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**A STRUCTURED OPTIMIZATION METHOD FOR INFORMATION RESOURCE
MANAGEMENT**

University of Houston

PH.D. 1985

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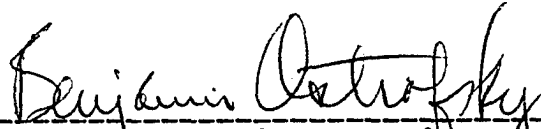
A Dissertation
Presented to
the Faculty of the College of Business Administration
University of Houston

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
Richard Edward Peschke
December, 1985

A STRUCTURED OPTIMIZATION METHOD FOR
INFORMATION RESOURCE MANAGEMENT

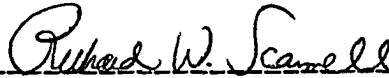
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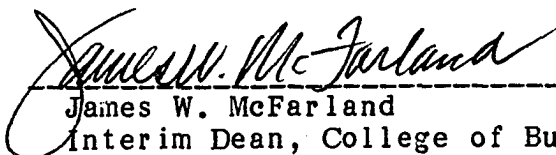
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To My Beloved Jeanne,
For Your Love, Courage . . .
And Your Devotion to Britt, Kirsten, and Me.

ABSTRACT

The mainstays of management activity and managers have traditionally been the organizational resources of manpower, money, material and machines. The inclusion of these support resources early in the acquisition process has had a significant impact on the support of major systems. However, traditional management of these resources alone, is no longer adequate to insure the successful accomplishment of organizational goals and objectives. In today's Information Revolution, there is a new resource seeking its place on the same level of importance as these traditional resources—Information. More than just processed data which provides the decision maker with decision making insights, information is the aggregate of facts, figures, text, voice and images, and their meaningful relationships. Organizational planning must include information and information systems in the early stages of the development process if system activities are to continue to insure mission support.

American society is transitioning from an industrial society to an information society and organizations must plan for, maintain and use information effectively in order to successfully accomplish their goals and objectives. Information is an active organizational resource that supports all levels of decision making from strategic decisions to operational support activities. Further, Information Resource Management (IRM) can be defined as a management function which develops and implements policies, programs and guidelines to plan for, manage and

control information and logistics resources. The IRM concept portrays information as an increasingly important organizational asset requiring the same managerial attention as other key organizational resources. A key activity in the system acquisition activities in the Department of Defense is Support Management, and one of the primary tasks of Support Management is the identification of the Management Data required to support the life cycle cost approach to system acquisition. IRM can provide the integration necessary to meet the system's information needs.

Much confusion currently exists in the management of information as an organizational resource. This confusion has led to cost overruns, time delays, lack of usable documentation and high maintenance costs. To improve this situation, a structured optimization method is proposed which should lead to improved IRM system performance, and improved organizational support.

Recent information requirements research is evaluated with respect to its ability to satisfy the need for a structured information system design-planning methodology. Most information requirements determination methods do not provide the necessary procedures for complete system development and implementation. The need for Information Resource Management exists throughout the life cycle of the system being developed and the organizational elements it supports, and a design methodology must be capable of supporting the complete system design.

The problem addressed by this dissertation is to develop an optimization methodology that has the structure and discipline to support the design and implementation of an information system that consistently meets the needs of an organization. This method, an

integral part of the complete design-planning methodology, defines a sequence of events and decisions which, when adequately resolved, provides an effective set of performance indicators for the evaluation of an Information Resource Management system. Second, formal criterion modeling procedures are developed, extending current work in the area, that specify the design requirements for an IRM system by accomplishing the following activities: 1) Develop criteria and their relative importance; 2) Define the parameter base and estimate parameter values; 3) Synthesize a criterion model; and 4) Identify the best alternative candidate system.

Synthesis of the Criterion Model involves a series of decomposition steps which establishes the relationships of the criterion elements, including parameters and submodels, that are measurable or able to be estimated within existing resources. The Criterion Function (CF) is the analytical function which is constructed from the combination of criteria, x_i , and their respective relative weights, a_i . The general formula for the Criterion Function is shown as Equation I.

Each Criterion can be represented as a function of the set of submodels, $\{z_j\}$, showing the analytical relationships that exist between the respective criterion and its constituent parameters, $\{y_k\}$. Substituting the submodel function for the Criterion term in Equation I yields Equation II.

$$CF = f_i \{a_i, x_i\} \quad \text{Equation I}$$

$$= f_i \{a_i, g_i \{z_j\}\} \quad \text{Equation II}$$

$$= f_i \{a_i, g_i \{h_j \{y_k\}\}\} \quad \text{Equation III}$$

where

$\{a_i, x_i\}$ = the set of relative weights, a_i , and criteria, x_i .

$\{z_j\}$ = the set of submodels.

$\{y_k\}$ = the set of directly measurable parameters.

The final decomposition step represents each submodel as a function of its parameters. The resulting Criterion Function equation is represented in Equation III. Set notation is used throughout to indicate that 0 (i.e., no feasible solution) is a possible outcome of the modeling process; however, this generally will not be the case if the Feasibility Study has been adequately completed. Decomposition of the Criterion Function to the parameter level allows the designer-planner to evaluate candidate system performance with directly measurable criterion elements.

This proposed structured optimization method specifically meets the need for a valid, practical multiattribute evaluation procedure for information system design. While any proposed method cannot guarantee a solution to every problem, this method provides the capability to identify the optimal system within available resources, a much needed, current capability. Illustrative computations for the proposed criterion function modeling procedures will use data from the USAF Ballistic Missile Office.

To demonstrate a method for accomplishing a design space search to locate the optimal candidate system from the set of possible candidate systems, a computer search routine is developed which employs a dynamic programming-type search of the 35-dimensional design space created by the criterion function model of the illustrative data. This program reports the optimal candidate system value and the associated parameter values for each of the 34 identified design parameters.

The application of a multiattribute design methodology is a practical way to describe alternative versions of a proposed information system. This research makes a contribution to the Information Resource Management concept by developing a structured optimization methodology that will allow the designer-planner to efficiently guide the information system design process toward consistently meeting the IRM requirements of the organization. Additionally, this research develops a formal criterion function modeling procedure that evaluates alternative candidate systems through explicit analysis of both qualitative and quantitative criteria.

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CHAPTER ONE

INTRODUCTION

The organizations that will excel in the 1980s will be those that manage information as a major resource.

John Diebold (1979)

Introduction

The purpose of this dissertation is to develop a structured optimization methodology that can be used by an information system designer or planner to plan for Information Resource Management requirements within an organization. The methodology defines a sequence of events and decisions which, when adequately resolved, provides an effective set of plans for the implementation of an Information Resource Management system to meet the needs of the organization. The use of the methodology is demonstrated via a case study of the USAF Ballistic Missile Office's Management Information Systems Division.

Background

The mainstays of management and managers have traditionally been the organizational resources of manpower, money, material and machines - the 4Ms. In the past, to be successful, a manager needed only to be concerned with the appropriate utilization and management of these resources. Management style in the early part of this century emphasized control of capital resources through the discipline of financial management. Manpower resources came under the personnel management discipline

in the 1930s, while the 1940s saw an emphasis on material resources and material management. Today, however, the world can surely be characterized as undergoing an Information Revolution (Head, 1979; Cleveland, 1982; Zmud, 1983; Martin, 1984). This revolution consists of a major transformation from that of an industrial society to an information society as indicated by the fact that more workers are now working with information than are producing goods (Naisbitt, 1982). For example, in the United States Federal Government, the largest single user of data processing systems in the world, over 75% of the white collar work force is involved in the processing of information (Grace, 1984). Prior to the beginning of this Information Revolution, only a few professionals such as librarians, historians and archivists viewed information as a "resource," and most managers considered information a "free good" which was automatically provided as part of the everyday organizational activities.

In an industrial society, capital is a vital organizational resource; however, in an information society, information itself becomes a vital organizational resource. Information, and its associated Information Resource Management (IRM) function which involves the delivery of the correct information to those who need it when they need it (Kull, 1982; Barnes, 1983), is the new element of management that is seeking its place on the same level of importance to the manager as the 4Ms.

What is Information?

The terms **Information** and **Data** must not be confused. Data are the raw material (facts and figures) from which information is processed. Only when data are processed in such a way as to allow the manager to

gain insights from which to make decisions and take actions, is information created (Bryce, 1983; Szewczak, 1983). The definition of "**Information**" used in this dissertation is one presented by Hoffman (1980):

Information is an aggregate (collection, accumulation) of statements, of facts and/or figures which are conceptually (by way of reason, logic, or any other mental 'mode of operation') interrelated (connected) (p. 293).

This definition can be represented more succinctly by the following formula:

Information = Facts, Figures + their meaningful connections.

Hoffman's definition suggests that information is more than just processed data. It is also processed text, voice and images (Mass, 1982). For example, Barnes (1983) suggests that only 10% of the information in a typical organization is processed data, with voice, text and images combining to make up the remaining 90%. Further, information is unique among organizational resources in that it can be either a physical commodity which exists in the form of a written report, or it can be an abstract, mobilizing agent which provides a catalyst for new organizational initiatives (Horton, 1977; Cleveland, 1982).

The term "**System**" is used to describe a combination of people, hardware and procedures, and the relationships that exist between these entities for the accomplishment of a unified purpose or objective (Kirk, 1973). With these definitions in mind, an "**Information System**" can then be viewed as a combination of people, equipment, facilities, procedures and other resources that are organized for the purpose of, but not limited to, creating, collecting, protecting, analyzing, storing, retrieving and disposing of information (AFR 700-1, 1984; Bubenko and Kallhammar, 1971; Lindgreen, 1971; Zmud, 1984).

Dr. Elizabeth Byrne Adams (1980) (Professor of Management at George Washington University), defines Information Resource Management as follows:

Information Resource Management is a management function to develop and implement policies, programs, and guidelines to plan for, manage, and control information and information resources.

It is significant to note that Professor Adams has not included any mention of computers or automated systems in her definition of IRM. To have done so would have been unrealistically limiting, as a vast majority of the information flowing in an organization is not stored in computers. One need only count the number of filing cabinets and telephones that exist in an organization today to confirm this point. Additionally, numerous authors have suggested that the higher the level of management, the lower the level of reliance on, or requests for, computer-generated information (Connell, 1981a; Haase, 1981a; Ives and Olson, 1981; and Mintzberg, 1975).

An "IRM System," then, can be defined as that set of activities that is designed to manage the information system as an organizational resource, and is concerned with the systematic management of all aspects of the information system. This IRM system seeks to insure the accomplishment of organizational objectives through the structure of the information resource, its content, completeness, authenticity, availability, timeliness, and accuracy (Anderson, 1982; Ricks and Gow, 1984; Vierck, 1981; Mass, 1982).

The principal assumption regarding information as a resource, and IRM as a managerial function, is that information, like the 4Ms, is an organizational resource which must be managed if organizational goals and objectives are to be successfully achieved (Haase, 1981b; Scott

Morton, 1982; Hirschheim, 1983). According to Matlin (1980), management of a resource suggests opportunities to conserve that resource, be effective and efficient in its use, and seek a payoff in the profits of the organization through the use of the resource itself.

Information, as a resource, exists in the organization for use by a variety of users, extending to purposes beyond that for which the information was originally generated (Levitan, 1982; Mass, 1982; Matlin, 1980). It is this continuing and expanding reuse of the information resource that determines the well being of organizations in an information society, and it is through additional knowledge that the information resource increases in value. Information is an active organizational resource supporting strategic management decisions, company operations and required support services, not just a collection of papers stored in filing cabinets.

To be an effective element of an organization's activities, this information resource must be planned for, controlled, organized and directed, that is, it must be managed. Additionally, as Nolan (1982) suggests, the information resource must be allocated and conserved to insure it will be available to meet the needs of the organization.

The Future of IRM

If information is to be managed as a vital organizational resource, a clear understanding of just what information management is, will be required. As Mass (1982) suggests:

Information management, the automation of records and data filing and retrieval can be an unsolvable puzzle to those who enter into it carelessly. The user [IRM system manager] must focus on the needs of his company to create an almost customized solution which will accommodate the various users of data (p. 18).

Surveys indicate most large organizations are committed to information system planning activities, but the quality and effectiveness of these plans vary widely (Head, 1979; Selig, 1982b; Power, 1983). Few planning models exist and those that do, lack formal procedures for monitoring the environment, and sometimes fail to recognize the opportunities related to information management (Kull, 1982; Selig, 1982b).

The Information Resource Management concept portrays information as an increasingly important organizational asset which requires the same managerial attention as other key resources (Anderson, 1982; Carey, 1982; Connell, 1981a; Haase, 1981a; Head, 1983). But, how does today's manager "manage" the information resource? Some contend that it is not a resource in the same sense as people, money, or material (Connell, 1981b; Landau, 1980). Landau (1980) suggests that normal economic theories do not apply well to information as a resource because information is not a depleting resource, but rather, it is a replicating resource. Cleveland (1982) suggests that, because information is unique among organizational resources, it would be a mistake to carry over, uncritically, those concepts used to manage the 4Ms to the management of information. On the other hand, others suggest that information is indeed like the other resources in that it can be identified, measured, planned for, budgeted and managed, and managers are becoming more aware of the competitive edge they receive from timely and comprehensive use of information resources (Connell 1981a; Anderson, 1982; Carey, 1982).

Adding to the confusion of whether information is a resource or not, is the fact that many corporate executives and managers do not fully understand information or information systems (Bryce, 1983). In order to successfully apply the information resource to the attainment

of organizational goals and objectives, management must have a clear understanding of what information is, how to manage it, and how to employ it successfully. The challenge for today's organizations comes in transforming this desire and need for a timely information resource into an effective information resource management system at a time when the "experts" in the field cannot agree on just how to handle the issue. What the experts do appear to agree on, however, according to a recent survey of leading information systems professionals, is the need to improve information system planning, and to effectively use the organization's data resources (Dickson et al., 1984).

The IRM problem Bryce (1983) identifies is the continuing existence of complaints from organizations that information systems which have been developed to manage the organization's information resources do not meet user needs. The identified problems include cost overruns, time delays in bringing the system online, lack of usable documentation, and excessive maintenance requirements once the system does come online. Bryce (1983) defines the problem as: "The total lack of the organization, structure and discipline to design and build good information systems with consistency (p. 88)"; and he goes on to suggest that "without a sound, standard system design methodology, these headaches will never be cured and the idea of managing information as a 'major resource' will be a corporate pipe dream (p. 88)."

The key, according to Ferreira (1979), to successful IRM is its ability to provide information to the manager when it is needed, where it is needed and in the proper form. In the future, the most important kinds of knowledge will not be in the form of individual elements of hard data; but rather, will be those generated through the correlation

of many interrelated elements of data and managerial expertise. The benefits to be gained from IRM include:

- 1) A better knowledge and understanding of data and information.
- 2) More manageable data and data structures.
- 3) Improved organizational productivity through better communication and use of resources (Nolan, 1982).

Management principles exist to manage the resources of manpower, machines, materials and money; however, only recently has research addressed the need for management principles to manage information as a vital organizational resource. The concept of IRM may provide the necessary framework to allow managers to handle information as a resource that can be controlled (Landau, 1980; Kull, 1982). Information Resource Management principles must address three dimensions for successful integration into the information age of the 1980s and beyond, according to Synnot and Gruber (1981). First is the dimension of planning. Organizational goals must be addressed through a carefully integrated business planning strategy. Current practices do not appear to adequately include IRM planning as part of the overall strategic business plan (Selig, 1982b; Cash et al., 1983). Dimension number two concerns the integration of people and resources through distributed information networks. This integration will result in new forms of shared management and control responsibilities. The final dimension that must be considered is technology. Integrated Information Resource Management systems will require a number of years to fully implement, and unless system planning accounts for the rapid changes that exist in technology today, the IRM system will be obsolete before it can be completed. The promise of IRM, though still in its formative stages, is

that the designer/analyst will have the necessary tools to consider the information resource in the same manner that management now considers manpower, material, money, and machines (Kull, 1982).

It is toward the need for a "sound, structured system design methodology" suggested by Bryce (1983) that this research activity is primarily focused. The end result of this research is the development of a structured optimization procedure which can be applied to support the completion of information system design activities. As Ostrofsky (1977) and Haupt (1978) point out, the selection, by system designers, of a specific configuration for an integrated system which will "best" satisfy the needs and requirements of the users is not a trivial problem. In fact, the system designer will expend considerable resources attempting to improve the design process. One major reason for this is information overload, which refers to the existence of more information in the decision-making process than the decision maker can personally consider in his or her head. The decision maker must use, whether implicitly or explicitly, some model of the decision-making activities which can reduce the complexity of the problem, while still providing meaningful information, and guide the decision maker to a final solution or recommendation. The structured optimizing procedure and explicit modeling activities developed in this research are intended to support the design and planning activities of the decision maker in his or her with efforts to consider the three dimensions of IRM design as detailed by Synnott and Gruber. The decision maker is that individual or group of individuals that is tasked with achieving an appropriate solution to an identified organizational need within the limits of available resources. Within the context of this research, the

terms "decision maker," "designer-planner," and "designer/analyst" will be viewed as synonymous.

Scope of This Research

The primary emphasis of IRM is not on the mechanics of processing information, but rather on the information itself as a major organizational resource. The primary area of IRM design interest in this research is at the level of the Organizational Information System (OIS). Figure 1, adapted from Siegel (1975), portrays the environmental and organizational elements that combine to form the activities that make up the organization. The organizational system interacts with the environment around it by providing products and services to the environment, and receiving feedback from elements of the environment which impact the activities within the organization.

The Organizational Information System provides all the information, in its various forms, needed by the organizational system to meet stated objectives and goals. The OIS is the major organizational focal point, or at least it should be according to Siegel (1975), where all information processing activities within the organization come together. Kull (1982) has suggested that MIS is just one of the many tools which are available for managing the organization's information resource. As Figure 1 suggests, many other tools are available within the OIS to support an organization's IRM needs. Information Resource Management system controls belong at the OIS level within the organization.

The design process, whether for hardware, software, or a complete IRM system, proceeds through a distinct life cycle of activities which begins with conceptualization and proceeds through development,

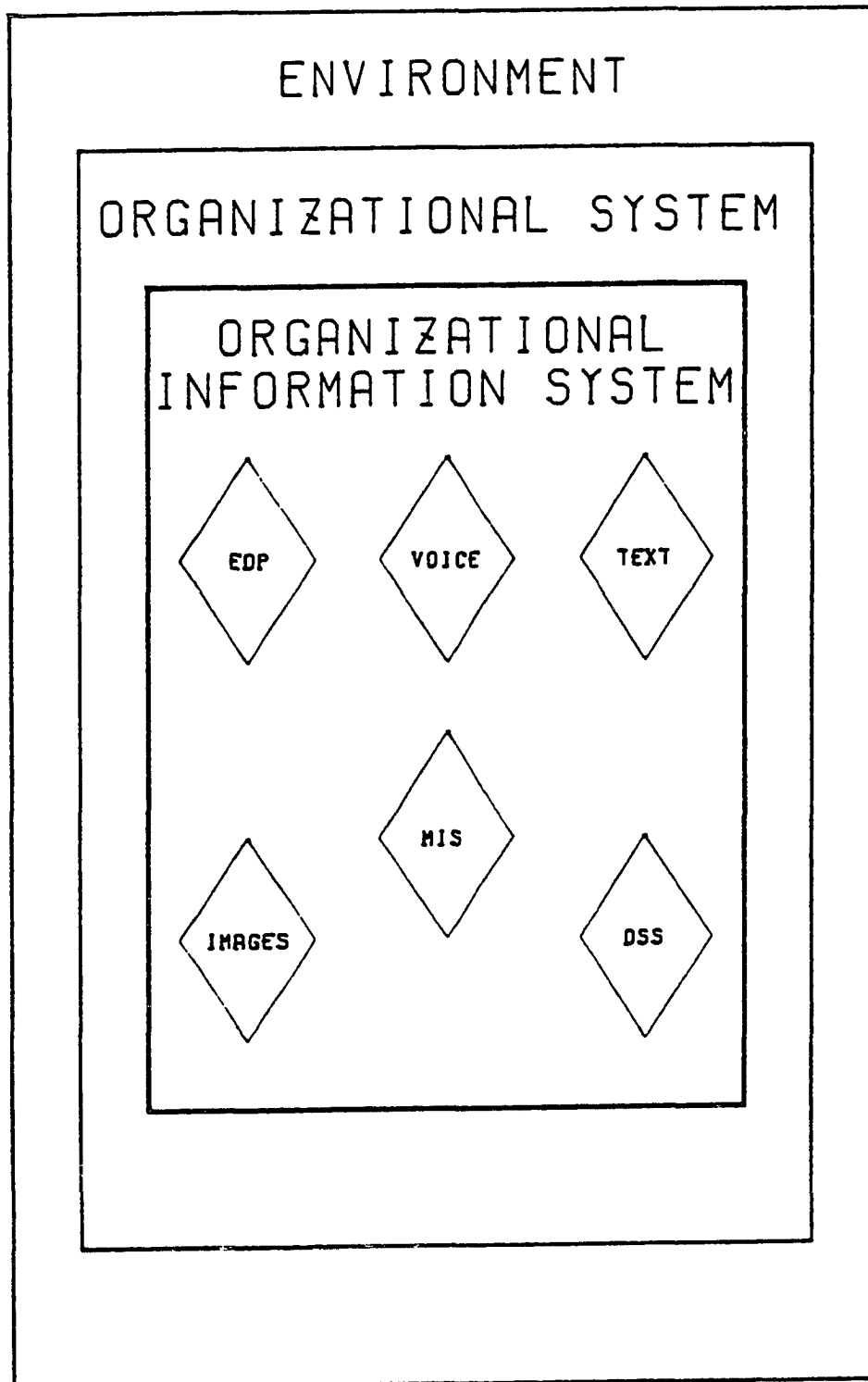


Fig. 1. Elements of the Organization (Siegel, 1975).

production, deployment, use, and, finally, retirement. This research concentrates on an important set of activities within this complete system life cycle—the procedures necessary to select the optimal course of action as it relates to the stated needs of the organization.

Figure 2 identifies, in the upper left hand corner, the elements which encompass the life cycle of activities associated with the implementation of a new system. Chapter Three discusses each phase of this life cycle in general terms. The primary focus of this research activity concentrates on those elements of the Preliminary Activities which have been identified in the circled inset. Chapters Four and Five contain a detailed discussion, including an illustrative example, of each identified activity.

The term "optimal", as defined by Ostrofsky (1977), is used in this research to mean the "best" system design from those designs that have been considered. Optimal is not to be confused with the term "optimum" which means the theoretical best system design for the defined criteria, regardless of whether or not it was considered (Ostrofsky, 1977). The term "optimization" is used to denote the activities involved in selecting the "best" candidate information system from those systems that have been evaluated.

The structured optimization method developed in this research will allow the designer/analyst to apply a multiattribute approach to the analysis and evaluation of available resources while planning the organization's IRM system. A benefit of applying IRM system design at the OIS level is improved communication between management in the organizational system and the information handlers within the OIS.

