.

Service Measures.--The next activity accumulated the information required by the Measurement Subsystem to calculate the measures of service for the DC-DU link. This activity accumulated the information necessary to develop the measure of the amount of sales dollars and orders within a certain interval of normal customer order cycle time days (NOCT = CT1 + CT2 + CT4). Based on the NOCT generated for the individual orders the following table was constructed for each quarter for the DC being processed:

DC(IDC)

NOCT-INTERVAL No.	Days	QTD Dollars	%	QTD Orders	%
1	0-3	SLSDOLS(1)	PCD(1)	SLSORDS(1)	PCO(1)
2	3-5	SLSDOLS(2)	PCD(2)	SLSORDS(2)	PCO(2)
3	5-7	SLSDOLS(3)	PCD(3)	SLSORDS(3)	PCO(3)
4	7-9	SLSDOLS(4)	PCD(4)	SLSORDS(4)	PCO(4)
5	>9	SLSDOLS(5)	PCD(5)	SLSORDS(5)	PCO(5)

The same measures of service also can be developed for the elements of the NOCT such as the percent of sales and/or orders within the CT4 outbound transit time intervals. The above table provided the measure of actual service which when compared against desired service produced the sales modification factor, SMF. The SMF in addition to adjusting sales based on service also determined the need for DC addition or deletion in the Locate algorithm as will be presented in the Monitor and Control Subsystem section of this chapter.

The final activity block allocated the sales information to the DU from the DC being processed. The amount of the order block allocated to the DU was established by the following transformations:

DCDUSLS(IDU,IDC) = 1/CBF * ORDBLK(ICT) * RDCPC (or RDCPLPC)

where:

DCDUSLS(IDU,IDC)	=	DU sales information i.e. dollars and weight
CBF	=	Customer blocking factor, ICT
ORDBLK(ICT)	=	Sales information in order block
RDCPC	=	Percent allocated to RDC-F equals 100%
RDCPLPC	=	Percent allocated to RDC-P equals <100%
IDC	=	Identification of DC
IDU	=	Identification of DU
ICT	=	Identification of customer type.

The control was returned to the D&E Sales Processing Event after completion of this final activity. The next routine of the Sales Processing Event was the Order Summary.

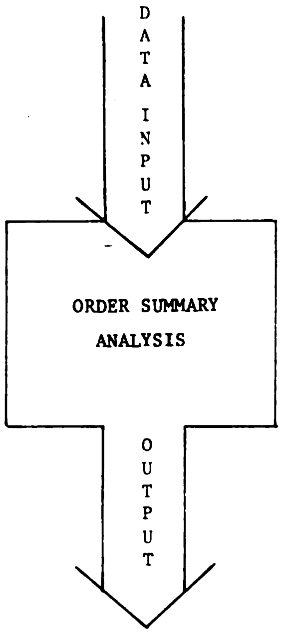
Fixed Event-Order Summary

The Order Summary Routine processed the order blocks summarized sales information and product detail at the DC level. Figure 5.8 presents the activity analysis diagram in terms of the outputs, inputs, and transformations for the Order Summary Routine. The flowchart is presented in Figure 5.9.

The first step of the ORDSUM Routine was to determine whether the DC being processed was an RDC-F or RDC-P. If it was an RDC-P, the order block summary had to be allocated (split) between the RDC-P and the PDC. The total order block was allocated to the DC being processed if it was either an RDC-F or a PDC. The next activity accumulated the sales information at the DC level. The sales for a RDC-P was based on the partial-line percent, RDCPLPC calculated in the Individual Order Routine.

Accumulation of the number of orders processed at the DC was the next activity. For a RDC-F or PDC the number of orders was a simple accumulation of the individual orders processed quarter-to-date at the DC. However, for an RDC-P the assumption was made that two orders were required for each order received and split at the RDC-P. Therefore, for each split order one order was accumulated at the RDC-P and one at the regional PDC.

The next activity accumulated the shipment weight allocated to the DC-DU links in the appropriate customer weight categories:



INPUTS

1. Full-line or partial-line DC
2. Sales information for the DC
3. Number of orders at the DC
4. Order block shipment weight
5. Inventory categories
6. Inventory-on-hand each product

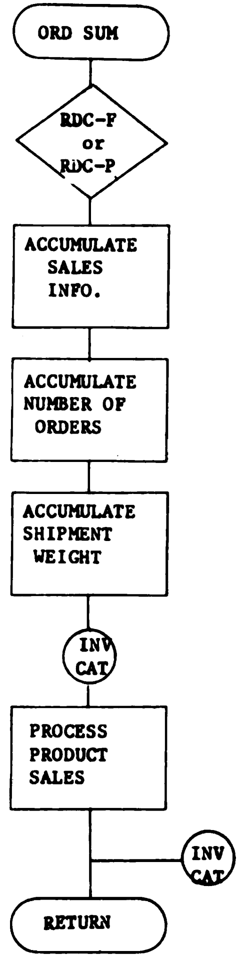
TRANSFORMATIONS

1. Accumulate sales information
2. Accumulate number of orders
3. Accumulate shipment weight
4. Process product sales

OUTPUTS

1. Completion of order block sales
   and product detail at the DC level

Figure 5.8--Activity Analysis: Order Summary



Process Order Block Summary at DC level, Partial-line or Full-line.

Check to determine if it is Full-line or Partial-line DC.

Accumulate sales information at the Partial-line or Full-line DC.

Accumulate number of orders at the Partial-line or Full-line DC.

Accumulate Order Block shipment weight in the appropriate weight category.

Process Full-line or Partial-line inventory categories.

Process all inventory categories, reduce product inventories-on-hand by product sales units from the Order Block.

Return to D & E Sales Processing Routine.

Figure 5.9--Flowchart: Order Summary Routine

Weight Categories

IWC	Pounds
1	≤ 50
2	$>50 \leq 200$
3	$>200 \leq 1,000$
4	$>1,000$

The transformation for accomplishing this was:

WTCAT(IWC) = PWTCAT(IWC) + 1/CBF * ORDBLKWT(ICT) *
RDCPC (or RDCPLPC)

where:

WTCAT(IWC)	=	Weight category, IWC
CBF	=	Customer blocking factor
ORDBLKWT(ICT)	=	Order block weight, ICT
RDCPC	=	Percent allocated to DC if an RDC-F equals 100%
RDCPLPC	=	Percent allocated to DC of an RDC-P equals <100%
IWC	=	Identification of weight category
ICT	=	Identification of customer type.

The Monitor and Control Subsystem used these accumulated weight categories to make adjustments in the outbound transportation weighted average freight rates in the Measurement Subsystem.

The next activity processed the order block's summarized product sales detail from the DC's inventories-on-hand for all of the tracked products contained in the individual order, and their respective inventory categories. The transformation used was:

IOH(ITP,ID) = IOH(ITP,(ID-1)) - ORDBLKTP(ITP)

where:

IOH(ITP,ID)	=	Inventory-on-hand end-of-day, ID for tracked product, ITP at the DC being processed
IOH(ITP,(ID-1))	=	Inventory-on-hand end-of-day, (ID-1) for tracked product, ITP at DC being processed
ORDBLKTP(ITP)	=	Order block demand for tracked product, ITP at the DC being processed
ITP	=	Identification of tracked product
ID	=	Identification of end-of-day.

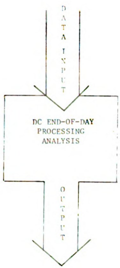
Fixed Event-DC End-of-Day

The End-of-Day Activities were primarily related to the review and update of the inventory levels and the shipment of product replenishments from the MCC's to the DC being processed. Figure 5.10 presents the activity analysis in terms of the inputs, outputs, and transformations developed for the End-of-Day Routine, The flowchart is presented in Figure 5.11.

Inventory Status.--The initial activity in this routine updated the inventory status variables under the following conditions:

1. Normal updating of time-integrated inventory-on-hand
2. Stockout of the product.

The normal updating at the end of the quarter divided by the number of workdays in the quarter provided the average



INPUTS

1. In-solution DC being processed
2. Potential DC code being processed
3. Total no. of MCC's
4. Present MCC product reorders received
5. No. of multiple product reorders at MCC
6. Wt. on order at MCC + ship. dispatch policy indicator
7. DC-MCC linked tracked products
8. DC-MCC weight proportion
9. DC-MCC RT1 and RT4 elements
10. DC type + PDC assignment
11. Service time variance functions
12. Total no. of inventory categories
13. Partial line inventory category indicator
14. Type inventory policy code
15. Review period length for inventory policy ROP1 + ROP2
16. Replenishment S-level
17. Inventory-on-hand
18. ROQ + outstanding ROQ indicator
19. Pound ratio of total product sales
20. MCC scheduled shipment dispatch policy customer $OBT\text{-}CT_4$

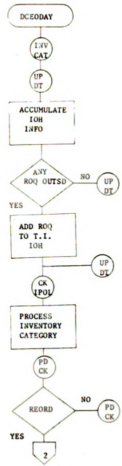
TRANSFORMATIONS

1. Accum IOH information
2. Check for any ROQ outstanding
3. Add ROQ to time-integrated IOH
4. Process inventory categories
5. Check for any reorders
6. Process product reorders
7. Dispatch DC-MCC reorders
8. Check for MCC-DC shipments
9. Calculate RT_4
10. Make shipment dispatch to DC
11. Update reorder lead time
12. Accumulate shipment weight

OUTPUTS

1. Total no. of multiple product reorders
2. Accum total reorder lead times
3. Present MCC product reorders received
4. No. of multiple product reorders received at MCC
5. Wt. on order at MCC + SDP indicator
6. Time integrated IOH
7. Present stockout days per tracked product
8. ROQ + ROQ indicator
9. QTD single product reorders
10. Time-integrated stocked-out cases
11. Total tracked product case sales
12. DC-MCC weight accumulators
13. QTD domestic, tracked product case sales
14. QTD regional, tracked product case sales
15. DC shipment + arrival attributes
16. MCC order arrival attributes

Figure 5.10--Activity Analysis: DC end-of-day Processing



DC End-of-Day activities for processing an in-solution DC's inventory levels.

Process all inventory categories.

Update inventory level status variables.

Accumulate inventory-on-hand information adjust time-integrated stockout and inventory-on-hand variables plus stockout delay if necessary.

Any reorders outstanding for this tracked product?

If yes, add ROQ to time-integrated IOH to develop a total inventory approximation.

Loop through all tracked products in the inventory category.

Determine inventory control policy for the inventory category being processed.

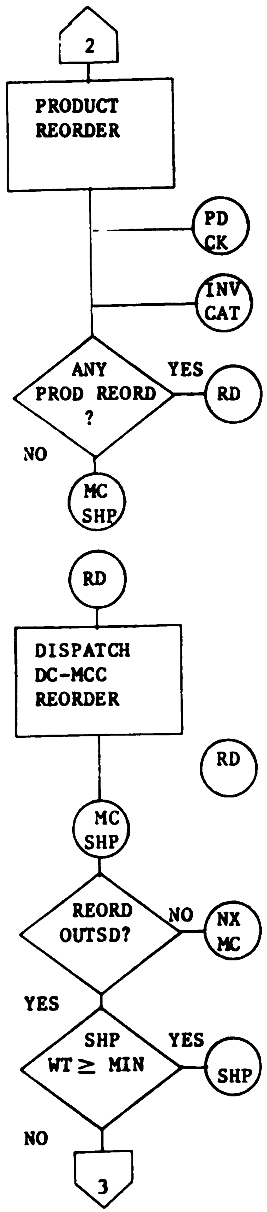
Process the inventory category with:
1. Reorder point policy
2. Optional replenishment policy
3. Hybrid policy

Determine if reorder required.

For each product in inventory category check to determine if reorder required.

Does the tracked product need reordering? If no check next product. If yes, setup product reorder.

Figure 5.11--Flowchart: DC End-Of-Day Processing Routine



Establish product reorder for the DC-MCC, if ROQ not outstanding.

Loop through all tracked products in the inventory category.

Loop through all inventory categories.

Any tracked products reordered? If yes, set up DC-MCC Reorder Dispatches. If no, process MCC-DC shipment dispatch links.

Reorder Dispatch Routine.

Dispatch the DC-MCC reorder using Extrapolated Weight, weight split percentages, and $RT_1 + RT_2$ lead times.

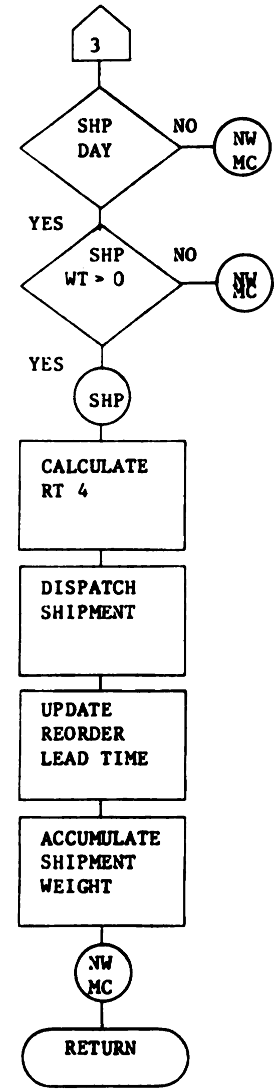
Loop through all MCC's supplying the DC being processed.

End-of-Day MCC-DC Shipment Dispatch Routine for DC being processed.

Any reorders outstanding for this MCC-DC link? If yes, process for shipment. If no, loop through next MCC.

Is shipment weight ≥ minimum? If yes, make minimum shipment. If no, check for scheduled dispatch.

Figure 5.11--Continued



If minimum shipment not achieved, is this the day for scheduled shipment dispatch day? If no, check next MCC.

If shipment weight accumulated for this MCC-DC link is greater than zero, make a shipment.

Calculate transit time from MCC-DC.

Make shipment dispatch to the DC.

Update reorder lead time accumulator for this MCC-DC link.

Accumulate the shipment weight in the category for the MCC-DC link.

Loop through all MCC's supplying the DC being processed.

Return to the D & E normal Daily Sales Processing Routine.

Figure 5.11--Continued

inventory at the DC for the product. The transformation for this activity was:

TINTIOH(ITP,ID) = TINTIOH(ITP(ID-1)) + IOH(ITP,ID)

where:

TINTIOH(ITP,ID)	= Time-integrated (QTD) inventory-on-hand for end-of-day, ID for tracked product, ITP
TINTIOH(ITP,(ID-1))	= Time-integrated (QTD) inventory-on-hand for end-of-day, ID-1 for tracked products
IOH(ITP,ID)	= Inventory-on-hand for end-of-day, ID for tracked products, ITP.

and:

AVGINV(ITP) = TINTIOH/NWKDYS

where:

AVGINV(ITP)	= The average inventory-on-hand for tracked product, ITP quarter-to-date
TINTIOH(ITP)	= Time-integrated inventory-on-hand for tracked product, ITP quarter-to-date
NWKDYS	= Number of workdays, quarter-to-date.

The stocked out situation required updating of two variables. A time-integrated stocked out cases variable was updated by adding the number of case units that were stocked out for the current day. The transformation for the second condition was:

$$TINTSOCU(ITP,ID) = TINTSOCU(ITP,(ID-1)) + \left|-IOH\right|(ITP,ID)$$

where:

TINTSOCU(ITP,ID)	=	Time-integrated (QTD) stocked-out cases for end-of-day, ID for tracked product, ITP
TINTSOCU(ITP,(ID-1))	=	Time-integrated (QTD) stocked-out cases for end-of-day, ID-1 for tracked product, ITP
$\left\|-IOH\right\|$ (ITP,ID)	=	Absolute value of negative inventory-on-hand for end-of-day, ID for tracked product, ITP.

This variable provided the Measurement Subsystem with the information to determine the customer service penalty time, CT3 for inventory stockouts. As previously stated in the Supporting Data System-Measurement the normal customer order cycle, NOCT plus CT3 equaled the total customer order cycle, OCT. The calculation of CT3 is presented in the Measurement Subsystem.

The second variable calculated for measures of stockout was the stockout days for the product. This variable, updated each day that a product was stocked out, enabled the calculation of the average and standard deviation of the product stockout days given that a stockout had occurred. The transformations to calculate the stockout days were:

$$NDASO(ITP,ID) = NDASO(ITP,(ID-1)) + 1$$

where:

NDASO(ITP,ID)	=	Number of days (QTD) a stockout occurred for tracked product, ITP for end-of-day, ID

NDASO(ITP,(ID-1)) = Number of days (QTD) a stockout occurred through day, ID-1 for product, ITP.

If there were any DC product reorders outstanding the reorder quantity, ROQ was added to the time-integrated inventory-on-hand to approximate the total average inventory for this product at the DC. The transformation was stated as follows:

If a reorder is outstanding for the product from the DC, then

TOTINTIOH(ITP,ID) = TINTIOH(ITP,ID) + ROQ(ITP)

where:

TOTINTIOH(ITP,ID) = Total time-integrated (QTD) inventory-on-hand for the end-of-day, ID for tracked product, ITP

TINTIOH(ITP,ID) = Time-integrated (QTD) inventory-on-hand for end-of-day, ID for tracked product, ITP

ROQ(ITP,ID) = Reorder order quantity outstanding for tracked product, ITP at end-of-day, ID.

Looping through all of the tracked products within an inventory category was necessary since the inventory policy was assigned to categories rather than individual products and certain summary data was accumulated only by inventory category.

Selection of the inventory policy was the next major activity of the routine. As previously discussed in the Supporting Data System--Operations and Monitor and Control three basic inventory management policies, level-3, were developed:

1. Optional replenishment system
2. Reorder point system
3. A hybrid of the reorder point system and the optional replenishment system.

The details of these three policies are presented as a Monitor and Control Subsystem Routine-Inventory Management Module. In this section the emphasis is on the operation of inventory control, the level-1 and level-2 inventory problem. The assigned policy was selected for the inventory category using an inventory policy indicator set at the initialization of the run. The assumptions were made that all tracked products in an inventory category would be managed by the same inventory policy.

If the policy was an optional replenishment policy with periodic review the routine checked to determine if the current day corresponded to the time for inventory review for the inventory category. If it is time for a review the reorder transformation was as follows:

$$ROQ(ITP) = S(ITP) - IOH(ITP), \text{ If } IOH(ITP) < ROP2(ITP)$$

where:

ROQ(ITP) = Quantity reordered of tracked product, ITP

S(ITP) = The replenishment level set by M&C for tracked product, ITP

IOH(ITP) = Inventory-on-hand tracked product, ITP

ROP2(ITP) = Reorder point set for optional replenishment system set by M&C for tracked product, ITP.

If the policy established for the inventory category was the daily reorder point system the reorders were established by the following transformations:

$$ROQ(ITP) = S(ITP) - IOH(ITP), \quad \text{If } IOH(ITP) < ROP1(ITP)$$

where:

ROQ(ITP) = Reorder quantity for tracked product, ITP

S(ITP) = EOQ(ITP) + ROP1(ITP)

EOQ(ITP) = Economic order quantity, set by M&C Subsystem for tracked product, ITP

ROP1(ITP) = Reorder point set by M&C Subsystem for tracked product, ITP

IOH(ITP) = Inventory-on-hand of tracked product, ITP.

The hybrid system combined the above policies to develop the following reorder transformations:

$$ROQ(ITP)=S(ITP) - IOH(ITP), \quad \text{If either}$$

1. $IOH(ITP) \leq ROP1(ITP)$ for the daily reorder point, or
2. $IOH(ITP) \leq ROP2(ITP)$ for the inventory check at the review period for the optional replenishment system.

Product Reorders.--In each of the above situations if no reorder was necessary the next tracked product for the inventory category was processed. At this point the number of single product reorders and the total tracked product case sales were updated to approximate case sales for the product as follows:

$$SPDRORD(ID,ITP) = SPDRORD((ID-1),ITP) + 1$$

where:

SPDRORD(ID,ITP) = Single product reorders QTD for end-of-day, ID for tracked product, ITP

SPDRORD(ITP,(ID-1)) = Single product reorders QTD for end-of-day, ID-1 for tracked product, ITP.

and

$$\sum_{ITP}^{n} TRKPDCU(ITP,ID) = \sum_{ITP}^{n} TRKPDCU(ITP,(ID-1)) + \sum_{ITP}^{n} ROQ(ITP,ID)$$

where:

TRKPDC(ITP,ID) = Case unit sales QTD for end-of-day, ID for tracked product, ITP

TRKPCU(ITP,(ID-1)) = Case unit sales QTD for end-of-day, ID-1 for tracked product, ITP

ROQ(ITP,ID) = Reorder quantity for end-of-day, ID for tracked product, ITP

n = Number of tracked products.

After the inventory categories had been processed a check was made to determine if any single product reorders had been required. If single product reorders had been generated the next step required dispatching of these reorders from the DC to the MCC, the DC-MCC communications link, RT1. If no reorders were required for any products within all inventory categories for the DC the routine checked for shipment dispatches from MCC to DC, the MCC-DC link, RT4.

Reorder Dispatch.--The prior activities generated the single product reorders for each product that required replenishment at the DC. The Reorder Dispatch Routine developed the multiple-product reorders that were dispatched to the MCC supply points for the DC being processed. The basis for the dispatch of multiple product reorder was presented in the Supporting Data System--Operations, the MCC-DC Link Analysis. The transformations for calculating the amount of weight moved from MCC-DC link thus was determined as follows:

WTMCC(IMC,IDC) = PCMCC(IMC,IDC) * TRKWT(IDC) * EXRT

where:

WTMCC(IMC,IDC)	=	Weight moved from MCC(IMC) to DC (IDC) for the replenishment order
PCMCC(IMC,IDC)	=	Percent of total weight assigned to MCC(IMC) for shipment to DC (IDC) as part of replenishment order
TRKWT(IDC)	=	Tracked product weight for the replenishment shipment
EXRT	=	Extrapolation ratio of tracked products relative to total products
IMC	=	Identification number of MCC
IDC	=	Identification number of DC.

The reorder lead time element, the reorder transmittal time, RT1, was generated using the concentric circles for constant time and the variance functions for variability as previously stated for CT1. The reorder processing and preparation time, RT2, at the MCC was likewise developed similar to its counterpart, CT2 of the customer order cycle. The RT1 and RT2 were developed for each of the MCC's serving as a supply point for the DC being processed. The values of the RT1 and RT2 were, however, different than the values of the elements CT1 and CT2. For example, RT2 values were of the magnitude 2, 4, 6, days whereas CT2 values were 0, 1, or 2 days. The final activity of the Reorder Dispatch Routine looped through all MCC's serving the DC.

Shipment Dispatch.--The shipment of outstanding reorders was the final routine of the DC End-of-Day Routine. This subroutine, the MCC-to-DC Shipment Dispatch processed any reorder shipments ready to be dispatched to the DC. If there were no outstanding reorders the next MCC supply was checked. If reorders were outstanding and if the amount of weight accumulated was sufficient for either minimum truck load or carload, a shipment was dispatched to the DC. If the weight was insufficient to meet minimum shipment requirements the next check determined if the current day was the time for a scheduled shipment if scheduled distribution was set for Monday, Wednesday, and Friday and today is Monday the weight would be dispatched as a scheduled shipment. However, if simulated time is Tuesday and weight was below the minimum TL or CL the weight would be held one day until the next scheduled shipment on Wednesday.

The transit time from MCC-DC, RT4 was generated similar to the corresponding element of the customer order cycle, CT4.

The next activity, Dispatch Shipment, established the attributes of the variable event, DC Shipment Arrival. These attributes included:

1. Time of arrival at the DC
2. Tracked products in the shipment arriving at the DC.

The time of arrival at the DC was calculated as follows:

TOADC = TNOW + RT4

where:

TOADC = Time (day) of arrival at DC being processed

TNOW = Time now, current time (day) on the simulated calendar

RT4 = Transit time in days generated for the MCC-DC shipment.

The total number of multiple product reorders was also updated at this time as follows:

DCMCC(IMC,ID) = DCMCC(IMC,(ID-1)) + NRORDMC(IMC,ID)

where:

DCMCC(IMC,ID) = Total number of multiple product reorders by end-of-day, ID for the MCC, IMC

DCMCC(IMC(ID-1)) = Total number of multiple product reorders by end-of-day, ID-1 for the MCC, IMC

NRORDMC(IMC,ID) = Number of multiple product reorders for end-of-day, ID for the MCC, IMC.

The accumulated reorder lead time was updated at this time by:

ACRORDLT(IDM,ID) = ACRORDLT(IDM,(ID-1)) + RT4(IDM)

where:

ACRORDLT(IDM,ID) = Accumulated total reorder lead time QTD for DC-MCC link, IDM for end-of-day, ID

ACRORDLT(IDM,(ID-1)) = Accumulated total reorder lead time QTD for DC-MCC link, IDM for end-of-day, ID-1

RT4 = Transit time for DC-MCC link, IDM

IDM = Identification of DC-MCC link.

The next activity accumulated the dispatched shipment weight in the appropriate weight categories. The final step required that all MCC's supplying the DC be checked to determine if any shipments were to be made. At the completion of this step the control was returned to the Demand and Environment Sales Processing Routine which called the DC End-of-Day Routine after processing all customers sales for the day.

Variable Event--MCC Order Arrival

The next two Operations Subsystem Events were variable time events, the MCC Order Arrival and DC Shipment Arrival. Figure 5.12 presents the activity analysis in terms of the outputs, inputs, and transformations for the MCC Order Arrival event. The flowchart is presented in Figure 5.13. The routine was called to process a reorder arriving at the MCC loading dock ready for shipment to the DC.

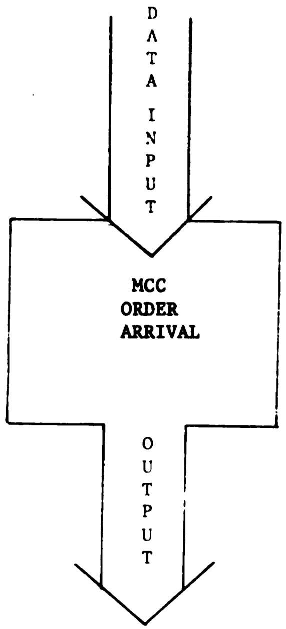
The processing once the reorder arrived at the MCC included adding the products on the reorder to the list of tracked products for the next shipment to be dispatched to the DC. The number of multiple product reorders for the DC-MCC link being processed was increased by one. The total weight to be shipped in the next MCC-DC shipment was the last activity of this routine after which control returned to the Executive to select the next scheduled event.

The transformation for shipment quantity or detail was of the form:

SHPDT(IMC,IDC) = OR(SHPDT(IMC,IDC),ATRIBPD)

where:

SHPDT(IMC,IDC)	= Shipment product detail for the reorders placed by DC(IDC) to MCC(IMC)
OR(SHPDT(IMC,IDC),ATRIBPD)	= Order placed by DC(IDC) to MCC(IMC) with product order detail contained in the product detail file identified by the attribute, ATRIBPD.



INPUTS

1. MCORAR event attributes:
   a. Time of arrival
   b. Event code
   c. In-solution DC code
   d. Products on reorder
   e. MCC code
   f. Total shipment weight
2. Total number of tracked products

TRANSFORMATIONS

1. Update product receipt
2. Update reorders
3. Update weight

OUTPUTS

1. Present MCC received products on reorder
2. Number of multi product reorders received at MCC
3. Weight on order at MCC + SDP indicator

Figure 5.12--Activity Analysis: MCC Order Arrival Processing

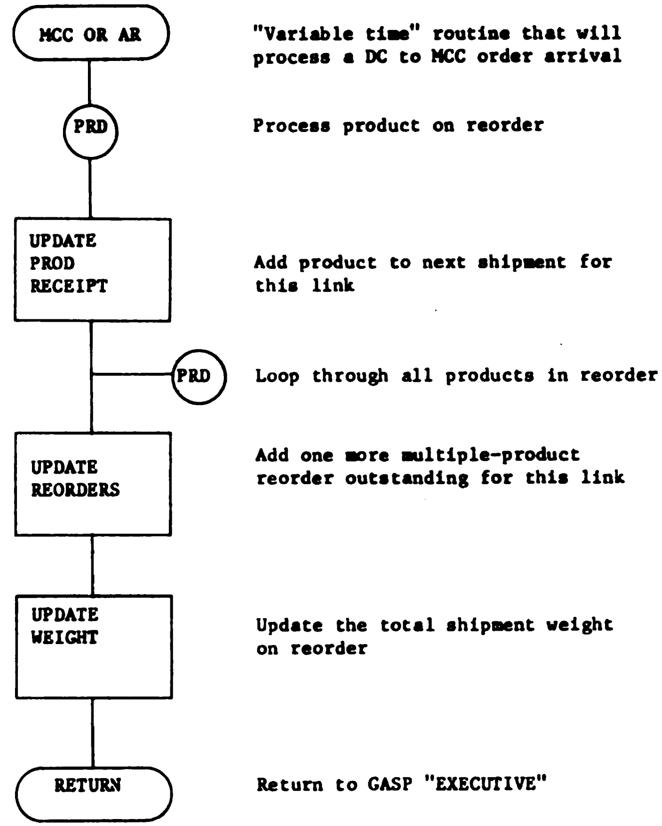


Figure 5.13--Flowchart: MCC Order Arrival Processing Routine

The number of reorders was updated by a linear, first-order difference equation as follows:

DCMCCOR(IMC,IDC) = DCMCCOR(IMC,IDC) + 1

where:

DCMCCOR(IMC,IDC) = Total number of orders on the MCC(IMC) dock ready for shipment to the DC(IDC).

The total weight of the shipment currently being assembled at the MCC was incremented with each order for the given DC if a shipment had been made to this DC within the past ten days. The transformation was a linear, first-order difference equation as follows:

DCMCCWTAL(IMC,IDC) = DCMCCWTAC(IMC,IDC) + ORWT(IMC,IDC)

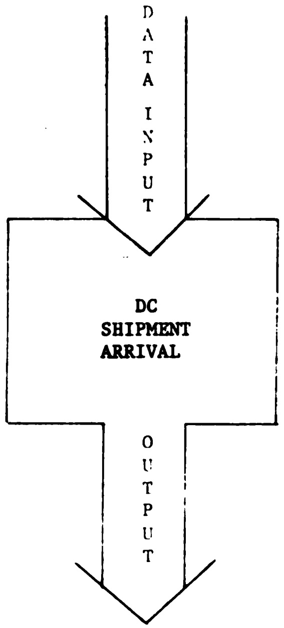
where:

DCMCCWTAC(IMC,IDC) = Accumulated shipment weight for the next shipment for the MCC(IMC) - DC(IDC) link

ORWT(IMC,IDC) = Weight of an order for shipment from MCC(IMC) to DC(IDC).

Variable Event--DC Shipment Arrival

The last routine of the Operations Subsystem, also a variable Event processed the shipment arrival of products to update the inventory status variables at the DC. Figure 5.14 presents the activity analysis in terms of the outputs, inputs, and transformations for the DCSHPAR Routine. The flowchart is presented in Figure 5.15.



INPUTS

1. DCSMPAR event attributes:
   a. Time of arrival
   b. Event code
   c. Products in reorder
   d. In-solution DC code
2. Total number of tracked products
3. Inventory on hand
4. ROQ + outstanding ROQ indicator

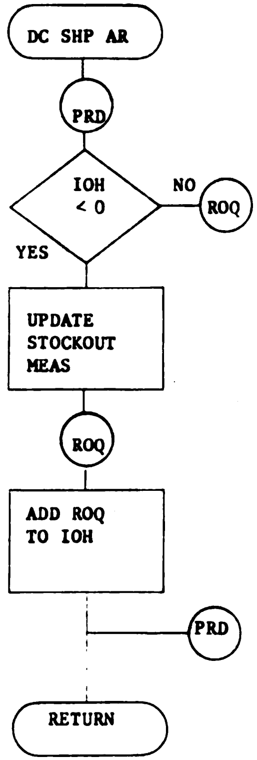
TRANSFORMATIONS

1. Update stockout measures
2. Add reorder quantity to IOH

OUTPUTS

1. Inventory on hand
2. Present stockout days per product
3. ROQ + outstanding ROQ indicator
4. Qtd. number of product stockouts
5. Percent case units backordered
6. Average stockout delay accumulators
7. Standard deviation stockout delay accumulators

Figure 5.14--Activity Analysis: DC Shipment Arrival Processing



Variable time routine that will process a MCC to DC shipment arrival

Process all products received

See if inventory-on-hand is negative

If so, update inventory stockout measures

Process reorder quantity

Add products reorder quantity to inventory-on-hand, reset ROQ indicator

Loop through all products in shipment arrival

Return to GASP "EXECUTIVE"

Figure 5.15--Flowchart: DC Shipment Arrival Processing Routine

The products listed on the shipment were checked against the DC inventory-on-hand. If a product on the shipment was stocked-out the percentage of case units backordered, and the mean and standard deviation of product stockout delays were updated.

The final activities updated the IOH for all tracked products received in the shipment from the MCC. The transformation was a linear, first-order difference equation as follows:

$$IOH(ITP,(ID+1)) = IOH(ITP,ID) + ROQ(ITP,ID))$$

where:

IOH(ITP,(ID+1))	=	Inventory-on-hand for beginning of day, ID+1 for tracked product, ITP
IOH(ITP,(ID)	=	Inventory-on-hand for end-of-day, ID for tracked product, ITP
ROQ(ITP,ID)	=	Reorder quantity received for end-of-day, ID for tracked product, ITP.

Summary

The Operations Subsystem events; the three fixed-time events Individual Order, Order Summary, and DC End-of-Day, and the two variable events MCC Order Arrival and DC Shipment Arrival, provide the activities and sequencing necessary to simulate the operation of the total physical distribution system structured for the LREPS model. The next section of the Operating System presents the Measurement Subsystem, which develops the measures of cost, service, and flexibility.

Measurement Subsystem

The function of the Measurement Subsystem is to process the results of the previous operating period to develop values of the target variables cost, service, and flexibility (robustness). These variables provide the basis for evaluation and selection from among the various sets of sequential decision outcomes of the LREPs model. The design criteria for the Measurement Subsystem required that it provide service, cost, and flexibility information that is suitable for strategic decision making. Extrapolation of inventory characteristics was also required.

The output included a measure of total physical distribution costs, which required consideration of fixed investment cost of the physical distribution centers, inventory costs, distribution center operations (throughput) costs, transportation costs, and communications costs. Basic measures of customer service included the total order cycle, percent customers served within a set of designated service times, percent sales volume served within a set of designated service times, stockouts and order cycle delays due to inventory policy, service to major customers, and finally, a measure of service relative to competition. The final criteria was that the subsystem develop the necessary output to develop measures of flexibility (robustness) or as previously defined, the degree of "non" risk associated with a particular decision.

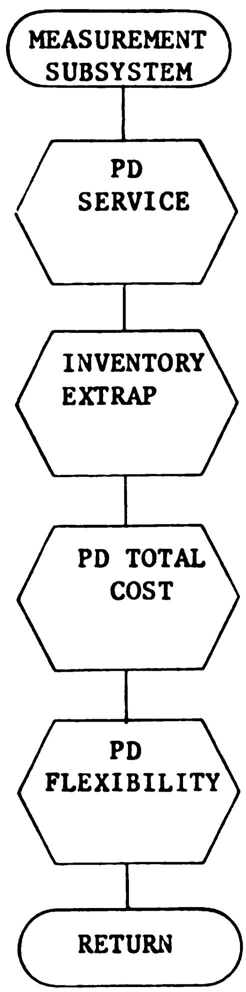
The general flowchart illustrating the processing sequence for the Measurement Subsystem and the order of presentation in this section is presented in Figure 5.16. In summary, at the end of each quarter the Monitor and Control Subsystem triggered a fixed event which called the Measurement Subsystem Routine. The routine selected a region, IR, and a DC, IDC, within the region. The service, cost, and flexibility subroutines were then processed and the output recorded for each DC, IDC in-solution during the past quarter in the region, IR. This procedure was repeated for each region, IR, where IR = 1,...,NR and NR equals the number of regions. The Measurement Subsystem is presented via three major routines. In order of presentation they are:

1. The Service Measures Routine
2. The Inventory Extrapolation Routine
3. The PD Cost Routine.

Service Measures

The first set of activities of the Measurement Subsystem is the routine to calculate the measures of service. Figure 5.17 presents the activity analysis in terms of the outputs, inputs, and transformations for the service activities which are performed for each in-solution DC. The measures of service developed in the Measurement Subsystem were:

1. Customer service penalty time, CT3
2. Mean and standard deviation of customer normal order cycle time, NOCT



Measurement Subsystem includes Service, Cost, Extrapolation and Flexibility.

Set of Service Activities.

Set of Inventory Extrapolation Activities.

Set of Cost Activities.

Accumulation of data to develop "Robustness" in Report Generator System.

Return to fixed time schedules - M & C Subsystem.

Figure 5.16--Flowchart: Measurement Subsystem

3. Mean and standard deviation of customer outbound transportation time, CT4

4. Total customer order cycle time, OCT

5. Percentage of case units backordered

6. Mean and standard deviation of product stockout delays

7. Normal order cycle time proportions

8. Domestic average service time

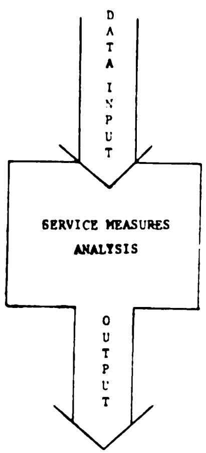
9. Average lead time for each DC-MCC link.

The flowchart for development of the service measures is presented in Figure 5.18.

Customer Service Penalty Time.--The customer service penalty time, CT3, resulted from DC stockouts of tracked products during the past quarter's operations. The normal order cycle time, consisting of the DU to DC order transmission time, CT1, the order processing and preparation time, CT2, and the DC to DU transit time, CT4, when increased by CT3 is defined as the average total customer order cycle time. The calculation of the CT3 customer penalty time was performed for each inventory category and then a weighted average, based on total tracked product sales was developed for the DC as follows:

$$\text{DCCPT3(IDC)} = \frac{\sum_{\text{ITP}=1}^{\text{ITNPC}} \text{AVINCP(ITP,IDC)}}{\sum_{\text{ITP}=1}^{\text{ITNPC}} \text{PRCTDC(ITP,IDC)}}$$

for:



INPUTS

1. In-solution DC being processed
2. Total cases sold for tracked products
3. QTD order sales
4. QTD stockouts
5. Number of MCC's in-solution
6. Total number of product reorders
7. Customer order cycle time, decision parameter, OCT
8. QTD dollar sales
9. Total number of inventory categories

TRANSFORMATIONS

1. Calculate customer penalty, T3, time
2. Calculate mean & std dev of normal order cycle time
3. Calculate mean & std dev of outbound transit time, OBT
4. Calculate average total order cycle time, total OCT
5. Calculate percent case units back ordered
6. Calculate mean and std dev of stockout delay
7. Calculate average lead time for each DC-MCC link
8. Calculate normal OCT array information

OUTPUTS

1. Inventory category penalty time, T3
2. DC customer penalty time, T3
3. DC average & std dev of normal OCT
4. DC average & std dev of OBT
5. DC average total OCT
6. DC percent cases backordered
7. DC average & std dev of stockout delay
8. DC-MCC average reorder lead time
9. Normal OCT sales dollars proportions
10. Normal OCT order proportions
11. Normal OCT sales dollars
12. Domestic average total OCT

Figure 5.17--Activity Analysis: Service Measures

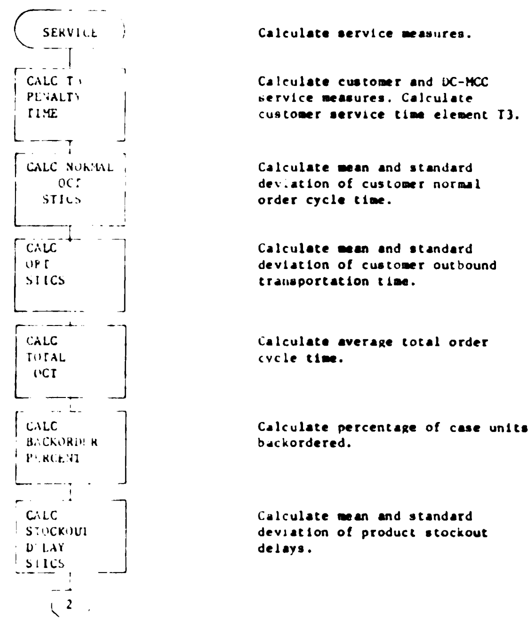


Figure 5.18--Flowchart: Service Measures

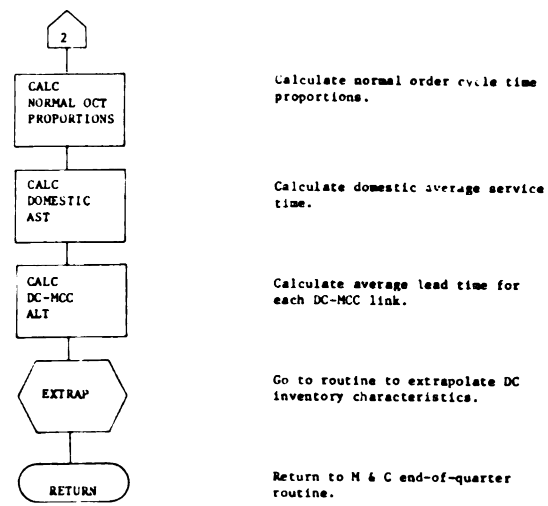


Figure 5.18--Continued

ITP=1, ... , ITNPC and,

$$\text{AVINCP(ITP,IDC)} = \frac{\text{ACPT3(ITP,IDC)}}{\text{PRCTDC(ITP,IDC)}}$$

where:

DCCPT3(IDC)	= DC customer penalty time, CT3 for DC (IDC)
AVINCP(ITP,IDC)	= Average inventory category penalty time, CT3 for DC(IDC) for tracked product, ITP
PRCTDC(ITP,IDC)	= Total units sold of tracked product, ITP for DC(IDC)
ITP	= Tracked product identification number
IDC	= Identification number of DC
ACPT3(ITP,IDC)	= Accumulated penalty time, CT3 of tracked product, ITP for DC(IDC).

Mean and Standard Deviation of NOCT.--The calculation of the mean and standard deviation of the previously defined normal customer order cycle time (NOCT) was calculated using the QTD order sales and the accumulated NOCT for all orders. The procedure included the following transformations:

$$\text{AVNOCT(IDC)} = \frac{\text{ACNOCT(IDC)}}{\text{DCQDOSL(IDC)}}$$

and

$$\text{STDNOCT(IDC)} = \left(\frac{\text{MNOCT(IDC)}}{\text{DCQDOSL(IDC)}} - (\text{AVNOCT(IDC)})^2\right)^{\frac{1}{2}}$$

where:

AVNOCT(IDC) = Average NOCT for DC(IDC)

ACNOCT(IDC) = Accumulated NOCT for all orders for DC(IDC)

DCQDOSL(IDC) = QTD order sales for DC(IDC)

IDC = DC identification number

STDNOCT(IDC) = Standard deviation of NOCT for DC(IDC)

MNOCT(IDC) = Mean of the square of accumulated NOCT for all orders for DC(IDC).

Mean and Standard Deviation of OBT.--The calculation of the mean and standard deviation of customer outbound transit time, CT4, required the accumulation of QTD outbound transit time and order sales for the DC. The calculation was made as follows:

$$\text{AVOBT(IDC)} = \frac{\text{ACOBT(IDC)}}{\text{DCQDOSL(IDC)}}$$

and

$$\text{STDOBT(IDC)} = \left(\frac{\text{MNOBT(IDC)}}{\text{DCQDOSL(IDC)}} - (\text{AVOBT(IDC)})^2\right)^{\frac{1}{2}}$$

where:

AVOBT(IDC) = Average OBT for DC(IDC)

ACOBT(IDC) = Accumulated QTD outbound transit time for DC(IDC)

DCQDOSL(IDC) = QTD order sales for DC(IDC)

STDOBT(IDC) = Standard deviation of OBT for DC(IDC)

MNOBT(IDC) = Mean of the square of accumulated OBT for all orders for DC(IDC)

IDC = DC identification number.

Total Customer Order Cycle.--The sum of the normal customer order cycle time, (CT1+CT2+CT4) NOCT and the customer penalty time, CT3, previously defined as the total order cycle time, was calculated as follows:

$$AVOCT(IDC) = DCCPT3(IDC) + AVNOCT(IDC)$$

where:

AVOCT(IDC) = Average total OCT for DC(IDC)

DCCPT3(IDC) = Penalty time, CT3 for DC(IDC)

AVNOCT(IDC) = Average NOCT for DC(IDC)

IDC = DC identification number.

Percent Backorders.--The next activity developed the percent of tracked product case units backordered due to inventory stockouts, relative to the total tracked product case units sold for all inventory categories. This activity required the accumulated days delay due to stockouts and the total case units sold for all tracked products QTD for each DC. The transformations used were:

$$PCUBO(IDC) = \frac{CUBO(IDC)}{\sum_{ITP}^{ITNPC} PRCTDC(ITP,IDC)} * 100$$

where:

PCUBO(IDC) = Percent case units backordered for DC(IDC)

CUBO(IDC) = Case units backordered for DC (IDC)

PRCTDC(ITP,IDC) = Total case units sold for tracked product, ITP for DC(IDC)

ITP = Tracked product identification number

IDC = DC identification number.

Stockout Delays.--The mean and standard deviation of tracked product delivery delays due to product stockouts required the accumulated QTD days delays and the stockouts QTD for all inventory categories. The transformations were performed as follows:

$$\text{AVSODL(IDC)} = \frac{\text{ACSODL(IDC)}}{\sum\limits_{\text{ITP}} \text{PRCTDC(ITP,IDC)}}$$

and

$$\text{STDSODL(IDC)} = \left(\frac{\text{MNSODL(IDC)}}{\sum\limits_{\text{ITP}} \text{PRCTDC(ITP,IDC)}} - (\text{AVSODL(IDC)})^2 \right)^{\frac{1}{2}}$$

where:

AVSODL(IDC) = Average stockout delay in days

ACSODL(IDC) = Accumulated stockout delay in days, QTD

STDSODL(IDC) = Standard Deviation of the stockout delay in days

MNSODL(IDC) = Mean of the square of accumulated stockout delay, QTD

PRCTDC(ITP,IDC) = Total case units sold for tracked product, ITP for DC(IDC)

ITP = Tracked product identification number

IDC = DC identification number.

<u>NOCT Proportions</u>.--The proportions of DC(IDC) sales dollars and sales orders delivered to its customers within a set of specified normal customer order cycle time (NOCT) intervals were calculated using the transformations:

$$PCD(IOT) = SLSDOLS(IOT) \sum_{IOT=1}^{NOT} SLSDOLS(IOT), \text{ and}$$

$$PCO(IOT) = SLSORDS(IOT) \sum_{IOT=1}^{NOT} SLSORDS(IOT)$$

where:

PCD(IOT) = Percent sales dollars within normal customer order cycle time interval, IOT for the DC(IDC), QTD

PCO(IOT) = Percent sales orders within NOCT interval, IOT for the DC(IDC), QTD

SLSDOLS(IOT) = Sales dollars within interval IOT for the DC(IDC) QTD

SLSORDS(IOT) = Sales order within interval IOT for the DC(IDC) QTD

IOT = NOCT intervals

NOT = Number of order cycle intervals.

<u>Domestic Service Time</u>.--The domestic average total customer order cycle time, a weighted averaged based on customer orders, was calculated at the end of each quarter as follows:

$$DOMACT = \sum_{IDC=1}^{NDC} TORDSDC(IDC) * AVGOCT(IDC) / \sum_{IDC=1}^{NDC} TORDSDC(IDC)$$

where:

DOMACT	=	Domestic average total customer order cycle time weighted by all DC's
TORDSDC(IDC)	=	Total orders for the DC(IDC)
AVGOCT(IDC)	=	Average total customer order cycle time, OCT for DC(IDC)
IDC	=	DC identification
NDC	=	Number of DCs.

Reorder Lead Time.--The average total reorder lead time for each DC-MCC link for an in-solution DC was defined as the sum of the DC-MCC reorder transmission time, RT1, the reorder processing and preparation time, RT2, the waiting time prior to shipment from the MCC, RT3, and the MCC-DC shipment transit time, RT4. The data requirements to calculate this measure of service were the total number of multiple product reorders and the number of MCC's in-solution. The transformations used for this activity were:

$$\text{AVDCMCLT(IDM)} = \sum_{\text{IRO}} \text{ROCT(IDM,IRO)/NMORDS(IDM)}$$

where:

AVDCMCLT(IDM)	=	The average DC-MCC reorder lead time for each DC-MCC link, IDM
ROCT(IDM,IRO)	=	The reorder cycle time for the DC-MCC link, IDM for reorder, IRO
NMORDS(IDM)	=	The number of multiple product reorders for the DC-MCC link, IDM

IDM = Identification number of DC-MCC link

IRO = Reorder identification number.