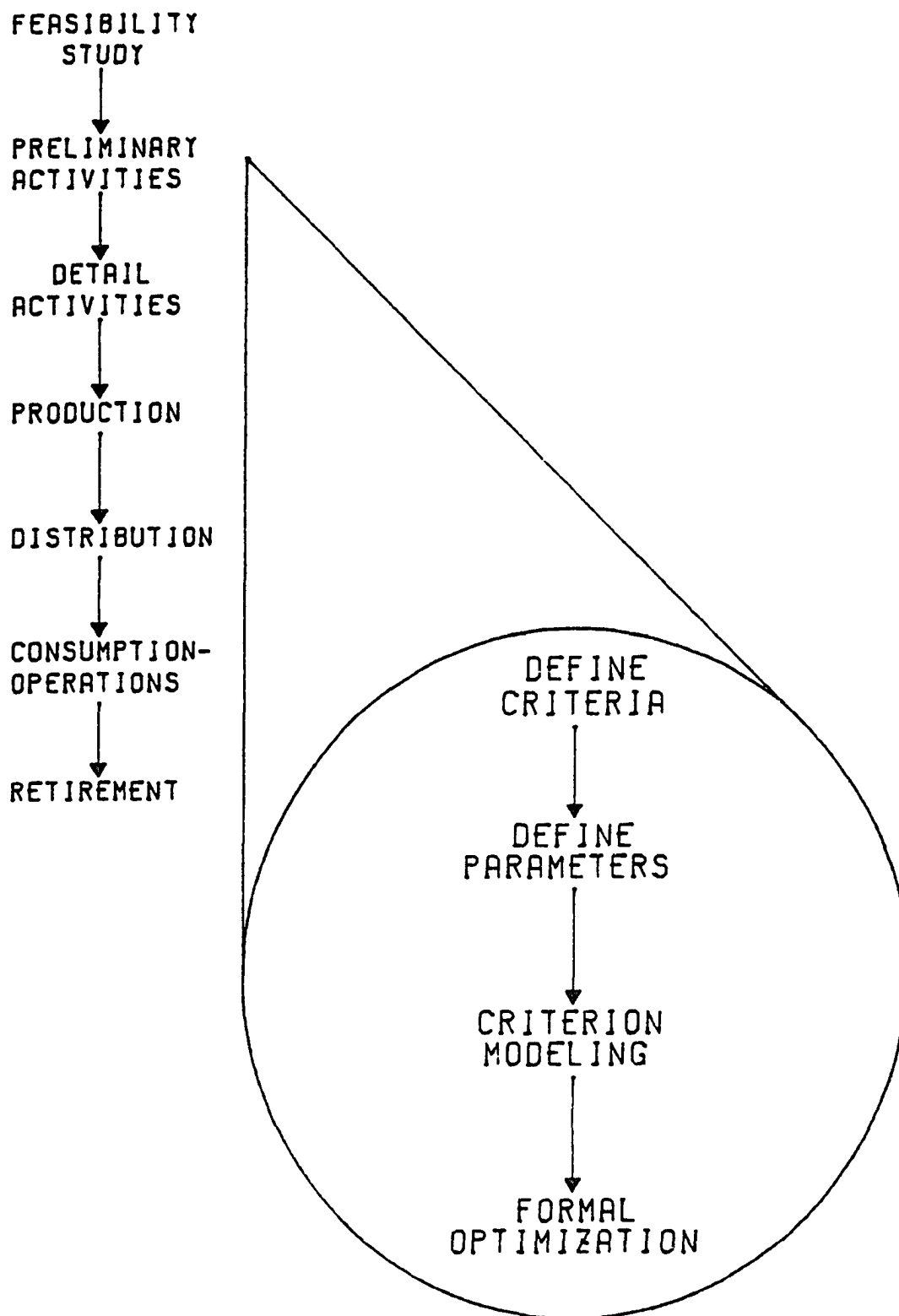


Fig. 2. Scope of the Research.

Problem Statement

Almost all organizations have experienced a rapidly increasing demand for information processing resources (Head, 1979). This increasing demand has brought with it, a concern that information systems implemented within the organization be effective in supporting organizational goals and objectives. Currently, the consideration of alternative system designs is often not done because of the complexity and cost involved in describing and evaluating these alternative systems (King and Epstein, 1983). According to King and Epstein, a valid and practical multiattribute evaluation approach would contribute significantly to the design of information systems. The problem addressed by this research is to develop an optimization methodology that has the structure and discipline to support the design and implementation of information systems that consistently meet the needs of the organization.

Research Objectives

Existing Information Resource Management design methods appear to be inadequate for meeting the existing and anticipated information needs within and between organizations without modification and enhancement (Benjamin, 1982; Bryce, 1983; King and Epstein, 1983). The objective of this research is to develop, and illustrate a structured multiple attribute optimization methodology that will result in an optimal information architecture to meet the stated needs and objectives of the organization. This structured methodology will describe alternative versions of a proposed information system and will permit the selection of the "best" candidate design from the proposed alternative systems by simultaneously considering both qualitative and quantitative multiple

criteria, including relevant interactions. As Ebenstein and Krauss (1981) suggest, "Only a formal program can weigh, measure and compare interrelated variables (p.23)."

Contributions of This Study

The application of a multi attribute design methodology is a practical way to describe alternative versions of a proposed information system. The systematic procedure developed in this research study makes a major contribution to information system design by providing:

- 1) A structured optimization methodology that will efficiently guide the information system designer/analyst toward meeting the IRM requirements of the organization.
- 2) A formal criterion function modeling procedure that will evaluate alternative candidate systems through explicit analysis of both qualitative and quantitative criteria and identify the "best" system from among the systems studied.

Organization

The following approach is used in this research activity to develop a structured optimization method for information resource management which will be capable of evaluating the planning, personnel and technology needs that will be required to effectively manage information as a major organizational resource. The approach consists of these steps.

First, in Chapter Two, the work that has been done in the area of information system requirements determination is identified. Several approaches are summarized and their limitations with respect to IRM system design are identified.

In Chapter Three, several general purpose decision-making models are examined and evaluated as to their potential for describing the IRM system design problem. The chapter concludes with a discussion of which of the models has the most promise with respect to IRM system design.

In Chapter Four, a Multiple Criteria Decision Making (MCDM) framework is used to begin the development of a structured optimization methodology which specifically meets IRM system design requirements of the organization. The initial steps of the optimization methodology, consisting of criteria definition, criterion element definition, identification of criteria interactions, and assignment of criterion relative importance measures are developed using sample data from the USAF Ballistic Missile Office to illustrate the application of each step of the methodology.

Chapter Five, continues the development of the structured methodology by identifying the appropriate range of values for each of the criterion elements defined in Chapter Four. Next, the criterion function model is developed which is used to evaluate the performance of each identified candidate information system. As in Chapter Four, sample data is used to demonstrate the implementation of each step of the methodology.

Finally, a summary of the research, including results and contributions, limitations, and recommendations for future research are presented in Chapter Six.

CHAPTER TWO

INFORMATION REQUIREMENTS DETERMINATION

Introduction

An information system, if it is to be effective, must meet the needs of the organization it is designed to serve. A correct and complete identification of the organization's information requirements is the key element of the design, planning, and subsequent implementation, of an Information Resource Management system. According to Davis (1982) and Yadav (1983) there has been relatively little research done in the area of information requirements determination for an organization, and as a result, few practical, well-formulated procedures exist for identifying the organization's information requirements.

Those research activities that have been done in the fields of organization and management have concentrated on the issues of determining organizational information requirements and the method best suited for that purpose (Zachman, 1977; Davis, 1982; Yadav, 1981, 1983; Bowman et al., 1983). Davis (1982) identified four methods of determining information requirements at the organizational level. These methods are 1) Normative Analysis; 2) Strategy Set Transformation; 3) Critical Factor Analysis; and 4) Process Analysis. A fifth method, also identified by Davis, Input-Process-Output Analysis, is also applicable at the organizational level even though its primary emphasis is at the application level. A sixth, and final, approach is reviewed which applies, to

a specific problem, a combination of elements of Critical Factor Analysis and Process Analysis into what is referred to as Requirements, Needs, and Priorities (RNP) Analysis (Batiste and Jung, 1984). Each of these methods and implementation procedures is described in turn.

Normative Analysis

Normative Analysis is described by Beer (1981) as planning based on what the organization ought to be doing as a result of developing its resources while still operating within the bounds of feasible actions. Business Information Analysis and Integration Technique (BIAIT) employs a normative planning methodology to determine organizational information requirements (Davis, 1982).

BIAIT is the result of research work begun by Burnstine (1979) and was originally intended to be a means of describing an organization's needs for computer services from the viewpoint of information handling requirements rather than the consumer services provided by the organization. The primary focus of BIAIT is on orders (the driving force within an organization) and suppliers (Carlson, 1979; Davis, 1982; Bowman et al., 1983). Figure 3 outlines the process involved in applying BIAIT.

Seven questions are tailored to the level of the organization being evaluated. Each question is answered either "Yes" or "No." From the possible 128 unique answer combinations, a generic model of the organization is created which identifies common business functions, information processing requirements, business objectives, and occupations (Davis, 1982). Next, the generic model is tailored to the actual needs of the organization under study. From this customized model of the information flow, reports and data requirements are identified. After

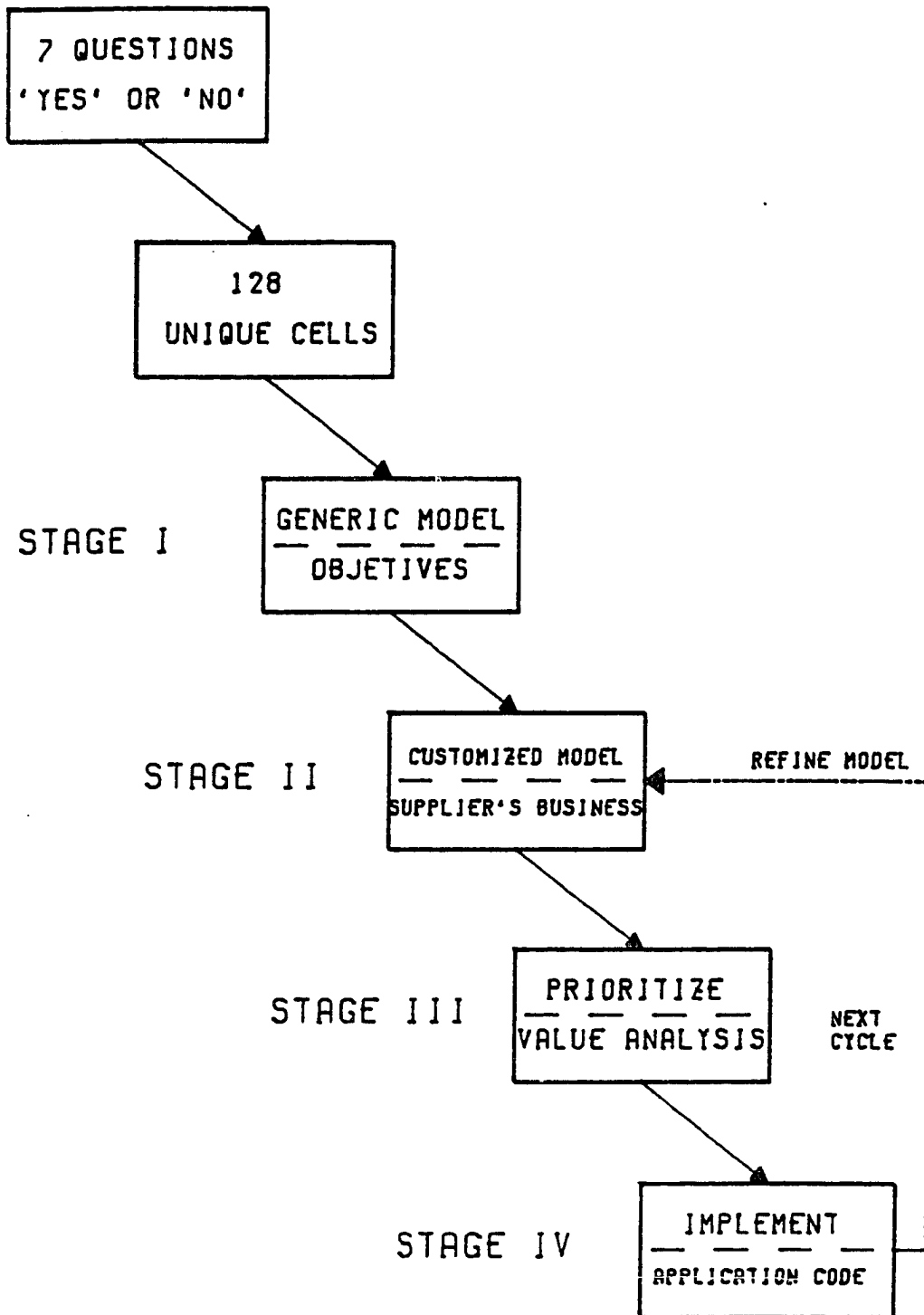


Fig. 3. The BIAIT Process (Carlson, 1979).

the model is customized, the analyst completes a value analysis of required activities and prioritizes these activities to insure the activities that are most important to the organization's goals and objectives are accomplished first (Carlson, 1979). Finally the analyst and programming assistants begin the implementation process via application code generation. This whole process is designed to insure full agreement between management and the analyst on a planned course of action before any implementation actions are begun.

BIAIT has two significant advantages. First, its model building activities can be easily automated due to the structured nature of the normative process that is employed. Second, preliminary results from the procedure can be obtained in only a few weeks. However, a weakness of the method is its proprietary nature. The code is not widely available and as a result has not been widely used or tested (Beheshtian and Buss, 1984). Another weakness of this normative procedure is the need to tailor the findings to fit the specific needs of the organization under study. This reduces the usefulness of the method as a general, structured planning methodology and makes efforts to automate the process extremely difficult.

Strategy Set Transformation

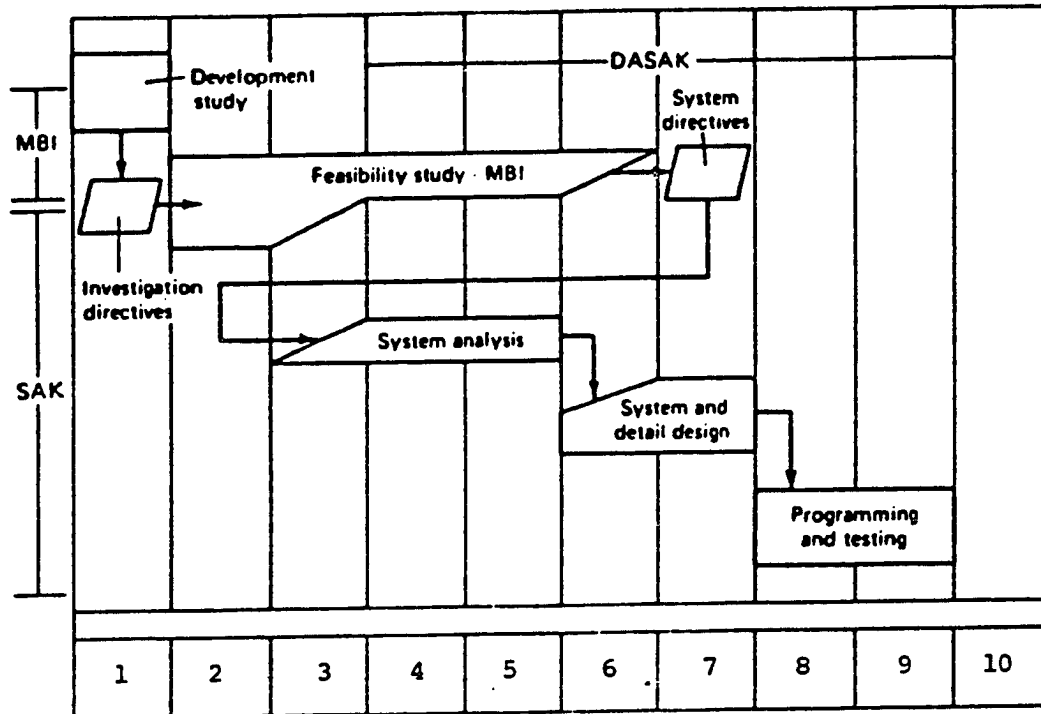
The Strategy Set Transformation methodology also obtains information requirements at the organizational level (King, 1978). The identified requirements are derived from the stated goals and objectives of the organization. Research work in this area has been done on two fronts. Wigander et al. (1984) have developed a two step approach using the method for business analysis (MBI) and the structured analysis and

design method (SAK), which encompasses the system development process and which helps insure that the information system remains supportive of the organization's goals and objectives. The second area of research has been done by Yadav (1981; 1983), with the development of the Organization Analysis and Requirements Specification Methodology (OARSM). The OARSM is intended to insure that the organizational system is fully supported by its Organization Information System (OIS).

Method for Business Analysis and Structured Analysis and Design

Wigander et al. (1984) introduced a structured development model which encompasses system development activities from a feasibility study to system programming. The method consists of two interrelated activities: The Method for Business Analysis (MBI) which is applied to the feasibility study activities; and Structured Analysis and Design (SAK) which supports the structured analysis and design for the phases following the feasibility study through to completion of system programming.

The model displayed in Figure 4 was developed over a number of years by the Swedish consulting firm AB Programator and reflects the implementation relationship of both MBI and SAK packages. The Development Study phase is seen by the authors to be a continuing task whereby the organization insures the information systems remain supportive of the organization's goals and objectives. This development study may result in a set of directions which trigger the feasibility study (or MBI activity) which is then used to analyze the organization and its activities, and propose an information system for possible development. The MBI method delimits and analyzes the organization's "activities" to identify the elements which will be included in the remainder of the MBI study.



Key to Analysis and Design Phases

1. Development Study
2. Business Study
3. Subsystem Study
4. Information Study
5. Process Study
6. System Design
7. Detail Design
8. Programming
9. Testing and Implementation
10. Postimplementation Study

Fig. 4. Method for Business Analysis and Structured Analysis and Design (Wigander et al., 1984).

After these elements have been identified, a detailed analysis of each is performed to determine required information flows. The final MBI activity defines the formalized information system, determines detailed information requirements and submits a detailed report to management for approval, selection of the new information system design, and development of an implementation schedule.

With management approval, the development process continues into the Structured Analysis and Design (SAK) phase. As seen in Figure 4, SAK consists of three major subphases. First, the system analysis is continued and the MBI report is decomposed to facilitate further work. Second, the System and Detailed Design subphase first develops a logical information system design, independent of operating hardware and support facilities, and then develops the physical system which is specific to existing or proposed hardware and support facilities. The final activity in the SAK phase is programming and testing which codes, tests and implements the selected information system.

Advantages of the MBI/SAK approach include the use of a feasibility study to delimit the information requirements determination problem, and the availability of computer application programs to implement the procedures. A disadvantage of this method is that there is no specific procedure explicitly identified to objectively evaluate alternative approaches or select the "best" approach so the designer-planner is unable to determine if the "best" system has been defined.

Organization Analysis and Requirements Specification Methodology

The OARSM provides a set of guidelines and tools to facilitate and systematize the understanding of an organization's information require-

ments (Yadav, 1981). The guidelines form the framework in which the analyst can study and analyze an organization's goals and objectives. The tools are used to build a detailed conceptual model of the organization's functions which is then used to specify the information requirements for the organization.

Figure 5 presents the five steps that make up the set of guidelines used in the OARSM. Steps 1 and 2 develop an overall perspective of the organization prior to evaluating individual organizational functions. Step 3 analyzes, in detail, the goals, objectives, and structures of each function that has been identified to be supported by the OIS.

The interactive tools are applied in Step 4 to analyze the managerial functions previously identified in Step 3. Upon adequate completion of Step 4, the methodology will have guided the analyst to a sufficiently detailed understanding of the organization to enable him or her to specify its information requirements. This specification is used in Step 5 to describe the characteristics of an information system that will effectively support the organization's information needs.

OARSM provides a comprehensive framework which guides the study and understanding of an organization's information needs, and a set of automated tools that support consistency and completeness checks and generate a knowledge base of managerial activities. However, the number of automated tools is insufficient to do a complete, organization study, and the framework does not exhaustively address the implications of organizational components to the information requirements (Yadav, 1981).

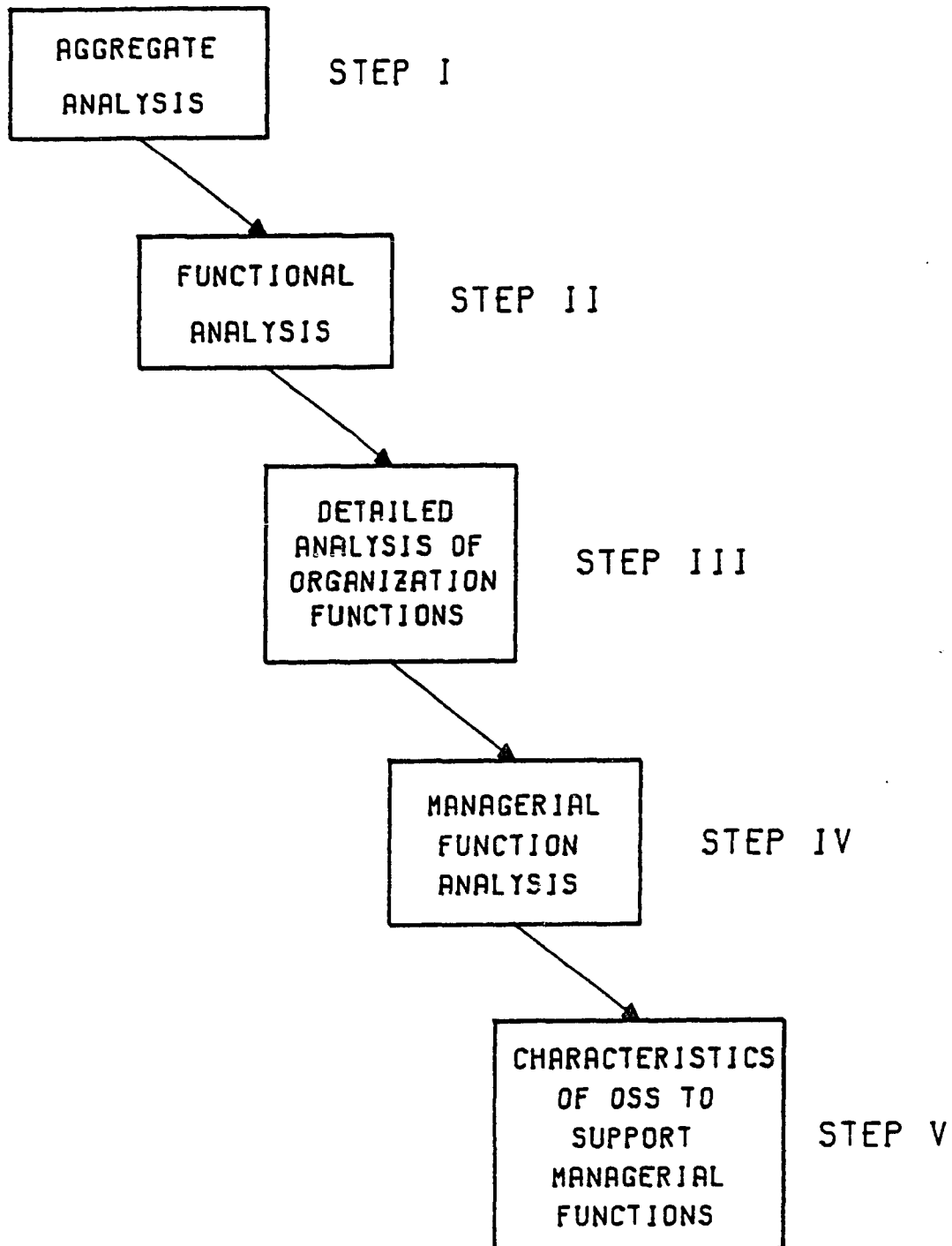


Fig. 5. Organization Analysis and Requirements Specification Methodology (Yadav, 1981; 1983).

Critical Factor Analysis

Critical factor analysis is a method used to identify the significant decisions or factors that can be used in determining information requirements (Davis, 1982; Wahi et al., 1983; Yadav, 1983). Critical Success Factors (CSF) employs the critical factor analysis method.

The Critical Success Factors method is based on the concept that the manager should receive only that information which most strongly affects the attainment of his or her goals (Benjamin, 1982; McLean, 1982; Rockart, 1982). Usually a small number of factors will be ultimately identified as a result of a series of interviews with the manager. A typical number of CSF will range from 3 - 10 per manager (Selig, 1982a; Rockart, 1982).

Six major sources of CSF have been identified as a result of the research done by Rockart (1982). These include the:

- 1) Industry the business is involved in.
- 2) Competitive Strategy and Industry Position of the business.
- 3) Environment.
- 4) Temporal Factors within the business and industry.
- 5) Managerial Role.
- 6) Managerial "View of the World."

The CSF are unique to each industry, business within an industry and manager within a business (Bowman et al., 1983). Therefore, the first step in applying the CSF methodology requires a thorough study of the structure of the particular industry and business. As a result, there is no clear set of procedures that apply equally well to each situation (Yadav, 1983). The three major uses of the Critical Success Factors method include:

- 1) Clarifying the focus of the manager on key areas where organizational performance must be satisfactory.
- 2) Developing top management information needs.
- 3) Setting information system priorities.

The advantages of CSF are that it is comparatively inexpensive to perform; it can be accomplished in a relatively short period of time; and it provides improved insight and understanding into what information requirements are important to the business. A significant disadvantage is that CSF is not comprehensive. While it provides a high level focus on business needs, the CSF approach is too general in scope to handle operational level concerns (Batiste and Jung, 1984). Also, the effectiveness of the method is highly dependent on the skill of the analyst in preparing interview questions and evaluating the manager's answers. Finally, the process is highly topical and temporal (McLean, 1982).

Critical Factor Analysis is a first step in providing the definition of potential problem/opportunity factors which can ultimately lead to the definition of specific information requirements that will support the decision making process. To be more effective, however, more detail is needed to decompose the resulting material into more workable pieces. As with the other information requirements determination methods discussed so far, CSF does not provide, on its own, the capabilities needed to effectively support information requirements evaluations. The method should be combined with other procedures, such as the optimization procedure developed in this research, to provide a more complete, structured design methodology that will yield more consistently successful IRM systems.

Process Analysis

The fourth method described by Davis (1982) for determining organizational information requirements is called "process analysis" because it focuses on the organization's processes. The principle behind this process is that the organization's processes--the decisions or activities needed to manage the resources of the organization--are the foundation for the information system requirements determination. Two process analysis methodologies are Business Systems Planning (BSP) and Business Information Control Study (BICS).