Inventory Extrapolation

The next major set of activities, EXTRAP developed additional measures of inventory characteristics. This routine was necessary to extrapolate or generalize the average inventory characteristics developed from the results of activities of the tracked products to the total product line. Figure 5.19 illustrates the activity analysis in terms of the outputs, inputs, and transformations required for development of the inventory characteristics. Figure 5.20 presents the sequence of calculations for the set of activities.

Category Modifier.--The first activity of the Inventory Extrapolation Routine calculated the category modifier, CM, which was used to extrapolate the inventory characteristics for a particular inventory category. CM was calculated by the following transformation:

CM(IC) = TNCTPD(IC)/TKPDCT(IC)

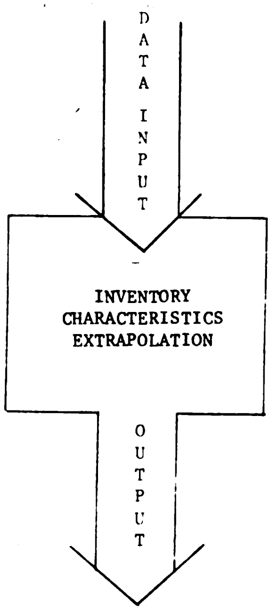
where:

CM(IC) = Inventory category modifier to extrapolate inventory characteristics to all products in the category, IC

TNCTPD(IC) = Total number of products in the inventory category, IC

TKPDCT(IC) = Tracked products in the inventory category, IC

IC = Inventory category identification.



INPUTS

1. Category modifier
2. In-solution DC being processed
3. Beginning model product code
4. Ending model product code
5. Total no. of category products
6. Time-integrated IOH
7. Cost of goods sold per case

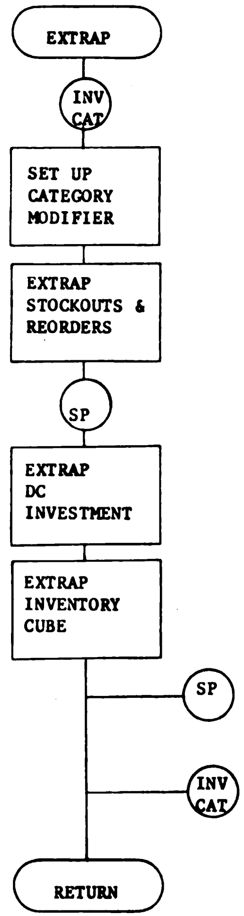
TRANSFORMATIONS

1. Calculate category modifier
2. Extrapolate stockouts and single product reorders
3. Extrapolate product's average DC investment
4. Extrapolate product's average cubic inventory

OUTPUTS

1. DC extrapolated average investment
2. QTD stockouts
3. QTD single-product reorders
4. Time-integrated IOH

Figure 5.19--Activity Analysis: Inventory Characteristics Extrapolation



Extrapolate DC Inventory Characteristics.

Process all inventory categories.

Calculate the modifier to extrapolate this inventory category's characteristics.

Extrapolate stockouts and single-product reorders.

Process all tracked products in category.

Extrapolate product's average DC investment.

Extrapolate product's average cubic inventory.

Loop through tracked products.

Loop through inventory categories.

Return to MEAS service measure's routine.

Figure 5.20--Flowchart: Inventory Extrapolation Routine

Thus, if all products were tracked, the CM(IC) would equal one and no extrapolation would occur. However, in the initial version of LREPS, the extrapolation ratio was of the order of from four to twenty depending on the inventory category, since the percent of products tracked varied from approximately 25 percent in the A category to 5 percent of the C category.

Stockouts and Single Orders.--The extrapolation of stockouts and single product reorders was calculated next based on the following transformations:

EXSKOTDC(IC) = CM(IDC) * TKSKOTDC(IC)

where:

EXSKOTDC(IC) = Extrapolated stockouts for inventory category, IC

CM(IC) = Category modifier for inventory category, IC

TKSKOTDC(IC) = Tracked product stockouts for inventory category, IC

and:

EXRORDC(IC) = CM(IC) x TKSPRORD(IC)

where:

EXRORDC(IC) = Extrapolated reorders for inventory category, IC

CM(IC) = Category modifier for inventory category, IC

TKSPRORD(IC) = Tracked single product reorders, IC.

Average Cubic Inventory.--The next activity extrapolated the average cubic inventory-on-hand as follows:

$$EXTKCUB(IC) = TINTIOH(ITP,IC) * CUBCS(ITP) * CM(IC)$$

where:

EXTKCUB(IC)	=	Extrapolated average inventory cube for each inventory category, IC
TINTIOH(ITP,IC)	=	Time-integrated inventory-on-hand for each tracked product, ITP in inventory category, IC
CUBCS(ITP)	=	Cube per unit for tracked product, ITP
CM(IC)	=	Category multiplier for inventory category, IC.

Average Investment.--The extrapolated investment of the tracked products was next calculated as follows:

$$EXTKINVST(IC) = \sum_{ITP=1}^{ITNPC} TINTIOH(ITP,IC) * CGCU(ITP,IC) * CM(IC)$$

where:

EXTKINVST(IC)	=	Extrapolated average inventory investment for each inventory category, IC
TINTIOH(ITP,IC)	=	Time-integrated inventory-on-hand for each tracked product, ITP in inventory category, IC
CGCU(ITP,IC)	=	Cost of goods sold per case unit for tracked product, ITP
CM(IC)	=	Category modifier for inventory category, IC
ITP	=	Tracked product identification

IC = Inventory category

ITNPC = Number of tracked products.

The above extrapolations were processed at the end of each quarter for all tracked products in an inventory category and all inventory categories. After both these loops were completed control returned to the Measurement Service Routine.

PD Cost Components

The final section of the Measurement Subsystem presents the transformations that developed the costs of each of the components of the physical distribution system. Figure 5.21 presents the activity analysis in terms of the outputs, inputs, and transformations. The flowchart, Figure 5.22, illustrates that the order of processing these cost components was:

1. Outbound transportation cost for the DC-DU links

2. Inbound transportation cost for the MCC-DC links

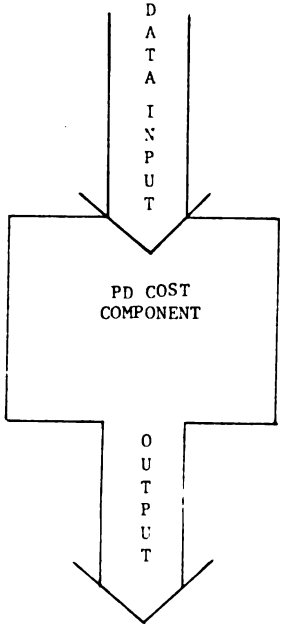
3. Throughput cost for movement of goods through the DC

4. Communications cost for order transmittal and order processing

5. Facility investment costs for the equivalent annual cost resulting from capital expenditures (rent or lease) on DC's

6. Inventory carrying cost.

Outbound Transportation Cost.--Outbound transportation was defined as the transportation cost developed for shipments made from a DC to an assigned DU, the DC-DU



INPUTS

1. In-solution DC being processed
2. DU-DC assignments and weight
3. DU being processed
4. DC type and PDC assignment
5. Highway distance DC-DU links
6. RDC-F & RDC-P QTD sales by weight, lb.
7. DC total QTD weight sales
8. Region being processed
9. Regional "a" and "b" negotiated rate modifiers
10. Regression equation coefficients, "c" and "d"
11. Real rate increase modifiers "e" and "f"
12. Year of simulated time
13. Total number of DU's being processed
14. DC type rate correction factor
15. PDC pooled shipment rate modifying factor
16. DC-MCC freight rates
17. Accumulated DC-MCC weight
18. No. of PDC and RDC weight categories
19. DC size indicator
20. Throughput cost rate by DC size and type
21. DC communication cost factor
22. Regional communication cost factor
23. Domestic communication cost factor
24. DC total QTD order sales
25. DC total QTD line sales
26. Fixed communications costs for DC, region, and domestic
27. Variable cost per order for DC, region, and domestic
28. Variable cost per line for DC, region, and domestic

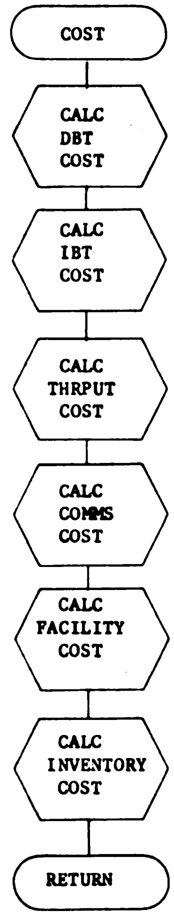
TRANSFORMATIONS

1. Calculate outbound transportation costs
2. Calculate inbound transportation costs
3. Calculate throughput costs
4. Calculate communications costs
5. Calculate facility investment cost

OUTPUTS

1. DC outbound transportation cost
2. DC inbound transportation cost
3. DC throughput costs
4. DC communications costs
5. DC facility costs

Figure 5.21--Activity Analysis: PD Component Cost Routine



Calculate PD component costs for the previous quarter.

Calculate outbound transportation costs, DC-DU.

Calculate inbound transportation costs, MCC-DC.

Calculate throughput costs, movement of goods through the DC's.

Calculate communications cost for DC, region and domestic.

Calculate facility investment cost for building, land and equipment.

Calculate inventory holding and ordering costs.

Return to the M & C End-of-Quarter routine.

Figure 5.22--Flowchart: PD Component Cost Routine

link. The general approach used to develop the outbound costs, regression equations based on regional weighted average freight rates, was discussed in the Supporting Data System--Measurement.

The first set of activities processed the DUs assigned to the DC to develop the outbound transportation cost. The transformation used outbound freight rates for RDC-F developed as follows:

$$OR(IDC,IDU) = ((1.0+R1)^{IY}*a) \ *R3+ \ ((1.0+R2)^{IY}*b)*R4*XDIS$$

where:

OR(IDC,IDU)	=	Freight rate in dollars per pound for DC(IDC)-DU(IDU) link
R1,R2	=	Regional annual compound rates at which cost structure as defined by the "a" and "b" coefficients is assumed to be changing
R3,R4	=	Regional adjustment factors to reflect the use of negotiated rates at the RDCs instead of class rates
a,b	=	Coefficients of regression equation
IY	=	The simulated year, 1.....10, where base is 1969
XDIS	=	Distance in spherical miles adjusted to highway miles for the DC(IDC)-DU(IDU) link.

The R1, R2 factors were included to automatically adjust the freight rates based on the expected rate of change over time. The R3 and R4 adjustment factors allowed the adjustment of the rates to reflect negotiated freight rates for the DC-DU links. These factors were developed by region.

For example, if the volume through a DC was greater than one million pounds for the quarter, the R3 and R4 factors were set at values less than one to reflect the use of negotiated rates. If the volume was below the above amount, R3 and R4 were set equal to one.

The distance was obtained from the distance routine previously mentioned in Supporting Data System--Monitor and Control that converted latitude-longitude of the DC and DU to a highway distance for the DC-DU link.

The above outbound rate was further modified for the RDC-P's to reflect the higher costs of the smaller average size shipments from a partial-line DC:

$$ORC(IDC,IDU) = OR(IDC,IDU) * RCF$$

where:

ORC(IDC,IDU) = Corrected outbound transportation rate for DC(IDC)-DU(IDU) link where DC(IDC) is an RDC-P

OR(IDC,IDU) = Outbound transportation rate for DC(IDC)-DU(IDU) link where DC(IDC) is an RDC-F

RCF = Rate correction factor to reflect higher cost of small shipments from partial-line DC

The outbound freight rate, OR was also modified for PDCs because it was assumed that the larger volumes being shipped from the PDCs warranted pooled or consolidated shipments to the DU's. These pooled shipments were shipped via the scheduled distribution policy discussed in the Operations Subsystem. The transformation for this modification was:

ORC(IDC,IDU) = OR(IDC,IDU) * POOLCF(IDC)

where:

ORC(IDC,IDU) = Corrected outbound transportation rate for the DC(IDC)-DU(IDU) link where DC(IDC) is a PDC

OR(IDC,IDU) = RDC-F outbound transportation rate for DC(IDC)-DU(IDU) link

POOLCF(IDC) = Rate correction factor to reflect pooled rates for large, mixed TL or CL shipments

IDC = DC Identification number

IDU = DU Identification number.

For each PDC if the distance and accumulated weight for the PDC-DU links were above set minimums the POOLCF was set at a value less than one to reflect pooled rates. The outbound transportation cost transformation was then of the form:

$$OTBD(IDC) = \sum_{IDU} ORC(IDC,IDU) \times WT(IDC,IDU)$$

where:

OTBD(IDC) = Outbound transportation costs for DC(IDC) for the quarter

ORC(IDC,IDU) = Corrected (or OR(IDC,IDU) freight rate for outbound transportation DC(IDC)-DU(IDU) link

WT(IDC,IDU) = Total accumulated weight shipped for DC(IDC)-DU(IDU) link for the quarter.

Inbound Transportation Cost.--Inbound Transportation Costs were developed for shipments from the manufacturing control centers, MCC's to the DC, the MCC-DC link. The inbound costs for each DC was calculated using transformations of the form:

$$INBD(IDC) = \sum_{IMC} \sum_{IC} (IR(IWC,IMC,IDC) * WTCAT(IWC,IMC,IDC)$$

where:

INBD(IDC)	=	Inbound transportation costs for DC(IDC) for the quarter
IR(IWC,IMC,IDC)	=	Freight rate for inbound transportation MCC(IMC)-DC(IDC) link for weight category, IWC
WTCAT(IWC,IMC, IDC)	=	Weight shipped MCC(IMC)-DC(IDC) for category, IWC for the quarter
IWC	=	Weight category identification
IDC	=	DC identification number
IMC	=	MCC identification number.

The freight rates were obtained via rate tables for each of the MCC-DC links and three weight categories: <5,000 lbs, 5,000-24,000 lbs, and >24,000 lbs. The weight for each MCC-DC link was accumulated in the Operations Subsystem. The calculation of inbound transportation cost for the MCC-PDC used the identical transformation, but the freight rate for the >24,000 weight interval was applied to all weight accumulated for the PDC links.

Throughput Cost.--The throughput cost activity calculated the cost of preparing the customer orders for shipment. The transformation was of the form:

$$THRUPC(IDC) = THRUCF(IS,IT) * WTSL(IDC)$$

where:

THRUPC(IDC) = Throughput cost for DC(IDC) for the quarter

THRUCF(IS,IT) = Throughput average cost factor by DC size interval, IS,IT

WTSL(IDC) = Throughput average cost factor by DC(IDC) for the quarter

IS = DC size interval identification

IT = DC type identification.

The basis for the throughput cost factors was discussed in the Supporting Data System--Measurement. The total weight moved through the DC was accumulated via an Operations Subsystem activity.

Communications Cost.--The cost of order transmittal and preparation up to the point of the physical preparation of the order were defined as communication cost. The transformations which develop the fixed cost and variable cost for the DC were of the form:

COMFCDC(IDC) = CMFCDC(IS,IT)

where:

COMFCDC(IDC) = Communications fixed cost for DC(IDC) for the quarter

CMFCDC(IS,IT) = Communications fixed cost for DC size interval IS, type IT

and:

COMVCODC(IDC) = CMVCODC(IS,IT) * NMORDS(IDC)

where:

COMVCODC(IDC)	=	Communications variable cost for orders processed for DC(IDC) for the quarter
CMVCODC(IS,IT)	=	Communications variable cost factor for orders for size, IS, type IT
NMORDS(IDC)	=	Number of orders processed for DC(IDC) for the quarter.

and:

COMVCLDC(IDC) = CMVCLDC(IS,IT) * NMLNS(IDC)

where:

COMVCLDC(IDC)	=	Communications variable cost for lines processed for DC(IDC) for the quarterly
CMVCLDC(IS,IT)	=	Communication variable cost factor for lines for size, IS, type IT
NMLNS(IDC)	=	Number of lines processed for DC(IDC) for the quarter.

The fixed and variable cost factors were developed for the five size intervals IS and three types IT (PDC, RDC-F, and RDC-P) as previously discussed in the Supporting Data System--Measurement.

Communications costs were also developed at the regional and national levels to allow the flexibility of simulating regional or centralized order processing systems. The transformations for the regional costs were of the form:

COMFCRG(IR) = CMFCRG(IS)

where:

COMFCRG(IR) = Communications fixed cost for region, IR for the quarter

CMFCRG(IS) = Communications fixed cost for regional size interval, IS

and:

COMVCORG(IR) = CMVCORG(IS) * NMORDRG(IR)

where:

COMVCORG(IR) = Communications variable cost for orders processed for region (IR) for the quarter

CMVCORG(IS) = Communications variable cost factor for orders for regional size interval, IS

NMORDRG(IR) = Number of orders processed for region, IR for the quarter

and:

COMVCLRG(IR) = CMVCLRG(IS) * NMLNSRG(IR)

where:

COMVCLRG(IR) = Communications variable cost for line processed for region, IR for the quarter

CMVCLRG(IS) = Communications variable cost factor for lines for regional size interval, IS

NMLNSRG(IR) = Number of lines processed for region, IR for the quarter.

Facilities Investment Cost.--The facility investment cost activity developed the fixed cost per quarter for capital investment in equipment, building, and land. The transformations developed for this activity were:

FINV(IDC) = INVEST(IS,IT)

where:

FINV(IDC) = Total investment in dollars for equipment, building, and land for DC(IDC)

INVEST(IS,IT) = Fixed total capital investment for a DC size interval, IS and type, IT for the quarter

and:

FINVC(IDC) = CLF(IDC) * ((FINV(IDC) * PCSD(IS,IT)/DPE

+ FINV (IDC) * PCLD(IS,IT)/DPB))

where:

FINVC(IDC) = Facilities cost allocated for the quarter for DC(IDC)

CLF(IDC) = Cost of living factor by DC(IDC)

PCSD(IS,IT) = Percentage of investment dollars assumed with short depreciation period (equipment) by DC size interval, IS, type IT

DPE = Depreciation period, for equipment was 15 years

PCLD(IS,IT) = Percentage of investment dollars assumed with long depreciation period (building and land) by size interval DC, IS, type IT

DPB = Depreciation period for building and land, 50 years.

Inventory Costs.--The calculation of the cost of inventory carrying and handling product inventories by DC for the quarter required the following transformations:

INCCST(IDC) = AVDCINV(IDC) * DICC

where:

INCCST(IDC) = Inventory carrying and handling cost for DC(IDC) for the quarter

AVDCINV(IDC) = Average inventory investment for the DC for the quarter

DICC = Daily carrying charge.

The cost of preparing multiple-product reorders for shipment dispatch at each of the supplying MCC's for the DC being processed required the following transformation:

$$\text{DCMCRCST(IDC)} = \sum_{\text{IMC}}^{\text{NMCCS}} \text{NOMPRDS(IDC,IMC)} * \text{MCROCST(IMC)}$$

where:

DCMCRCST(IDC) = Reorder cost for all of the MCC's supplying the DC(IDC)

NOMPRDS(IDC,IMC) = Number of multiple product reorders for all MCC's supplying the DC

MCRCOST(IMC) = Reorder cost for each MCC(IMC) supplying the DC

IMC = MCC identification.

The cost of processing the reorder for the DC-MCC link was not included in the inventory cost routine because it had already been included in the DC communications cost. After calculation of the inventory costs control was transferred to the Monitor and Control Quarterly Routine.

Summary

The Measurement Subsystem as presented provided the capability for measuring each of the target variables of service, cost, and flexibility. In addition a special routine to generalize up the tracked product statistics was required. The next and final section in the Operating System, the Monitor and Control Subsystems, presents the information feedback control loops, algorithms, routines, and activities required to develop the dymanic aspects of the control function.

Monitor and Control Subsystem

The function of the Monitor and Control Subsystem is to monitor or supervise the activities of the Operating System and control the information feedback loops used for sequential decision making within the model. The Supervisory or Monitoring function included the general overall executive level control for scheduling and selection of fixed and variable time events, initialization of the model, running of the model, and the Gateway activities associated with the inflow and outflow of information linked to the Operating System.

The control function operated at a lower level, within the Operating System, reviewing, comparing, and developing the feedback responses to simulate management decisions. The Controller also updated the physical distribution system variables as a result of the scheduled changes.

The activities of the Monitor and Control Subsystem are presented in two sections. The first presents the general nature of the linkages and sequencing of events required for the Supervisory function of the LREPS model. The second section presents the details of the information-feedback control loops and the procedures for system update developed as part of the Controller function. The Controller function contained the algorithms for addition and deletion of distribution centers, expansion of distribution centers, inventory management, and sales modification. These algorithms via information feedback provided the dynamic aspects of the LREPS model, and as such receive the primary emphasis in this section.

Supervisor or Monitor Function

The Monitor or Supervisor function included (1) The Executive, (2) The Gateway, and (3) The Fixed-time Scheduler subfunctions. The general nature of the requirements for the Supervisory function were discussed in the Supporting Data System-Monitor and Control. This section presents for the LREPS model a brief discussion of the operation of the subfunctions.

The Executive.--The Executive controlled the sequence of activity execution for the Operating System. This function was performed by an event oriented simulation language, GASP-IIA. The Executive had the responsibility of selecting the next event to be processed from a file that was constructed on a chronological basis with a First-In-First-Out (FIFO) priority rule for sequencing the events within the smallest time unit, the day. At each discrete point in time, the day, the Executive selected the events for the day in FIFO order for processing. Figure 5.23 presents the flowchart for the Executive subfunction.

The LREPS model included seven fixed time events and two variable time events defined as follows:

1. The event that initialized the LREPS Operating System for start of LREPS simulation planning horizon cycle, Beginning-Of-Cycle, BOCYC

2. The event to initiate the normal sales processing activities for the day, DAILY

3. The event to initiate the processing of beginning-of-month activities, MONTHLY

4. The event to initiate the processing of the end and beginning-of-quarter activites required for Operating System information input/output and control of the feedback responses, QUARTERLY

5. An event similar to the Quarterly event, but with some additional half-year activities, HALF-YEAR

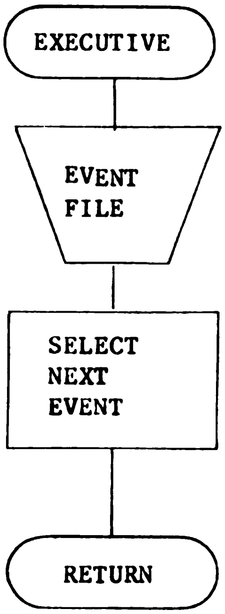
6. An event similar to the Half-Year event, but with some additional yearly activities, YEARLY

7. The event that completed the LREPS Operating System activities of a simulation cycle and generated the required information to terminate the execution, End-Of-Cycle, EOCYC

8. A variable event that initiated the Operations Subsystem processing of a MCC order arrival from the DC, MCC-Order-Arrival, MCORA

9. A variable event that initiated the Operations Subsystem processing of a DC shipment arrival, DC-Shipment Arrival, DCSHPAR.

Each of the fixed-time events is presented briefly in this section in the order listed above. The two



Events filed by day and within day by FIFO.

Select next imminent event from the list of possible; BOYC, DAILY, MONTHLY, QUARTERLY, HALF-YEAR, YEAR and EOCYC. If end of planning horizon, "stop" by processing EOCYC.

Return to Fixed-Time Scheduler.

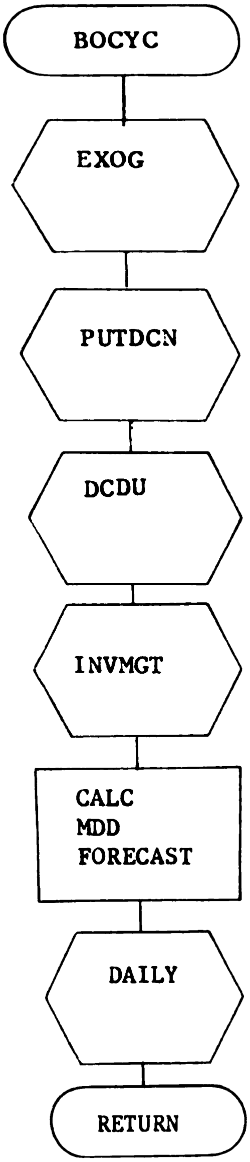
Figure 5.23--Flowchart: Supervisor Function-Executive Routine

variable events were presented in the Operations Subsystem and thus are not discussed in this section.

The fixed time event, BEGINNING-OF-CYCLE, essentially consisted of a set of initialization activities required for each simulation cycle of a complete planning horizon. The flowchart is presented in Figure 5.24. The BOCYC event included:

1. Exogenous input
2. List of in-solution DC's
3. DC-DU link information
4. Beginning inventory levels and control information
5. Calculation of modified annual domestic forecast
6. A call to the Daily Event to process the first days sales activities.

The fixed time events, DAILY, MONTHLY, QUARTERLY, HALF YEAR, and YEARLY were generally similar in processing sequence. Each of the events was called by the Executive Routine on the Clock Time "TNOW" corresponding to the appropriate calendar day of the year. Figure 5.25 presents the activities from which each event was constructed. The sequence was to process the daily activities included in the Daily Event each calendar day. The Daily Event linked the Routines; Daily Domestic Sales Dollar Forecast and Sales Processing each of which was discussed in the Demand and Environment Subsystem. Upon completion of the daily processing for all in-solution RDC's, and the PDC



Beginning of cycle event activity.

Link to routine to read LREPS exogenous inputs.

Link to routine to make DC facility initialization.

Link to routine to develop DC to DU link information.

Link to routine to initialize DC inventories plus calculate inventory parameters.

Calculate modified annual domestic forecast.

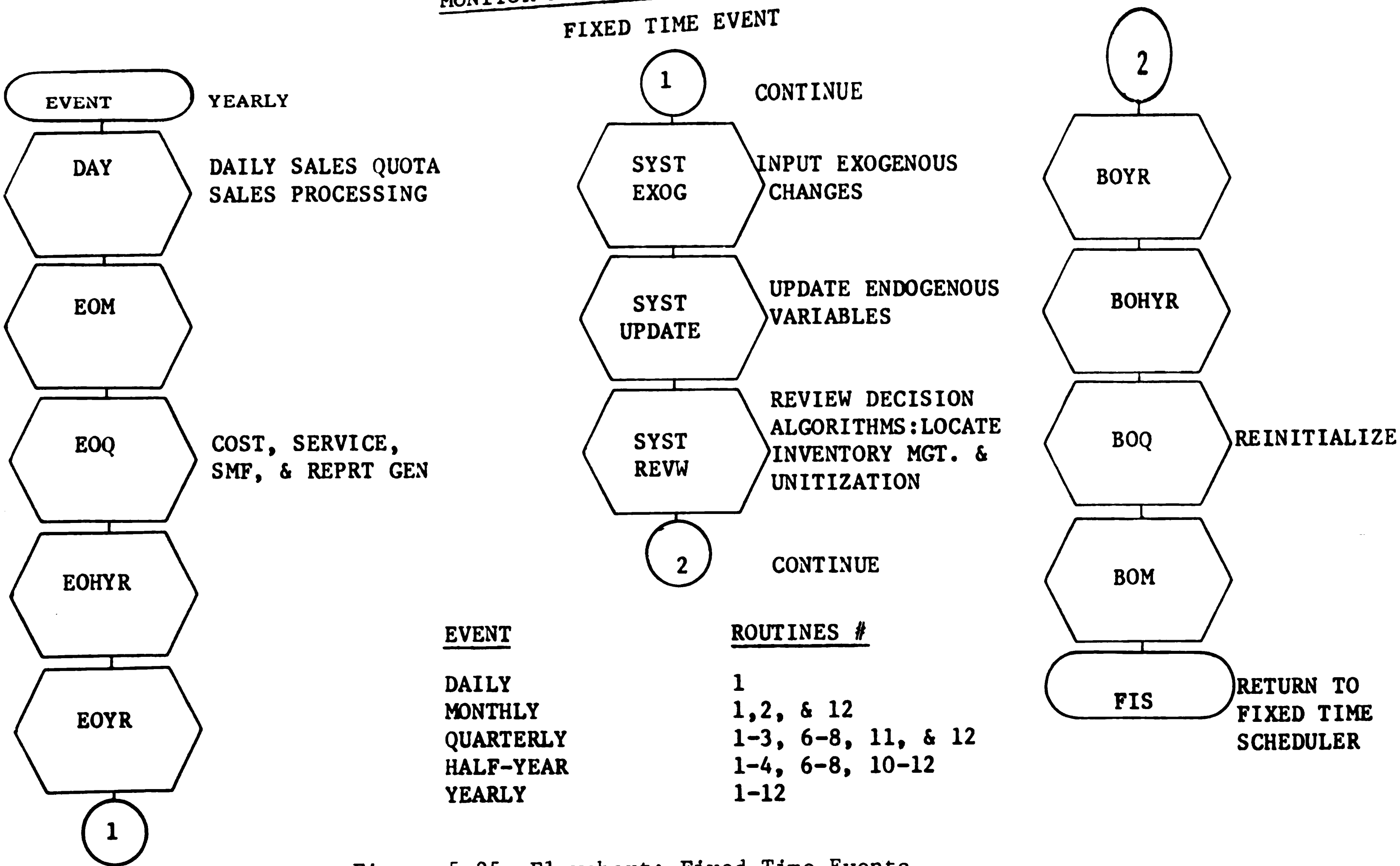
Link to routine to process first days activities.

Link to GASP EXECUTIVE

Figure 5.24--Flowchart: Beginning-Of-Cycle-Event

MONITOR AND CONTROL SUBSYSTEM

FIXED TIME EVENT



EVENT	ROUTINES #
DAILY	1
MONTHLY	1,2, & 12
QUARTERLY	1-3, 6-8, 11, & 12
HALF-YEAR	1-4, 6-8, 10-12
YEARLY	1-12

Figure 5.25--Flowchart: Fixed Time Events

for each region the control was returned to the Fixed-Time Scheduler to generate the next fixed time event.

The Monthly Event consisted of the Daily Event activities plus End-of-Month and Beginning-of-Month activities. In the initial version of LREPS the only additional activity in the Monthly Event was the calculation of the Monthly Sales Forecast, using linear regression as follows:

$$TDSF(IMO) = a + IMO * b$$

where:

TDSF(IMO) = Domestic sales dollars forecast for coming month, IMO

IMO = Month identification

a,b = Regression coefficients.

The Quarterly Event consisted of processing the activities of the Daily and Monthly Events, and the End-of-Quarter, the linkages to the control, and Beginning-of-Quarter routines. The End-of-Quarter routine developed the measures of cost and service, which were previously presented in the Measurement Subsystem, and prepared the results for output to the Report Generator System. The control linkages are presented in the next Section of this chapter. The BOQ activities served as the routine to initialize the endogenous variables for the next quarter's activities. After processing of the Quarterly Event, control was returned to the Fixed-Time Scheduler.

The Half Year Event in the initial LREPS version was a dummy event placed in the system for future flexibility.

The annual or Yearly Event included the processing of the routines Daily, End-of-Month, End-of-Quarter, and End-of-Year Events, and the control linkages, the Beginning-of-Year, Beginning-of-Quarter, and Beginning-of-Month routines. The two new activities performed by the Yearly Event were to increment year by one and develop a new monthly sales forecast. The transformation for incrementing the year was a linear, first-order difference equation of the form:

$$\text{Year}(IY+1) = \text{Year}(IY) + 1$$

where:

$\text{Year}(IY+1)$ = Coming year, $IY + 1$

$\text{Year}(IY)$ = Previous year, IY

IY = Year identification number.

The new monthly sales forecast was calculated using linear regression of the form previously illustrated in the Monthly Event. The End-of-Cycle Event, EOCYC, ended the execution of the simulation run for a planning horizon.

Gateway.--The three primary routines that made up the Input/Output or Gateway subfunction were:

1. End-of-Quarter routine, EOQ
2. Exogenous input routine, EXOG
3. Beginning-of-Quarter routine, BOQ.

The EOQ routine prepared and was responsible for the output of the End-of-Quarter results from the Operating System. This output was used by the Report Generator System to develop the special and standard management reports. The flowchart for the EOQ routine is presented in Figure 5.26.

The first major activity of this routine looped through all the DU's to develop exponential averages of DU dollars and weight sales for the quarter. The transformations were of the form:

DUSD(IQ,IDU) = Alpha*(DUSF(IQ,IDU) + DUSP(IQ,IDU))
+ (1-Alpha)*(DUSD((IQ-1),IDU))

where:

DUSD(IQ,IDU) = New exponential average sales dollars for DU(IDU) for quarter, IQ

Alpha = Smoothing constant, initially set at 0.25

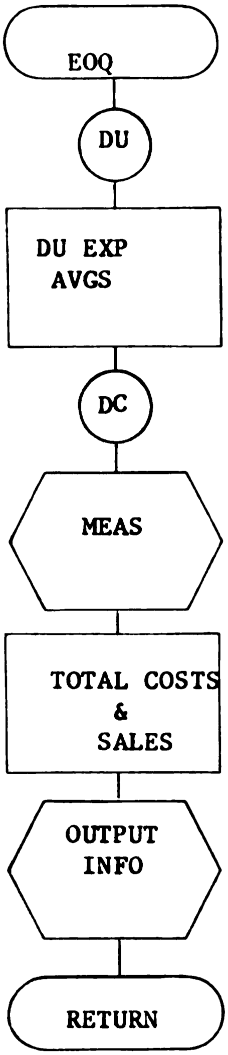
DUSF(IQ,IDU) = Demand unit sales QTD for DU(IDU) from full-line DC's

DUSP(IQ,IDU) = Demand unit sales QTD for DU(IDU) from partial-line DC's

DUSD(IQ,IDU) = Previous exponential average sales for DU(IDU), through quarter, IQ-1.

and,

DUSW(IQ,IDU) = Alpha*(DUWF(IQ,IDU) + DUWP (IQ,IDU))
+ (1-Alpha)*(DUWD(IQ-1),IDU))



Routine to prepare and output end-of-quarter results.

Process each DU.

Prepare exponentially averaged DU sales dollars and weight looping through all Du's.

Develop the measures of cost and service for each in-solution DC.

Call Measurement Subsystem routine to calculate measures of cost and service.

Sum PD total lost and sales for DC, region and domestic.

Call Report Generator Subsystem routine output in-solution DC statistics, regional statistics, domestic statistics, and data base.

Return to the Monitor and Control Quarterly Event.

Figure 5.26--Flowchart: End-Of-Quarter Routine

where:

DUWD(IQ,IDU) = New exponential average sales weight pounds for DU(IDU) for quarter, IQ

Alpha = Smoothing constant, initially set at 0. 25

DUWF(IQ,IDU) = Demand unit sales weight in pounds QTD for DU(IDU) from full-line DC's

DUWP(IQ,IDU) = Demand unit sales weight in pounds QTD for DU(IDU) from partial-line DC's

DUWD((IQ-1),IDU) = Previous exponential average sales weight for DU(IDU) through quarter, IQ-1

IDU = DU identification

IQ = Quarter identification.

The next set of activities looped through the DC's by region to calculate the measures of service and cost via the link to the Measurement Subsystem. The transformations used for the individual cost components were presented in the Measurement Subsystem. After returning to the Monitor and Control Subsystem, the total cost per DC, per region, and for the domestic were calculated next in the EOQ routine using the following transformations:

DCCST(IDC,IQ) = OTBD(IDC,IQ)+INBD(IDC,IQ) + CMDC(IDC,IQ) + FINVC(IDC,IQ) + THRUPC(IDC,IQ) + INVNC(IDC,IQ)

where:

DCCST(IDC,IQ) = Total DC cost for DC,IDC for quarter, IQ

OTBD(IDC,IQ)	= Outbound transportation cost for DC,IDC for quarter, IQ
INBD(IDC,IQ)	= Inbound transportation cost for DC,IDC for quarter, IQ
CMDC(IDC,IQ)	= Communications cost for DC,IDC for quarter, IQ
FINVC(IDC,IQ)	= Facilities investment cost allocated to DC,IDC for quarter, IQ
THRUPC(IDC,IQ)	= Throughput cost for DC,IDC for quarter, IQ
INVNC(IDC,IQ)	= Inventory cost for DC,IDC for quarter, IQ

and:

$$REGCST(IR,IQ) = \sum_{IDC} DCCST(IDC,IR,IQ)$$

where:

REGCST(IR,IQ)	= Total PD cost for region, IR for quarter, IQ
DCCST(IDC,IR,IQ)	= Total PD cost for DC,IDC in region, IR for quarter, IQ
IR	= Region identification

and:

$$DOMCST(IQ) = \sum_{IR} REGCST(IR,IQ)$$

where:

DOMCST(IQ)	= Total domestic PD cost for the quarter, IQ
REGCST(IR,IQ)	= Total PD cost for region, IR for quarter, IQ.

The sales dollars by region and domestic total used transformations of the form:

$$REGDOL(IR) = \sum_{IDU} DUSF(IDU) + \sum_{IDU} DUSP(IDU)$$

where:

REGDOL(IR) = The sales dollars QTD for all DC-DU links in region, IR

DUSF(IDU) = Demand unit sales dollars QTD for DU(IDU) from full-line DC's

DUSP(IDU) = Demand unit sales dollars QTD for DU(IDU) from partial-line DC's

and:

$$DOMDOL = \sum_{IR} REGDOL(IR)$$

where:

DOMDOL = The total domestic dollars QTD for all DC-DU links in the system

REGDOL(IR) = The sales dollars QTD for all DC-DU links in region, IR.

The calculation of sales weight by region and domestic required transformations of the form:

$$REGWT(IR) = \sum_{IDU} DUWF(IDU) + \sum_{IDU} DUWP(IDU)$$

where:

REGWT(IR) = The sales weight in pounds for QTD for all DC-DU links in the region, IR

DUWF(IDU) = Demand unit sales weight in pounds for QTD for DU(IDU) from full-line DC's

DUWP(IDU) = Demand unit sales weight in pounds for QTD for DU(IDU) from partial-line DC's.

and:

$$DOMWT = \sum_{IR} REGWT(IR)$$

where:

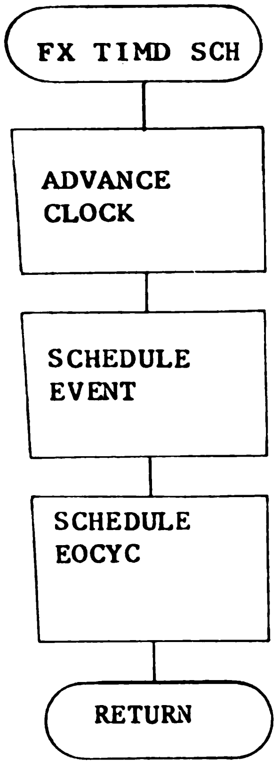
DOMWT = The total domestic sales weight in pounds QTD for all DC-DU links in the system

REGWT(IR) = The sales weight in pounds QTD for all DC-DU links in the region, IR.

The last major activity of the EOQ routine provided the link to the Report Generator System, via which the output information was passed for off-line print-out of the management reports and special analyses.

The LREPS exogenous inputs required for the Operating System are listed in Appendix 1. These variables were read in via the Monitor and Control routine EXOG. The final routine associated with the Gateway subfunction was the Beginning-of-Quarter, BOQ, activity which reinitialized endogenous variables for the next quarter's activity.

Fixed-Time Scheduler.--The Fixed-Time Scheduler used current clock time generated within the LREPS model to schedule the next imminent event. Figure 5.27 presents the sequence of processing of the Fixed-Time Scheduler. The initial activity advances the clock time to the next day, since a call is made to the Fixed-Time Scheduler only after completion of the activities for the day, TNOW. The transformation for advancing the clock was a linear, first-order difference equation as follows:



Start Fixed Time Scheduler.

Processing for day complete - advance clock to next day incremental TNOW by one day.

Schedule next imminent fixed-time event by comparing TNOW against fixed-time events.

Schedule end of cycle event if end planning horizon.

Return to EXECUTIVE ROUTINE.

Figure 5.27--Flowchart: Fixed Time Scheduler

$$TNOW(ID+1) = TNOW(ID) + 1$$

where:

$TNOW(ID+1)$ = Clock time of day, ID + 1

$TNOW(ID)$ = Clock time of day, ID.

The next activity scheduled the imminent fixed-time event by selecting the event that equaled the day TNOW(ID+1). For example, using the calendar of 252 working days; 21 per month, 63 per quarter, and 126 per year, if current clock time, TNOW(ID+1) equaled day 63 the fixed-time scheduler placed the quarterly event ccde in the event file of the Executive routine. Control then transferred to the Executive routine which first selected for processing any variable events scheduled previously for the 63rd day in FIFO order. After completion of processing of the variable events the Executive selected and processed the quarterly fixed time event. Once the fixed time event or variable event was called the routines which make up the events were processed.

In summary, the sequence of control using the Fixed-Time Scheduler and Executive routine for each day, ID, of the simulation was as follows:

1. Compare clock time with fixed event time using the Fixed-Time Scheduler, selecting the appropriate fixed time event for the workday, ID

2. Schedule the fixed time event for day, ID, via the Executive routine sequence file, placing the event code in the file

3. Transfer control to the Executive routine

4. Process all variable events tagged for occurrence on day, ID, in FIFO order

5. Select the fixed time event previously scheduled for day, ID

6. Process the routines of fixed time event

7. Transfer control back to the Fixed-Time Scheduler, advance the clock time to day, ID+1

8. Repeat steps (1)-(7) until clock time is equivalent to the planning horizon at which time the End-of-Cycle event is called and processed ending the simulation cycle.

Controller Function

The Controller, which generated the information feedback responses for sequential decision making, consisted of two major sets of routines:

1. The set of routines that reviewed and developed the endogenous feedback responses, REVIEW:

    a. The routine of calculating the DC and regional sales forecast modification factors, DCSMOD

    b. The routine of calculating a new regional total to tracked product weight ratio for MCC shipment weight extrapolation, RWRC

    c. The calculation of new inventory control variables and selection of new inventory management policies, INVMGT

    d. The facility location algorithms for determining the requirement for, and scheduling any DC facility systems additions or deletions, LOCATE

    e. The facility expansion algorithms for determining the requirement for, and scheduling a DC expansion, EXPAND

2. The set of routines that activated any exogenously or endogenously scheduled activities for changing the PD system, UPDATE:

   a. The quarterly activity of implementing any scheduled DC facility additions, PUTDCN

   b. The quarterly activity of implementing any scheduled DC facility deletions, DELDC

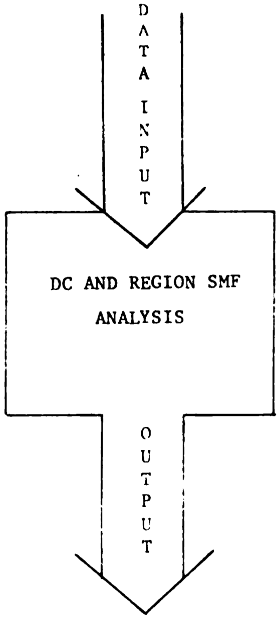
   c. The quarterly activity of implementing any scheduled DC facility expansions, MODIFY.

Each of the above routines is presented within the controller function in the order listed above.

Sales Modification Factors.--The routine DCSMOD calculated the DC and regional Sales Modification Factors, SMF's. These factors were used to modify sales forecast for deviations of service from the desired level. Figure 5.28 presents the activity analysis in terms of the outputs, inputs, and transformations for the Sales Modification routine. The flowchart is presented in Figure 5.29.

The first activity used the actual service in terms of the percentage of sales dollars within the established order cycle intervals, i.e., (IOT = 3,5,7,9, > 9 days) and the desired service percentage within a specified interval to develop the new exponentially smoothed SMF for each in-solution DC. The transformation was of the form:

```
EDCSMF(IDC,IQ) = Alpha*ACDCSMF(IDC,IOT,IQ) +
          (1-Alpha)*EDCSMF(IDC,(IQ-1))
```



INPUTS

1. Total customer order cycle sales dollar percentages
2. No. of in-solution DC's
3. No. of in-solution regions
4. Desired level of service for each region

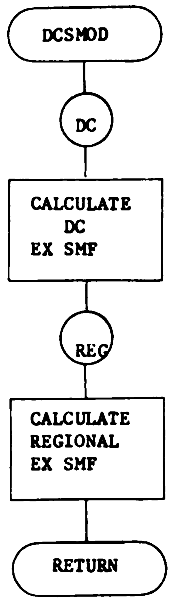
TRANSFORMATIONS

1. Calculate DC exponential average SMF
2. Calculate regional
3. Exponential average SMF

OUTPUTS

1. DC sales modification factor, SMF
2. Previous quarter regional SMF
3. Exponential average of regional SMF
4. Exponential average of DC-SMF

Figure 5.28--Activity Analysis: DC and Region SMF



Calculate DC and regional SMF's.

Process each DC in-solution.

Calculate actual service for each DC for the quarter in terms of percent of sales dollars and orders within the order cycle industry. Calculate new exponentially averaged SMF.

Process each region.

Calculate the previous quarter regional SMF and new exponentially averaged regional SMF.

Return to Monitor & Control quarterly event.

Figure 5.29--Flowchart: DC And Region SMF Routine

and:

ACDCSMF(IDC,IOT,IQ) = PCD(IDC,IOT,IQ)/DSDSV(IR,IOT,IQ)

where:

EDCSMF(IDC,IQ)	= New exponentially smoothed sales modification factor for DC(IDC) for quarter, IQ
Alpha	= Smoothing constant, initially set at 0.25
ACDCSMF(IDC,IOT,IQ)	= Actual sales modification factor for DC,IDC order cycle interval, IOT for quarter, IQ
PCD(IDC,IOT,IQ)	= Percent sales dollars within interval, IOT for quarterly, IQ
DSDSV(IR,IOT,IQ)	= Desired service stated for initial LREPS as percent sales dollars within interval, IOT for region, IR for quarter, IQ
EDCSMF(IDC,(IQ-1))	= Previous exponentially smoothed sales modification factor for DC(IDC) for quarter, IQ-1
IOT	= Order cycle sales interval identification.

The new exponentially smoothed sales modification factor was calculated for each in-solution DC.

The next activity of the routine calculated the sales modification factor for each region using accumulated sales by region within each order cycle interval to develop the percentage by order cycle interval, IOT. The exponentially smoothed regional SMF's were calculated using transformation of the identical form used for the DC calculations as follows:

ERGSMF(IR,IQ) = Alpha*ACRSMF(IR,IOT,IQ) + (1-Alpha)
*ERGSMF(IR,(IQ-1))

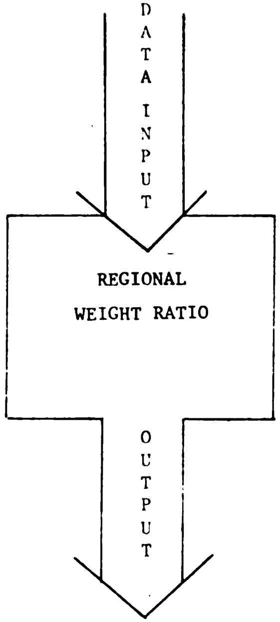
and:

ACRSMF(IR,IOT,IQ) = PCD(IR,IOT,IQ)/DSDSV(IR,IOT,IQ)

where:

ERGSMF(IR,IQ)	= New exponentially smoothed sales modification factor for region (IR) for quarter, IQ
Alpha	= Smoothing constant, initially set at 0.25
PCD(IR,IOT,IQ)	= Percent dollars within interval, IOT for quarter, IQ for region, IR
DSDSV(IR,IOT,IQ)	= Desired service stated for initial LREPS as percent of sales dollars within interval, IOT for region, IR for quarter, IQ
ERGSMF(IR,(IQ-1))	= Previous exponentially smoothed sales modification factor for region, IR for quarter, IQ-1
IOT	= Order cycle sales interval identification.

Regional Weight Ratio.--The regional weight ratio calculated a new regional total to tracked product weight ratio for MCC shipment weight extrapolation each quarter. Figure 5.30 presents the activity analysis in terms of the outputs, inputs, and transformations for the regional weight ratio calculation. The flowchart is presented in Figure 5.31.



INPUTS

1. Number of DC's in-solution
2. Number of regions
3. DC weight sales QTD
4. DC-PDC assignments
5. Regional tracked product weight sales QTD

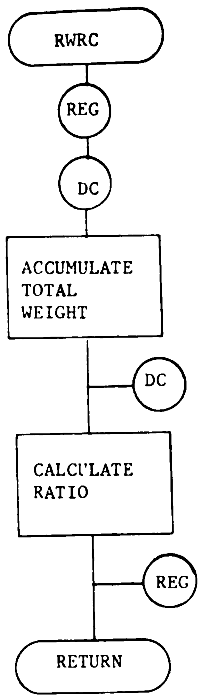
TRANSFORMATIONS

1. Accumulate total weight of all products for each DC to regional total
2. Calculate ratio of total weight to tracked product weight for the region

OUTPUTS

1. Regional weight ratio

Figure 5.30--Activity Analysis: Regional Weight Ratio



Regional weight ratio calculation routine to calculate new regional weight ratio.

Process each region.

Process each in-solution DC in the region.

Accumulate DC's weight to region's total weight.

Loop through all in-solution DC's.

Calculate weight ratio for region.