Business Systems Planning is a methodology for identifying the business requirements (IBM, 1981). BSP systematically analyzes an organization in terms of its data classes and business processes and relates these to the information requirements within the organization (Davis, 1982; McLean, 1982; Yadav, 1981, 1983). BSP applies a top-down approach to data and functional analyses and a bottom-up approach to recommended implementation actions (IBM, 1981; Bowman et al., 1983). Figure 6 reflects the top-down, bottom-up approach employed by BSP.

BSP describes the relationship between the business function and the data from an organizational perspective. A two phase approach using interviews with executives and middle managers seeks to identify those functions and data which are critical to the organization from a long-term perspective (Zachman, 1977; 1982b; Beheshtian and Buss, 1984).

BSP has a number of positive features. First, it is well documented, comprehensive and thorough. Second, the process is transferable and easily learned. Third, it keeps the perspective of the analysis on the needs of the organization. A number of serious drawbacks do exist however. First, it is very expensive, time consuming, labor intensive,

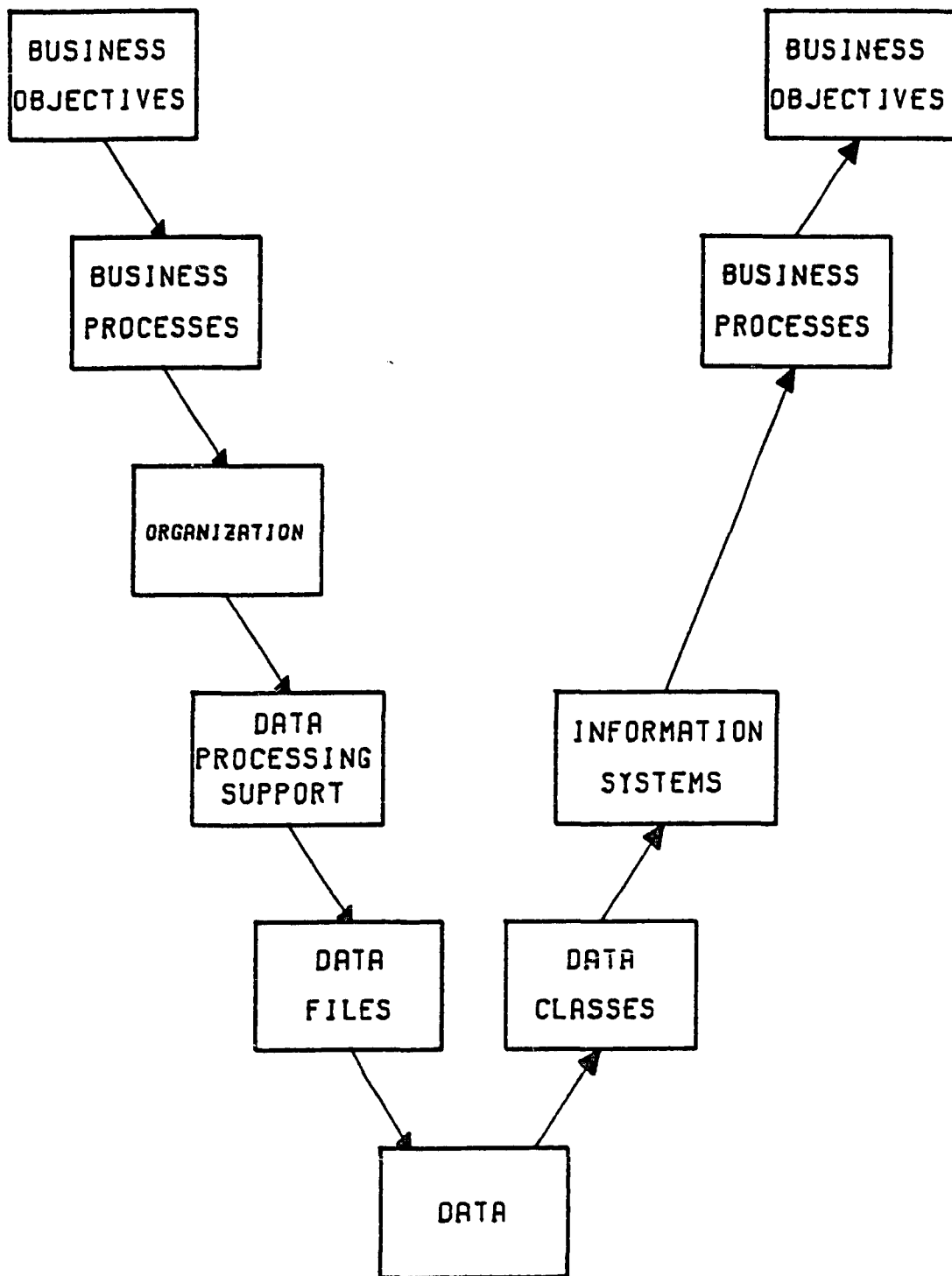


Fig. 6. Top-Down, Bottom-Up Relationship in BSP Studies (IBM, 1981).

and the skill of the analyst/interviewer is a critical factor in the success of the whole process. Second, there is no framework to aid the understanding of the total organizational structure, and this lack of focus makes it difficult to develop plans for what to do next. Third, BSP provides a systems architecture derived primarily from heuristic and subjective decisions, and tends to satisfice the IRM requirements of the organization since no objective optimization procedure is employed. The most significant weakness is the difficulty in bridging the gap between the planning activity and implementation (Zachman, 1982a; Ostrofsky and Kiessling, 1984). No design results come from the BSP process.

Even with its weaknesses, BSP seems, ". . ." to be the most comprehensive of all the existing methodologies in providing guidelines for understanding activities of an organization (Yadav, 1981, p. 37)." A logical extension of BSP is the Business Information Control Study (BICS) which was also developed at IBM and uses the BIAIT procedure described previously (Kerner, 1979; Yadav, 1981).

BICS and BSP have common roots in their attempts to describe a business at the organizational level in terms of its information requirements (Zachman, 1982a). BICS is similar to BSP in that both employ a top-down analysis; study the business from the organizational level; are data oriented; and use a management interview technique.

BICS consists of the following major activities:

- 1) Construct a business model.
- 2) Verify the business model.
- 3) Examine the current information system.
- 4) Analysis and implementation specifications using BIAIT.

BICS enters into the analysis through the orders received by the organization, and evaluates data and organization structure from a short-term perspective. Data classification criteria are generated through definitions, and the structure is analyzed from sets of predefined categories.

The major strengths of the BICS approach include a reproducible structure; a great deal of future potential; and a minimum amount of time is required for completion. Major weaknesses of BICS are that it is not well supported with an adequate theoretical foundation; it has limited documentation; and validation work has not been extensive. Also, the approach is inflexible due to its use of predefined models.

Both BSP and BICS provide a basic understanding of the functional activities of an organization and its information requirements. These approaches provide needed insight into the issue of obtaining a balance between the long-term and short-term information requirements determination strategies that must be accomplished if an organization is to function effectively.

Input-Process-Output Analysis

Input-process-output is a systems approach to determining information requirements which starts with a top-down analysis of an organization and proceeds to subdivide the organization's activities into subsystems. This subdivision process is continued until information processing is defined as separate activities (Davis, 1982). A very comprehensive example of this approach is the Information Systems Work and Analysis of Changes (ISAC) method.

Lundeberg et al. (1981) developed the Information Systems work and Analysis of Change (ISAC) methodology to address the needs, problems and

ideas for change experienced by system users, and to provide a series of manageable procedures to arrive at the final specifications for manual and/or computer routines. Figure 7 depicts the relationships between the following ISAC activities:

- 1) Change Analysis.
- 2) Analysis and Design of Information System;
 - 2.1) Activity Studies,
 - 2.2) Information Analysis,
 - 2.3) Data System Design,
 - 2.4) Equipment Adaptation.
- 3) Other Development Activities.
- 4) Realization of Information Systems.
- 5) Implementation.

The ISAC model is initiated when a problem or need for change is identified in an existing information system or a desired new capability is proposed. The Change Analysis activity precedes information system development; is conducted when the identified need warrants further investigation; and consists of a detailed description of current system activities, an analysis of the identified problem, and a study of proposed alternatives to solving the problem.

The Analysis and Design activity produces the model(s) that describe(s) the different aspects of the information system. The analysis and design models are generated through a two phase approach. First, the problem oriented Activity Studies delimit future information while Information Analysis describes the future system's desired performance. The second phase of analysis and design is data oriented, with Data System Design concentrating on equipment independent design solutions

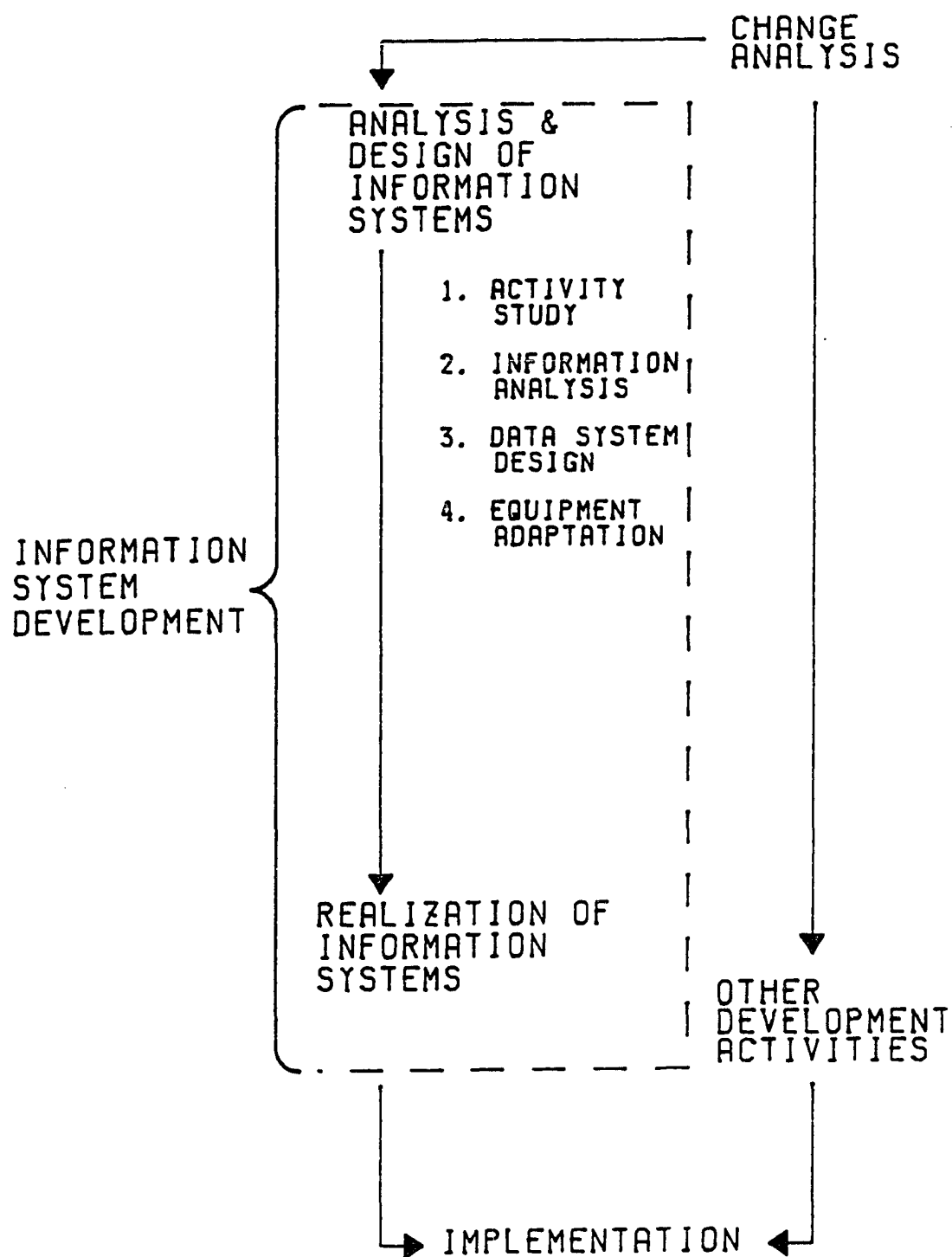


Fig. 7. Information System Development (Lundeberg et al., 1981).

(logical design) and Equipment Adaptation evaluating needed equipment specific modifications (physical design) to accommodate the desired information system operations.

Plans for the selected course of action are evaluated with respect to existing systems, other organizational activities, and the models developed during the analysis to insure schedules, resources, manual procedures and computer programs will fully support the proposed system. The final stage in the model is information system implementation.

Advantages of this type of analysis are that it is systematic and comprehensive, and the top-down approach gives reasonable assurance of a complete analysis. One disadvantage of this approach is that organizational setup implications are not addressed, effectively limiting the scope of the analysis. A second disadvantage is that while this methodology tries to tie problem analysis and data analysis together, it does not have a well defined problem analysis procedure, nor does it address the implementation of organizational structure during analysis of the problem (Yadav, 1983). This lack of an analysis framework confounds the designer's efforts and reduces the probability of implementing the most effective information system.

Requirements, Needs, and Priorities Analysis

The Requirements, Needs, and Priorities (RNP) analysis is an example of the application of a structured approach for determining an information system project definition (Batiste and Jung, 1984). It combines the concepts of BSP and CSF with traditional requirements analysis and attempts to minimize the resources required to define a project. RNP does not use BSP's detailed analysis of data requirements,

and it employs CSF only at the organizational level. Its purpose is to define and justify a particular information system project, not draft the requirements document (Batiste and Jung, 1984).

The RNP approach is conducted in three phases. The Executive Session is used to gain an organizational level perspective on the business problem and to define the detail and scope of the study. A process flow model is constructed which is used in conjunction with the CSFs to identify the problems that are to be addressed. The final step in the first phase requires each participant to rank the identified problems in order of their criticality.

The second phase of the RNP approach is the Task Force Analysis. The purpose of this analysis is to develop solutions to the identified problems. Three to five days are spent evaluating the available information using Directed Group Assessment to establish a consensus opinion on how the problems impact the organization and the relative importance of each to the successful operation of the organization. The CSFs and problems represent requirements and needs, respectively, and the operational ranking identifies the priorities (Batiste and Jung, 1984).

Once the problems have been prioritized and recommended courses of action have been developed, the third phase, the Executive Presentation, is completed. In this phase the task force makes an oral presentation of its findings and recommendations to the organization's executives. The executive sponsor is asked for permission to proceed. It is at this point that the RNP approach is completed and further design-planning activities in the development cycle must be developed.

The RNP approach has the advantage of applying the best elements of the BSP and CSF methods to a narrowly defined organizational problem and

is presented here as an example of the application, albeit narrowly defined, of information requirements determination procedures. The analysis is relatively fast--five to seven days--and improves the likelihood of identifying critical problems because it evaluates more than just a list of problems. The use of the Directed Group Assessment method can also create a synergistic analysis if properly accomplished. The disadvantages of RNP include its being (1) limited to a high level organizational perspective and (2) applied only to the early stage of the development cycle. As Zmud (1983) points out, the Directed Group Assessment method may have limited success due to domineering participants monopolizing group discussions.

Zachman (1982a) suggests that some organization level description of information requirements is needed for the following reasons:

- 1) Due to resource limitations, system investment opportunities must be chosen that have the greatest potential benefit.
- 2) The necessity to produce short-term results in the organization requires a design-planning process that will maximize integration of systems and minimize the need for redesign.
- 3) Resource constraints and technology limits will have considerable impact on what is implemented.

Davis (1982) points out that humans are not unbiased in the way they select and use data. Because of this, there is a tendency when establishing information requirements, to lean toward requirements based on current procedures, currently available information sources, and recent events. The information system analyst/designer must be alert to these biases and compensate for them. The best way to compensate is

through the use of a structured problem solving methodology which will create a more efficient, unbiased solution approach.

Conclusion

The information requirements determination methods reviewed above are summarized in Table 1. The RNP procedure is not included in Table 1 as it is an example of a specific application and not a general method. The performance factors included in the summary table suggest those activities which this researcher feels are important, not only to the successful analysis of information requirements, but more importantly, to the successful implementation of an Information Resource Management system. These general solution procedures do not result in system design specifications, completed solution alternatives or cost-benefit determinations. Rather, they separate the issue of determining the information requirements of an organization from the design requirements of an information system (Yadav, 1983). Figure 8 reflects the relationship of the information requirements determination procedures to the overall Information Resource Management activity conducted by the OIS function within the organization. Once the information requirements have been identified, additional analyses must be performed to evaluate and select the "best" application considering the organization's limited resources.

The ISAC (Lundeberg et al., 1981) and MBI/SAK (Wigander et al., 1984) models are important attempts to address the information resource management development process using a structured methodology. While these methods specifically address the requirements of, and need for, feasibility studies to delimit the size of the problem and focus the

TABLE 1

SUMMARY OF INFORMATION REQUIREMENTS DETERMINATION PROCEDURES

	ORGANIZATION-LEVEL ANALYSIS	DOCUMENTED OUTPUT	SUPPORTS CONCEPTUAL MODELING	SUPPORTS ORGANIZATION MODELING	WELL DEFINED PROCESS AUTOMATION SETUP	DEFINES INFORMATION ANALYSIS	RESULTS OBTAINED QUICKLY	ADDRESSES LIFE-CYCLE OF THE INFORMATION RESOURCE	OBJECTIVE OPTIMIZATION
BUSINESS INFORMATION ANALYSIS & INTEGRATION TECHNIQUE (BIAIT) (Burnstine, 1979)	*	Y	Y	N	Y	Y	Y	N	N
BUSINESS INFORMATION CONTROL STUDY (BICS) (Kerner, 1979)	Y	Y	N	N	N	Y	N	Y	N
BUSINESS SYSTEM PLANNING (BSP) (IBM, 1981)	Y	Y	Y	N	N	N	N	N	N
CRITICAL SUCCESS FACTORS (CSF) (Benjamin, 1982)	P	P	N	N	N	N	Y	N	N
INFORMATION SYSTEMS WORK & ANALYSIS OF CHANGES (ISAC) (Lundeberg et al., 1981)	Y	Y	Y	N	N	N	N	N	N
METHOD FOR BUSINESS ANALYSIS & STRUCTURED ANALYSIS & DESIGN (MBI/SAK) (Wigander et al., 1984)	Y	Y	N	N	Y	Y	Y	N	N
ORGANIZATION ANALYSIS & REQUIREMENTS SPECIFICATION METHODOLOGY (OARSM) (Yadav, 1981)	P	Y	Y	P	Y	Y	Y	N	N
Y = YES N = NO P = PARTIALLY * = MUST BE TAILORED									

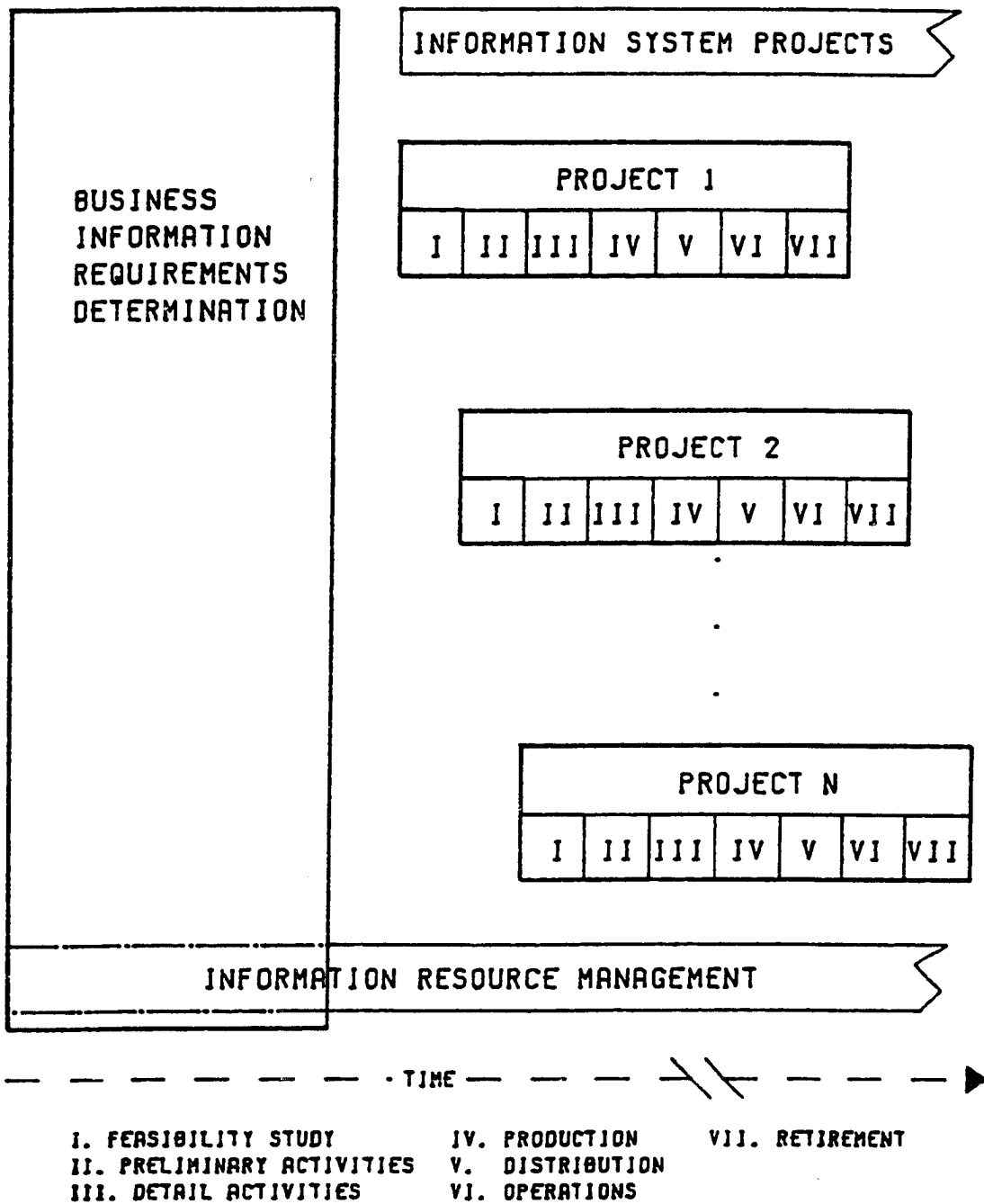


Fig. 8. Relationship of information requirements determination procedures to IRM system development (Adapted from IBM, 1981).

design effort, neither approach explicitly deals with the optimization of alternative solutions or the process by which the "best" alternative will be selected.

The review of relevant literature dealing with information requirements confirms there is no specifically developed sound, structured system design methodology to support an organization's Information Resource Management development requirements. Chapter Three presents several general purpose decision making models and evaluates each as to its potential for successful application to IRM design requirements.

CHAPTER THREE

DECISION-MAKING MODELS

The trouble with most problems is that they do not know what kind of problem they are.

Fenwicke Holmes (1977)

Introduction

In most management decision-making situations there are too many alternatives to expect experience, judgement, or intuition to provide adequate solutions, even with perfect information (Ackoff, 1967). Humans have too limited a capacity in short term memory to satisfactorily process all the information that is encountered during a decision-making situation (Janis and Mann, 1977; Davis, 1982; Szewczak, 1983). What is needed is some form of simplified, abstract description of the real system. One approach is to use an explanatory model which can simplify the real system and allow the decision maker to deal with the otherwise complex system.

Model

The term "**Model**", like many other terms in management activities, is often used with little regard for what the word really means. Coyle (1977) presents this definition of an analytical "model": "A model is any formal description in words, diagrams and/or mathematical equations, of the structure and workings of a system, together with unambiguous, acceptable, definitions of its parts" (p. 6). It is this definition of the term that will be used throughout this research effort.

Model construction is a complex process which generally exists as an art rather than a science in most fields. This is especially true when modeling management activities because there are few fundamental laws of behavior, policy inputs are hard to quantify and a human decision-maker is an integral part of the system (Pritsker, 1977). Because models are an abstraction of the real world, only the more important elements of the system, based on a knowledge of the model's purpose and the knowledge of the designer-planner, should be included and the less important elements left out. Decision-making models are intended to reduce real world complexities through the process of abstraction to allow the decision maker to concentrate on the important aspects of the problem at hand. If the model is too abstract, it will not adequately reflect the true nature of the decision-making process and as such, a great deal of its usefulness will be lost. One essential element in the construction of a model is the notion that the problem being modeled can be decomposed into its component parts which are evaluated individually, and then reassembled into one general recommendation (Fischhoff, 1983).