Loop through all in-solution regions.

Return to M & C QUAR event activity.

Figure 5.31--Flowchart: Regional Weight Ratio Routine

For each region the accumulated weight of all in-solution DC's of the region was used to develop the weight ratio. The transformation was of the form:

$$WTRTREG(IR) = \sum_{IDC} WTSL(IDC,IR)/TPWTRG(IR)$$

where:

WTRTREG(IR) = Weight ratio of total weight of all products to tracked products for region, IR for the previous quarter

WTSL(IDC,IR)= Sales weight processed for the quarter through each DC(IDC) of region, IR

TPWTRG(IR) = Tracked product weight for region, IR for the quarter.

The weight ratio was used to extrapolate up the weight of the tracked products for each MCC shipment in the region to the total weight representative of all products.

Inventory Management.--The inventory management routine provided the capability for testing the effect of three inventory policies:

1. Reorder point policy
2. Optional replenishment policy
3. A hybrid of the reorder point and replenishment policies.[1,2]

This routine, therefore, provided the inventory management decision rules and developed the inventory parameters used in inventory control in the Operations Subsystem. As stated in the Supporting Data System inventory management and control in the LREPS model was established by inventory product category rather than by individual tracked product. The basic policies and transformations for the inventory categories provided the LREPS model with the capability for implementing a dynamic inventory management algorithm. The activities included within the routine included:

1. Calculate initial average reorder lead time for new DC's
2. Calculate exponential average product demand
3. Average daily demand for each tracked product for DC being measured
4. Determine standard deviations of reorder lead time, review period and average daily demand for DC being measured
5. Calculate buffer stock and EOQ for each tracked product being measured
6. Select appropriate inventory policy
7. Calculate ROP1 level-1 reorder point
8. Calculate ROP2 level-2 reorder point
9. Calculate initial inventory level for new DC's coming in-solution
10. Calculate S-level for existing in-solution DC's after processing all tracked products and in-solution DC's
11. Return control to Monitor and Control Subsystem.

The routine was called at the Beginning-of-Cycle to set the initial values of inventory and quarterly to update the inventory control parameters based on the past quarter sales volume and inventory condition. The inventory management system as designed therefore included the time interactions or recursive relationships necessary to be classified as a dynamic model. Figure 5.32 presents the activity analysis in terms of the outputs, inputs, and transformations for the inventory management routine. The flowchart is presented in Figure 5.33.

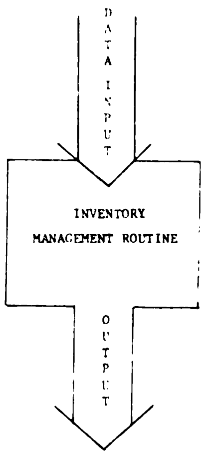
Initially a check was made to determine if the DC being processed was a new DC just coming into solution. If yes, the initial activity of the inventory management routine was to calculate the initial average reorder lead time between the new DC and each of its supplying MCC's. The initial lead time, ROCT was calculated as the sum of the averages of the reorder lead time elements, RT1, RT2, RT3, and RT4.

For each tracked product the level of quarterly sales for the next quarter was calculated in the next activity using an exponentially averaged total product demand for each of the tracked products. The transformations were:

PTPDEM(IQ,ITP) = (1-Alpha)*PTPDEM((IQ-1),ITP) +
Alpha*ATPDEM((IQ-1),ITP)

where:

PTPDEM(IQ,ITP)	=	Predicted sales for tracked product, ITP for quarter, IQ
Alpha	=	Exponential smoothing constant, initial value set at 0.25
PTPDEM((IQ-1),ITP)	=	Predicted sales for tracked product, ITP for quarter, IQ-1



INPUTS

1. Potential DC pointer
2. DC cumulative weighted index
3. No. of in-solution DC's
4. No. of in-solution MCC's
5. DC-MCC tracked product supply links
6. DC-MCC T1 & T4 factors
7. Total no. of tracked products
8. Total no. of inventory categories
9. QTD tracked product case sales
10. Inventory category variables
11. Daily inventory carrying charge
12. Service time variance fns
13. MCC T2 order prep time factors
14. No. of workdays per simulated year
15. Tracked product cost of goods sold
16. DC tracked product avg daily demand
17. DC tracked product buffer stock
18. DC tracked product EOQ
19. DC std dev lead time
20. DC std dev review period length
21. DC std dev avg daily demand
22. Tracked product ordering cost
23. In-solution DC being processed
24. Potential DC being processed

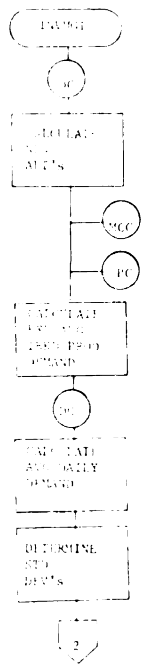
TRANSFORMATIONS

1. Calculate average reorder lead time
2. Calculate exponential average product demand
3. Calculate average daily demand for each tracked product
4. Determine standard deviations of reorder lead time, review period, and average daily demand
5. Calculate buffer stock and EOQ
6. Select appropriate inventory policy
7. Calculate ROP1 and ROP2
8. Calculate initial inventory level
9. Calculate S-levels

OUTPUTS

1. DC tracked product ROP's
2. DC tracked product S-level
3. DC tracked product initial inventory level
4. DC-MCC avg reorder lead time
5. Exp avg tracked product case sales

Figure 5.32--Activity Analysis: Inventory Management



Process each in-solution DC.

Calculate DC-MCC initial average reorder lead time.

Loop through all MCC links for the DC being processed.

Loop through all in-solution DC's.

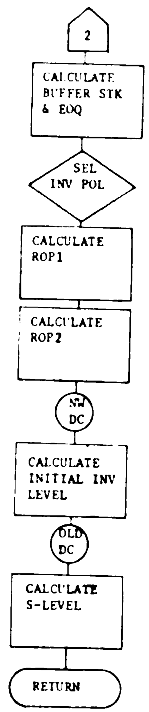
Exponentially average tracked product's domestic.

Process each in-solution DC and all tracked products for the DC.

Calculate the DC average daily demand for the tracked product.

Determine standard deviations of lead time, review period and average daily demand.

Figure 5.33--Flowchart: Inventory Management Routine



Calculate buffer stock and EOQ for tracked products.

Select appropriate inventory policy for the tracked product.

Calculate ROP1 for tracked products using either reorder point or hybrid policy.

Calculate ROP2 for tracked products using either replenishment or hybrid policy.

Calculate initial inventory levels for new DC's coming in-solution.

Calculate tracked product S-levels for each in-solution DC.

Return to M & C Executive Routine.

Figure 5.33--Continued

ATPDEM((IQ-1),ITP) = Actual sales for tracked product, ITP for quarter, IQ-1.

The next series of activities calculated the specific tracked product inventory control variables for each in-solution DC. For each DC-MCC link the average daily demand for each tracked product of the DC being processed was developed using the following transformation:

ADEM(IQ,ITP) = PTPDEM(IQ,ITP) * DCWI(IDC)*NWKDYS/4

where:

ADEM(IQ,ITP) = Average daily demand for tracked product, ITP for quarter, IQ

PTPDEM(IQ,ITP) = Predicted total demand for tracked product, ITP for quarter, IQ

DCWI(IDC) = Cumulative weighted index for DC(IDC)

NWKDYS = Number of workdays in the year, 252.

The next activity determined the standard deviations of average reorder lead time, review period, and average daily demand. The standard deviation of reorder lead time was calculated assuming the lead times were poisson distributed as follows:

$$SDLT(ITP) = AVGLT(ITP)^{\frac{1}{2}}$$

where:

SDLT(ITP) = The standard deviation of lead time for tracked product, ITP

AVGLT(ITP) = Average reorder lead time for the tracked product, ITP.

The standard deviation of the average review period length was calculated assuming a uniform distribution using the transformation:

SDRP(ITP) = AVGRP(ITP)/ (12)

where:

SDRP(ITP) = Standard deviation for the review period for tracked product, ITP

AVGRP(ITP) = Average review period length for tracked product, ITP.

The standard deviation of daily demand was calculated assuming that demand was a poisson distribution using the transformation:

SDEM(ITP,IQ) = ADEM(ITP,IQ)

where:

SDEM(ITP) = Standard deviation of the daily demand for tracked product, ITP

ADEM(ITP,IQ) = Average daily demand for tracked product, ITP for quarter, IQ.

The next activity calculated the buffer stock and economic order quantity, EOQ, for each tracked product for the DC being processed. The transformation for the buffer stock was:

BUF(ITP,IQ) = NSD(ITP)*(SDLT(ITP))*SDEM(ITP) + ADEM(ITP,IQ) * SDRP(ITP)

where:

BUF(ITP) = Buffer or safety stock for tracked product, ITP

NSD(ITP) = Factor for the number of standard deviations or level of safety desired for the tracked product, ITP

SDLT(ITP) = The standard deviation of lead time for tracked product, ITP

SDEM(ITP) = The standard deviation of the daily demand for tracked product, ITP

ADEM(ITP,IQ) = Average daily demand for tracked product, ITP

SDRP(ITP) = The standard deviation of the review period for tracked product, ITP.

The EOQ was calculated using the standard EOQ formula as follows:

$$EOQ(ITP,IQ) = ((2*PTPDEM(ITP,IQ)*DCWI*ORDCST(IDC,IQ))/DICC*63*CGCU(ITP))^{\frac{1}{2}}$$

where:

EOQ(ITP,IQ) = Economic order quantity for tracked product, ITP for quarter, IQ

PTPDEM(ITP,IQ) = Predicted total demand for tracked product, ITP for quarter, IQ

DCWI(IDC) = Sum of weighted index for DC(IDC)

ORDCST(IDC,IQ) = Order cost for DC(IDC) for quarter, IQ

DICC = Daily inventory carrying charge

CGCU(ITP) = Cost of goods sold per case unit for tracked product, ITP.

After calculating the buffer stock and the EOQ the next activity selected appropriate inventory policy for the tracked product being processed. If the product category was assigned a reorder point policy or a hybrid system the transformations for the reorder point, ROP1 were:

BUF(ITP,IQ) = NSD(ITP)* SDLT(ITP)*SDEM(ITP)

and:

ROP1(ITP,IQ) = BUF(ITP,IQ) + AVGLT(ITP)*ADEM(ITP,IQ)

where:

BUF(ITP,IQ)	=	Buffer or safety stock for tracked product, ITP, for quarter, IQ
NSD(ITP)	=	Factor for the number of standard deviations for tracked product, ITP
SDLT(ITP)	=	The standard deviation of lead time for tracked product, ITP
SDEM(ITP)	=	The standard deviation of daily demand for tracked product, ITP
ROP1	=	Reorder point level-1, used for reorder point policy and hybrid policy
AVGLT(ITP)	=	Average reorder lead time for the tracked product, ITP
ADEM(ITP,IQ)	=	Average daily demand for tracked product, ITP for quarter, IQ.

At this time the value of ROP2 was set equal to ROP1 if the product category policy was the reorder point system. If the product used the replenishment policy or hybrid system the transformation was:

ROP2 = BUF(ITP,IQ) + ADEM(ITP,IQ)*(AVGLT(ITP) + AVGRP(ITP)/2)

where:

ROP2 = Reorder point level-2, used for the optional replenishment system and hybrid system

BUF(ITP,IQ) = Buffer or safety stock for tracked product, ITP for quarter, IQ

ADEM(ITP,IQ) = Average daily demand for tracked product, ITP for quarter, IQ

AVGLT(ITP) = Average reorder lead time for the tracked product, ITP

AVGRP(ITP) = Average review period length for tracked product, ITP.

If the DC was new the initial inventory was calculated as follows:

INIV(ITP) = EOQ(ITP) + BUF(ITP)

where:

INIV(ITP) = Initial inventory for tracked product, ITP

EOQ(ITP) = Economic Order Quantity for tracked product, ITP

BUF(ITP) = Buffer for safety stock for tracked product, ITP.

The standard S-level was calculated for each inventory policy as follows:

SLINV(ITP) = EOQ(ITP) + ROP2(ITP)

where:

SLINV(ITP) = S-level inventory for tracked product, ITP

EOQ(ITP) = Economic Order Quantity for tracked product, ITP

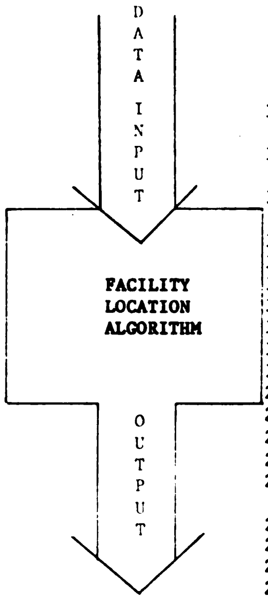
ROP2(ITP) = Reorder point level-2.

These activities were performed for each tracked product for each in-solution DC. After completion of these activities control was returned to the Executive routine-Review. The inventory management routine demonstrates an example of modular and universal aspects of the LREPS model since this routine should be flexible to handle the policies of a large variety of multi-product companies. The theoretical inventory management module can also be replaced by a specific heuristic inventory policy module for a particular company. This was accomplished during initial runs of the LREPS model.

Facility Location.--The facility LOCATE algorithm reviewed the need, selected the location(s), and scheduled the addition and/or deletion of DC's in the PD system configuration. The LOCATE algorithm included the following routines:

1. Review of domestic constraints
2. Review of regional decision rules for feasibility and priority for PD system changes
3. Process list of regions to select region for PD system change
4. Process list of DC's to select location for addition or deletion
5. Implement DC addition
6. Implement DC deletion.

Figure 5.34 presents the activity analysis in terms of the outputs, inputs, and transformations for the LOCATE algorithm. The flowchart is presented in Figure 5.35.



INPUTS

1. Domestic investment for in-solution DCs
2. Domestic max total investment for in-solution DCs
3. Dom total investment for in-process DCs
4. Dom max total investment for in-process DCs
5. Dom no. of in-process add DCs and delete DCs
6. Dom max no. of in-process and in-solution DCs
7. Dom no. of in-solution DCs
8. Regional max no. of DCs allowed
9. Regional max no. of DCs that can be added and deleted
10. Regional max no. in-solution and in-process DC investment
11. Regional no. of in-process add DCs and delete DCs
12. Regional total in-solution and in-process DC investment
13. Regional no. of in-solution DCs
14. Regional exp avg SMF
15. No. of in-solution regions and DUs
16. List of feasible DCs per DU
17. DC dollar size capacities
18. GASP day of simulated time
19. Delay time to add DC
20. In-solution DC total PD cost
21. In-solution DC QTD weight sales
22. Max no. DCs put in-process/quarter
23. Expected regional SMF
24. List of reg SMF's plus later eligible DC list
25. No. of DCs in-process this quarter
26. No. of DUs being processed
27. In-solution DC being processed
28. Potential DC being processed
29. No. of region being processed

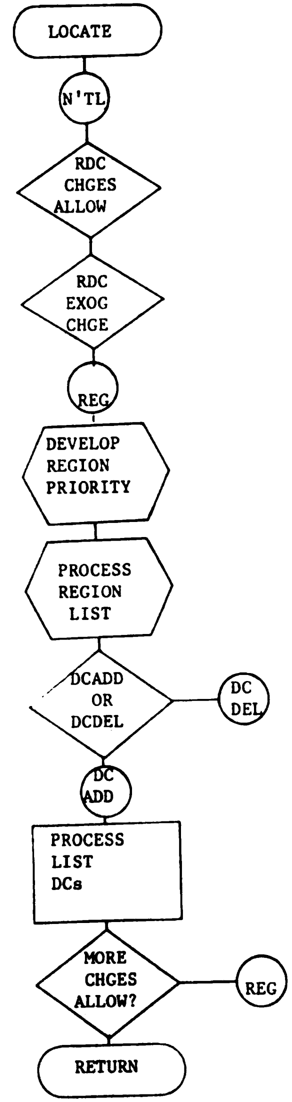
TRANSFORMATIONS

1. Review national constraints
2. Development of regional priority list
3. Process regional priority list
4. Process list of potential DCs
5. Add DC
6. Delete DC

OUTPUTS

1. Time of DC change + type change
2. No. of in-process add DCs and delete DCs
3. Total in-process DC investment
4. Total dom in-process DC investment
5. Dom no. of in-process add DCs and delete DCs
6. Dom no. of in-process DCs added this quar

Figure 5.34--Activity Analysis: Facility Location Algorithm



Algorithm to schedule RDC additions and deletions

Process national level

Check national constraints to determine if RDC additions or deletions are feasible this quarter

Check to determine if RDCs are to be added or deleted on a fixed basis through exogenous input

Process each region

Check regional constraints, calculate expected SMF, and if required add region to the list of regions for possible additions or from desired service

Process regional list selecting the region that has the highest priority for system change and feasibly can make the change

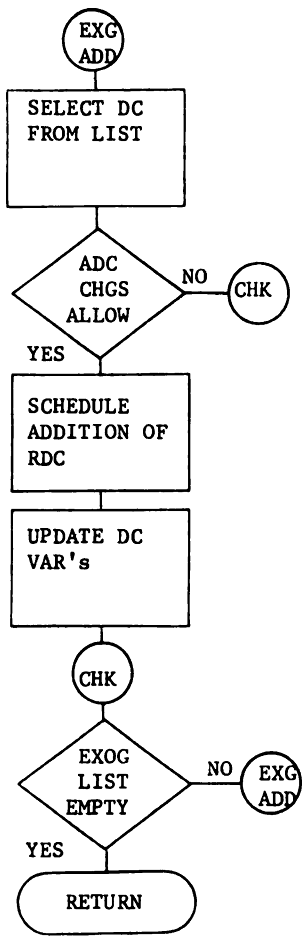
Check to determine if desired change is an addition or deletion

Process the list of DCs to select the DC which adds the greatest additional service if a new DC is desired, or which reduces the unit cost the most if a deletion is desired

Check to determine if more changes can feasibly be made

Return to the Monitor and Control Quarterly Event

Figure 5.35--Flowchart: Facility Location Algorithm Routine



Routine to schedule exogenously RDC's into process of being added

Select next DC from list

Check domestic and regional constraints to see if more additions can be scheduled

Schedule addition of RDC

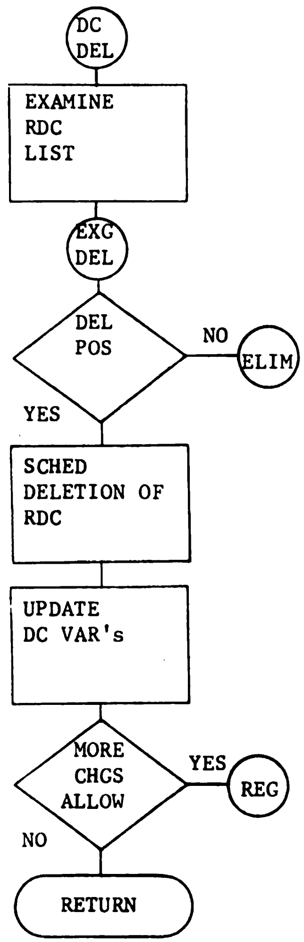
Update domestic and regional variables for RDC in-process of addition

Process all DC's in exogenous list

Check to see if list is empty

Return to M & C QUAR event activity

Figure 5.35--Continued



Attempt to delete a RDC from list

Examine list of eligible in-solution RDC's for possible deletion

Routine for possible deletion of specific RDC

Does the selected RDC fit the criterion for deletion?

Schedule deletion of RDC

Update domestic and regional variables for RDC in process of deletion

Check domestic constraints to see if more deletions can be made

Return to M & C QUAR event activity

Figure 5.35--Continued

The first routine of the LOCATE algorithm checked the domestic constraints established as management parameters. Any reasonable number of constraints could have been implemented via this activity. For the initial LREPS model the constraints were:

1. Total PD System in-solution constraints
    a. Maximum number of DC's in-solution
    b. Maximum dollar investment in DC's in-solution
2. Total PD System in-process constraints
    a. Maximum number of DC's in-process of addition
    b. Maximum number of DC's in-process of deletion
    c. Maximum dollar investment in DC's in-process

The possibility therefore to add a new DC existed if and only if:

$$(NUMDCS < MAXDCS), \text{ and } (INVSTS < MXINVS), \text{ and }$$
$$(NMINPS < MXIPAS), \text{ and } (INVSPS < MXIVPS)$$

where:

NUMDCS = Domestic total number of DC's in solution

MAXDCS = Domestic maximum allowable number of DC's in-solution

INVSTS = Domestic total dollar investment for in-solution DC's

MXINVS = Maximum domestic allowable dollar investment for in-solution DC's

NMINPS = Domestic number of DC's in-process of addition

MXIPAS = Maximum domestic number of DC's in-process of addition

INVSPS = Domestic total dollar investment for in-process DC's

MXIVPS = Maximum domestic total dollar investment for in-process DC's.

The possibility to delete existed if and only if:

(NMBDLS < MXIPAS)

where:

NMBDLS = Domestic number of DC's in-process of deletion

MXIPAS = Maximum domestic number of DC's in-process of deletion.

If at this point both of the above sets of constraint conditions were negative, at least one constraint was equaled or exceeded in each of the addition and deletion constraint sets, the control was returned to the Monitor and Control Subsystem and LOCATE was not processed for the quarter.

If both sets of variables were below the constraints the next step checked to determine if exogenous changes, add and/or delete were programmed for the quarter. The introduction of DC locations via LREPS exogenous input (EXOG) for addition and/or deletion took precedence over the "Free" run of the LOCATE algorithm. This allowed the decision maker to introduce new DC's or delete DC's if desired at any given quarter. However, in any one quarter DC changes were allowed only via one method, either endogenous through LOCATE or exogenously through EXOG, not both.

If PD System change was set to be endogenous via LOCATE rather than exogenous the next LOCATE routine reviewed the regional decision rules in terms of:

1. Reviewing the regional constraints
2. Determining the priority by region for PD system change.

The regional constraints for the initial version of LREPS were similar to the domestic contraints. Addition of a DC in each region therefore was feasible if and only if:

(NDCREG(IR) $<$ MXDCREG(IR)), and

(INVSTSREG(IR) $<$ MXINVSREG(IR)), and

(NMINPSREG(IR) $<$ MXIPASREG(IR)), and

(INVSPSREG(IR) $<$ MXIVPSREG(IR))

where:

NDCREG(IR) = Number of DC's in-solution in region, IR

MXDCREG(IR) = Maximum allowable number of DC's in-solution in region, IR

INVSTSREG(IR) = Dollar investment for in-solution DC's in region, IR

MXINVSREG(IR) = Maximum allowable dollar investment for in-solution DC's in region, IR

NMINPSREG(IR) = Number of DC's in-process of addition in region, IR

MXIPASREG(IR) = Maximum number of DC's in-process of addition in region, IR

INVSPSREG(IR) = Dollar investment for DC's in-process in region, IR

MXIVPSREG(IR) = Maximum allowable dollar investment for DC's in-process of addition in region, IR.

The possibility of deletion of a DC from a region existed if and only if:

(NMBDLSREG(IR) < MXIPASREG(IR))

where:

NMBDLSREG(IR) = Number of DC's in-process of deletion in region, IR

MXIPASREG(IR) = Maximum number of DC's in-process of deletion in region, IR.

Any region where either of the above sets of constraints were equaled or exceeded was bypassed and thus not considered further.

The next set of activities within the routine developed the regional priority for PD system change. The priority was calculated in terms of the Regional LOCATE Sales Modification Factor, RLCSMF. The RLCSMF was similar to the SMF used to modify forecasted sales at the DC level based on the ratio of actual to desired service. However, the RLCSMF was calculated to reflect not only actual service of in-solution DC's but also an assumed level of service for the in-process DC's which come on-line after a four quarter delay time. The RLCSMF for the quarter was developed using the following transformations:

RLCSMF(IR) = ((NDCREG(IR)/(NDCREG(IR)+NMIPSREG(IR))
*EXPSMF(IR)+(NMINPSREG(IR)/(NDCREG(IR)
+NMINPSREG(IR))*SMFNDC(IR)-SMFBASE(IR))/
SMFBASE(IR)

where:

RLCSMF(IR) = Locate sales modification factor for region, IR

NDCREG(IR) = Number of DC's in-solution for region, IR

NMIPSREG(IR) = Number of DC's in-process of addition for region, IR

EXPSMF(IR) = Exponential smoothed sales modification factor, for region, IR

SMFBASE(IR) = Reference of base sales modification factor, at which the ratio of actual to desired service equaled 1.0 for the region, IR

SMFNDC(IR) = Sales modification factor set for each in-process DC, and used as initial value for first quarter DC in-solution for the region, IR.

A DC in-process by definition does not contribute to the regional service. However, a value was assumed for each in-process DC to acknowledge the fact that the in-process DC, by being selected implementation in one year, reduced the need for further addition of DC's via LOCATE in the same region during each of the next four quarters. This concept is similar to the use of inventory position to indicate the inventory-on-hand plus on order. In the case of facilities the facility position equaled the DC's in-solution plus the DC's in-process. The recognition that a DC was in-process by taking credit for the service it will provide when it comes on-line, reduced the chances of adding a second unnecessary DC in the same region in the immediate quarters following a previous quarter addition of a DC.

The RLCSMF for each region was compared against the "upper" and "lower" limits for the SMFBASE set as management parameters. The "upper" limit established the level above which the region was considered to have a surplus of service thus being a candidate for deletion of a DC. The region was included in the list for deletion, RLISTDL, if and only if:

$$RLCSMF(IR) \geq UPLMTSMF(IR)$$

where:

RLCSMF(IR) = Combined estimate of sales modification factor including the exponential average SMF for in-solution DC's and the assumed SMF for in-process DC's in the region, IR. The assumed value was set at a value between the regional SMF average and 1.0.

UPLMTSMF(IR) = Upper limit of SMF above which surplus service existed. Initial LREPS model set the limit at 1.2.

The "lower" limit established the level below which the region was considered to have a deficiency of service thus being a candidate for addition of a DC. The region was included in the list that required addition, RLISTAD, if and only if:

$$RLCSMF(IR) < LWLMTSMF(IR)$$

where:

RLCSMF(IR) = Combined estimate of sales modification factor including the exponential average SMF for in-solution DC's and the assumed SMF for in-process DC's in the region, IR. The assessed value was set at a value between the regional average and 1.0.

LWLMTSMF(IR) = Lower limit of SMF below which deficiency of service existed. Initial LREPS model set limit equal to 0.9.

After all regions were reviewed if no regions were placed in the RLISTDL or RLISTAD the control was returned to the Monitor and Control Quarterly event. Given, however, that at least one region was placed in RLISTDL or RLISTAD the next routine processed the list of regions to select the region for PD system change in terms of:

1. Selection of the region with the highest priority
2. Determination of action, if any, to be taken within the region.

The first activity determined the region with the highest priority for PD system change. In the initial version of LREPS addition was given priority over deletion. Therefore, if the RLISTAD included at least one region the region with the greatest deviation from the LWLMTSMF was selected as the region to attempt to add a DC. The next set of activities determined if a DC could be added to this region using an iterative process which selected the DC that, if added, would contribute the greatest sales volume from the list of potential DC's in the region. The iterative process was as follows for the selected region:

1. Process each DU accumulating the sales to the most "favorably" located potential DC, Rank 1; DCSLS(IDC) = $\sum$DUSLS(IDC) for each DC potential in the region

where:

DCSLS(IDC) = Potential sales of DC, IDC and
DUSLS(IDC) = Sales for each DU assigned to the DC,IDC.

2. Eliminate from the list of potential DC's the DC with the lowest accumulated sales; the minimum DCSLS(IDC)

3. Accumulate the DU sales to the remaining DC's using the best DC-DU rank possible given that a DC(IDC) was eliminated and some DU's must be assigned to lower rank (less favorable-further distant) DC(IDC)

4. If only two DC's remain continue to Step 5, otherwise return to Step 2 and eliminate another DC, continuing until only two potential DCs remain for evaluation

5. Select the DC from the remaining two DCs that has the higher sales accumulation, this DC becomes the primary candidate for addition in the region.

The selected DC was then checked to determine if the sales accumulated was greater than the minimum sales required to meet the minimum size DC. The DC was scheduled for addition if and only if:

$$DCSLS(IDC) \geq MINDC$$

where:

DCSLS(IDC) = Potential sales dollars accumulated for the potential DC, IDC

MINDC = Minimum sales dollars for a potential DC to be considered for addition.

The first activity of the Implement DC Addition routine involved establishing time for the new DC to come in-solution. The transformation was of the form:

$$TMINDC(IDC) = TNOW + TMINPR$$

where:

TMINDC(IDC) = Day of simulated calendar when DC,IDC in-process comes in-solution

TNOW = Day of simulated calendar when decision made to add DC,IDC

TMINPR = Delay time required for adding new DC,IDC.

The second activity of the Implement DC Addition routine updated the DC in-process variables as follows:

NMINPS = NMINPS + 1

NMINPSREG(IR) = NMINPSREG(IR) + 1

INVSPS = INVSPS + FINV(IDC)

INVSPSREG(IR) = INVSPSREG(IR) + FINV(IDC)

where:

NMINPS = Domestic number of DC's in-process of addition

NMINPSREG(IR) = Number of DC's in-process of addition, in region, IR

FINV(IDC) = Capital investment for DC,IDC

INVSPS = Domestic investment in-process

INVSPSREG(IR) = Investment in-process in region, IR.

The final activity in the Add routine checked the updated domestic constraint variables to determine if more DCs could be added, if service deficiency still existed. If the constraints were not exceeded the process was repeated again starting with the review of the regional constraints.

If no regions were below the lower limit, RLISTAD was empty and the RLISTDL was checked to determine the greatest deviation from the upper limit to attempt deletion of a DC. If no region was above the upper limit, RLISTDL was also empty and control was returned to the Monitor and Control Quarterly activity.

Given that the region was above the upper limit of the base or desired SMF the control, after processing the Add routine in RLISTAD, was transferred to the Delete routine. The first activity of the Delete routine reviewed the possibility of endogenous deletion of a DC. This was accomplished by reviewing the list of in-solution DCs in the region. A DC could only be a candidate for deletion if the following conditions were present:

1. The DC was currently in-solution
2. The DC was not currently being deleted.

The above process developed the preliminary list of eligible DCs from which the DC with the maximum cost per pound of throughput was selected as the primary candidate for deletion. The transformation for developing the cost per pound was:

DCSTLB(IDC,(IQ-1)) = DCTOTCST(IDC,(IQ-1))/DCWT(IDC,(IQ-1))

where:

DCSTLB(IDC,(IQ-1))	= Cost per pound of sales for DC(IDC) for the previous quarter, IQ-1
DCTOTCST(IDC,(IQ-1))	= Total cost for DC(IDC) for the previous quarter, IQ-1
DCWT(IDC,(IQ-1))	= Total weight moved through the DC(IDC) for the previous quarter, IQ-1.

The DC with the highest cost per pound for the region was then selected for possible deletion. The next activity in the Delete routine checked to determine if the DC had been in-solution at least two years. If not, the DC was not eligible for deletion and the region was eliminated from further consideration.

If the DC had been in-solution long enough, the Implement DC Deletion routine scheduled the deletion using the following transformations:

TMOSDC(IDC) = TNOW + TMINPR(IDC)

where:

TMOSDC(IDC) = Day of simulated calendar for DC(IDC) to be removed from in-solution list

TNOW = Current day of simulated calendar time

TMINPR(IDC) = Delay time in days required for deleting an in-solution DC(IDC).

The in-process DC variables were then updated as follows:

NMBDLS = NMBDLS + 1

NMINPSREG(IR) = NMINPSREG(IR) + 1

where:

NMBDLS = Domestic number of DCs in-process of deletion

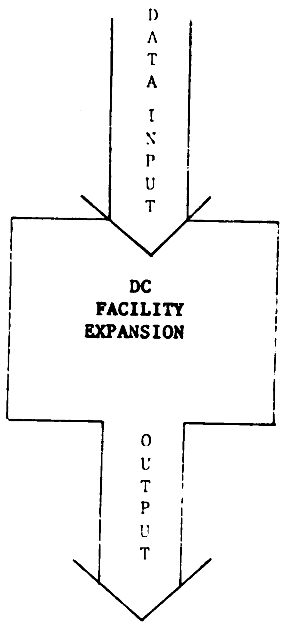
NMBDLSREG(IR) = Number of DCs in-process of deletion for region, IR.

The final activity of DC delete checked the constraints to determine if more deletions are required. If yes, the control was transferred to check regional constraints. Otherwise the control was returned to the Monitor and Control Quarterly activity.

If the deletion had been designated as being exogenous the same basic deletion routine was used, however, the DC candidate(s) and the priority for deletion were specified by the exogenous input. The same process was then followed as for the endogenous deletion. The constraints were initially set in LREPS so that only one DC could be scheduled for deletion per quarter.

The Exogenous Add routine was established so that up to ten DCs could be added in any one quarter. A list of DCs in the priority desired was read as an exogenous input and the DCs were added in their respective regions until the domestic and/or regional constraints were reached. Once all of the exogenous DCS were processed or the constraints were reached, the control was returned to the Monitor and Control Quarterly activity.

Expand DC Capacity.--The last algorithm included in the Review section used an information feedback control loop to expand in-solution DC's. Figure 5.36 presents the activity analysis in terms of the outputs, inputs, and transformations for the Expansion algorithm. The flowchart is presented in Figure 5.37. The routine EXPAND, developed similar in logic to the LOCATE algorithm, consisted of the following routines:



INPUTS

1. Domestic in-solution DC investment
2. Max dom in-solution and in-process DC investment
3. Max dom no. of in-process DCs
4. Dom in-process DC investment
5. Domestic and regional constraints on-off flag
6. Dom no. of in-process add DCs and delete DCs
7. Regional in-solution and in-process DC investment
8. Max reg in-solution DC investment
9. Max reg in-process DC add investment
10. No. of in-process add DCs--reg
11. Max no. of in-process add DCs
12. Potential DC in-solution
13. DC QTD dollar sale
14. DC dollar size capacity
15. No. of in-solution DCs and regions
16. Day of simulated time
17. Delay time to expand DC
18. Avg inv't by DC size + type
19 Maximum DCs in system
20. DC sales to capacity ratio
21. List of DCs for possible expansion
22. In-solution DC being processed
23. Potential DC being processed
22. No. of region being processed

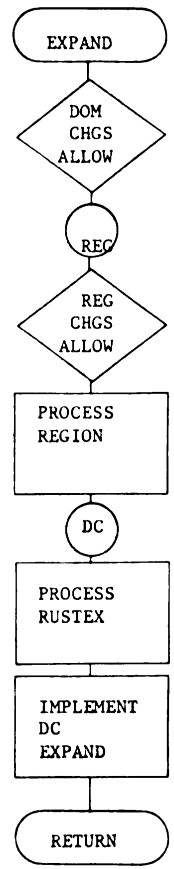
TRANSFORMATIONS

1. Review domestic constraints
2. Review regional decision rules
3. Process list of regions and DCs
4. Implement DC expansion

OUTPUTS

1. Time of DC change + type change
2. Domestic in-process investment
3. Domestic no. of in-process DCs
4. Regional in-process investment
5. Exp avg quar dollar sales
6. No. of in-process add DCs--reg

Figure 5.36--Activity Analysis: DC Expansion Algorithm



DC Expansion Algorithm

Check domestic constraints to determine if DC expansion can be accomplished this quarter

Process each region for feasible changes

Review regional constraints to determine if DC expansion can be accomplished this quarter

Process each DC in the region. Calculate sales/capacity ratio, SRATIO. Add any DC with SRATIO greater than limit to RLISTEX for possible expansion

Process each DC for possible change

Select DC with largest SRATIO

Schedule DC expansion, and update domestic and regional DC in-process variables

Return to M & C Quarterly Event

Figure 5.37--Flowchart: DC Expansion Algorithm

1. Review of domestic constraints

2. Review of regional decision rules

3. Process list of regions to select region for PD system change

4. Process list of DC's to select DC for expansion

5. Implement DC expansion.

The first routine reviewed the domestic constraints to determine if any expansion could take place. If not, the EXPAND algorithm was bypassed and control returned to the Monitor and Control Quarterly Activity. The domestic constraints for the expansion algorithm allowed expansion if and only if the following constraints were not violated:

(NMINPS < MXIPAS), and (INVSPS < MXIVPS), and
(INVSTS < MXINVS)

where:

NMINPS = Domestic number of DC's in-process of addition

MXIPAS = Maximum domestic number of DC's in-process of addition

INVSPS = Domestic total dollar investment for in-process DC's

MXIVPS = Maximum domestic total dollar investment for in-process DC's

INVSTS = Domestic total dollar investment for in-solution DC's

MXINVS = Maximum domestic total dollar investment for in-solution DC's.

The next routine, given that the domestic constraints were not violated, checked the regional constraints. The region could expand one or more of its DC's if and only if the following constraints were not violated:

(INVSTREG(IR) < MXINVSREG(IR)), and

(NMINPSREG(IR) < MXIPASREG(IR)), and

(INVSPSREG(IR) < MXIVPSREG(IR)

where:

INVSTREG(IR) = Dollar investment for in-solution DC's in region, IR

MXINVSREG(IR) = Maximum allowable dollar investment for in-solution DC's in region, IR

INVSPSREG(IR) = Dollar investment for DC's in-process in region, IR

MXIVPSREG(IR) = Maximum allowable dollar investment for DC's in-process of addition in region, IR

NMINPSREG(IR) = Number of DC's in-process of addition in region, IR

MXIPASREG(IR) = Maximum number of DC's in-process of addition in region, IR.

If expansions could take place in the region the in-solution DC's of the region were checked to determine which if any DC required expansion. This was accomplished by first calculating the ratio of current sales to capacity for each in-solution DC as follows:

SRATIO(IDC) = DCSLS(IDC)/DCCAPAC(IDC,IS)

where:

SRATIO(IDC) = The ratio of sales dollars to sales dollar capacity for the DC, IDC

DCSLS(IDC) = Sales dollars for the DC,IDC for the quarter

DCCAPAC(IDC,IS) = Capacity of the DC,IDC of size, IS in sales dollars.

This ratio was then compared to a specified ratio, LMTRATIO which was set as a management parameter by the exogenous input. A DC was defined as requiring expansion if and only if:

SRATIO(IDC) $\geq$ LMTRATIO(IS)

where:

SRATIO(IDC) = The ratio of sales dollars to sales dollar capacity for the DC,IDC

LMTRATIO(IS) = Ratio of sales dollars to capacity for DC size, IS at which expansion decision sould be made such as 60 percent.

Each DC above the LMTRATIO was then entered in RLISTEX as a DC requiring expansion. If the list contained any DC's after all DC's were processed the DC with the largest sales to capacity SRATIO above LMTRATIO was selected and scheduled for expansion. The time for expansion was set in the same manner as the time for addition and deletion of a DC. The transformation was of the form:

TMINEX(IDC) = TNOW + TMEXP

where:

TMINEX(IDC) = Day of simulated calendar when DC(IDC) expansion comes insolution

TNOW = Day of simulated calendar when decision made to expand DC

TMEXP = Delay time required for expanding DC.

The domestic and regional in-process constraint variables were then updated as follows:

INVSPS = INVSPS + FINV(IDC,IQ) - FINV(IDC,(IQ-1))

NMINPS = NMINPS + 1

INVSPSREG(IR) = INVSPSREG(IR) + FINV(IDC,IQ) - FINV(IDC,(IQ-1))

where:

INVSPS = Domestic investment in-process

FINV(IDC,IQ) = Capital investment for DC(IDC) in-solution at quarter, IQ after expansion

FINV(IDC,(IQ-1)) = Capital investment for DC(IDC) in-solution at quarter, IQ-1 before expansion

NMINPS = Domestic number of DC's in-process

INVSPSREG(IR) = Investment in-process in region, IR.

The domestic constraints were then checked to determine if any other expansions could be made in the PD system. If the constraints were not reached the routine returned to the list of candidates for expansion and to attempt to expand another DC. If the constraints were reached the control was returned to the Monitor and Control Quarterly activity.

Implement DC Addition.--The last set of routines of the Controller were the Update routines. These routines implemented the scheduled changes to the PD system. The first routine within the Update Function of the Controller was the quarterly routine of implementing any scheduled DC facility addition, PUTDCN. Figure 5.38 presents the activity analysis in terms of a DC addition. The flow-chart is presented in Figure 5.39.

The first activity checked to determine if it was time for the DC to come in-solution. The DC was brought in-solution if and only if:

TMINDC(IDC) = TNOW

where:

TMINDC(IDC) = Day when DC(IDC) now in-process was scheduled to come in-solution

TNOW = Current work day of simulated calendar.

Assuming that the DC was due to come in-solution the next activity updated the following in-solution variables using linear, first-order difference equations:

NUMDCS = NUMDCS + 1

NDCREG(IR) = NDCREG(IR) + 1

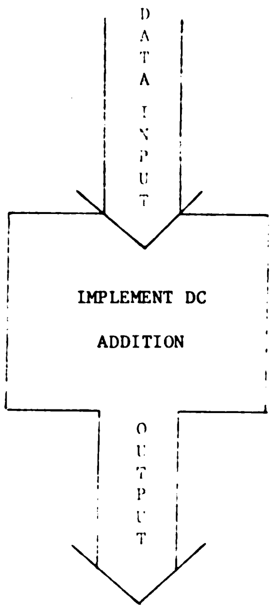
INVSTREG(IR) = INVSTREG(IR) + FINV(IDC)

INVSTS = INVSTS + FINV(IDC)

where:

NUMDCS = Domestic total number of DC's in-solution

NDCREG(IR) = Number of DC's in-solution in region, IR



INPUTS

1. Day of simulated time, THOW
2. Total no. of DU's
3. List of feasible DC's to DU's
4. Total no. of tracked products
5. DC size capacities
6. DC type + PDC assignment
7. DC exp avg dollar sales
8. Time of DC change + type change
9. Avg inv't by DC size + type
10. No. of DU being processed
11. In-solution DC being processed
12. Potential DC being processed
13. No. of region being processed

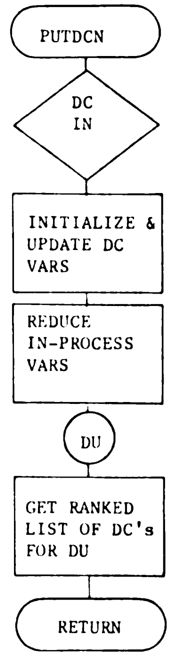
TRANSFORMATIONS

1. Check to determine if DC to be added
2. Initialize and update in-solution DC variables for incoming DC
3. Reduce in-process variables
4. Process each DU
5. Process each DC in the DU list of feasible DC's until best in-solution DC selected

OUTPUTS

1. No. of in-solution DC's
2. In-solution DC variables
3. In-solution DC pointer
4. REG no. of in-process DC's--add
5. Regional in-solution investment
6. Regional in-process investment
7. Reg no. of in-solution DC's
8. Dom no. of in-process DC's
9. Domestic in-solution investment
10. Domestic in-process investment
11. DC tracked product S-level
12. NOCT sales dollar proportions
13. PD system change indicator

Figure 5.38--Activity Analysis: Implement DC Addition



DC addition implementation routine

Check to determine if DC in-process is to come in-solution now at TNOW

Initialize and update in-solution DC variables for each DC being implemented at TNOW

Reduce number of DC's in-process of being added - regionally and domestically

Process each DU

Get ranked list of feasible DC's that can serve this DU. Process each DC in DU list until highest ranking in-solution DC found for assignment to DU

Return to M & C QUAR event

Figure 5.39--Flowchart: Implement DC Addition

INVSTREG(IR) = Dollar investment for in-solution DC's in region, IR

INVSTS = Domestic total dollar investment for in-solution DC's.

The next activity reduced the necessary domestic and regional in-process variables using linear, first-order difference equations of the form:

NMINPS = NMINPS - 1

INVSPS = INVSPS - FINV(IDC)

NMINPSREG(IR) = NMINPSREG(IR) - 1

INVSPSREG(IR) = INVSPSREG(IR) - FINV(IDC)

where:

NMINPS = Domestic number of DC's in-process of addition

INVSPS = Domestic total dollar investment for in-process DC's

NMINPSREG(IR) = Number of DC's in-process of addition in region, IR

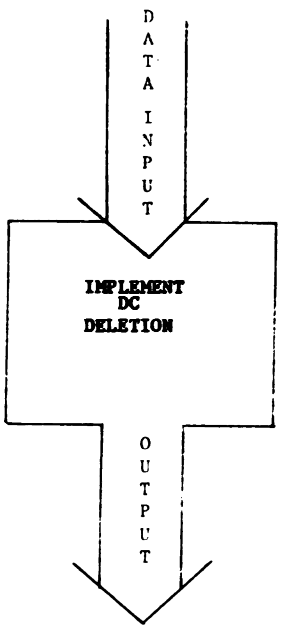
INVSPSREG(IR) = Dollar investment for DC's in-process in region, IR.

The remaining activities of the routine linked each DU to the best insolution DC that could serve it. The basis for selecting the best DC was a heuristically pre-determined ranked list of DC's that could feasibly serve the DU being processed. Each of the feasible DC's for the DU starting with Rank 1 or best, was checked against the list of in-solution DC's until a match occurred. The DU was then assigned to the matched DC for service for the forthcoming quarter(s).

Implement DC Deletion.--The next major Update routine presented is the deletion of DC's from the PD system configuration. Figure 5.40 presents the activity analysis in terms of the outputs, inputs, and transformations for deletion of in-solution DC's the DELDC routine. The flowchart is presented in Figure 5.41. The routine consisted of reducing the in-solution and in-process variables.

The form of the difference equations for these transformations were previously presented for bringing a DC in-solution, PUTDCN. The final activity of this routine deleted the DC's remaining inventories-on-hand and assigned any outstanding stockout commitments to the regional PDC.

Implement DC Expansion.--The activity analysis for implementation of the DC Capacity Expansion routine, MODIFY, is presented in terms of the outputs, inputs, and transformations in Figure 5.42. The flowchart is presented in Figure 5.43. For this routine if the current time, TNOW, was the scheduled time for expansion the DC size indicator was incremented to the next appropriate size interval. The next activity reduced the domestic and regional in-process variables, number in-process and investment in-process. The in-solution variables investment for the region and domestic were increased to reflect the larger capacity size interval DC. After reviewing all in-process DC's to determine if expansion was to occur at this time the routine returned to the Monitor and Control Quarterly activity.



INPUTS

1. Day of simulated time, TNOW
2. DC type and PDC assignment
3. Time for DC change
4. Average investment by DC size and type
5. Total number of tracked products
6. Number of in-solution MCCs
7. Number of the region and DC being processed
8. Number of in-solution regions

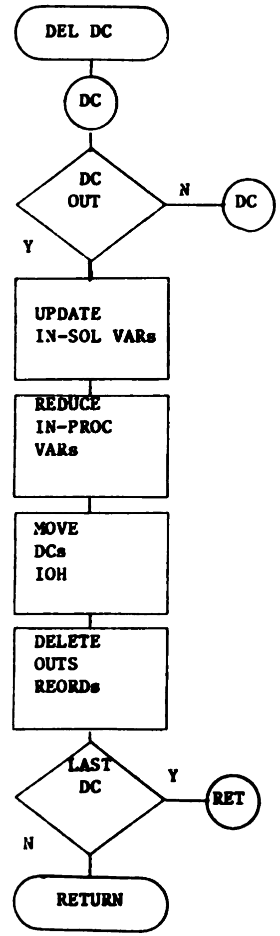
TRANSFORMATIONS

1. Reduce in-solution variables
2. Reduce in-process variables
3. Assign remaining IOH to PDC
4. Assign outstanding stockout commitments to the PDC

OUTPUTS

1. Number of in-solution DCs
2. In-solution DC variables
3. Region number of in-process DCs being deleted
4. Region number of in-solution DCs
5. Region total in-solution investment
6. Domestic number of in-process DCs being deleted
7. Domestic in-solution investment
8. DC-MCC link variables
9. DC tracked product variables

Figure 5.40--Activity Analysis: Implement DC Deletion



Routine to delete DC from solution

Check each in-solution RDC

Check to see if DC to go out

Update in-solution variables for deletion of DC

Reduce in-process variables for actual deletion

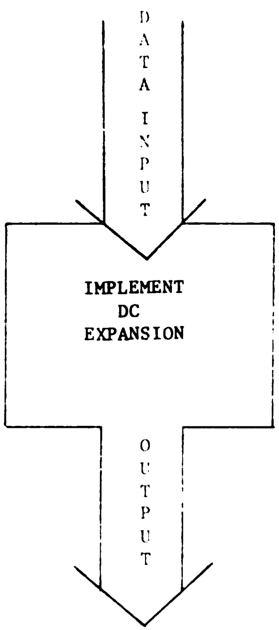
Move deleted DCs inventory-on-hand (IOH) to its assigned PDCs IOH

Delete any outstanding DC-MCC reorders for deleted DC

Check to see this is last in-solution DC being processed

Return to Monitor and Control Quarterly activity

Figure 5.41--Flowchart: Implement DC Deletion



INPUTS

1. Day of simulated time, TNOW
2. DC type and PDC assignment
3. Time for DC change and type change
4. Average investment by DC size and type
5. Number of in-solution DCs

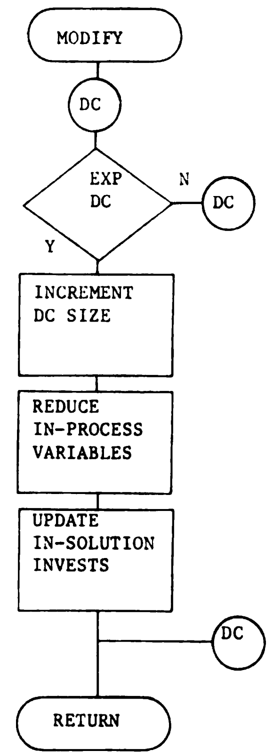
TRANSFORMATIONS

1. Check current time against scheduled time
2. Reduce domestic and regional in-process variables
3. Increase in-solution variables

OUTPUTS

1. Domestic number of in-process DC additions
2. Domestic in-solution DC investment
3. Domestic in-process DC investment
4. Regional in-solution DC investment
5. Regional in-process DC investment
6. Regional number of in-process DC additions

Figure 5.42--Activity Analysis: Implement DC Expansion



Routine to expand size of in-solution DCs

Check to see if DC to be expanded

Increment DC size indication by one

Reduce regional and domestic in-process variables

Update regional and domestic in-solution investments

Loop through all in-solution DCs

Return to Monitor and Control Quarterly Event activity

Figure 5.43--Flowchart: Implement DC Expansion

Summary

The Monitor and Control Subsystem, performs the Supervisory and Controller Functions. In reporting the Monitor and Control Subsystem the Controller Function received the primary emphasis because the Controller provides, via information feedback control loops, the dynamic aspects of the model which enabled the consideration of the sequential decision problem.