A model is evaluated as "good" based on its WORTH (the use to which the model is put), and its VALUE (the model's simplicity relative to the real world) (Cleland and King, 1972). The value of a model, to the decision maker, arises from the increased ability to understand obscure behavior characteristics through the model which could not be done by observing the real system directly (Forrester, 1961). A serious misunderstanding about models exists which suggests models cannot be developed until every constant and functional relationship is accurately determined. To employ this attitude would lead to the omission of some potentially significant factors which are unmeasured or unmeasurable

intangible influences on the decision. The omission of these subjective factors has the same consequence as saying they have no effect on the decision at hand. Therefore, it is better to build the model with whatever information is available and plan for revisions when additional information is obtained.

Logical Flow Models

The Logical Flow Model is a decision-making model in which the integral elements can be diagrammed to graphically show the relationships among the various alternatives and actions (Lucas, 1982). Logical Flow decision-making Models address the following activities:

- 1) Identification of relevant courses of action which the decision maker may implement.
- 2) Identification of the consequences, or outcomes, from choosing each identified alternative.
- 3) Identification of a rank ordering of the preferences for the alternatives based on the value of that alternative from previously defined decision-making criteria.
- 4) Selection of an alternative for implementation from those evaluated.

The following examples show three different perspectives of Logical Flow decision-making Models. These models are evaluated as to how effectively they model the real world facing the decision maker. The three Logical Flow models that are examined include The Econological Model, The Optimizing Decision Model, and The Bounded Rationality Model.

The Econological Model

The basic tenet of the Econological Model is that the decision maker is economically rational and that the decision-making process is accomplished in a logical, step-by-step manner (Behling and Schriesheim, 1976. p 17). This model is presented in Figure 9.

Decision-making activities of the Econological Model consist of:

- 1) **Discovery of Symptoms.** This is the essential first step. Unless the diagnosis of the symptoms is correct, subsequent activities will be a waste of resources and probably will not yield the best available solution.
- 2) **Definition of the Problem to be solved and Development of Criteria.** Both occur at the same time. This single attribute decision criterion will be used later to rank order the outcomes of each alternative.
- 3) **Develop All Alternatives.** The decision maker identifies and tests all alternative courses of action or problem solutions.
- 4) **Determine All Outcomes.** The outcomes for each alternative are identified, quantified, and converted to a common base value such as dollars or utils for comparison.
- 5) **Select Best Alternative.** Each outcome is evaluated against the previously defined criterion and the alternative which optimizes the decision maker's advantage is selected.
- 6) **Act.** Implement the decision.

There are several weaknesses in the Econological Model. As Behling and Schriesheim (1976) point out, the model assumes the decision maker has complete knowledge of and can anticipate all future events. This is seldom the case.

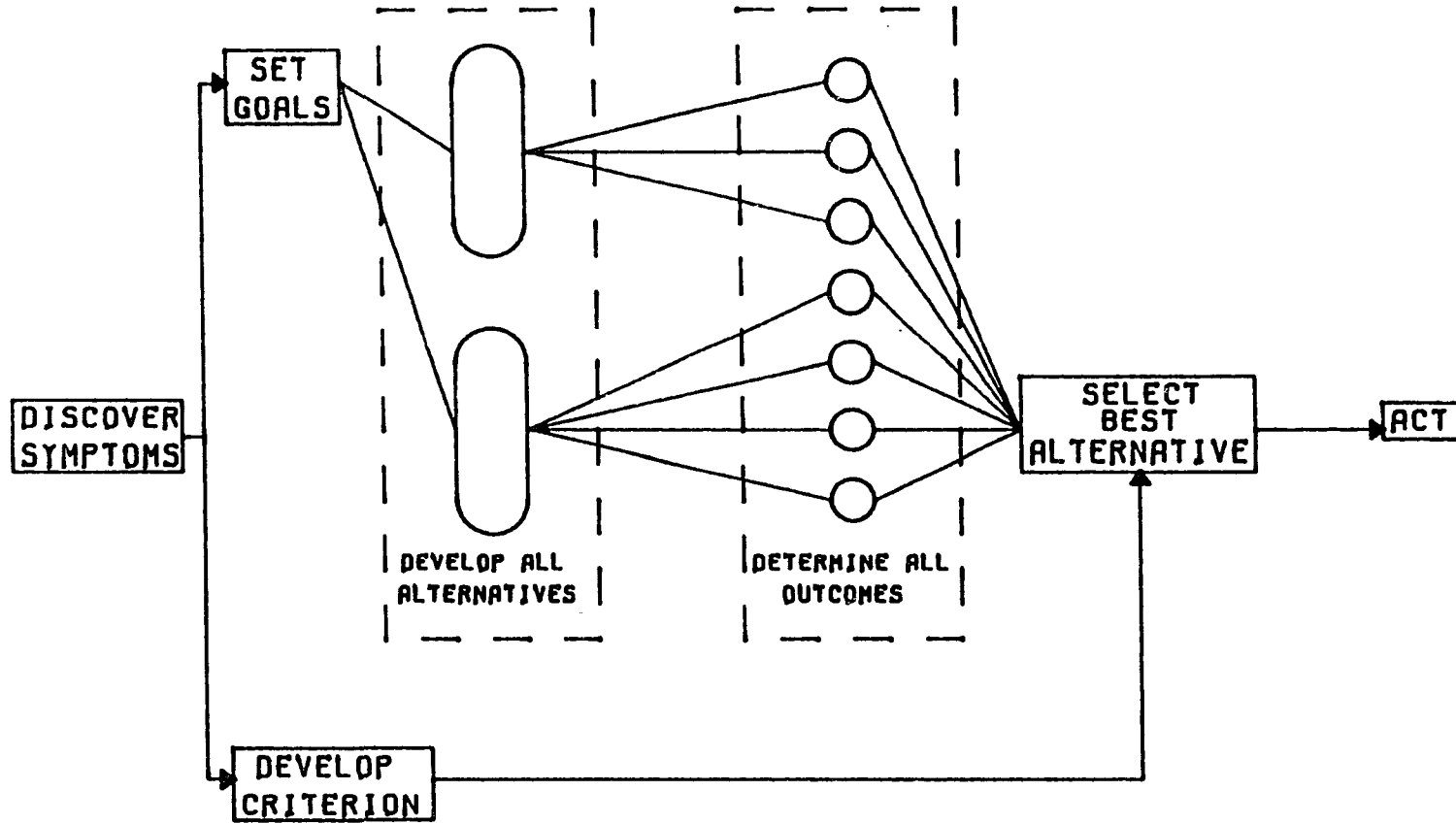


Fig. 9. The Ecological Model (Behling and Schriesheim, 1976).

Second, the use of utility functions to compare alternatives is inherently subjective because the decision maker must relate his/her values to a particular course of action. While this subjectivity is an important element in the decision-making process, a more quantitative technique must be developed which explicitly includes the subjective aspects of the decision making process, and rigorously applied to improve the probability of selecting the most appropriate alternative.

Third, according to Newman et al. (1972), the decision maker can rarely follow the phases of the decision-making process in the order detailed in Figure 9. The decision-making process is usually not as nicely organized as the model would indicate. Because of the discovery of new information, or redirection from within the organization, the decision maker may be forced to return to previously accomplished steps to incorporate the new information. While this iterative process may be implicitly implied by, or understood from, the model, what is needed is an explicit capability for iteration throughout the model in which the decision maker is allowed to return to a previously accomplished activity to reevaluate and reaccomplish appropriate steps from that point forward when new information is obtained. The inclusion of this explicit capability for iteration allows for a more controlled decision making environment and more effective use of available resources.

Further, it is not possible for the decision maker to know if all alternatives and outcomes have been considered. Some rational approach must be developed to consider an adequate number of alternatives and outcomes to insure the best of those potential solutions that have been identified is found, while keeping the decision-making process within appropriate resource limits.

Optimizing Decision Model

A second type of Logical Flow decision-making model is the Generalized Open-Loop, Single Stage, Optimizing Decision Model presented by Easton (1973). This optimizing strategy uses a normative model which sets standards the decision maker strives to attain. Figure 10 illustrates this model.

This decision model expands the Econological Model by including assignment of Weights to the Objectives and selection of a Choice Rule for identifying the best alternative. The term, Objectives, refers to prescriptive conditions which are adopted by the decision-maker to identify the desired results of the decision-making activity. To implement the Choice Rule the decision-maker develops an analytical means of combining the weighted scores to allow a meaningful comparison of each alternative. The optimizing model provides the capability for evaluating tradeoffs between alternatives by ordering and retesting alternatives, and the weighting of each objective. As a result, this approach applied to the same problem, will likely identify a better solution than the Econological Model.

Several weaknesses still exist in this model. The model does not explicitly support iteration. Second, while this model identifies the existence of situations which can have more than one decision-making criterion, it does little to help the decision-maker evaluate alternatives using multiple attribute decision criteria and, in fact, requires an evaluation of alternatives based on a single, unspecified future states of nature (Easton, 1973). Third, as in the Econological Model, the Optimizing Model is too abstract and as such has omitted important aspects of the real world decision-making process.

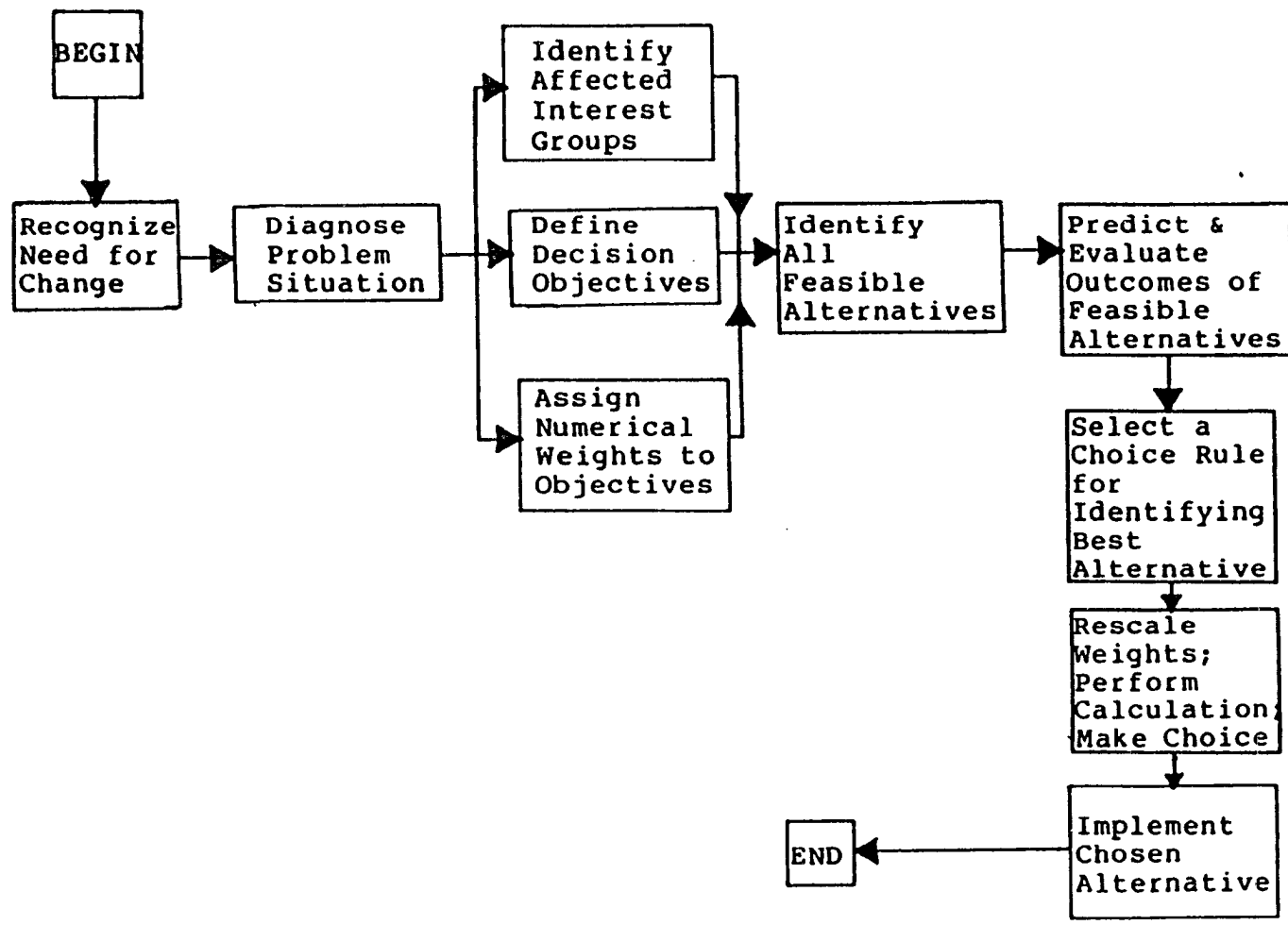


Fig. 10. Generalized, Open-Loop, Optimizing Model (Easton, 1973).

Bounded Rationality Model

A third type of Logical Flow decision model is the Bounded Rationality or "Administrative Man" Model (Behling and Schriesheim, 1976) in which decision makers seek a solution to a problem by considering far less information than was considered in the two previous models. The Bounded Rationality Model describes decision-making in terms of a sequential consideration of alternatives, uses heuristics for alternative development, and applies satisficing as opposed to optimizing in the selection of the alternative to be implemented (Behling and Schriesheim, 1976; Janis and Mann, 1977). Figure 11 illustrates this model.

The activities of the Bounded Rationality Model include:

- 1) Define the Problem. This element is common to all models. The decision maker must first identify the problem.
- 2) Establish a Level of Aspiration. This level of desired success is set, based on the decision maker's previous experiences in similar situations.
- 3) Employ Heuristics. These rules of thumb are applied to identify an alternative which is thought to meet the established aspiration level. The notion of iteration is first seen at this point in the model. If no feasible alternative is identified, the decision maker reestablishes (lowers) the level of aspiration and repeats the heuristic evaluation.
- 4) Appraise Alternative. When a feasible alternative has been identified, it is rigorously evaluated to determine if, in fact, it can meet the established level of aspiration. If not, the decision maker returns to the previous step to find a new feasible alternative.

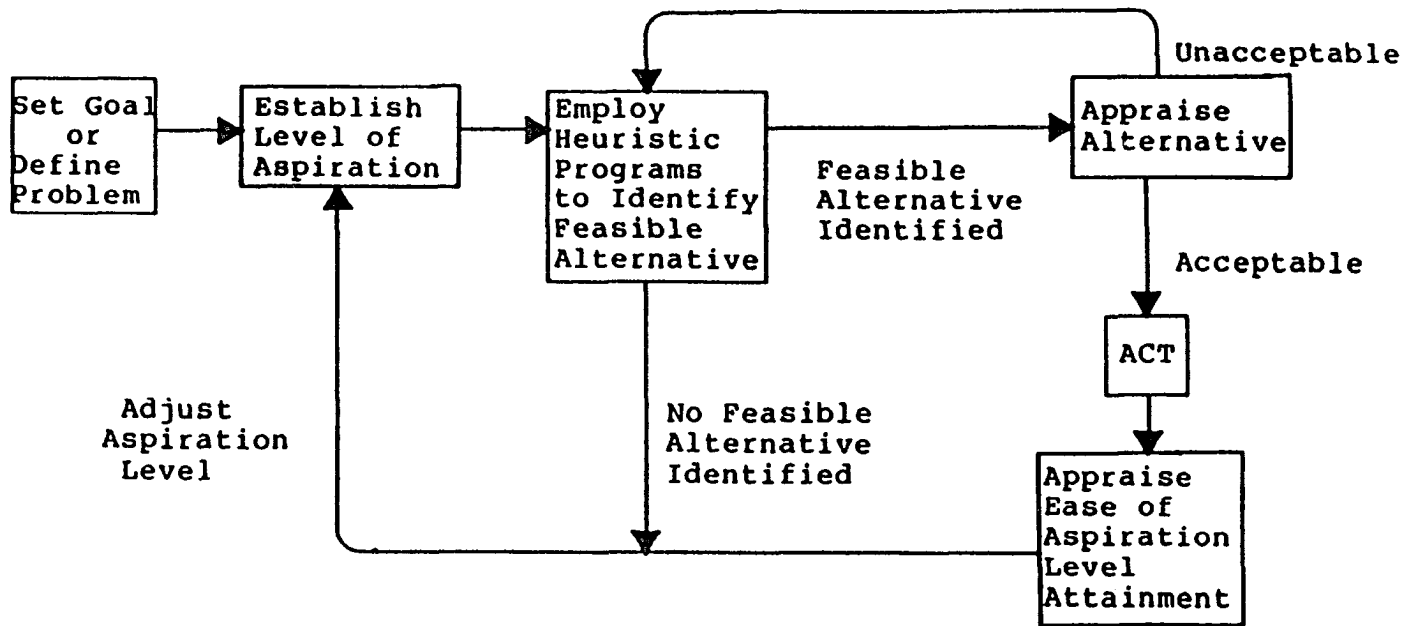


Fig. 11. Bounded Rationality Model (Behling and Schriesheim, 1976).

- 5) Act. Once an acceptable alternative is found, it is enacted.
- 6) Appraise Ease of Attainment. A final appraisal is made after the selected alternative is enacted to determine how easily the aspiration level was met. This information is stored for future use, should a similar situation be encountered.

While this model shows improvement over the previous models through the limited inclusion of iteration, it has a number of serious weaknesses. Cybert and March (1963) describe three characteristics of the feasible alternative search employed in the Bounded Rationality Model which are not entirely desirable. First, the decision maker is only motivated in response to a current problem. Second, the search activity is minimal in that it begins with obvious solutions and progresses only if these fail the alternative appraisal. Third, the process is biased by the decision maker's set of experiences. Additionally, the completeness and correctness of the established level of aspiration are limited by the decision maker's training, prejudices, customs and attitudes (Davis, 1982). This could seriously impact the model's usefulness.

In the previous models, the decision maker attempts to identify the optimal alternative, while in the Bounded Rationality Model, the decision maker seeks only to find a satisficing solution. March and Simon (1958) distinguish between the two activities as follows:

An alternative is optimal if: (1) there exists a set of criteria that permits all alternatives to be compared, and (2) the alternative in question is preferred, by these criteria, to all other alternatives. An alternative is satisfactory if: (1) there exists a set of criteria that describes minimally satisfactory alternatives, and (2) the alternative in question meets or exceeds all these criteria. . . . Finding that optimal alternative is a radically different problem from finding a satisfactory alternative. . . . To optimize requires processes several orders of magnitude more complex than those required to satisfice (p 140-141).

As pointed out by Bross (1953), one big advantage of a model is that it creates a frame of reference for considering a problem, even if the model does not lead directly to a solution. The results of the model may suggest inadequacies which can then be addressed and redefined in an effort to improve the model and the process it represents.

The models described above employ the four activities of a logical-flow decision-making model with varying degrees of success, and create abstractions of the real world in diverse ways. These models are neither all bad nor all good, but they are too abstract and thus lose the necessary detail needed by the decision maker to successfully relate the model to the real world. Additionally, they do not explicitly provide the iteration that the decision maker requires to effectively include additional information in the decision-making process as it is obtained. These models restrict the alternative evaluation to a single attribute criterion, provide no detail on how to evaluate multiple attribute criterion situations, and provide little of the necessary detail to insure an objective evaluation of how well the selected alternative will satisfy the stated problem. According to Easton (1973), finding good alternatives is a key to successful decision making, because the quality of the ultimate decision can be no better than the best alternative allows.

As Zeleny (1976) states, "The real question concerns the process by which the decision maker structures the problem, creates and evaluates the alternatives, identifies relevant criteria, and adjusts their priorities and processes information (p. 153)." The design-planning methodology described next provides the "process" Zeleny describes, and reduces the weaknesses in the logical flow models described above.

Design-Planning Methodology

To compensate for the fact that many decision-making models portray an incomplete picture of the real world activities facing the decision maker, a model is needed that has sufficient detail to grasp the scope and nature of the activities required to implement a problem solution, but yet is not so detailed as to become cumbersome to implement. The design-planning methodology that is described next is such a model. It provides the iteration capabilities needed to incorporate additional information, and it is capable of evaluating multiple decision criteria simultaneously.

The sequentially structured decision-making process presented by Ostrofsky (1977), if properly applied, will allow the decision maker to efficiently use the resources that are available. This structured decision making process is an extension of Asimow's (1962) work which delineates the decision structure used by a designer.

Figure 12 illustrates the major phases in the life of any activity. The Production-Consumption Phase describes the operational life of the activities resulting from the decision maker's actions. The true success, or value, of a decision is brought to light only after the Production-Consumption Phase has been entered.

It is in the Primary Design-Planning Phase, therefore, that the decision maker works to select a feasible solution to meet the needs of the user in the Production-Consumption Phase. The explicit inclusion of this relationship focuses the decision maker's attention on achieving a useful solution to an existing problem.

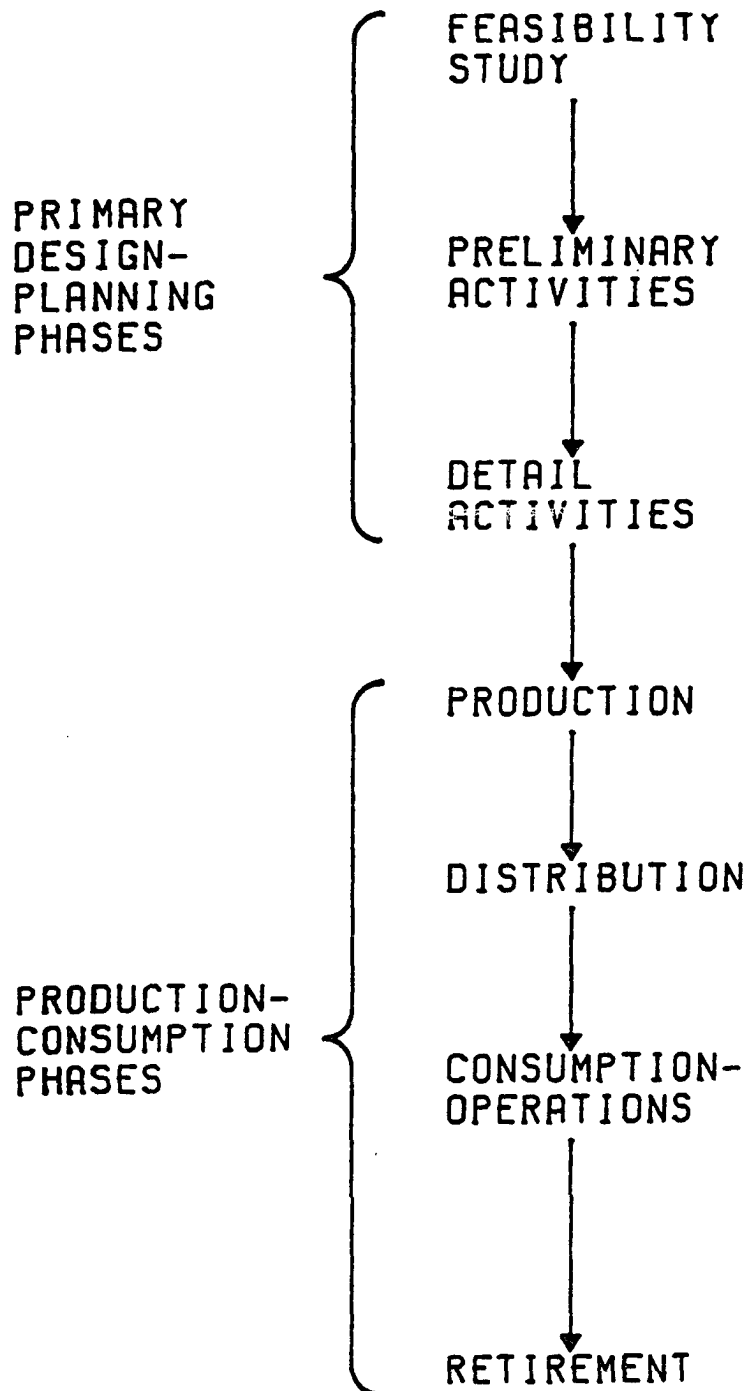


Fig. 12. Major phases in the life-cycle of a system (Ostrowsky, 1977).

The three major elements of Ostrofsky's Primary Design-Planning Phase include:

- 1) The Feasibility Study, which culminates in a set of useful solutions capable of meeting stated organizational need.
- 2) The Preliminary Activities, which identify the optimal, or "best", candidate system from the set of solutions generated in the Feasibility Study.
- 3) The Detail Activities, which involve planning for the activities required to insure that the selected optimal solution meets the needs of the Production-Consumption Phase.

Figure 13 illustrates a Logical Flow decision-making model of the specific activities which comprise the major elements of the Primary Design-Planning Phase.

Figure 13 is more detailed than the other models described previously. This additional detail provides the increased usefulness to the decision-maker. The principle of iteration is explicitly active throughout the model allowing the decision-maker to return to any previous step any time new information is obtained which warrants such action and then to reevaluate the subsequent decision steps incorporating the new information.

An additional capability which compliments the principle of iteration is what Asimow (1962) calls the Principle of Least Commitment. This principle suggests that in the phase-to-phase progression through the methodology, no irreversible decision should be made until it must be made, thereby permitting maximum flexibility of choice. Thus the decision maker can progress through the model keeping the maximum number of feasible alternatives available for consideration.

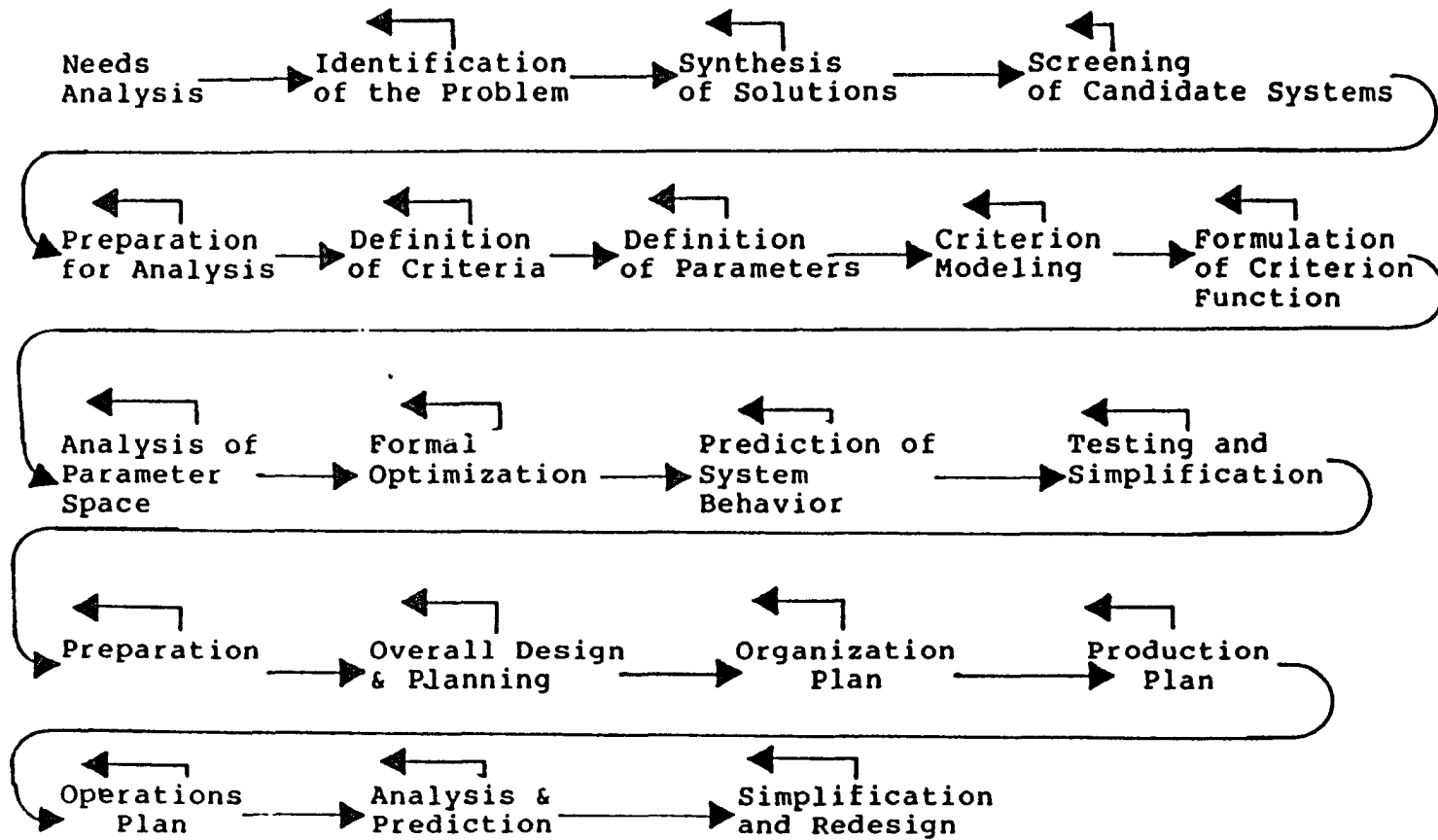


Fig. 13. Model of the Design-Planning Phase of the Design Methodology (Ostrosky, 1977).

The activities of the Feasibility Study include:

- 1) Needs Analysis. The decision maker examines the needs of the system to determine if further expenditure of resources is warranted in attempting to solve the problem.
- 2) Identification and Formulation of the Problem. This sets limits on the design requirements to help insure that the selected solution actually meets the established requirements. This is done through an evaluation of desired and undesired outputs, and environmental and intended inputs for each of the activities in the Production-Consumption Phase. The construction of a matrixed compilation of this evaluation creates additional insight into the problem and requires the decision maker to conduct all further activities within the scope of this evaluation.
- 3) Synthesis of Solutions. Activities that will adequately meet the established needs are combined. Each set of activities makes up one candidate system, or potential solution.
- 4) Screening of Candidate Systems. Only those candidates which are clearly unsatisfactory for technical or financial reasons are eliminated at this time. Either the system cannot be built with current technology, or there are insufficient funds available to continue (Ostrosky, 1977; 1978).

It is important to remember that the purpose of the Feasibility Study is to develop a "set" of feasible solutions. This set can contain no feasible solutions (the null set) and therefore the decision-making process would either end at this point or would iteratively return to develop new needs.

As a result of the Feasibility Study, the decision maker has developed a set of useful solutions which will meet the stated needs. Next, the Preliminary Design phase evaluates each useful solution, or candidate system, to find the one with the optimal performance. Preliminary Design activities include:

- 1) **Preparation for Analysis.** This step is included at the beginning of the Preliminary Activities to allow the decision maker to reexamine the steps completed in the Feasibility Study, evaluate new information that may have become available, and take the appropriate action to incorporate the new information before proceeding. This step is especially important if a considerable period of time has elapsed since completing the Feasibility Study.
- 2) **Definition of Criteria.** The means of evaluating each candidate system are established. It is important to note that if the decision maker omits a criterion at this point, it will not be included when the optimal candidate system is selected. However, through iteration, if the decision maker detects an omission, he/she can return to this step and add new criteria and reaccomplish the subsequent activities.
- 3) **Definition of Parameters.** Parameters are the elements of each design criterion that can be directly measured and are used to explicitly define the criterion during optimization.
- 4) **Criterion Modeling.** The relationships of each criterion with respect to its elements and the values of its relative importance are combined into quantitative functions.

- 5) **Formulation of the Criterion Function.** All criteria and their relative weights are brought together into one analytical function so that a single merit value can be assigned to each candidate system. By computing a performance indicator which is a fraction of the allowable values of a criterion, a unit value can be achieved that is consistent for all criteria and hence allows inclusion in the criterion function. This criterion function then yields a single value for each candidate system.
- 6) **Analysis of the Parameter Space.** A detailed analysis is accomplished to insure that the candidate system with the best criterion function value is realizable, given existing technology. (e.g., Can a 200 MPH sports car really be made that will seat 8 people and get 200 MPG in town?)
- 7) **Formal Optimization.** This is a two step process which yields the "best" alternative from the candidates under consideration. Each candidate system is optimized to achieve the "best" combination of criterion values. Then each candidate system is compared with the others and the system with the "best" value is selected.
- 8) **Projection of System Behavior.** The selected system is compared with the needs of each step in the Production-Consumption Phase to insure compatibility and needs fulfillment.
- 9) **Testing and Simplification.** The chosen candidate system is validated with respect to the stated needs (Ostrowsky, 1977; 1978).

The final steps in the model comprise the Detail Activities and are intended to insure proper implementation of the chosen optimal candidate system (Ostrofsky, 1977).

These steps include:

- 1) **Preparation for Design.** The decision maker reviews all information and data used thus far in the decision-making process. Any improvements in the existing information or any improved knowledge of system operation can be implemented through iteration.
- 2) **Overall Design and Planning.** The decision maker communicates the final decision to those who will be implementing it.
- 3) **Organization, Production and Operations Plans.** The decision maker evaluates all aspects of organization activities to insure compatibility between the organization's capabilities and the selected decision.
- 4) **Analysis, Prediction, Simplification and Redesign.** The decision maker predicts how the selected course of action will actually perform in the Production-Consumption Phase and reviews his/her activities for future system improvements.

A major advantage of such a structured decision process is that the decision maker can logically record all decision-making activities throughout the life of the project. Then, if a selected outcome is found unacceptable for some reason, the decision maker can go back through his/her records and, knowing how the decision was made, make necessary changes. A potential disadvantage of this methodology is the ease with which the designer/analyst can return to earlier steps to reconsider new data. This is a disadvantage only to the point that the

iteration process inhibits decision-making and wastes resources by delaying decisions unnecessarily and slowing progress on the project.

The structured methodology presented by Ostrofsky separates objective and subjective inputs to the decision-making process. Both types are required during decision making, but each must be determined separately, and explicitly included in the decision-maker's evaluation of the alternatives.

Recent research by Folkson (1982) and Wu (1983) have identified key issues which impact the development of the design-planning process. This process is meant to be a framework for the design analysis which will lead to the selection of an optimal system design and also a management tool to help the designer insure that all relevant aspects of the development activity are addressed during the process.

Wu (1983) expanded the nature of the design-planning process and explicitly included the dimension of time across the design criteria as it is correlated to the organizational objectives and goals. He developed a strategic multicriterion decision method and a set of models which are an extension of the design-planning models developed by Ostrofsky (1983), and demonstrated their applicability as a solution for the strategic management of design change activities associated with the National Aeronautics and Space Administration's (NASA) Space Transportation System (the Space Shuttle) program.

Folkson (1982) addressed the issue of Multiple Criteria Decision Making (MCDM) and its relationship to the system design-planning activities. His work expanded an existing design methodology to include the explicit analysis of interactions among criteria. Much of the existing

literature concerning MCDM (Fishburn, 1970; Keeney, 1973; MacCrimmon, 1973; Keeney and Raiffa, 1976; Starr and Zeleny, 1977; and Zeleny, 1982) has gone to considerable lengths to test for and require independence among and within criteria. Folkeson's work demonstrated an approach that models the interaction of criteria in the design process used to develop aircraft support equipment. This multiple criteria approach will be applied to the IRM structured optimization procedures developed in Chapters Four and Five of this research.

Conclusion

Greenwood (1969) states that a decision model is incomplete unless it is able to prescribe behavior in the most complex as well as the most simple cases. The Design-Planning Methodology developed by Ostrofsky, in contrast with the other models, provides the completeness the decision-maker needs to approach any problem, confident that conscientious application of the methodology will provide the means to control information overload and logically arrive at a solution which efficiently uses available resources.

As a result of the literature review to this point, information can be classified as an organizational resource which is vital to the successful operation of the organization. However, the literature is void of any substantive discussion of a structured decision-planning methodology that is directly applicable to the total design of an IRM System.

Chapter Two reviewed the information requirements determination literature. A summary of the methods reviewed is contained in Table 1 and suggests these methods do not provide the specific guidance needed to plan and implement a successful IRM system within an organization.

Chapter Three reviewed four approaches to modeling the decision-making process. Table 2 summarizes and compares these methods. The design-planning methodology developed by Ostrofsky will be applied to the Information Resource Management system design problem. This method is used because it provides the structure that is required to sequence, in an orderly fashion, those decisions which must be adequately resolved in order to develop an effective set of plans for an information resource management system to satisfy the established organizational needs. The design-planning methodology will be tailored to meet the specific needs of IRM design. The end result of this research is the development of a standard planning structure which will enable the Information Resource Management system designer within the organization to effectively manage information as a major organizational resource.

Naisbitt (1982) suggests that the time orientation in the information society is toward the future and that because change is occurring so rapidly, we must anticipate the future rather than react to today. A clear working definition of IRM and a structured design methodology such as the one proposed in this research will provide the "future orientation" required to insure that information systems will effectively manage the vital information resources and support the objectives of the organization.

The tenet of this research is that information is indeed an organizational resource that must be managed in much the same manner as the 4Ms discussed previously. On this basis, Chapter Four uses the Multiple Criteria Decision Making framework to begin the development of a Structured Optimization Procedure for Information Resource Management. Criteria development and parameter definition are accomplished using

TABLE 2
SUMMARY OF DECISION-MAKING MODELS

	LOGICAL, STEP-BY-STEP PROCEDURE	ECONOMICALLY RATIONAL DECISION-MAKER	IDENTIFIES A LOGICAL SET OF FEASIBLE ALTERNATIVES	OBJECTIVELY COMPARES ALTERNATIVES	SUPPORTS ITERATION IN THE DECISION-MAKING PROCESS	LOGICALLY BOUNDS ALTERNATIVES	OBJECTIVELY BOUNDS THE DECISION PROCESS	EVALUATES TRADEOFFS BETWEEN ALTERNATIVES	SELECTS THE "BEST" ALTERNATIVE	MULTIATTRIBUTE APPROACH
THE ECONOLOGICAL DECISION-MAKING MODEL (Behling and Schriesheim, 1976)	Y	Y	N	N	N	N	N	N	N	N
THE BOUNDED RATIONALITY DECISION-MAKING MODEL (Behling and Schriesheim, 1976)	N	N	N	N	Y	N	N	N	N	N
THE OPTIMIZING DECISION-MAKING MODEL (Easton, 1973)	Y	Y	Y	N	N	Y	Y	Y	N	N
THE DESIGN-PLANNING METHODOLOGY (Ostrowsky, 1977)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Y = YES N = NO										

illustrative data from the USAF Ballistic Missile Office. In Chapter Five, the development of the criterion modeling procedure is continued with completion of the model synthesis activities, and a demonstration of the selection of the optimal candidate system using the Criterion Function Model developed from the illustrative data.

CHAPTER FOUR

STRUCTURED OPTIMIZATION METHOD DEVELOPMENT

One of the major challenges for designers of information systems today is to devise ways to provide systems which are truly responsive to real world changes.

- Grace M. Booth

Introduction

Information requirements determination is a necessary and important aspect of Information Resource Management system design. The literature reviewed in Chapter Two identifies several methodologies that are available to the designer-planner to accomplish the initial activities associated with describing the information need and justifying the effort required to design and, more importantly, implement an IRM system that supports the goals and objectives of the organization.

Chapter Three reviewed several generalized decision making methodologies that are available to the designer to complete the design and implementation of an IRM system. The chapter's conclusion recommended the extension and use of the design-planning methodology developed by Ostrofsky (1977) to implement IRM system design activities. This methodology has the structure needed to guide the designer-planner through the IRM design process, and to handle adequately, the multiple criteria decision making environment that exists in design analysis activities.

As stated previously, the purposes of this research are to develop a structured optimization procedure that can be used by the designer-planner to evaluate Information Resource Management needs within an

organization, and further, to extend existing formal criterion function modeling procedures to IRM system design by demonstrating the following activities:

- 1) Development of Criteria and their relative importance.
- 2) Definition of parameters and estimation of parameter values.
- 3) Synthesis of a Criterion Model.
- 4) Demonstration of a method to identify an optimal alternative candidate system.

Figure 14 contains a flow diagram of the activities and decision steps which make up the structured optimization method proposed in this research. The initial steps of the optimization procedure, consisting of criteria definition, criterion element definition, identification of criteria interactions and the assignment of criterion relative importance are presented and illustrated in this chapter using sample data from an information system organization in the USAF's Ballistic Missile Office. Chapter Five continues the optimization procedure by demonstrating the method required to identify the appropriate range of values for each identified parameter, develop submodel relationships, develop criterion relationships, and complete criterion function modeling and identify the optimal IRM candidate system. The illustrative data in this research effort is being used to demonstrate the application of the steps in the optimization method.

In developing any design tool, such as the structured optimization method for IRM system design, emphasis should be placed on the tool's generality and flexibility to insure the tool will be:

- 1) Usable at various levels of detail and at various stages of the development process within the organization.

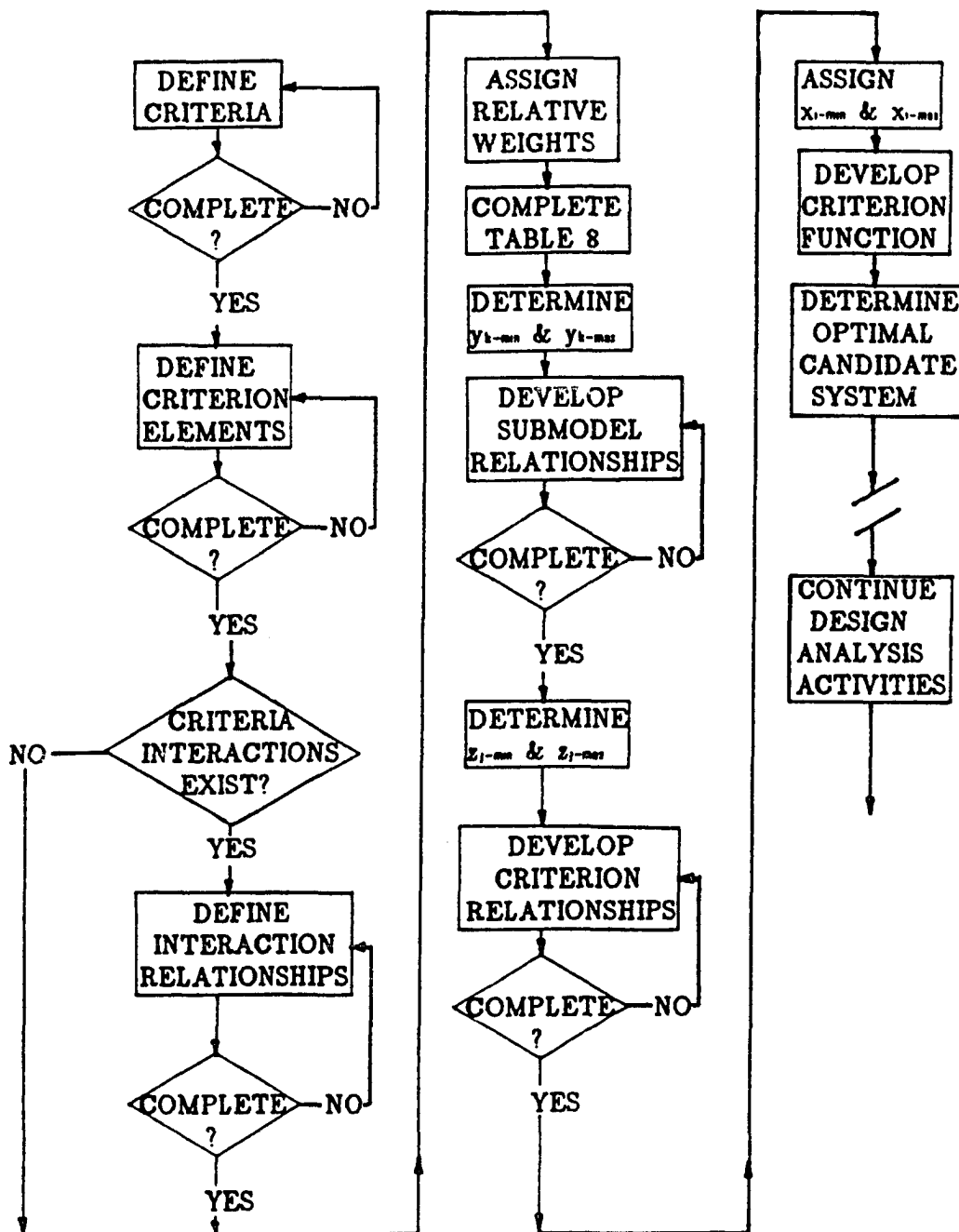


Fig. 14. Structured Optimization Method Flow Diagram

- 2) Capable of incorporating new theoretical, as well as practical concepts, and new methods of analysis in the future.
- 3) Applicable to, and easily fit into the organization's methods of operation.
- 4) Amenable to both quantitative and qualitative analysis (Bubenko and Kallhammar, 1971).

Ballistic Missile Office

The principal emphasis of this research is the development of a structured **method** which is applicable to the optimization of an IRM system design problem. The sample data which is used to support the development of this method comes, in part, from a study involving the USAF Ballistic Missile Office. The mission of the Ballistic Missile Office (BMO) is to plan for, implement, and manage the programs to acquire and modify ballistic missile systems for the United States Government. To manage such large programs, BMO is divided into discrete functional activities called Project Element Offices (PEOs) which manage systems, subsystems and individual components for a particular program. Numerous additional organizations have been established within BMO to provide required administrative and staff support for these PEOs. The support organization referenced in this research is the Management Information Systems Division (BMO/ACD).

BMO/ACD has been tasked with identifying, developing, implementing and managing an Information Resource Management system that will promote increased productivity, efficiency and effectiveness among the integrated organizational elements of the Ballistic Missile Office. The first step of this task was conducted by Science Applications, Inc.

(SAI) (1981) when they evaluated the existing office environment and activities, defined functional requirements for an IRM system within BMO and presented three design concepts to satisfy the defined needs of the organization. The data collected by SAI are specific to the USAF Ballistic Missile Office and are used for the purpose of illustrating the structured optimization method and criterion function modeling procedure developed in this research project.

Criterion Function Conditions

The Criterion Function provides the quantitative formulation of the specified design objectives. The remaining material in this research is directed toward the development of a Criterion Function Modeling procedure, applicable to IRM systems, that will allow the designer-planner to evaluate alternative candidate systems on a cardinal scale and ultimately identify, for implementation, the "best" of the evaluated candidate systems. The conditions that must be satisfied prior to beginning the optimization procedures displayed in Figure 14 are listed below and result from the series of events that must occur in the complete implementation of the design-planning methodology (Figure 2, Chapter One). The limited scope of this research does not include the actual completion of these activities. Rather, they are identified to indicate the necessity for their completion in the life cycle of design activities.

Condition Number 1

A Feasibility Study has been completed according to the steps described in Chapter Three of this research. Specifically:

- 1) The needs analysis has been accomplished.
- 2) The requirements have been stated, and an Input-Output

matrix, which bounds the problem, has been completed.

- 3) The Concepts, or basic approaches, for the solution of the problem have been defined.
- 4) Candidate systems have been identified and screened to insure the existence of a set of useful solutions to the problem.

Condition Number 2

The Preliminary Design Activities (Chapter Three) have been accomplished to the point where criteria can be meaningfully identified and analytical model development can commence. The degree of completeness to which the criteria are modeled from the design parameters is assumed adequate for the ensuing computational activities.

Assumptions

The following assumptions are implicit to the criterion function modeling activities when conditions 1 and 2 apply:

- 1) Knowledge of the candidate systems is adequate and will result in meaningful criterion measures in terms of the design parameters.
- 2) The persons evaluating the criteria and their relative importance are rational, and have an appropriate level of understanding commensurate with the stage of system development.
- 3) The decisions formulated from the criterion function consider only the criteria identified for the design of the system under consideration.
- 4) One candidate system does not dominate all others for the identified criteria so that further analysis is required to select the optimal candidate system.

- 5) The value of the optimal system merits the expenditure of resources involved in its selection.

Completion of the design-planning methodology requires the optimal candidate system that is identified from the proposed optimization method and criterion function modeling procedure be further evaluated in the Detail Activities phase of the complete design planning methodology (see Chapter Three) in final preparation for the activities associated with the Production/Consumption Phase of the system life cycle.

Definition of Criteria

The first step of the Structured Optimization Method which leads to the development of a Criterion Function Model is the definition of criteria, which are the basic characteristics against which the performance of a candidate system can be evaluated. The choice of criteria for the evaluation results directly from the Input-Output Matrix which was completed during the Feasibility Study. Because each criterion is a measure or standard by which performance of a system is evaluated, it is different from the stated goals and objectives of the system. In a sense each criterion acts as a measure of a stated goal or objective, and therefore can be used to evaluate the performance of the system. The notation for criteria used throughout this research will be " x_i ", where $i = 1, \dots, n$, with n being the number of identified criteria included in the criterion function model.

Using information from the case study organization and existing literature (e.g., Ein-Dor and Segev, 1981; Davis and Olson, 1985), four criteria have been identified as appropriate measures to demonstrate the method for evaluating the performance of the identified IRM candidate

systems. A series of individual interviews was conducted with persons knowledgeable in the area of IRM system planning and responsible for implementation within BMO to confirm the definitions and appropriateness of the criteria. The resulting criteria and definitions are:

- x_1) Comparative Cost - The cost of a given candidate system relative to a standard cost.
- x_2) Control - The activity which measures deviations from planned performance and initiates appropriate corrective actions.
- x_3) User Satisfaction - The measure of the alternative candidate system's implementation success.
- x_4) Usefulness - The measure of the perceived ability of an alternative candidate system to support organizational goals and objectives.

Table 3 summarizes the identification of criteria to this point in the optimization procedure. Additional information will be added to this table in subsequent steps.