Operating System Summary

The four subsystems presented in this chapter represent the Operating System, of the LREPS simulation model. At this point the reader has been introduced to the input data and analyses requirements via the Supporting Data System, Chapter IV, and the transformations via the Operating System, Chapter V. The next chapter, The Report Generator System presents the desired output information content and format for the initial LREPS model.

CHAPTER V--FOOTNOTE REFERENCES

[1]Packer.

[2]Naylor.

CHAPTER VI

REPORT GENERATOR SYSTEM

Introduction

The third and final stage of the LREPS model is the Report Generator System. The Report Generator System consists of a series of computer programs which are run off-line using data generated by the Operating System. The primary purpose of the Report Generator System is to prepare standard and special analyses using the output data from the LREPS simulation runs. Analysis indicated that information was required at the (1) DU level, (2) the DC level, and (3) the total physical distribution systems level. At each level the information requirements were established based on the expected use of the model for physical distribution management decision making and researcher experimentation.[1] This chapter presents the requirements of the Report Generator System under three major sections:

1. Output information content
2. Output information frequency
3. Output information formats.

Figure 6.1 presents the activity analysis for the development of the Report Generator System in terms of the desired outputs, required inputs, and selected transformations. The flowchart for the system is illustrated in Figure 6.2.[2]

Output Information Content

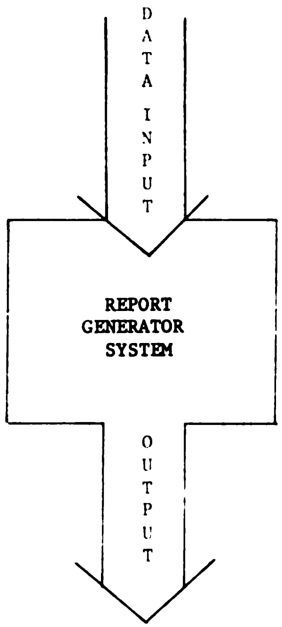
The LREPS model capabilities, previously discussed in Chapter I in terms of target variables, control variables, and uncontrollable variables required that the information content of the Report Generator System include the following types of information:

1. Operational information
2. Status information
3. Sensitivity analysis and validation information
4. Flexibility-Robustness information.

Operational Information

The operating reports, similar to the profit and loss statement, were required to provide information related to the activity level of the model entities over the reporting period(s). Examples of the LREPS operating information required for management decision making and researcher experimentation included:

1. DU level
    a. Sales dollars for the period
    b. Sales weight for the period



INPUTS

1. Instruction to print titles and descriptions
2. Quarter identification
3. Instruction to print quarter summary
4. DC identification

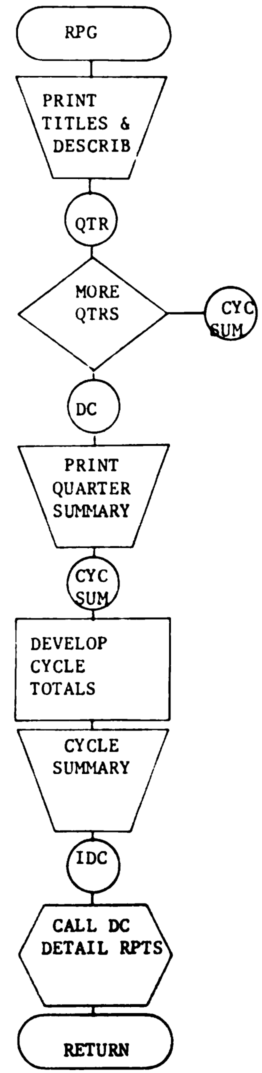
TRANSFORMATIONS

1. Development of simulation cycle totals
2. Process DC detail reports

OUTPUTS

1. Titles and descriptions
2. Quarter summary
3. Cycle summary
4. DC detail reports

Figure 6.1--Activity Analysis: Report Generator System



Report Generator System

Print titles and description of reports

Process each quarter

If no more quarters, transfer to CYC SUM

Process each DC in-solution for the quarter

Print DC summary report for the quarter

Cycle summary routine

Develop the totals for the cyclic summary report for the planning horizon

Print cycle summary report

Process each DC that has been in-solution for at least one quarter

Call and process the DC Detail Report Routine

Return to the M & C Executive routine

Figure 6.2--Flowchart: Report Generator System

2. DC level

    a. Cost--total and PD component costs for transportation, throughput, communications, facility investment, and inventory

    b. Sales--dollars, weight, cube, cases, lines, and orders

    c. Service--customer order cycle, back-order time, outbound transportation time

    d. Inventory--average Inventory-on-Hand, number of stockouts, number of reorders, backorders, and stockout delay

3. Total PD System

    a. Costs--discounted and end-of-planning horizon totals

    b. Sales--discounted and end-of-planning horizon totals

    c. Service Time--averages and variances for planning horizon both regional and national

    d. Status Data--average investment

    e. Flexibility--investment and robustness.

Status Information

The status reports, similar to balance sheets, were required to provide information related to the system state or status of the physical distribution network profile, market profile, product profile, and competitive profile at the end of the reporting period. Examples of the LREPS status information required for management decision making and researcher experimentation included:

1. DU level

    a. Weighted index

    b. DC assignment

2. DC level

    a. Number of DU's served

    b. List of DU's served

    c. Inventory-on-Hand

    d. Accumulated weighted index

    e. Dollar size capacity

    f. Sales modification factor

3. Total system

    a. Number and list of DU's per region

    b. Number and list in-solution in each region

    c. Number and list of DC's in-process of addition in each region

    d. Number and list of PDC's in each region

    e. Number and list of DC's in-process of deletion in each region

    f. Number of tracked products and their characteristics.

Sensitivity Analysis and Validation Information

The LREPS information requirements for sensitivity analysis and validation are presented in detail in the monograph.[3] In general sensitivity analysis requires information output that provides the capability for determining the effect on the target variables of sales, cost, service, and flexibility for various levels of the factors presented in Chapter I, Figure 1.5. Validation analysis requires information output that enables the determination of the stability of the model and reasonableness of the model results.

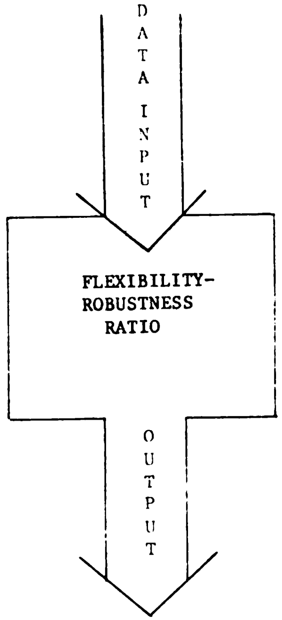
Flexibility-Robustness Information

The concept of flexibility or robustness developed for the LREPS model relates to the example stated in Chapter III in which the robustness-score is the ratio of the number of occurrences of a given potential DC location, among the set of good systems, to the number of good systems. The robustness measures developed for the initial LREPS version include:

1. Ratio of quarters a DC was in-solution to the total quarters simulated for one planning horizon, assuming most probable factor levels
2. Ratio of quarters a DC was in-solution to the total quarters simulated for a set of planning horizon cycles assuming most probable factor levels
3. The ratios of number 1 and 2 above combining the three factor levels for sales: pessimistic, most probable, and optimistic.

Figure 6.3 presents the activity analysis in terms of the outputs, inputs, and transformations for the Flexibility-Robustness Analysis. The flowchart is presented in Figure 6.4.

The primary use of the Flexibility-Robustness Ratios are to improve decision making under uncertainity. For example, a DC location or subset of locations that has a relatively high ratio for Flexibility-Robustness measure number 3, which combines three factor levels, should result in a more flexible physical distribution



INPUTS

1. Flexibility-robustness measure 1, 2, or 3
2. Results for each LREPS cycle

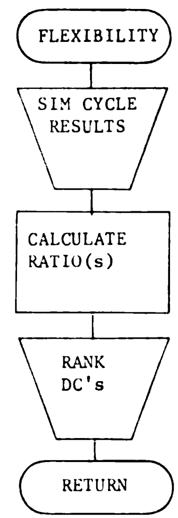
TRANSFORMATIONS

1. Calculate the flexibility-robustness ratio(s), FRR

OUTPUTS

1. FRR for each DC and/or subsets of DC's
2. Ranking of FRR

Figure 6.3--Activity Analysis: Flexibility-Robustness Ratio



LREPS simulation cycle or planning horizon results for one or more cycles

Calculation of the Flexibility-Robustness Ratios, FRR for various factor levels for each DC and subsets of DC's.

Rank DC's or subsets of DC's by the FRR

Return to the Report Generator System

Figure 6.4--Flowchart: Flexibility-Robustness Ratio Routine

system than a DC location which has a high ratio for only one factor level.

Output Information Frequency

The definition of the reporting period(s) was an important factor in the development of the Report Generator System. The smallest unit of time and thus the most frequent reporting period possible in the LREPS model is the day. The largest unit of time and thus the longest reporting period is the total planning horizon. In designing the LREPS model, especially the Measurement Subsystem, and the Monitor and Control Subsystem, primary emphasis was placed on the management information requirements for decision making. The primary objective of the LREPS model is for strategic planning and rather than operating or tactical decision making. The reporting of daily, weekly, or monthly totals was therefore not considered to be of primary importance. The quarterly and longer operating periods were believed to be the most useful in terms of relevant information for strategic planning and decision making. As the full capabilities of the LREPS model are explored generation of information for additional operating periods such as for the day and/or week for given intervals of time within a simulation cycle could prove useful for analysis of the dynamics of inventory management.

Output Information Formats

There were an infinite number of report formats that could have been designed for the initial LREPS version. The purpose of this section of the chapter is to illustrate examples of reports designed and implemented in conjunction with the first set LREPS computer runs. These formats will undoubtedly be revised somewhat for future simulation runs, but they illustrate the scope of the information available from the LREPS model. The management use of these reports is presented in detail in the monograph.[4]

The management report formats for the initial set of LREPS simulation runs included:

1. Summary Reports
    a. End-of-Planning Horizon Report
    b. Quarterly Report
2. Distribution Center Detail Reports
    a. Sales Report
    b. Cost Report
    c. Total Customer Order Cycle Report
    d. Reorder Cycle Report
    e. Inventory Condition Report
    f. Identification Report
    g. Percent Sales Within Order Cycle Interval Report
    h. DC-DU Weight Accumulation Report
    i. MCC-DC Weight Accumulation Reports.

Summary Reports

The End-of-Planning Horizon Summary Report included the information content resulting from a complete ten-year planning cycle or horizon. The report contained the following information for each DC(IDC) which had been in-solution for at least one quarter throughout the planning horizon:

1. Sales dollars
2. Total PD system costs
3. Contribution to profit, sales minus PD cost
4. Total customer order cycle time
5. Average cubic inventory-on-hand.

The Quarterly Report Summaries provided the following information content for each quarter for which a DC(IDC) was in-solution:

1. Sales dollars
2. Total PD system costs
3. Contribution to profit, sales minus PD cost
4. Total customer order cycle time
5. Average cubic inventory-on-hand.

DC Detail Reports

The Distribution Center Detail Reports were generated for each quarter that a DC(IDC) was in-solution. The DC Sales Report contained the following information content for a given DC(IDC) by each quarter:

1. Quarter (IQ) being reported
2. Sales dollars processed

3. Weight in pounds processed
4. Cubic volume processed
5. Cases of product processed
6. Lines processed
7. Orders processed.

The DC-Cost Report contained the following information content for a given DC(IDC) by each quarter:

1. Quarter (IQ) being reported
2. Outbound transportation cost
3. Inbound transportation cost
4. Throughput cost
5. Communications cost
6. Facilities investment cost
7. Inventory carrying and ordering costs
8. Total PD cost for the given DC(IDC).

The DC-Customer Order Cycle Report contained the following information content for the DC(IDC) for each quarter the DC was in-solution:

1. Quarter (IQ) being reported
2. Total customer order cycle time
3. Backorder penalty time
4. Normal customer order cycle time
5. Standard deviation of the normal customer order cycle time
6. Outbound transit time
7. Standard deviation of the outbound transit time.

The DC-Reorder Cycle Report contained the following information content for a given DC(IDC) by each quarter the DC was in-solution:

1. Quarter (IQ) being reported
2. Number of multi-product reorders for each MCC(IMC) supply point to the DC(IDC)
3. Average reorder lead time for each MCC(IMC) link to the DC(IDC).

The DC-Inventory Condition Report contained the following information content for a given DC(IDC) for each quarter the DC was in-solution:

1. Quarter (IQ) being reported
2. Average cubic inventory-on-hand
3. Total number of stockouts
4. Total number of reorders
5. Percent case units backordered
6. Average stockout delay
7. Standard deviation of the average stockout delay.

The DC-Identification Report contained the following information content for a given DC(IDC) for each quarter the DC was in-solution:

1. Quarter (IQ) being reported
2. Number of DU's served by the DC(IDC)
3. Sales Modification Factor
4. DU Weighted Index sum
5. Dollar size capacity of the DC(IDC).

The DC-Percent Sales Within Order Cycle Interval Report was designed and implemented as two reports. The first report, the DC-Normal Order Cycle Time Dollar Proportions Report contained the proportion of sales dollars within each of the Normal Order Cycle Time Intervals for each quarter the DC(IDC) was in-solution. The second report, the DC-Normal Order Cycle Time Order Proportions Report contained the proportion of sales orders within each of the Normal Order Cycle Time Intervals for each quarter the DC(IDC) was in-solution. The intervals for the initial version of LREPS were: 3, 5, 7, 9, and 11 days.

The DC-DU Weight Accumulation Report contained the following information content for a given DC(IDC) for each quarter the DC was in-solution:

1. Quarter (IQ) being reported
2. Weight accumulated for the outbound weight breaks:

   $0 \leq 50$, $>50 \leq 200$, $>200 \leq 1000$, and >1000 pounds.

The MCC-DC Weight Accumulation Report consisted of a report for each MCC(IMC) which served as a supply point for the given DC(IDC). Each report contained the following information for each quarter the DC was in-solution:

1. MCC(IMC) supply point being reported
2. Quarter (IQ) being reported
3. Weight accumulated in each of the weight break intervals:

   $2000 \leq 5000$, $>5000 \leq 24{,}000$, and $>24{,}000$ pounds.

Report Generator System Summary

This chapter, the Report Generator System, presented the basic information output content, frequency, and formats developed for the initial LREPS model. In addition an initial measure of the target variable flexibility-robustness was presented. The final chapter considers the results and implications for future research.

CHAPTER VI--FOOTNOTE REFERENCES

[1]Bowersox, *et al.*, Monograph.

[2]Marien.

[3]Bowersox, *et al.*, Monograph.

[4]*Ibid.*

CHAPTER VII

RESULTS AND IMPLICATIONS

Introduction

This chapter presents in two sections the results and implications of the formulation of the LREPS mathematical model. The first section discusses the results in terms of the relative achievement of the design criteria previously defined in Chapter I. The implications for future research are presented in the second section.

Results Relative to Design Criteria

The design criteria, stated in Chapters I and III, were defined in terms of the following three categories:

1. General research criteria
    a. Modular construction
    b. Universal model application
2. Physical distribution problem criteria
    a. Total physical distribution system
    b. Long-Range planning horizon
    c. Sequential decision problem

3. Model operating criteria
    a. Operating time
    b. Operating capabilities
    c. Operating realism
    d. Operating input requirements

General Research Criteria

The concepts of modular construction and universality were defined in Chapter III. The development of the LREPS mathematical model to achieve these concepts was considered a primary objective in the research project.

Modular Construction.--The purpose of modular construction was twofold. First, it allowed the design, construction, and implementation of the LREPS model in a series of steps. At each step additional modules and more sophisticated modules were implemented and tested until the total LREPS model was operational. Second, once designed the modular construction provided the flexibility of modifying the LREPS model via substitution of various modules without redesign, reprogramming, or change in the data base.

The criteria of modular design was achieved in the development of the mathematical model as illustrated by the following two examples. First, parallel development of the subsystems, components, and activities was possible after the input-output requirements for the activities of each subsystem were defined. The LREPS model was then constructed and implemented using the activities as building blocks or modules.[1] Second, the LREPS model as formulated contains numerous modules which by simple substitution and essentially no reprogramming can be replaced by modules with different transformations but requiring the same information input and capable of generating the same information output. Examples of activities where more than one module option was implemented included the:

1. Locate algorithm
2. Inventory management routine
3. Order file generator.

The first modules implemented for the locate algorithm added DCs at fixed time intervals in the sequence presented in a fixed list of potential locations. The second algorithm allowed exogenous addition and also included decision rules for adding DCs via information feedback loops. The third algorithm allowed addition and deletion via both the monitor and control exogenous routine and the information feedback control loop--the locate algorithm.

The inventory management routine was implemented with two modules. For the first module safety stocks and economic order quantities were developed by heuristic management rules whereas the second used the standard inventory EOQ formulation. Both modules used the inventory policies presented in the Monitor and Control Subsystem, Chapter V.

Two modular options were implemented for the Order File Generator. Option 1 included only actual customers in the order file whereas Option 2 also included pseudo orders and pseudo customers. The above discussion illustrates a partial list of activities where more than one option has been implemented.

Universal Model Application.--The concept of universality, also defined in Chapter III, referred to the applicability of the model to a broad range of firms that fit the general system audit and structure of Figures 1.1 and 1.2. The final test of the achievement of this design criteria will be the application of the LREPS model to a number of manufacturing firms in different industries and/or to a number of divisions in the same firm. However, there are a number of general areas that illustrate the relatively high degree of universality that has been achieved for application of the LREPS model to manufacturers of consumer packaged goods. These areas include:

1. Performance or target variables
2. Market profile
3. Product profile
4. Physical distribution system profile.

The basic target variables of sales, cost and service are common to all total physical distribution systems. Each of these variables was classified as a target variable in the LREPS model since the model can be run to search for the set of system configurations over time that maximum sales, maximize service, or minimize cost. The model does not produce the optimum system configuration given the objective or desired level of the target variable(s) but using manual or computer search techniques it is feasible to obtain a near optimum or satisficing solution for the given level of input factors and decision rules. The scope of the individual measures of these target variables and the flexibility with which additional measures can be included in the LREPS model illustrates the relatively high degree of achievement of universality in terms of the performance measures.

Two of the important areas related to the degree of universality of the market profile factors are the demand unit structure and the procedure for generating customer demand.

The demand unit selected for the initial version of LREPS, the Zip Sectional Center, should itself be somewhat universal for consumer packaged goods. However, the modular development of the model would also allow the use of any of the demand units evaluated in the Supporting Data System--Demand and Environment. These included the county, Standard Metropolitan Statistical Area (SMSA), the state, and the economic trading area (ETA).

The LREPS model currently includes the capability for generating demand based on existing customer types and existing order statistics such as average dollar size, weight, lines, cases, and cube via the Order File Generator. The pseudo order matrix portion of the Order File Generator allowed the incorporation of any desired percentage of sales to be generated from new or pseudo customers with existing or different order statistics. The percentage can be set to change over the simulation cycle to reflect the change in customer split via the Monitor and Control Subsystem--Exogenous Routine. This flexibility of the demand unit and options for defining and generating customer demand illustrates again the universal nature of the basic LREPS model.

The product profile factors are also important if the model is to be considered universal. In the LREPS model existing products are included in the tracked product list in one of several product categories used for inventory control. Additional new or existing products can be added in the existing categories or in new product categories up to a total of fifty products and ten product categories. The product attributes used in the simulation are universal in that only characteristics such as units per case, weight per case, cube per case, freight rate per cst, and so on are required in the transformations. Therefore, the effect of new products can be added and tested relatively easily.

The profile of the PD components is also important to the universality of the LREPS model. The inventory policies included in the LREPS inventory management routine reorder point, optional replenishment, and a hybrid combination of reorder point and replenishment should be applicable to the majority of manufacturers of consumer packaged goods. The inventory component also has the flexibility of multiple categories of products such as by usage, density, freight classification, and value. The number of tracked products can be varied from one to fifty without reprogramming. Each of the above attributes adds to the universality of the LREPS model.

The transportation component included the capability to simulate the various modes, average transit times, and reliability of transit times via concentric circle ring sets and variance functions. The transportation network included the outbound, DC-DU and inbound, MCC-DC links. The capability also exists in the model to simulate the direct transportation link from replenishment center to demand unit, RC-DU for consolidated shipments. These transportation links are common to many of the manufacturers of consumer package goods. Transportation links which the LREPS currently does not explicitly include, but which can be included via adjustments of cost and transit times are the crossshipments between two DC's and two MCC's.

The communications component included the capability for simulating various modes, average time delays, and reliability via concentric ring sets and variance functions. The network explicitly includes links for order transmittal time from demand unit to distribution center, DU-DC, and distribution center to replenishment center, DC-RC. The communication links for centralized demand unit to the central location, and regional, demand unit to regional PDC can be simulated implicitly via the time delay ring sets and variance functions.

The facility network component was restricted in the number of MCC's, PDC's, and DC's that could be in-solution at any one quarter. The current limit for simulating the continental U. S. is five MCC's, five PDC's, and twenty DC's. The modular development of the model does allow the maximum limit for any one of the regions when the region is run separately. The limits of the number of locations therefore does not greatly reduce the universality of the model. The Locate algorithm should prove to be extremely flexible in terms of universal application since the DC's can be added or deleted by exogenous input or via dynamic feedback control loops based on comparison of actual to desired service, and/or cost.

The unitization component included the capability to simulate a range of DC sizes, a range of levels of automation, and partial-line and full-line DC operations. The expansion algorithm allowed the expansion of any in-solution DC to a larger size interval based on the ratio of actual DC operating volume in terms of sales dollars to the capacity limit designated for the DC size interval.

The above discussion indicates that the general research design criteria were essentially achieved in the LREPS mathematical model.

Physical Distribution Problem Criteria

The physical distribution problem criteria relate to the stated requirement of Chapter I that the mathematical model consider:

1. The total physical distribution system
2. A long-range planning horizon
3. The sequential decision problem.

Each of these design criteria was given primary emphasis in developing the LREPS mathematical model.

Total PD System.--The total physical distribution system as defined in this research included the interrelated activity centers or components from the production line to the point of ownership transfer. These components were defined as the distribution facility network, inventory allocations, transportation, communications, and unitization. The LREPS mathematical model in both the Supporting Data System and the Operating System listed the desired outputs, the required inputs, and the selected transformations for each of the elements of these components.

The presentation in Chapter V of the transformations for the activities for each of the physical distribution components and the demonstration of the scope of the information content of the reports as presented in

Chapter VI indicate the high degree of achievement of this particular design criteria.

As indicated in the Literature Review, Chapter II the criteria that the model consider all of the components of the physical distribution system essentially required that the general solution be one of simulation rather than an analytical or optimum technique. The development of a total PD model also required that the service variables be developed in terms of temporal measures such as the average and standard deviation of the customer order cycle.