TABLE 3

CASE STUDY CRITERIA

Criterion, x_i
x_1 = Comparative Cost
x_2 = Control
x_3 = User Satisfaction
x_4 = Usefulness

Definition of Criterion Elements

The criteria developed in the previous step are essential for the evaluation of the performance of each identified candidate system. Usually, definition of these criteria is such that direct measurement of their characteristics is usually impossible. For example, criterion x_4 , Usefulness, does not lend itself to direct measurement. What is needed, then, is a set of elements that identify characteristics of the criteria which allow the designer-planner to measure the performance of each candidate system.

The identification and description of the design elements emerges from a detailed understanding of the characteristics of the candidate systems, the criteria used to measure the candidate system's performance, and the purpose for which the design effort has been undertaken. The designer-planner can effectively define an exhaustive set of elements that constitute each criterion using knowledge of the technology available to support the design activity, supplemented by such other techniques as "Brainstorming" and "Delphi" methods. Previous work done by Lucas (1978a, 1978b); Ein-Dor and Segev (1981); Ginzberg (1981a; 1981b); Ostrofsky et al. (1981); Science Applications, Inc. (1981); and Davis and Olson (1985); as well as others, was used to develop set of criterion elements for this case study. Table 4 is the summary table of the constituent elements which have been identified for each criterion in the case study.

The "elements" column in Table 4, for each criterion, should be completed before completing the "codes" column. The assigned codes relate to the nature of the characteristics of each element according to the following definitions:

TABLE 4
SUMMARY OF CRITERIA AND CRITERION ELEMENTS

Criterion	Elements	Code
X(1) COMPARATIVE COSTS	New Equipment & Software Costs	a
	Installation Costs	a
	Recurring Maintenance Costs	a
	Baseline Cost with IRM	a
	Baseline Cost without IRM	a
	Recurring Supply Costs	a
	Productivity Gain Estimate	a
X(2) CONTROL	Reliability of Data	b
	Source of Data	a
	Intended Accuracy	a
	Interval Between Reports	a
	Support for Standards	b
	Output Quality Rating	a
	# of Applications with Common Data	a
	# of Functions Served by the Application	a
	Proportion of Data in Shared Files	a
	Integrity	b
	Error Checking	a
	Influence of Information on Organization	a
	Security	a
System Backup	a	
X(3) USER SATISFACTION	[Q] Quality of the System	b
	Input Quality Rating	a
	Output Quality Rating	a
	Online Performance Rating	a
	Capacity	a
	Response Time	a
	[A] Attitudes & Perceptions	b
	Output Quality Rating	a
	Online Performance Rating	a
	Management Support	a
	Model Simplicity	a
	Quality of the System	c
	[D] Decision Style of the User	b
	Number of Inquiries	a
	User's Technical Orientation	a
	Attitudes & Perceptions	c
	[S] Situational Factors	b
User's Time in Job	a	
User's Education Level	a	
User's Age	a	
# of Functions Served by Application	a	

TABLE 4--Continued

Criterion	Elements	Code
X(4) USEFULNESS	Reliability of Data	b
	Source of Data	a
	Intended Accuracy	a
	Interval Between Reports	a
	Flexibility	b
	Activity Time Allocations	a
	# of Functions Served by the Application	a
	Online Performance Rating	a
	Availability	b
	Total Time	a
	Down Time	a
	Output Quality Rating	a
	Age of Information	b
	Type of Data	a
	Interval Between Reports	a
Processing Delay	a	

"a" describes a directly measurable element (e.g., weight, cost or information processing time). These directly measurable characteristics are defined to be "PARAMETERS" and are essential to the modeling activity developed in Chapter Five.

"b" describes an element that is measured from a model that includes some of the "a" elements. These elements become "SUBMODELS" and constitute the bridge between the parameters and the criteria.

"c" describes those elements that are included in other elements, but are listed separately due to their importance in the overall understanding of the criterion, or as a result of the heuristic process used to identify the element. For example, the submodel "Attitudes and Perceptions" is defined as a submodel of the Criterion "User Satisfaction" and is also used to define the submodel "Decision Style of the User."

"d" describes an element that is not measurable within existing resources, but, again, is included to insure a complete description of the criterion. The designer-planner must insure that this element is not critical to the model prior to its exclusion (Ostrofsky, 1977).

The submodel is that attribute of a criterion that links the parameters, y_k , to the criterion, x_i . Submodels are important elements of the criterion function modeling process because they provide a means of defining important, complex, relationships that cannot be directly measured by a single parameter. Submodels, made up of parameters and, if necessary, constants, once formulated, relate to the criterion just as the parameters described previously.

A probability value is a good example of a submodel in that a probability cannot be directly measured, but can be calculated from established relationships of a number of directly measurable elements (parameters). An example of a probability value used as a submodel is a meteorologist's prediction of rain. The meteorologist does not have an instrument which directly measures the probability of rain, but rather uses the relationships of directly measurable elements such as temperature, wind direction and speed, humidity, etc. to formulate a relationship which is a statement of the probability of rain for a forecast period. Figure 15 depicts the relationships between each of the four types of criterion elements that constitute a criterion.

The analytical relationship that exists between the Criteria, x_i , Parameters, y_k , and Submodels, z_j can be stated as follows:

$$x_i = f_i\{z_j\} \quad (4-1)$$

$$z_j = g_j\{y_k\} \quad (4-2)$$

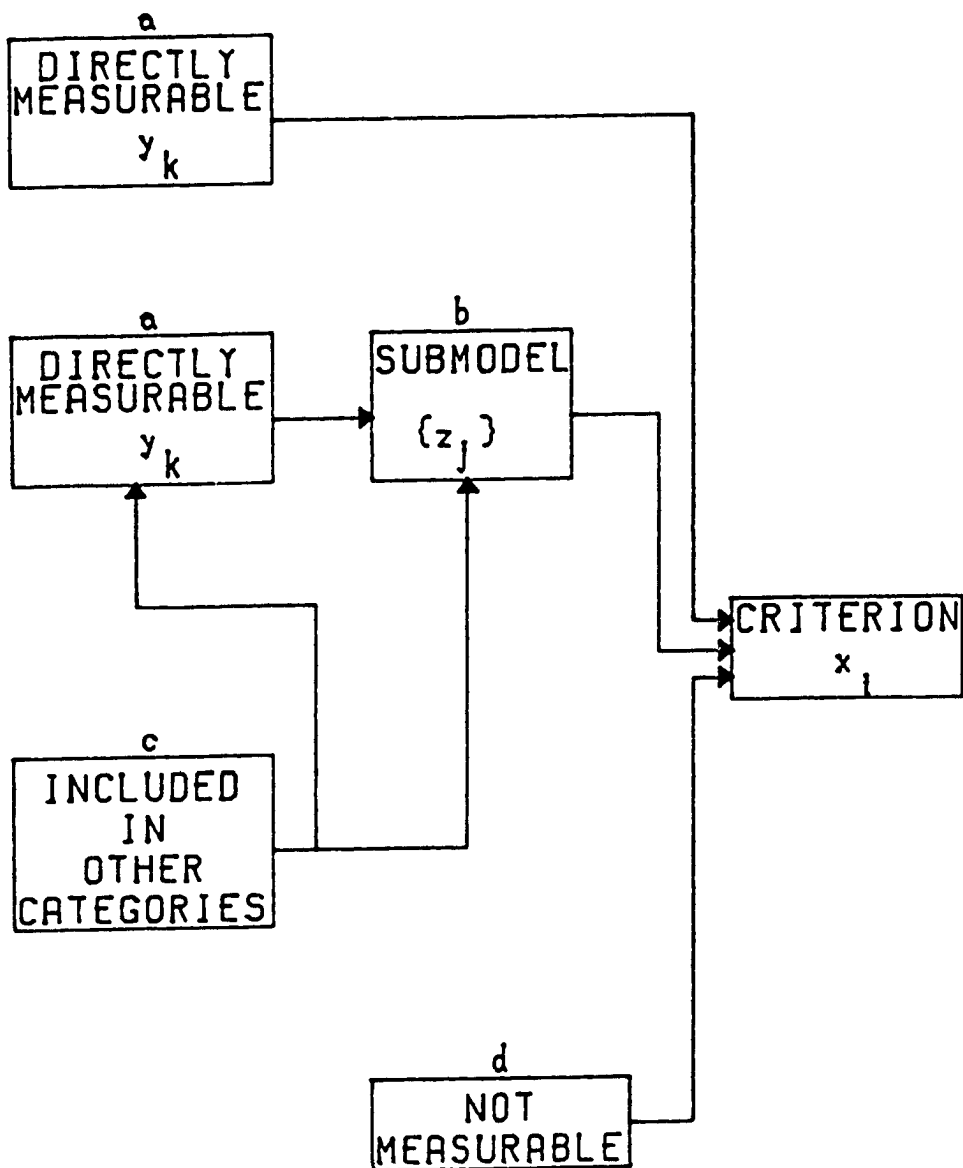


Fig. 15. Constituents of a criterion for a set of candidate systems (Ostrosky, 1977, p 88).

therefore;

$$x_i = f_i \{g_j \{y_k\}\} \quad (4-3)$$

Equation (4-1) states that the i th criterion is a function of the set of submodels, z_j , and Equation (4-2) further defines the submodel z_j as another function of the set of parameters, y_k . Combining Equations (4-1) and (4-2) produces Equation (4-3) which defines each criterion, x_i , in terms of the defined parameters identified in Table 4. This relationship of parameters to criteria is used in Chapter Five to model the criteria in one analytical function and arrive at an evaluation of the performance of each of the identified candidate systems.

After completing Table 4, a series of evaluations are conducted to insure the "CONSISTENCY," "COMPLETENESS," and "COMPACTNESS" of each element identified for each criterion (Ostrowsky, 1977). The designer-planner, using the system design information that has previously been gathered, conducts this series of evaluations to insure that:

- 1) Each element is defined the same way each time it is used (Consistency).
- 2) The list of elements is exhaustively complete, based on the knowledge of the designer-planner, to insure that all the relationships necessary for the complete definition of each criterion are included in the evaluation (Completeness).
- 3) The list of elements contains the smallest number of parameters ("a" elements) necessary to define the performance of each submodel and criterion as each parameter identified must be modeled in the criterion function (Compactness).

Table 5 compiles and organizes the relationships between the Criteria, x_i ; Parameters, y_k ; and Submodels, z_j identified in Table 4.

TABLE 5
RELATING PARAMETERS TO CRITERIA THROUGH SUBMODELS

	x(1) COMPARATIVE COSTS				x(2) CONTROL				x(3) USER SATISFACTION				x(4) USEFULNESS			
	z ₂₁	z ₂₂	z ₂₃	z ₂₄	z ₃₁	z ₃₂	z ₃₃	z ₃₄	z ₄₁	z ₄₂	z ₄₃	z ₄₄	z ₄₅	z ₄₆	z ₄₇	z ₄₈
Parameters, y(k)																
1. New Equipment and Software Costs	x															
2. Installation Costs	x															
3. Recurring Maintenance Costs	x															
4. Baseline Cost with IRM	x															
5. Baseline Cost without IRM	x															
6. Recurring Supply Costs	x															
7. Productivity Gain Estimate	x															
8. Output Quality Rating		x			x	x				x						
9. Activity Time Allocations													x			
10. Error Checking			x													
11. Security			x													
12. System Backup			x													

TABLE 5--Continued

	x(1) COMPARATIVE COSTS			x(2) CONTROL			x(3) USER SATISFACTION			x(4) USEFULNESS			
	z ₂₁	z ₂₂	z ₂₃	z ₃₁	z ₃₂	z ₃₃	z ₃₄	z ₄₁	z ₄₂	z ₄₃	z ₄₄		
Parameters, y(k)													
13. # of Applications With Common Data		x											
14. # of Functions Served by Application		x					x		x				
15. Proportion of Data in Shared Files		x											
16. Input Quality Rating				x									
17. Online Performance Rating				x	x				x				
18. Capacity				x									
19. Response Time				x									
20. Management Support					x								
21. Model Simplicity					x								
22. Number of Inquiries							x						
23. User's Technical Orientation							x						

TABLE 5--Continued

	x(1) COMPARATIVE COSTS				x(2) CONTROL				x(3) USER SATISFACTION				x(4) USEFULNESS			
	221	222	223	224	231	232	233	234	241	242	243	244	245	246	247	248
Parameters, y(k)																
24. User's Time in Job								x								
25. User's Education Level								x								
26. User's Age								x								
27. Source of Data	x								x							
28. Influence of Information on the Organization			x													
29. Intended Accuracy	x								x							
30. Total Time													x			
31. Down Time													x			
32. Type of Data															x	
33. Interval Between Reports	x								x						x	
34. Processing Delay															x	

TABLE 5--Continued

	x(1) COMPARATIVE COSTS	x(2) CONTROL	x(3) USER SATISFACTION	x(4) USEFULNESS
	z ₂₁	z ₂₂ z ₂₃	z ₃₁ z ₃₂ z ₃₃ z ₃₄	z ₄₁ z ₄₂ z ₄₃ z ₄₄
	R	S	I D A D S	R F A A
	E	U N	U T E I	E L V G
	L	P T	A T C T	L E A E
	I	P E L	I I U	I X I
	A	O G	I T S A	A I L o
	B	R R	T U I T	B B A f
	I	T I Y	D O I	I I B
	L	T	E N O	L L I I
	I	f Y	o S N	I I L N
	T	o	f S A	T T I F
	Y	r	W T L	Y Y T O
			t Y	Y R
	o	S	h P L F	o M
	f	T	e E E A	f A
		A	R C	T
	D	N	S C T	D I
	A	D	Y E D	A D
	T	A	S P R	T N
	A	R	T T S	A
		D	E I	
		S	M O	
			N	
			S	
Submodels, z(ij)				
21. Reliability of Data	-			
22. Support for Standards		-		
23. Integrity			-	
31. Quality of the System				- x
32. Attitudes & Perceptions				
33. Decision Style				
34. Situational Factors				
41. Reliability of Data				
42. Flexibility				
43. Availability				
44. Age of Information				

This table helps to insure that each element conforms to the series of evaluations performed previously, and helps insure the existence of the most effective set of parameters for the criterion function modeling activity. When Table 5 is completed the designer-planner emerges with a set of data elements that defines the relationships of all the criterion elements required to identify the characteristics of the criteria and allow the evaluation of the performance of each candidate system.

Definition of Criteria Interactions

Having identified the criteria and the criterion elements for the case study IRM design example it is necessary to evaluate possible interactions or interdependences among the criteria. Interaction between criteria exists when a change in the value of one criterion affects the value of one or more of the remaining criteria. Folkesson (1982) has shown that the effect of criteria interactions can have a significant impact on the identification of the optimal candidate system. It is important to note that the interaction being considered at this point, is between criteria and does not address possible parameter interaction. Figure 16 demonstrates the use of a matrix framework for criteria interaction evaluation which identifies all potential criteria interactions when four marginal criteria have been identified. Figure 16a identifies potential First Order Interactions. The matrix indicates, with an "x", which combinations of potential criteria interactions must be evaluated by the designer planner. For example, this matrix indicates that the designer-planner must evaluate the possibility that a change in the value of criterion 3 may cause a change in the value of criterion 4. Figure 16b continues the evaluation by identi-

	1	2	3	4
1	-			
2	x	-		
3	x	x	-	
4	x	x	x	-

a. Potential First Order Criteria Interactions.

	12	13	14	23	24	34
12	-					
13	x	-				
14	x	x	-			
23				-		
24				x	-	
34	*					-

(* = Potential Third Order Interaction)

b. Potential Second Order Criteria Interactions.

	123	124	134	234
123	-			
124	x	-		
134			-	
234				

c. Potential Third Order Criteria Interactions.

(Note: Blank squares indicate duplicate relationships that need not be reevaluated.)

Fig. 16. Matrix Framework for Potential Criteria Interaction Evaluation when four Marginal Criteria Exist.

ifying potential Second Order Interactions and Figure 16c identifies potential Third Order Interactions. These matrices identify the potential criterion interactions that must be investigated. The designer-planner must know what the interaction relationship between the criteria is, if it exists, and must evaluate each potential interaction for appropriateness to the design problem. Equation (4-1) calculates the number of potential criteria interactions that must be evaluated for a given number of marginal criteria and interaction level.

$${}^nC_r \quad (4-1)$$

where;

n = the total number of marginal criteria being evaluated

r = [(Criteria Interaction Order) + 1]

and

$n \geq r$.

As criteria interactions are evaluated by the designer-planner and found to be nonexistent, higher order interactions containing the nonexistent interactions also become nonexistent. This condition is stated in the following theorem:

THEOREM 1. Any higher order criterion interaction containing nonexistent lower order interactions, or their respective marginal criteria, also do not exist.

PROOF.

Assume criteria $x_1, x_2, x_3,$ and x_4 have been identified.

Then potential criteria interactions are;

First order - $x_{12}, x_{13}, x_{14}, x_{23}, x_{24}, x_{34}$.

Second order - $x_{123}, x_{124}, x_{134}, x_{234}$.

Third order - x_{1234} .

If criterion x_2 does not exist, then criteria interactions x_{12} , x_{23} , x_{24} , x_{123} , x_{124} , x_{234} and x_{1234} also do not exist. Figure 17 depicts the criteria interactions which have been identified for the BMO/ACD IRM Case Study. The identified criteria interactions were determined based on individual interviews with personnel at BMO and designer-planner knowledge. The relationships depicted in Figure 17 indicate that first order interactions exist between Criteria x_1 and x_2 , Criteria x_2 and x_3 , Criteria x_2 and x_4 , Criteria x_3 and x_4 , and a second order interaction exists between Criteria x_2 , x_3 , and x_4 . Appendix A presents a detailed discussion of criteria interaction and how it is modeled and evaluated.

Table 6 continues the development of the criterion function model by summarizing and correlating the identification of criteria and criteria interactions.

Assignment of Relative Weights

When more than one criterion exists, there is always a relative importance that exists among them. If this relative importance is not stated explicitly, the implicit understanding is that each criterion is equally important, and therefore a relative importance exists for each criterion. Assigning relative weights to each criterion provides the needed discrimination among criteria to select the "best" performing candidate system from those being evaluated. The notation for relative weights used throughout this research will be " a_i ", where $i = 1, \dots, n$ with n being the number of identified criteria to be modeled.

Assigning values to the relative weights can be done in a number of ways. The reader is referred to Keeney and Raiffa (1976); Folkson

(1982); Zeleny (1982); and Wu (1983), for example, for details on these methods. The relative weights can also be assigned through the heuristic procedure of having the managers, or other knowledgeable individuals, rate the value of each criterion on a scale of 0 to 10, and then normalize each rating such that the resulting a_i values meet the following conditions:

$$\sum a_i = 1.0 \quad \text{where } 0 \leq a_i \leq 1.0 \text{ and } i = 1, \dots, n$$

	1	2	3	4	
1	-				1. = Comparative Cost
2	x	-			2. = Control
3	0	x	-		3. = User Satisfaction
4	0	x	x	-	4. = Usefulness

(x = Existence of Interaction. 0 = No Interaction.)

a. First Order Criteria Interactions.

	12	13	14	23	24	34
12	-					
13	0	-				
14	0	0	-			
23				-		
24				x	-	
34	0*					-

(0* = No Third Order Interaction)

b. Second Order Criteria Interactions.

Fig. 17. Criteria Interactions Between Case Study Criteria.

TABLE 6
CASE STUDY CRITERIA AND CRITERIA INTERACTIONS

Criterion, x_i	
x_1	= Comparative Cost
x_2	= Control
x_3	= User Satisfaction
x_4	= Usefulness
Criteria Interactions, x_{ijk}	
x_{12}	= Comparative Cost / Control
x_{23}	= Control / User Satisfaction
x_{24}	= Control / Usefulness
x_{34}	= User Satisfaction / Usefulness
x_{234}	= Control / User Satisfaction / Usefulness

A more detailed discussion of the incorporation and evaluation of relative weights in the criterion function modeling process is found in Appendix A. Individual interviews were conducted with eleven knowledgeable individuals at BMO to determine the relative importance of each of the identified criteria and criteria interactions that were developed to evaluate the performance of proposed candidate IRM systems. Each individual was asked to rate each criterion and criteria interaction on a scale of 1 to 10 (with 10 being most important) as to that element's importance in measuring the performance of a candidate information system. These scores were summed and normalized to provide rating values which satisfied the conditions identified above. Table 7 summarizes these rating activities. Relative weight (a_i) values assigned to the identified criteria and criteria interactions, using the heuristic techniques described above for the BMO/ACD organization, are summarized in the now complete Table 8. This procedure was used to demonstrate one

TABLE 7
BMO PERSONNEL RELATIVE WEIGHT RATINGS

x_{ijk}	1	2	3	4	5	6	7	8	9	10	11	a_{tot}	a_i
x_1	7	5	3	7	10	7.5	9	8	10	3	7	76.5	.098
x_2	6	10	1	8	9	9	9	8	9	7	10	86.0	.110
x_3	7	8	2	7	9	10	8	10	8	9	10	88.0	.112
x_4	7	10	4	9	10	8.5	8	9	9	8	6	88.5	.113
x_{12}	7	7	5	5	9	7.5	9	7	8	6	5	75.5	.096
x_{23}	6	9	6	8	10	9	8	7	7	7.5	9	86.5	.110
x_{24}	8	10	7	6	10	9.5	8	8	7	9	8.5	91.0	.116
x_{34}	8	9	9	9	9	10	8	9.5	9	9	10	99.5	.127
x_{234}	8	8	8	8	9	9.5	8	9	8	7	10	92.5	.118
Totals												784.0	1.00

TABLE 8
CASE STUDY CRITERIA, INTERACTIONS AND RELATIVE WEIGHTS

Criterion, x_i	Weight, a_i
x_1 = Comparative Cost	a_1 = 0.098
x_2 = Control	a_2 = 0.110
x_3 = User Satisfaction	a_3 = 0.112
x_4 = Usefulness	a_4 = 0.113
Criteria Interactions, x_{ijk}	
x_{12} = Comparative Cost / Control	a_{12} = 0.096
x_{23} = Control / User Satisfaction	a_{23} = 0.110
x_{24} = Control / Usefulness	a_{24} = 0.116
x_{34} = User Satisfaction / Usefulness	a_{34} = 0.127
x_{234} = Control / User Satisfaction / Usefulness	a_{234} = 0.118
1.000	

approach available to the designer-planner that can be used to assign relative weights within the Structured Optimization Method. In another situation the designer-planner may find another procedure more appropriate for completing this step in the overall method.

Conclusion

Once the criteria, parameters and submodels have been identified and correlated (Table 5), criteria interaction relationships have been defined, and relative importance values have been assigned the criterion function modeling activities can begin. The criterion function that results from these modeling activities is an analytical function, constructed from the identified criteria, their criteria interactions, and respective relative importance values, which evaluates each candidate system that was defined in the Feasibility Study, ranks each candidate system on a cardinal scale, and identifies the one candidate system whose performance is better than the other identified candidate systems.

Because the identified criteria are usually not directly measurable, a synthesizing process must be undertaken in which the designer-planner establishes mathematical relationships between the sets of parameters, $\{y_k\}$ and submodels, $\{z_i\}$, and their respective criteria. The designer-planner accomplishes this synthesis with available information, and, as a result may determine the information is incomplete. The designer-planner must recognize this limitation and determine how much information is required, how it will be obtained, and how much subjective information can be tolerated and still complete a meaningful formulation and evaluation. These activities are important because the model is the designer-planner's representation of what performance means and, as a result, how each candidate system will be evaluated. The important element of this Structured Optimization Method, and the design-planning methodology as a complete process, which is missing in most of the literature, is the explicit recognition, and inclusion, of subjectivity during the early steps of the modeling process.

Chapter Five continues the IRM Structured Optimization Method started in Chapter Four and describes the Criterion Function modeling activities which lead to a single analytical function which accomplishes the formal optimization of the identified candidate systems, and includes the:

- 1) Identification of maximum and minimum values for each parameter.
- 2) Determination of maximum and minimum values for each submodel.
- 3) Formulation of the relationships that exist between the parameters, submodels and criteria which have been identified.
- 4) Determination of maximum and minimum values for each criterion.
- 5) Development of the Criterion Function and determination of the optimal candidate system.

CHAPTER FIVE

CRITERION MODEL SYNTHESIS

Where once there was time to plan completely, to test thoroughly, and to move carefully, now there is only an ever-accelerating pace of change.

- Colby Chandler

Introduction

The synthesizing activity relates each parameter to its respective criterion, either directly or indirectly through an appropriate submodel and defines the allowable value ranges for the parameters, submodels and criteria. This relationship is displayed in Figure 18. These ranges of values define the acceptable performance boundaries for each element. Values which fall outside the established ranges are considered unacceptable and not feasible. The minimum and maximum values established for each element are important as they affect the number of candidate systems that will be evaluated. If the range is set too small, some potentially desirable candidate systems may be eliminated from evaluation; if too large, extraneous candidates may be included which unnecessarily increases the evaluation process. The first step in developing these relationships is to establish minimum and maximum values for each parameter identified in Tables 4 and 5.

Parameter Values

The parameter values are developed from design data, user inputs and designer-planner knowledge. Table 9 tabulates and summarizes the

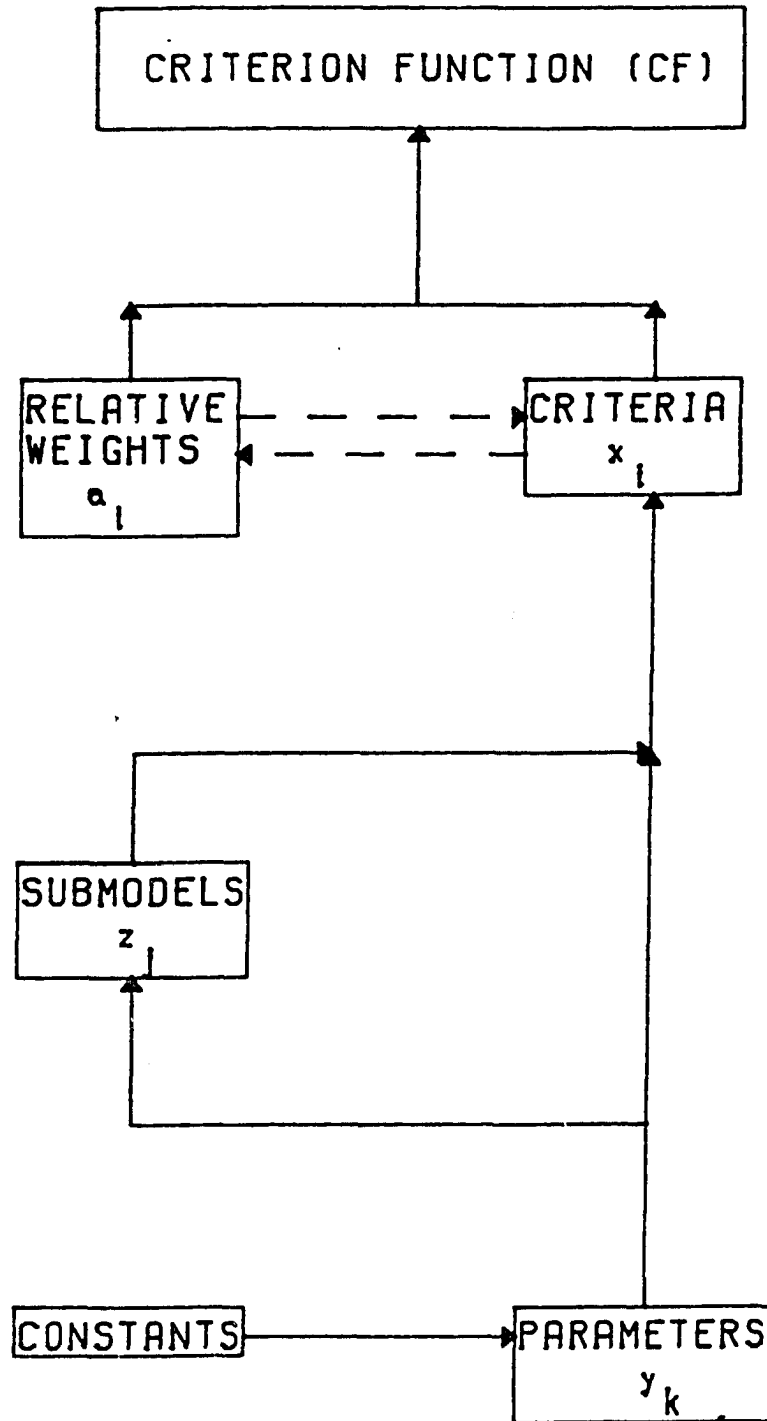


Fig. 16. Criterion Function Constituents (Ostrowsky, 1977, p 98).

TABLE 9
RANGE OF PARAMETERS

y_k	Description	y_{kmin}	y_{kmax}
y_1	New Equipment & Software Costs	\$ 1,356,000	\$ 2,045,000
y_2	Installation Costs	\$ 16,000	\$ 187,000
y_3	Recurring Maintenance Costs	\$ 1,159,000	\$ 1,174,000
y_4	Baseline Cost with IRM	\$345,824,000	\$352,876,000
y_5	Baseline Cost without IRM	\$369,077,000	\$369,077,000
y_6	Recurring Supply Costs	\$ 1,543,000	\$ 1,892,000
y_7	Productivity Gain Estimate	\$ 4,600,000	\$ 7,648,000
y_8	Output Quality Rating	1	5
y_9	Activity Allocation Times	0.0059	0.1283
y_{10}	Error Checking	1	5
y_{11}	Security	0.1	1.0
y_{12}	System Backup	0.1	1.0
y_{13}	# of Applications with Common Data	0.1	1.0
y_{14}	# of Functions Served by Application	1	14
y_{15}	Proportion of Data in Shared Files	0.1	1.0
y_{16}	Input Quality Rating	1	5
y_{17}	Online Performance Rating	1	5
y_{18}	Capacity	40	3241
y_{19}	Response Time	1 sec.	3 sec.
y_{20}	Management Support (Perceived)	1	5
y_{21}	Model Simplicity	1	5
y_{22}	Number of Inquiries	5	20
y_{23}	User's Technical Orientation	1	5
y_{24}	User's Time in Job	1	5
y_{25}	User's Education Level	1	5
y_{26}	User's Age	1	5
y_{27}	Source of Data	0.1	1.0
y_{28}	Influence of Info. on Organization	1	5
y_{29}	Intended Accuracy	0.01	0.25
y_{30}	Total Time	160 hours	160 hours
y_{31}	Down Time	0.05	0.25
y_{32}	Type of Data	0	1
y_{33}	Interval Between Reports	1 Day	365 Days
y_{34}	Processing Delay	1 Day	7 Days

minimum and maximum values for each of the parameters needed to model the information resource management design requirements for the Ballistic Missile Office.

Submodel Development

Once the range of values has been established for the parameters, a similar set of ranges are calculated for the submodels. These submodel values are a result of functional relationships that are defined for each submodel and its constituent parameters from existing literature, previous design activities, or the knowledge of the designer-planner. The functional relationships developed in this research have been formulated using heuristic procedures and the data available from the case study organization. The development activities are intended to illustrate the application of the structured optimization procedure. It may be appropriate in some cases to collect additional data which would allow the relationships to be developed from more quantitative functional relationships. This limits the applicability of the calculated results of this research, but it does not limit the procedures developed in this research. Appropriate functional relationships are described for each submodel identified in Table 5 to insure that each criterion is completely defined. The designer-planner must exercise care when evaluating functional relationships for the minimum and maximum values of the z_j 's if the relationship is not monotonical in nature. In this case it is possible for the $z_{j\min}$ or $z_{j\max}$ to occur at a point along the function other than at the minimum or maximum value of the function (Ostrofsky, 1977, p. 110).

Submodel z_{21} - "Reliability of Data"

Reliability of Data is defined to be the probability that the statistical data used by the organization will maintain a satisfactory consistency when the same measurements are repeated under similar conditions. It is a function of the source of the data, the intended accuracy of the data, and the data's prediction time span.

The definition and symbol of each of these elements is:

- y_{27}) Source of Data is a percentage of the total data used which is received from sources outside the organization. It is assumed that some external data will always be present.
- y_{29}) Intended Accuracy of the Data is a percentage value of the total number of errors compared with the total number of data entries that is acceptable in the data being used. The established acceptable range of errors recognizes the fact that some error will exist in the data, but the percentage of error is to be kept within established limits.
- y_{33}) Interval Between Reports is the time period between successive reports. Specific case study report intervals were reported as - 1, 2, 3, 5, 7, 10, 12, 14, 15, 22, 25, 30, 45, 60, 90, 120, 180, and 365 days.

The functional relationship of Reliability of Data for a given candidate system is modeled according to the reliability function as defined, for example, by Blanchard (1981). Equation (5-1) defines the relationship Reliability of Data used in this research effort and suggests that reliability is greater with more internal data, higher data accuracy and smaller intervals between reports.

$$z_{21} = e^{-(y_{27} * y_{29} * (y_{33}/365))} \quad \text{Equation (5-1)}$$

Appendix B contains computer listings of each of the subroutines used to calculate minimum and maximum values for each of the defined submodels. Figure 30, in Appendix B, shows the computer printout which uses Equation (5-1) to calculate the minimum and maximum values for this submodel. The output from this and all of the other submodel subroutines is contained in Table 10 at the end of this subsection.

Submodel, z_{22} - "Support for Standards"

Support for Standards of completeness and accuracy is defined as a specific approach to accomplishing a task which is applicable to all elements of the organization. This submodel is composed of the following four elements:

- y_8) Output Quality Rating is a subjective evaluation of the value of the information produced by the IRM system. The rating scale ranges from information with little value (1) to information with significant value (5).
- y_{13}) Number of Applications with Common Data is the percentage of activities which rely on common elements of data.
- y_{14}) Number of Functions Served by an Application reflects the number of functions within the case study organization which are served by the IRM system.
- y_{15}) Proportion of Data in Shared Files is the percentage of data within the organization which reside in common data files. It is assumed that each organization will have some small amount of its operating data in shared files due to the nature of the organization's interrelated functions.

The functional relationship which determines the Support for Standards for a given candidate system is:

$$z_{22} = ((y_8/5) * y_{13} * (y_{14}/14) * y_{15}) \quad \text{Equation (5-2)}$$

This relationship suggests that the higher the value of each of the constituent parameters the more the standards of completeness and accuracy of the IRM system are supported. Figure 31, in Appendix B, contains the printout of the subroutine which calculates the minimum and maximum values for the submodel Support for Standards.

Submodel, z_{23} - "Integrity"

Integrity describes those controls which assure that specified processing is applied only to the proper files by properly authorized individuals. Integrity insures IRM system representations are of actual current status of information, and supports reconstruction of accidentally destroyed data. The term also implies the use of security procedures to prevent unauthorized system access. It is made up of:

- y_{10}) Error Checking is a subjective evaluation of the system's ability to identify and correct input or processing errors. A value of 1 indicates very little ability to identify and correct errors.
- y_{11}) Security is a percentage value of the amount of the IRM system which requires secure access. It is assumed that in all cases at least a limited password access procedure will be employed.
- y_{12}) System Backup is that set of data which requires backup. The assumption is made that in all candidate systems, some part of the data will be backed up.

y₂₈) Influence of Information on the Organization is a subjective evaluation of the amount of direct influence the data have on the organization's activities. The degree of influence will affect the requirements of the other elements of Integrity.

The Integrity submodel for each candidate system is calculated as:

$$z_{23} = ((y_{10}/5) * (y_{28}/5) * y_{11} * y_{12}) \quad \text{Equation (5-3)}$$

The greater the value of each parameter, the higher the level of system integrity that will be realized. Figure 32, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the submodel Integrity, z₂₃.

Submodel z₃₁ - "Quality of the System"

The Quality of the System submodel evaluates the quality of the overall IRM system product in meeting the needs of the organization. It is composed of the following elements:

- y₁₆) Input Quality Rating is a subjective user evaluation as to the quality of the input data supporting their activities.
- y₈) Output Quality Rating is a subjective evaluation of the value of the information produced by the IRM system.
- y₁₇) Online Performance Rating is a subjective rating by the system users as to how well the system performs its designated functions.
- y₁₈) Capacity is the measure of the total volume of work performed over a given period of time. Case study data identified anticipated annual workload volume in the eleven responding organizations to be 7300, 1240, 478, 3158, 31933, 23487, 13678, 38897, 26883, 2893, and 4745 pieces of work. For

purposes of this evaluation the workloads were assumed to be uniformly distributed throughout the year. A monthly workload value was determined by dividing each by 12. Maximum monthly workload is anticipated to be 3241 pieces.

- y₁₉) Response Time is the average time interval between submission of a request for information and the return of the result. Long (1984) suggests this value should not exceed 3 seconds if user satisfaction is to be maintained.

The quality of a given candidate system is calculated as:

$$z_{31} = ((y_{16} + y_8 + y_{17})/15) * (1/y_{19}) * (y_{18}/3241) \text{ Equation (5-4)}$$

The closer the calculated value is to 1.0 the higher the quality of a given candidate system. Figure 33, in Appendix B, contains the printout of the subroutine which calculates the minimum and maximum values for the submodel Quality of the System, z₃₁.

Submodel z₃₂ - "Attitudes and Perceptions"

According to Lucas (1978b), a user's attitudes toward and perceptions of an information system are related to the successful implementation of that system. A decision maker's attitude, if forced to use a poor IRM system, will become progressively more negative and, as a result, system usage will generally decline. However, a positive attitude or perception regarding an IRM system will lead to increased use of the system and improved decision making support for the organization. The following elements are employed to develop the submodel, Attitudes and Perceptions:

- y₈) Output Quality Rating is a subjective evaluation of the value of the information produced by the IRM system.

- y₁₇) Online Performance Rating is a subjective rating by the system users as to how well the system performs its designated functions.
- y₂₀) Management Support is a subjective rating of management's involvement with the IRM development activity. High levels of perceived management support promote more favorable attitudes and perceptions on the part of the users. Lucas (1978b) suggests that significant organizational commitment is more important to successful IRM implementation than having top management select projects for implementation.
- y₂₁) Model Simplicity is a subjective evaluation by the users regarding the "ease of use" of the IRM system.
- z₃₁) Quality of the System reflects directly on the attitudes and perceptions of the users and, therefore, is also included in this submodel.

The functional relationship which determines the Attitudes and Perceptions for a given candidate system is:

$$z_{32} = \frac{(y_8 + y_{17} + y_{20} + y_{21})}{20} * (z_{31}) \quad \text{Equation (5-5)}$$

The sum of the four parameter values, which can each take on values from one to five, is normalized by dividing by 20. It is important to point out the presence of the submodel, Quality of the System, which is used in this submodel to define the relationship of attitudes and perceptions toward overall system performance. Figure 34, in Appendix B, contains the printout of the subroutine which calculates the minimum and maximum values for the submodel Attitudes and Perceptions, z₃₂.

Submodel z₃₃ - "Decision Style"

Keen and Scott-Morton (1979), Henderson and Nutt (1980), and others suggest that decision style is an important consideration in the design of information systems. The better the fit of an information system to the decision maker's decision style, the greater the likelihood that the decision maker will be satisfied with the system and use it. In this research activity Decision Style is composed of the following elements:

- y₂₂) Number of Inquiries identifies how many times a decision maker is likely to access the IRM system for additional information when formulating a decision scenario. Lucas' (1978b) research suggested the number of inquiries could be found in the range from 1 to 25. In this research it is assumed the range of inquiries will be from 5 to 20 and will exist as a function of the User's Technical Orientation.
- y₂₃) User's Technical Orientation is a subjective evaluation of how the decision maker approaches a new problem. A (1) suggests the decision maker possesses "Low Analytic" qualities which rely on trial and error, and spontaneous actions with emphasis on feedback (Benbasat and Schroeder, 1977). On the other hand, a (5) suggests the decision maker possesses "High Analytic" qualities which suggest a well planned approach to problem solving using formal analysis procedures. A "Low Analytic" may be expected to make more inquiries of the IRM system than a "High Analytic."
- z₃₂) Attitudes and Perceptions play an important role in the application of the IRM system. A decision maker's Decision Style will be affected by his/her Attitudes and Perceptions.

The functional relationship which determines the Decision Style for a given candidate system is:

$$z_{33} = \frac{(4 * y_{23})}{(y_{22})} * z_{32} \quad \text{Equation (5-6)}$$

The relationship between User's Technical Orientation and Number of Inquiries found in Equation (5-6) is based on the assumption that a "High Analytic" decision maker will make fewer inquiries than will the "Low Analytic" user. For purposes of demonstrating the Structured Optimization Method a relationship of 4 times the User's Technical Orientation has been established to model Decision Style. In another situation the designer-planner may determine a different relationship to be more appropriate. In either case, the methodology remains constant.

The closer the value for z_{33} is to 1.0 the better the fit of the IRM system to the decision maker's decision style. Figure 35, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the submodel Decision Style, z_{33} .

Submodel z_{34} - "Situational Factors"

Modeling Situational Factors, such as those listed below, can help the designer-planner understand, more completely, the likely impact of these factors on the implementation success of an IRM system. For example, older, less well educated people are likely NOT to use the IRM system, or at least may strongly resist its use (Lucas, 1975). The following elements are used to define the function, Situational Factors:

- y_{24}) User's Time in the Job is measured on the following five-point scale;

- 1 - Less than 1 year on the job,
- 2 - More than 1 year and less than 2 years on the job,
- 3 - More than 2 years and less than 4 years on the job,
- 4 - More than 4 years and less than 8 years on the job,
- 5 - More than 8 years on the job.

Individuals with less time in the job are more likely to use the IRM system (Lucas, 1975).

y₂₅) User's Education Level is measured on the following five-point scale;

- 1 - Completed high school,
- 2 - Attended college, but did not graduate,
- 3 - Completed a bachelor's degree,
- 4 - Completed some graduate courses,
- 5 - Completed a graduate degree.

Individuals with higher levels of education are considered more likely to use the IRM system.

y₂₆) User's Age is measured on the following five-point scale;

- 1 - 18 - 21 years of age,
- 2 - 22 - 25 years of age,
- 3 - 25 - 30 years of age,
- 4 - 30 - 40 years of age,
- 5 - Over 40 years of age.

Younger individuals are considered more likely to use the IRM system (Lucas, 1975).

y₁₄) Number of Functions Served by an Application reflects the number of functions within the case study organization which are served by the IRM system. Greater numbers of functions served by the IRM system will require more use of the system to accomplish the mission.

The functional relationship which determines the Situational Factors for a given candidate system is:

$$z_{34} = ((1/y_{24}) * (y_{25}/5) * (1/y_{26}) * (y_{14}/14)) \quad \text{Equation (5-7)}$$

Figure 36, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the submodel Situational Factors, z_{34} .

Submodel z_{41} - "Reliability of Data"

This submodel is the same as Submodel z_{21} which was developed earlier and is used here to define criterion x_4 . The functional relationship which develops Reliability of Data within criterion x_4 is:

$$z_{41} = e^{-(y_{27} * y_{29} * (y_{33}/365))} \quad \text{Equation (5-8)}$$

Figure 37, in Appendix B, shows the computer printout which calculates minimum and maximum values for the submodel Reliability of Data, z_{41} .

Submodel z_{42} - "Flexibility"

Flexibility is defined as the probability that a system will change or adjust to meet the changing nature of the users' requirements. In the case study example Flexibility is defined as the functional relationship of the following elements:

- y_9) Activity Time Allocation is the percent of daily activity time associated with each of the functions supported by the IRM system.
- y_{14}) Number of Functions Served by an Application reflects the number of functions within an organization which are served by the IRM system.
- y_{17}) Online Performance Rating is a subjective rating by the system users as to how well the system performs its designated functions.

The submodel for Flexibility for a given candidate system is based on the functional relationship of reliability as presented by, for example, Blanchard (1981). A candidate system with a value for z_{42} close to 1.0 is more flexible than the system with a value close to 0. A candidate system is considered to be more flexible with a smaller Activity Time Allocation, fewer Functions served, a faster Response Time, and a higher Online Performance rating. This functional relationship for a given candidate system is:

$$z_{42} = e^{-((y_9 * (y_{14} / 14)) / (y_{17} / 5))} \quad \text{Equation (5-9)}$$

Figure 38, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the submodel Flexibility, z_{42} .

Submodel z_{43} - "Availability"

Availability is a measure of the percentage of time the IRM system is in an operable state at any unknown random point in time. Availability, here, is defined to be a function of the following elements:

- y_{30}) Total Time is set at a normal operational number of hours each operating period. In the case study example this value is set at 160 hours per month.
- y_{31}) Downtime is a percentage of Total operating time that is used to accomplish routine preventive maintenance, and any required unscheduled maintenance and repairs.

Availability for any given candidate system is:

$$z_{43} = ((y_{30} - (y_{30} * y_{31})) / Y_{30}) \quad \text{Equation (5-10)}$$

Figure 39, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the submodel Availability, z_{43} .

Submodel z_{44} - "Average Age of Information"

The functional relationship between the submodel "Average Age of Information," described by Davis and Olson (1985) is the relationship of the interval between reports, type of data, and the processing delay. These elements are defined as:

- y_{32}) Type of Data indicates the data is either "Condition Data" which pertains to data at a specific point in time (e.g., the status of a contract as of 01/01/85), or it is "Operating Data" which pertains to changes in data over a period of time (e.g., contract funds expended during a specific month).
- y_{33}) Interval Between Reports is the time period between successive reports. Specific case study report intervals were reported as - 0, 1, 2, 3, 5, 7, 10, 12, 14, 15, 22, 25, 30, 45, 60, 90, 120, 180, and 365 days.
- y_{34}) Processing Delay is the time required to process the data following the closing of a reporting period and the publication of the final report.

The Average Age of Information for a given candidate system is:

$$z_{44} = y_{34} + ((y_{32} * y_{33}/2) + (y_{33}/2)) \quad \text{Equation (5-11)}$$

Figure 40, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the submodel Average Age of Information, z_{44} .

After each submodel is developed and coded, the computer subroutines are exercised to calculate the range of acceptable values for each. The resulting minimum and maximum values for each of the submodels is tabulated and summarized in Table 10. Note there are no submodel values for criterion, x_1 as it is defined completely using only

parameters. Values for each of the four criteria are calculated following the development of the criterion relationships.

Criterion Relationship Development

The next steps in the modeling process are to quantitatively define the functional relationships between the appropriate criterion elements identified in Tables 4 and 5, and, using the parameter and submodel values identified in Tables 9 and 10 respectively, determine the minimum and maximum values for each criterion.

Criterion x_1 - "Comparative Cost"

The criterion, Comparative Cost, has been defined to be the cost of a given candidate system relative to a standard cost. The "standard cost" in the case study organization is defined to be the baseline cost

TABLE 10

RANGE OF VALUES FOR SUBMODELS

x_i	z_{ij}	z_{ijmin}	z_{ijmax}
x_1	z_{21}	0.78	1.00
	z_{22}	0.00	1.00
x_2	z_{23}	0.00	1.00
	z_{31}	0.00	1.00
	z_{32}	0.04	1.00
	z_{33}	0.04	1.00
x_3	z_{34}	0.00	1.00
	z_{41}	0.78	1.00
	z_{42}	0.55	1.00
	z_{43}	0.75	0.95
x_4	z_{44}	1.50 Days	372.00 Days

for BMO/ACD to accomplish its organizational objectives without implementing an IRM system. The criterion elements which define Comparative Cost include the following (SAI, 1981):

- y₁) New Equipment and Software Costs are those associated with the purchase of hardware and software necessary to implement an IRM system. The case study costs are price quotes derived by configuring types and quantities of equipment and software to support identified approaches to IRM implementation. The costs used are annual values based on an eight year straight line depreciation calculation.
- y₂) Installation Costs are those costs associated with the installation and functional checkout of the equipment identified above. These costs represent annualized values over the expected eight year life of the system.
- y₃) Recurring Maintenance Costs are the baseline annual costs associated with maintaining the IRM system.
- y₄) Baseline Cost with IRM is a projection of what the baseline annual labor costs for BMO/ACD will be after an IRM system has been installed. This value does not reflect productivity savings but only the workload increase as affected by IRM system implementation and inflation.
- y₅) Baseline Cost without IRM (Standard Cost) is a projection of what the baseline annual labor costs for BMO/ACD will be if current operating procedures are continued and the IRM system is not implemented. This projection does account for anticipated workload increases and inflation.
- y₆) Recurring Supply Costs are an estimation of the additional unique supplies that will be required to support an IRM system. The case study supply costs represent an anticipated increase in workload and staff size, as well as inflation.

y_7) Productivity Gain Estimate is the projected productivity improvements which can be achieved as a result of IRM implementation and their translation into projected annual cost savings for the organization.

The Comparative Cost criterion for a given candidate system is:

$$x_1 = (y_5 - (y_1 + y_2 + y_3 + y_4 + y_6 - y_7)) \quad \text{Equation (5-12)}$$

Figure 41, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the criterion Comparative Cost, x_1 . The output from this and all of the other criterion subroutines is contained in Table 11 at the end of this subsection.

Criterion x_2 - "Control"

The criterion, Control, has been defined to be the activity which measures deviations from planned performance and initiates appropriate corrective actions. The Control criterion for a given candidate system is formulated as follows:

$$x_2 = (z_{21} * z_{22} * z_{23}) \quad \text{Equation (5-13)}$$

For purposes of this research and to demonstrate method, it is assumed that a straightforward multiplication of submodel values creates an acceptable representation of the performance of this criterion as it relates to the candidate systems. Figure 42, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the criterion Control, x_2 .