Long-Range Planning Horizon.--The long-range planning or strategic planning horizon can be defined in terms of a generally accepted fixed time period such as five years or ten years, or by a variable time period dictated by the expected rate and significance of technological and marketing environment change in the industry. For example, long-range planning in a highly innovative industry or firm could be as short as two years, whereas in the firm or industry with little innovation long-range planning might be defined as greater than ten years. The initial LREPS model has been designed to simulate forty quarterly periods of operating time and thus includes a ten year planning horizon which is sufficient duration to be classified as a long-range planning model. The model also has the capability of simulating a forty year horizon if each period is designated as one year.

This design criteria required that the LREPS model contain the capability for introducing change in the marketing environmental factors. This was accomplished by introducing the appropriate factor levels prior to the beginning of each operating period, quarterly or yearly, via the Monitor and Control Exogenous Routine. Examples of factors that were modified quarterly or annually to reflect the changing market environment included but were not limited to:

1. Sales forecast by demand unit
2. Transportation rates
3. Desired service levels by region
4. Customer split percentages for each customer type
5. Product mix
6. Safety stock factor and inventory policy designation for product categories
7. Desired constraint levels and decision rules for Locate and Expansion algorithms.

This approach is one of the two important areas of model dynamics described in Chapters I and II. The second area of dynamics, the information feedback control loops, is discussed in the next section.

Sequential Decision Problem.--The sequential decision problem as defined in this research has the property that future decisions are influenced by previous decisions. A solution approach to the sequential decision problem as indicated by the Literature Review, Chapter II, is the dynamic simulation model that incorporates information feedback control loops. This was the primary role of the control function of the Monitor and Control Subsystem. As presented in Chapter V the initial LREPS model contained the following four major examples of information feedback control loops:

1. The location algorithm
2. The inventory management routine
3. The expansion algorithm
4. The sales modification routine.

Each of these algorithms or routines is defined as a first order information feedback control loop in that each includes a sensor to detect the existing system state, a comparator to measure the difference between actual and desired system state, and an effector to cause the desired system change.

The Locate algorithm is sequential in that decisions at any given time TNOW, related to the addition of a potential DC or the deletion of an in-solution DC effect the location decisions at any time TNOW plus Δ time in the future. As stated in the Monitor and Control Subsystem this influence was accomplished via an information feedback control loop.

The Locate algorithm detects the calculated actual service in terms of the order cycle time (the Sensor) and compares this to the desired service level (the Comparator). The deviation between the actual and desired is then used to set the priorities for system change by region (the Effector). Finally, the algorithm selects the DC location to be added or deleted.

The inventory management routine likewise was developed to consider the sequential decision problem. At the end of each simulated day, TNOW, the inventories-on-hand (system state) is checked (the Sensor). The system state is compared to the reorder point or review period at which a decision must be made to reorder (the Comparator). If a decision state has been reached or triggered a replenishment order is generated (the Effector) to modify the future system state.

The expansion algorithm also illustrates an example of the use of information feedback control loops to solve the sequential decision problem within the LREPS mathematical model. The measured level of throughput for each DC at the end-of-quarter (the Sensor) compared against the upper limit or capacity for efficient operation of the DC (the Comparator) determines the need for expansion. The deviation from the desired system state serves as the basis for establishing the priority of selection of the appropriate DC for expansion (the Effector).

The adjustment of the sales forecast to reflect the surplus or deficiency of service relative to the desired level represents the fourth and final area of the sequential decision problem to be presented in this thesis. The actual level of service in terms of the percent of sales or orders within a designated order cycle time interval (the Sensor) was compared at the end of each month to the desired percentage (the Comparator). The surplus or deficiency of service was then used as the basis for increasing or decreasing the next period sales forecast (the Effector). The modification of sales of the DC as the result of poor service for example, lowers the sales dollars which were receiving the poor service (longer average service times) thus decreasing the average service time of the region. This in turn improves the actual to desired service ratio. Therefore, the future values of both the sales modification factor and sales are influenced by the current value of the SMF factor.

Although each of the above has been presented as an independent information feedback control loop they are interdependent since the decisions for any one control loop in any given quarter effect the future quarter decisions of each of the remaining information control loops. These routines and algorithms are examples of the second major aspect of a dynamic simulation model as discussed in Chapters I and II.

In summary the above discussion indicates that a high degree of achievement of the physical distribution problem criteria has been obtained in the LREPS mathematical model. Each of the components facility network, inventory, transportation, communications, and unitization has been modeled in LREPS thus achieving the design criteria that the model include the total physical distribution system. The development of the model to simulate ten years of operation with the capability of changing the environmental input factors essentially achieves the criteria for a long-range planning horizon. The sequential decision criteria is achieved via development of first order information feedback control loops.

Model Operating Criteria

The operating criteria or attributes of the LREPS model included the model operating time, the model capabilities, and the realism of the model.

Operating Time.--The LREPS operating limits were established in terms of the computer time required to simulate a complete ten year planning horizon. Due to the necessary tradeoff of computer core and computer input/output requirements the desired operating limit of thirty minutes was not achieved. The actual operating time for a ten year planning horizon required between one hour and one and a half hours depending on the assumed rate of growth of the sales forecast.[2]

Operating Capabilities.--The desired model capabilities, presented in Figure 1.5, in terms of the target, controllable, and uncontrollable variables were essentially achieved as indicated by the activity analyses discussed in Chapters IV and V and the scope of the output presented in Chapter VI.

Operating Realism.--To comment in detail on the realism of the LREPS model requires a complete analysis of the validation results, which was not completed at the time of preparation of this thesis. In general, however, analysis of the results of the simulation of the reference operating period, 1969 indicated that the critical variables were within acceptable limits. Table 7.1 presents a partial list of the variables included in the validation analysis of the reference year.

Operating Input Requirements.--One of the important aspects of the LREPS model is the input information content and required frequency of update. The content of the input information is illustrated to a great extent in Chapter IV, the Supporting Data System and in Appendix 1 which lists the variables.

The frequency of updating the input data is a difficult question to answer at this time. There are, however, many variables which a user would have to catalog to ensure that periodic review is conducted on the more critical input variables. For example, transportation could easily account for a large fraction of the total cost of a large distribution system. Therefore, the freight rates might have to be reviewed and changed annually. The invoices used to create the order file generator quite possibly might have to be modified each year to be representative of the changes in the customers

TABLE 7.1.--One-Year Validation Results.

Information Category	Simulated Versus Actual	PD Stages
Cust Sales	Within Limits Within Limits	DU, DC and domestic
Cust Dollar Sales/Order	Within Limits	DC and Domestic
Cust Wt Sales/Order	Within Limits	DC and Domestic
Line Items per Order	Within Limits	DC and Domestic
Cust Serv--		
NOCT-Avg	Within Limits	DC and Domestic
NOCT-Std Dev	No Data Avail.	DC and Domestic
T4-Avg	Within Limits	DC and Domestic
T4-Std Dev	No Data Avail.	DC and Domestic
Dollar-Preps	No Data Avail.	DC only
Order Preps	Within Limits	DC only
DC-MCC Reorder	Within Limits Within Limits Within Limits Within Limits	DC only DC only DC only DC only
DC Stockouts	No Data Avail. No Data Avail.	DC only DC only
DC Avg IOH	Within Limits	DC only
Cust ship Accums	Difficult to Compare Because of Small Sample Averages in Cust Order Blocks	DC and Domestic
MCC Ship Accums	Within Limits	MCC only
Total Pred Demand	Within Limits	Domestic only
PD Cost	Within Limits Within Limits Within Limits	DC and Domestic
Cum Wt Indices	Sales Allocation Basis Within Limits	DU, DC and Regional

purchasing patterns. In general the cost factors might all have to be reviewed much like inventory control using either a yearly or quarterly review of the cost levels or updating the values whenever a significant change occurs. To prevent the "GIGO" problem of "Garbage-In-Garbage-Out" a standard operating procedure for updating and logging all input data changes is absolutely essential if the model is to remain a viable management tool.

Implications for Future Research

The implications for future research are defined in terms of the following categories:

1. Enrichment and simplification of the activities within the existing scope of the LREPS model
2. Expansion of the LREPS scope for distribution systems
3. Expansion of the LREPS scope for manufacturing systems
4. Evaluation of the LREPS model for public systems.

Each of these categories is briefly discussed in the order listed above.

Enrichment and Simplification.--There are a number of activities within the existing LREPS model that should be evaluated for either enrichment or simplification. Enrichment as stated in Chapter III implies further sophistication and possibly greater detail for the activity whereas simplification implies reduction in complexity of the transformations and detail for the activity.

A partial list of the activities that should be evaluated for possible enrichment due to their critical nature includes, but is not limited to:

1. The transit time transformations-evaluation of the use of regression equations

2. The locate algorithm-evaluation of the use of linear programming

3. The sales modification routine-evaluation of a feedback control loop with lag and better methods of initialization of the DC-SMF's

4. The shipping policies-evaluation of different policies in effect simultanecusly at different distribution centers

5. The partial-line distribution centers-evaluation of different product categories for different partial-line distribution centers

6. The limits on the number of MCC's and PDC's-evaluation of increasing the maximum number of allowable MCC's and PDC's for the total model and the regional model

7. The throughput and communications cost components-evaluation of regression equations for the cost transformations for these components

8. The facilities cost component-evaluation of the use of the time value of money, the uniform annual equivalent series for the fixed investment cost

9. The effect of a greater number of tracked products-evaluation of the use of a larger sample of tracked products

10. The measures of flexibility-robustness-evaluation of additional measures of physical distribution system flexibility

11. The improvement of Report Generator System output formats-evaluation of additional output formats including plotting routines for the results of the simulation runs.

A partial list of the activities that should be evaluated for possible simplification to reduce the running time of the model includes:

1. The use of a larger basic time unit-evaluation of the use of a larger time unit such as the week rather than the current time unit, the day

2. The use of a larger order block and/or order group-evaluation of the use of larger order or group blocking factors

3. The use of regional modules as the simulation model-evaluation of the use of regional modules that could be run separately from the total domestic LREPS model

4. The use of a smaller number of tracked products-evaluation of the sensitivity of the results to a smaller number of tracked products.

Each of the above areas should be evaluated to determine the effect or sensitivity of model results for the recommended areas of simplification and enrichment.

Expansion of LREPS Scope for Distribution Systems.--There are a number of areas of future research that would test the universality of LREPS for physical distribution systems. First, the model based on the results reported in this chapter indicated that the LREPS model should be universal for physical distribution systems of manufacturers of consumer packaged goods. This, however, has yet to be tested. Second, the application of the LREPS model to physical distribution systems for manufacturers of industrial products presents interesting prospects for future research. Third, and finally the application to pure distribution systems such as warehouse systems, supermarket chains, and shopping center chains also seems feasible. These three areas represent only a sample of the possible applications to test the universality of the LREPS model for planning of physical distribution systems design.

Expansion of LREPS Scope for Manufacturing Systems.--The LREPS model should be evaluated to determine the feasibility of modeling additional functions related to manufacturing systems. First, expansion of the model horizontally to include unit inventory control and production capacity considerations at the manufacturing control centers would increase the scope to a production-distribution model.

A second additional application that would increase the scope is the use of the LREPS concept to develop a strategic planning model for input materials systems design. The model would provide the capability to assist in strategic planning of integrated input materials system which include components such as purchasing, inventory control, warehouse location, transportation, communications, and warehouse operation for raw materials and/or component parts.

The third application involves expansion of the scope of the model vertically to either a higher level to become part of a total corporate planning model or to a lower level to assist in operational planning. The fourth and final application suggested at this time is expansion of the scope of the model to combine parallel operations, for example the physical distribution operations of several major divisions within a single corporate structure.

Evaluation of the LREPS Model for Public Systems.--The components included in the LREPS model also exist in non-manufacturing problems where demand is stated in terms of service rather than a product. The LREPS model could conceivably be applicable to the following strategic planning problems of the public sector:

1. School systems
2. Solid waste disposal facilities
3. Airport systems
4. Fire station systems
5. Hospital systems
6. Equipment pools.

In the above situations the demand unit would probably be stated in terms of smaller units than the zip code. Examples of possible demand unit structures for the above systems might include subdivisions, politicial divisions within counties, street boundaries, individual households, or any special grid system developed for a specific problem. The product demand could be stated in terms of pseudo products (service). An example of the demand for service for the school systems could be the number of student classroom hours required for each grade per term by each subdivision or demand unit. The demand for service for the solid waste disposal system could conceivably be stated in terms of the volume requirements per category of waste per day by demand unit. In each of these situations the objective of a LREPS type model would be to aid in strategic planning including but not limited to the amount of resource or service units to stockpile for future demand (Inventory Control), and where to stockpile the service (Location Component).

Results and Implications Summary

The results presented indicate that the LREPS model has successfully combined and reported possibly for the first time a model which includes all of the physical distribution components, a strategic planning horizon, and the sequential decision process.

The implications of the model are even more exciting. The entities and components included in the LREPS model could enable the model to be truly as general as the title implies--Long Range Environmental Planning Simulator. In theory the model should be applicable to any problem that involves the following:

1. The inventory problem where there is a cost of holding the resource and the future demand for the resource is uncertain (the Inventory Component)

2. The number of inventory nodes is a decision variable over time (the Location Component)

3. The cost of holding and processing the resource at the inventory node is significant (the Warehouse Component)

4. The movement of the resource and the transmittal of information requires a cost in dollars and/or time for the demand units acquiring the resource at the inventory node and for the inventory node replenishment of the resource (the Inbound and Outbound Transportation Component, and the Communications Component)

5. The demand for the resource exists in either its original form or in processed form (the Demand Unit and Demand Allocation)

6. The objective of the system is to provide the resource to the demand units in terms of an acceptable average and variance of the availability and cost of the resource.

The doctoral program in general and the development of the LREPS research project in particular has provided significant challenge and reward. The implications of this research and the ideas for future research generated throughout my doctoral program and the LREPS project research present an equal if not greater challenge to apply these models and concepts to operating systems in business and society.

CHAPTER VII--FOOTNOTE REFERENCES

[1]Marien.

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APPENDIX 1

VARIABLES LIST[1]

[1]Extracted from E. J. Marien, "Development of a Dynamic Simulation Model for Planning Physical Distribution Systems: Formulation of the Computer Model" (unpublished dissertation, Michigan State University, 1970).

DLT = THE FREQUENCY WITH WHICH THE INFORMATION IS ALTERED
C=CYCLIC Q=QUARTERLY A=ANNUALLY D=DAILY
TYPE = AN INDICATOR OF SOURCE X=EXOGENOUS N=ENDOGENOUS
M-C, OPS, D-E, MEAS = ABBREVIATIONS FOR THE SUBSYSTEMS
S=THE PARTICULAR SUBSYSTEM SETS OR ALTERS THAT DATA
U=THE SUBSYSTEM USES THE DATA BUT LEAVES IT UNCHANGED

DEMAND UNIT INFORMATION

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
PROPORTION OF SSD≠S	C	X	U		U	
X COOR,	C	X	U			
Y COOR,	C	X	U			
WEIGHTED INDEX	A	X	U			
SERVICE RING NO,S	Q	N	S	U		
CUM, WTD INDEX	Q	N	S		U	
DC IN SOLUTION PTR(1-20)	Q	N	S	U	U	U
$ SALES EXP. AVE.	Q	N	S			
WT. SALES, EXP. AVG.	Q	N	S			
HIWAY DIST.	Q	N	S			U
$ SALES, QTD. FULL LINE	D	N	S	S		
$ SALES, QTD. PART LINE	D	N	S	S		
WT. SALES, QTD. FULL LINE	D	N	S	S		U
WT. SALES, QTD. PART LINE	D	N	S	S		U

POTENTIAL DISTRIBUTION CENTER INFORMATION

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
X COORDINATE	C	X	U			
Y COORDINATE	C	X	U			
A COEFF.-OBT REG EQ	C	X	U			U
B COEFF.-OBT REG EQ	C	X	U			U
R1-REAL RATE INC.	C	X	U			U
R2-REAL RATE INC.	C	X	U			U
TYPE-P,F,RDC*PDC ASSIGN.	Q	X	U	U	U	U
EXP AVG. SALES, $	Q	N	S			
EXP AVG. SALES, WT	Q	N	S			

IN SOLUTION DISTRIBUTION CENTER INFORMATION

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
BACK ORDER PENALTY TIME	Q	N	S			S
POTENTIALDC, IN SOLUTION	Q	N	S	U	U	U
NO. OF DUS IN DC	Q	N	S		U	
SALES MODIF. FACTOR	Q	N	S		U	
SUM OF DU WIS	Q	N	S		U	
TOTAL COST FOR QUARTER	Q	N	S			S
AVG. TOT. ORDER CYCLE TIME	Q	N	S			S
QTRLY $ SIZE IND	Q	N	S	U		U
NORMAL AV. OCT,S(T1+T2+T4)	D	N	S	S		S
ST. DEV., S(T1+T2+T4)**2	D	N	S	S		S
OBT, AV.T4+S(T4)	D	N	S	S		S
ST. DEV., S(T4)**2	D	N	S	S		S
CASE UNITS BACK ORDERED	D	N	S	S		S
AVG STOCKOUT DAYS,S(DELAY	D	N	S	S		S
STD DEV STOCKOUT DAYS,S(S	D	N	S	S		S
$ SALES, QTD	D	N	S	S		U
WT SALES,QTD	D	N	S	S		U
CUBE SALES, QTD	D	N	S	S		U
CASES SALES, QTD	D	N	S	S		U
LINES SALES, QTD	D	N	S	S		U
ORDERS SALES, QTD.	D	N	S	S		U

REGIONAL INFORMATION

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
MAX. ALLOW, DCS	Q	X	U			
MAX. ALLOW, DCS ADDED	Q	X	U			
MAX. BEING DELETED	Q	X	U			
QTD TRACKED PRD WT SALES	Q	N	S	S		
DESIRED SERVICE	Q	X	U			
MAX. ALLOWED $ INVSTMNT	Q	X	U			
MAX. ALLOWED INVSTMNT ADD.	Q	X	U			
SUM DC WEIGHTED INDICES	Q	N	S		U	
NO. DCS BEING ADDED	Q	N	S			
NO. DCS BEING DELETED	Q	N	S			
DC INVESTMENT $	Q	N	S			
DC INVST, $ BEING ADDED	Q	N	S			
ACTUAL SERVICE--LAST QTR	Q	N	S			S
ACTUAL SERVICE--EXP AVG-SMF	Q	N	S			
RATIO-ALL/SAMPLE PROD LBS	Q	N	S	U		
TOTAL PD COST	Q	N	S			S
MCC SHIP DISP POL--DAYS	Q	X	U	U		
REORDER COST--MCC	Q	X	U			U
NO OF DCS IS PER REG	Q	X	U			

DC--MCC LINK INFORMATION

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
NO. REORDERS MULT PROD	D	N	S	S		U
REORDER LEAD TIME ACCUM.	D	N	S	S		S
PRODUCTS ON ORDER IND.	D	N		S		
NO. REORDERS OUTSTANDING	D	N		S		
TOTAL WT ON ORDER+ SDP IND	D	N		S		

PRODUCT INFORMATION BY CATEGORY

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
INV SHIP CAT. (RDC-P)	C	X	U	U		
TOTAL NO. PRODUCTS	C	X	U			U
INVENTORY POLICY	Q	X	U	U		
REVIEW PERIOD LENGTH	Q	X	U	U		
SAFETY STOCK FACTOR	Q	X	U			

PRODUCT INFORMATION BY DC

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
REORDER POINTS 1 AND 2	Q	N	S	U		
S LEVEL	Q	N	S	U		
INVNTRY ON HAND OVER TIME	D	N	S	S		S
INVENTORY ON HAND	D	N	S	S		
PRODUCT STOCKOUT DAYS	D	N		S		

PRODUCT CATEGORY INFORMATION BY DC

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
NUMBER STOCKOUTS	D	N	S	S		S
NUMBER REORDERS	D	N	S	S		S
CU-DAYS-STOCKOUTS	D	N	S	S		S
CASE UNITS SOLD	D	N	S	S		S

OTHER VARIABLES

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
CGS/CASE BY PRODUCT	C	X	U			U
CUBE/CASE BY PRODUCT	C	X	U			U
WT/CASE BY PRODUCT	C	X	U	U		U
A, OBT RATE MODIFIER-R3	C	X	U			U
B, OBT RATE MODIFIER-R4	C	X	U			U
LINKED PROD SOURCE	C	X	U	U		
WT BREAKS FOR MCC	C	X	U	U		

OTHER VARIABLES--Continued

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
WT BREAKS FOR DC	C	X	U	U		
FEASIBLE DC ASSGN., PRIOR	C	X	U			
ORDER BLKS PER GRP SPLIT	C	X	U		U	
COST OF LIVING FACTOR	Q	X	U			U
DC CAP, CONSTRAINT BY SIZE	Q	X	U	U		U
FREIGHT RATES	Q	X	U			U
REG COMM COST FACTORS	Q	X	U			U
DOM COMM COST FACTORS	Q	X	U			U
REG CUST $ SPLT PCT-S,H,P	Q	X	U		U	
PDC, THRUPUT COST BY SIZ	Q	X	U			U
RDC-F, THRUPUT COST BY SIZ	Q	X	U			U
RDC-P, THRUPUT COST BY SIZ	Q	X	U			U
PDC, COMM. COST BY SIZE	Q	X	U			U
RDC-F, COMM. COST BY SIZE	Q	X	U			U
RDC-P, COMM. COST BY SIZE	Q	X	U			U
PD COMP, IN SOL DC COST	Q	N	U			S
WEIGHT CLASS ACCUM.	D	N	S	S		
SHIP. CAT. WT. BREAKS	D	N	S	S		U
TOTAL PROD DEM-QTD	D	N	S	S		
TOTAL PROD DEM-EA	Q	N	S			
SCH DAY--EVENT ARRAY	C	X	U			
SERVICE TIME VAR FNS	Q	X	U	U		
NO. SAMPLE PRODUCTS	C	X	U	U		U
NO. OF CATEGORIES	C	X	U	U		U
NO. DUS BEING PROCESSED	C	X	U		U	U
NO. REGN BEING PROCESSED	D	N	S		U	U
DAILY INV CARRYING CHARGE	C	X	U			U
MAX INVESTMENT IN DCS	C	X	U			
MAX BEING DELETED	C	X	U			
NO. SIMULATED WORKDAYS, YR	C	X	U		U	
DELAY TO ADD RDC-F	C	X	U			
DELAY TO ADD RDC-P	C	X	U			
DELAY TO ADD CSP	C	X	U			
DELAY TO DELETE RDC-F	C	X	U			
DELAY TO DELETE RDC-P	C	X	U			
DELAY TO DELETE CSP	C	X	U			
TOT AN DOM SALES FORECAST	A	X	U		U	
YEAR OF SIMULATION	A	N	S			U
MAX. SHIP. SIZE FOR CONS.	Q	X	U	U		
CUST. SHIP. DSPTCH PERCT.	Q	X	U	U		
MAX NO. DCS ALLOWED	Q	X	U			
MAX NO. BEING ADDED	Q	X	U			
MAX INVSTMNT IN PROCESS	Q	X	U			
NO. DCS BEING ADDED	Q	N	S			
INVSTMNT IN DCS IN SYSTEM	Q	N	S			
INVSTMNT IN DCS BEING ADD.	Q	N	S			
NO. DCS IN PD SYSTEM	Q	N	S			
TOTAL PD COST	Q	N	S			S
DOM. AVG. SERV. TIME	Q	N	S			S

OTHER VARIABLES--Continued

VARIABLE DESCRIPTION	DLT	TYPE	M-C	OPS	D-E	MEAS
NO. DCS BEING DELETED	Q	N	S			
NO. OF DU BEING PROCESSED	D	N	S	U	S	S
NO. DC BEING PROCESSED	D	N	S	U	U	U
POT DC ASSIGNMENT CODE	D	N	S	U	U	U
DC ASSIGNMENT CODE	Q	N	S			
TOCT PARAM	Q	X	U			U
DAILY SALES QUOTA, NAT.	D	N	U		S	
ORDER BEING PROCESSED	D	N		U	S	
ORDER BLOCK MODIFIER	D	N			S	
CUST. TYPE BEING PROCESSED	D	N			S	
NO. BLKS THIS CUST. TYPE	D	N			S	
CUSTOMER TYPE SALES	D	N			S	
CUST. TYPE SALES $ ACCUM.	D	N			S	
DC SALES FORECAST-SIM.	D	N			S	
NUMBER OF MCCS	Q	X		U		U
NUMBER OF REGIONS	Q	X	U			