Criterion x_3 - "User Satisfaction"

The criterion, User Satisfaction, has been defined to be the measure of the alternative candidate system's implementation success. The User Satisfaction criterion for a given candidate system is:

$$x_3 = z_{31} * z_{32} * z_{33} * z_{34} \quad \text{Equation (5-14)}$$

For purposes of this research and to demonstrate method, it is assumed that a straightforward multiplication of submodel values creates an acceptable representation of the performance of this criterion as it relates to the candidate systems. Figure 43, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the criterion User Satisfaction, x_3 .

Criterion x_4 - "Usefulness"

The criterion, Usefulness, has been defined to be the measure of the perceived ability of an alternative candidate system to support organizational goals and objectives. The Usefulness criterion for a given candidate system is:

$$x_4 = e^{-((z_{41} * z_{42} * z_{43} * (z_{44}/365))/(y_8/5))} \quad \text{Equation (5-15)}$$

Figure 44, in Appendix B, contains the printout of the subroutine which calculates minimum and maximum values for the criterion Usefulness, x_4 .

The criterion formulations just developed are used to calculate the range of values appropriate for each criterion. These values are tabulated and summarized in Table 11.

TABLE 11
RANGE OF VALUES FOR CRITERIA

x_i	Description	x_{imin}	x_{imax}
x_1	Comparative Cost	\$15,042,000	\$27,041,000
x_2	Control	0.10	1.00
x_3	User Satisfaction	0.00	1.00
x_4	Usefulness	0.00	1.00

Criterion Function Development

The criterion function (CF) is an analytical function created from a combination of criteria, criteria interactions, and their respective values of relative importance which provides a quantitative formulation of the established design-planning objectives. The general form of the criterion function which results from the model synthesis is:

$$CF = F(a_1x_1, a_2x_2, \dots, a_nx_n) \quad \text{Equation (5-16)}$$

where;

a = the relative importance of the respective criterion.

x = the criteria (and criteria interactions, if present) which are the measures of performance of the candidate system being evaluated.

Choosing the optimal candidate system requires the ability to compare the projected performance of each given candidate system in an objective manner. The criterion function is used to evaluate the performance of each candidate system and the resulting performance values are arranged on a cardinal scale which then allows the designer-planner to identify the optimal candidate system as the one having the highest CF value. The mathematics of probability theory, as detailed by Ostrofsky (1977), provides the means to assess the performance of the set of candidate systems in terms of criterion performance. Therefore, a major activity in the development of the criterion function is the transformation of criteria and criteria interaction functional relationships into a probability space.

Criteria Transformation

The first step in the transformation of a criterion into a probability space is to determine the values for the set of candidate systems

for each criterion and the relative frequency of occurrence of each candidate within the range of the minimum and maximum values for the criterion as previously established (See Table 11). Once these values have been calculated a Cumulative Distribution Frequency (CDF) is generated. Figure 19 shows the CDF generated from 324 candidate values for Criterion X_1 , Comparative Cost. These 324 values result from the combinations of parameters for Criterion X_1 and the values of each parameter. Note, from Figure 41, that parameter y_1 can assume one of three values. Similarly parameters y_3 , y_4 , and y_7 can also assume one of three values. Parameters y_2 and y_6 can take on only one of two values, and parameter y_5 is a constant. Therefore the number of possible candidate systems is $3 * 2 * 3 * 3 * 1 * 2 * 3 = 324$.

Curve fitting procedures are next applied to generate a theoretical function which acceptably estimates and best fits the observed candidate values identified in Figure 19. In the case of Criterion X_1 , a straight line theoretical function was fitted to the observed data using the functional relationship:

$$F(X_1) = A + B(X_1) \quad \text{Equation (5-17)}$$

where:

X_1 = observed normalized value of Criterion X_1 .

$$B = \frac{\sum (X_i * f(X_i)) - (\sum X_i * \sum f(X_i))/N}{\sum X_i^2 - ((\sum X_i)^2)/N}$$

$$A = \sum f(X_i)/N - B * \sum X_i/N$$

N = number of observations

The resulting theoretical formula generated for Criterion X_1 is:

$$F(X_1) = -0.072 + 1.0752(X_1) \quad \text{Equation (5-18)}$$

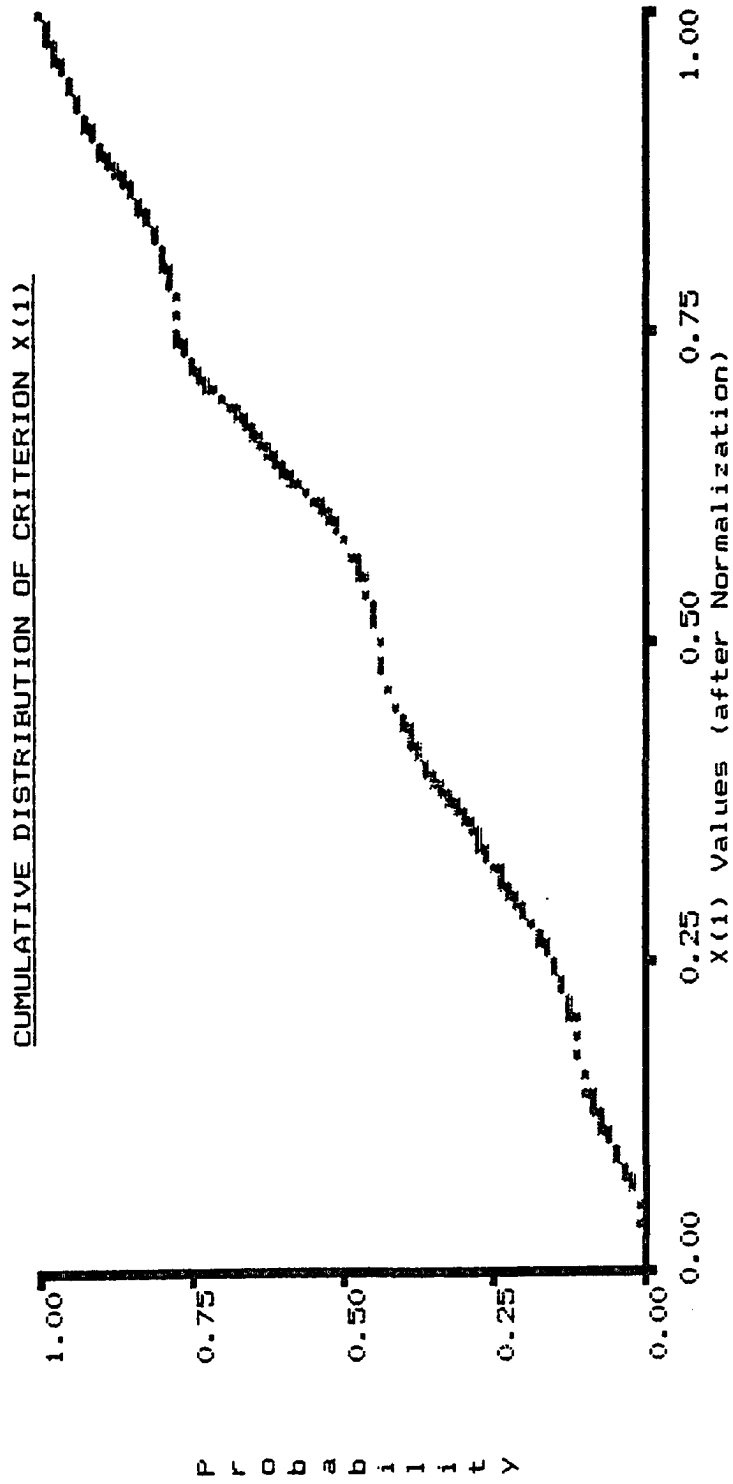


Fig. 19. Cumulative Distribution Frequency of Criterion X_1 .

Figure 20 depicts the theoretical function overlaid on the observed CDF data found in Figure 19. The Kolmogorov-Smirnoff (K-S) (Siegel, 1956) Goodness-of-Fit test was accomplished to insure the theoretical formula accurately estimated the observed values. Using a level of significance of 0.05, the MAX 'D' for the theoretical formula was found to be 0.0751. The K-S Test CRITICAL 'D' for this level of significance and a sample size of 324 is 0.0756 (Siegel, 1956, p.251). Therefore, there is not sufficient evidence to reject the hypothesis that Equation (5-18) is an acceptable representation of the observed distribution for Criterion x_1 , as defined in this research, and Equation (5-18) is used in the Criterion Function modeling later in this chapter.

Similar transformation activities were accomplished on the three remaining case study criteria. Figure 21 depicts the observed and theoretical plots for criterion X_2 , Control, Figure 22 depicts plots for criterion X_3 , User Satisfaction, and Figure 23 depicts the plots for criterion X_4 , Usefulness. Table 12 summarizes the evaluations and theoretical formulas for each of the four marginal criteria.

TABLE 12

SUMMARY OF CRITERIA TRANSFORMATIONS

X_i	$F(X_i)$	N	MAX 'D'	CRIT 'D'
1	$-0.072 + 1.0752(X_1)$	324	0.0751	0.0756
2	$1 - e^{-[2.8875(X_2)]}$	258	0.0671	0.0847
3	$1 - e^{-[8.6625(X_3)]}$	625	0.0377	0.0544
4	if $X_4 \leq 0.9223$ then $-0.007 + 0.421(X_4)$	151	0.0981	0.1085
	if $X_4 > 0.9223$ then $(X_4)^9$	164	0.0344	0.1062

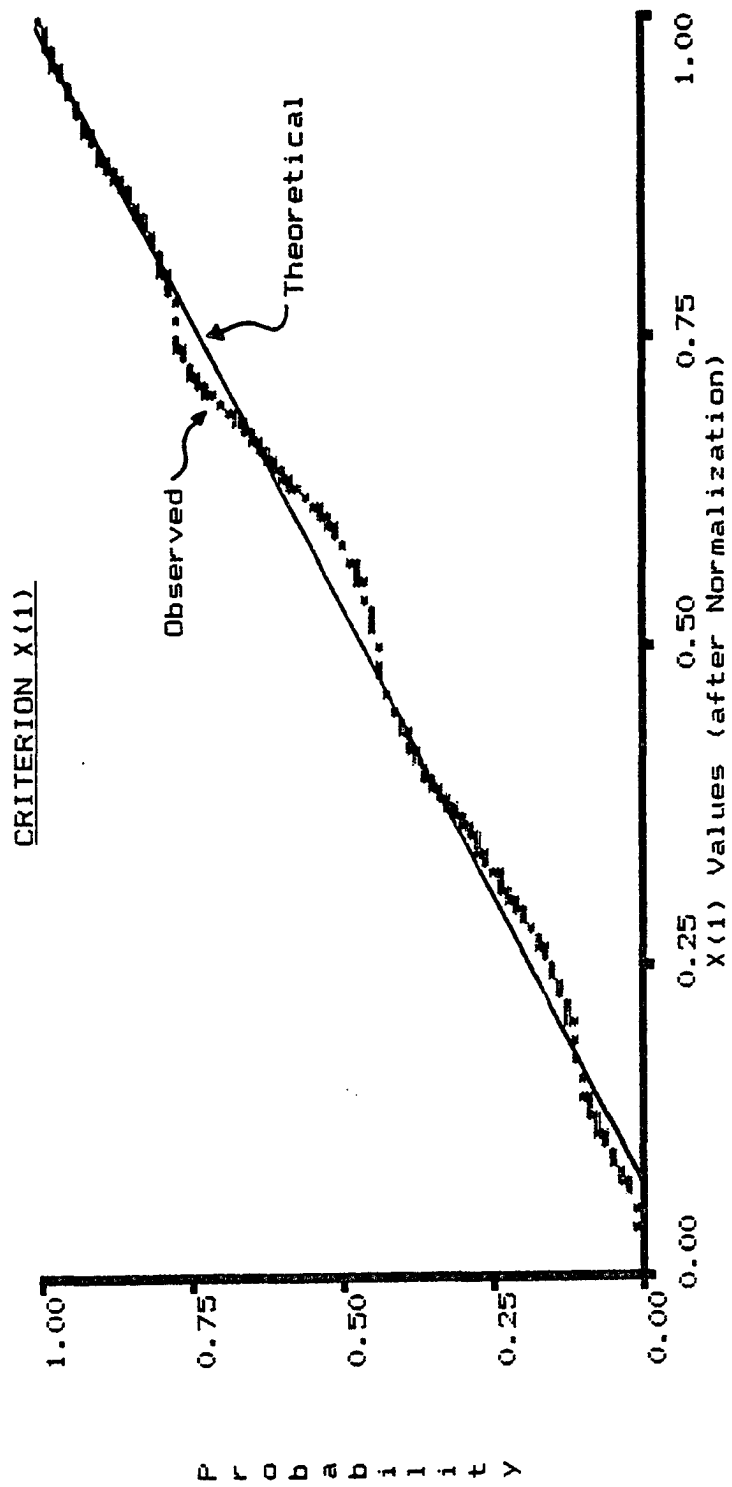


Fig. 20. Observed and Theoretical Plot of Criterion X_1 .

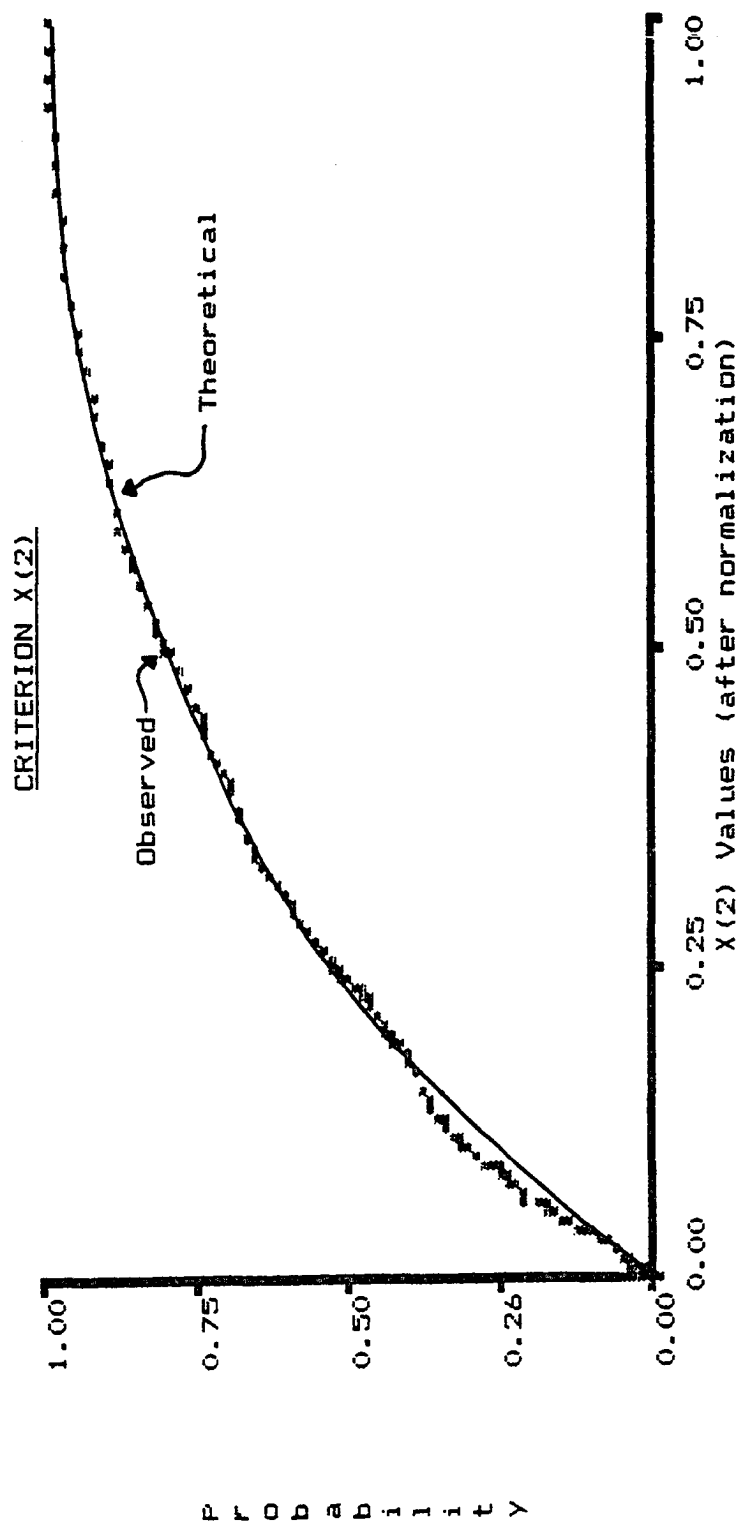


Fig. 21. Observed and Theoretical Plot of Criterion X_2 .

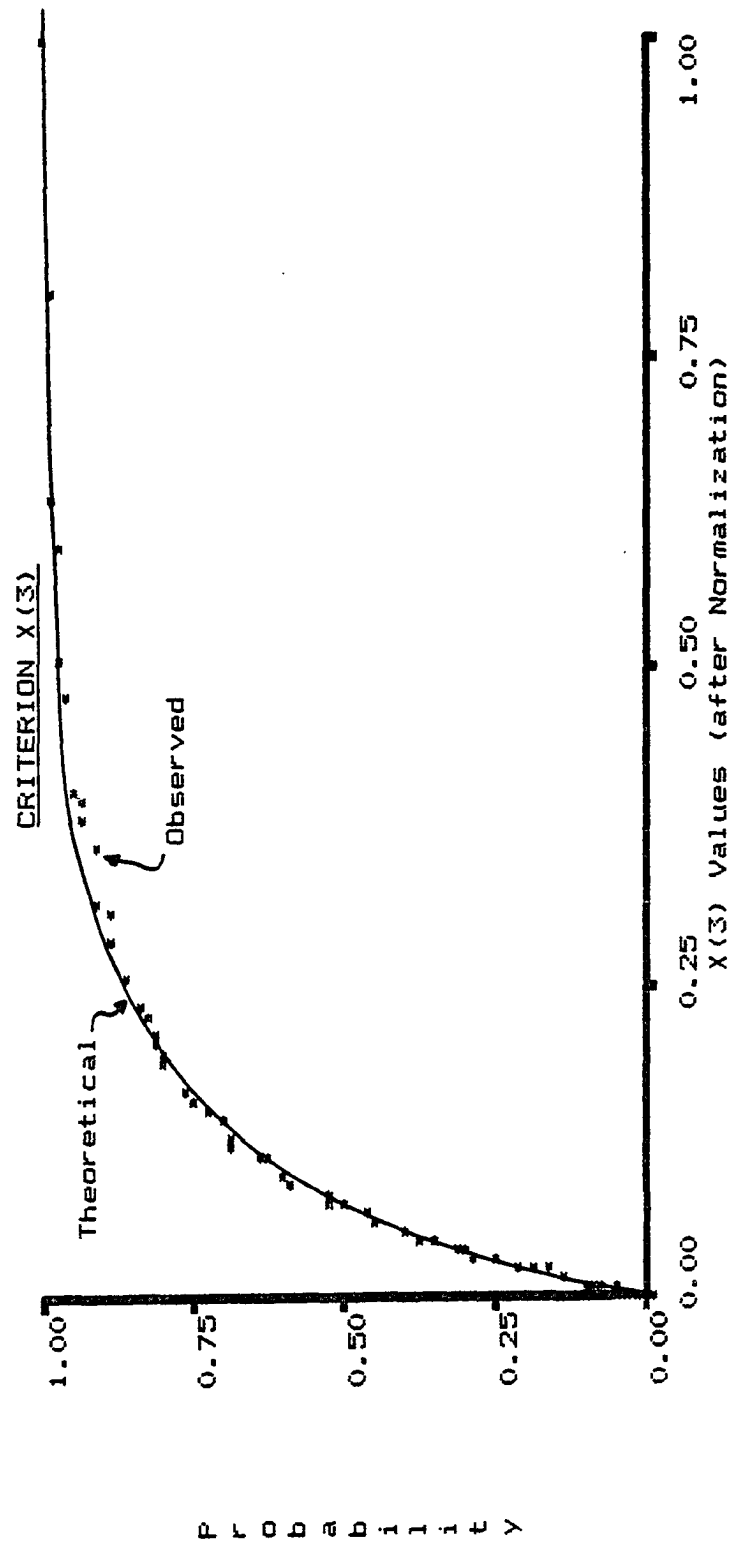


Fig. 22. Observed and Theoretical Plot of Criterion X₃.

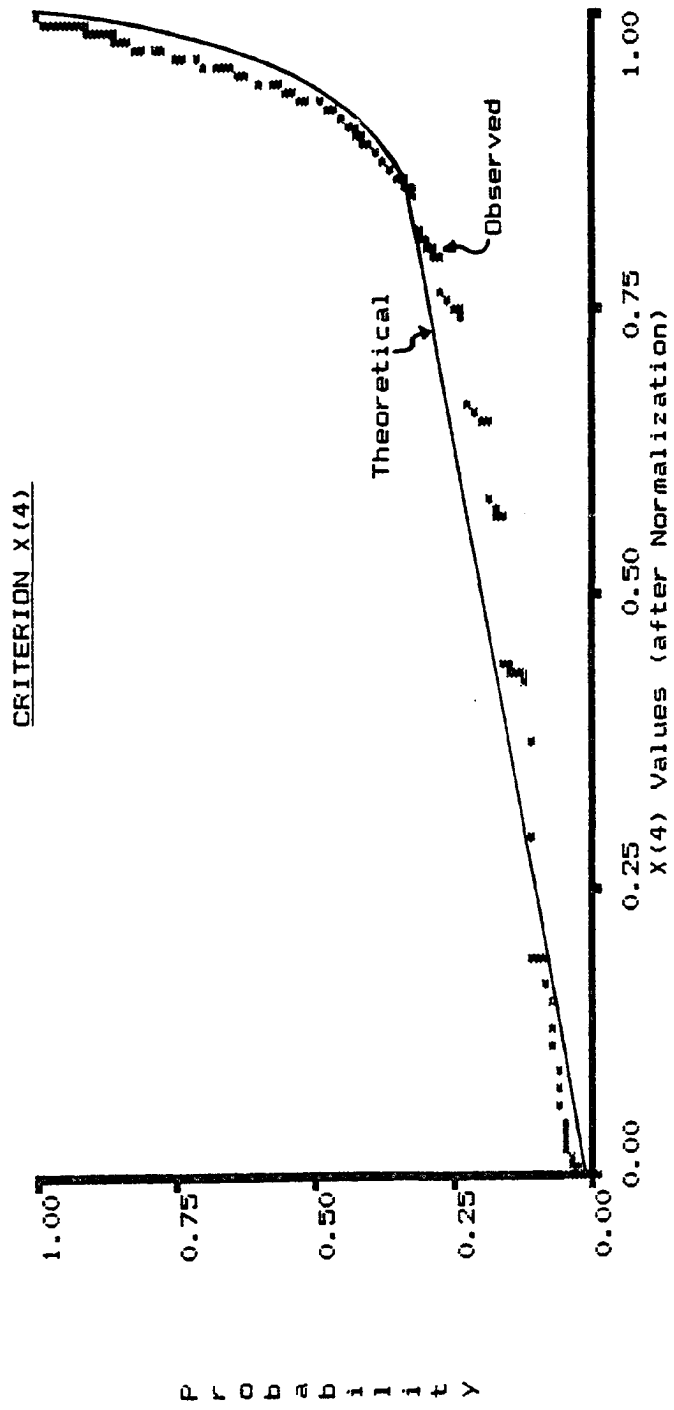


Fig. 23. Observed and Theoretical Plot of Criterion X₄.

Criteria Interaction Transformation

The next step in the criterion transformation process deals with criteria interaction. In this case, the transformation process converts the functional relationship between interdependent criteria into a joint probability distribution which can be used in the criterion function model for candidate system optimization.

The first step in the transformation of criteria interactions is to define the functional relationship that exists between the criteria. Based on the determinations from Chapter Four that an interaction exists between Criteria X_1 and X_2 , the designer-planner must establish the functional relationship that exists between these criteria. This functional relationship between interdependent criteria is derived from laboratory tests, field evaluations, or other means (Ostrofsky, 1977). For purposes of demonstrating method, the relationship between criteria X_1 and criteria X_2 used in this research has been determined to be parabolic in nature such that an increase in comparative cost causes an increase in the control function of the IRM system. However, the amount of increase in control begins to diminish as comparative cost reaches its maximum value. Curve fitting procedures as discussed in Choudhury (1979) were used to determine this functional relationship. The mathematical function which depicts this relationship is

$$g(X_1, X_2) = (.5 * p) \sqrt{X_1} \quad \text{Equation (5-19)}$$

where:

p = The distance between the focus and the directrix. In this case that value was calculated to be .2666.

Figure 24 graphically depicts this relationship.

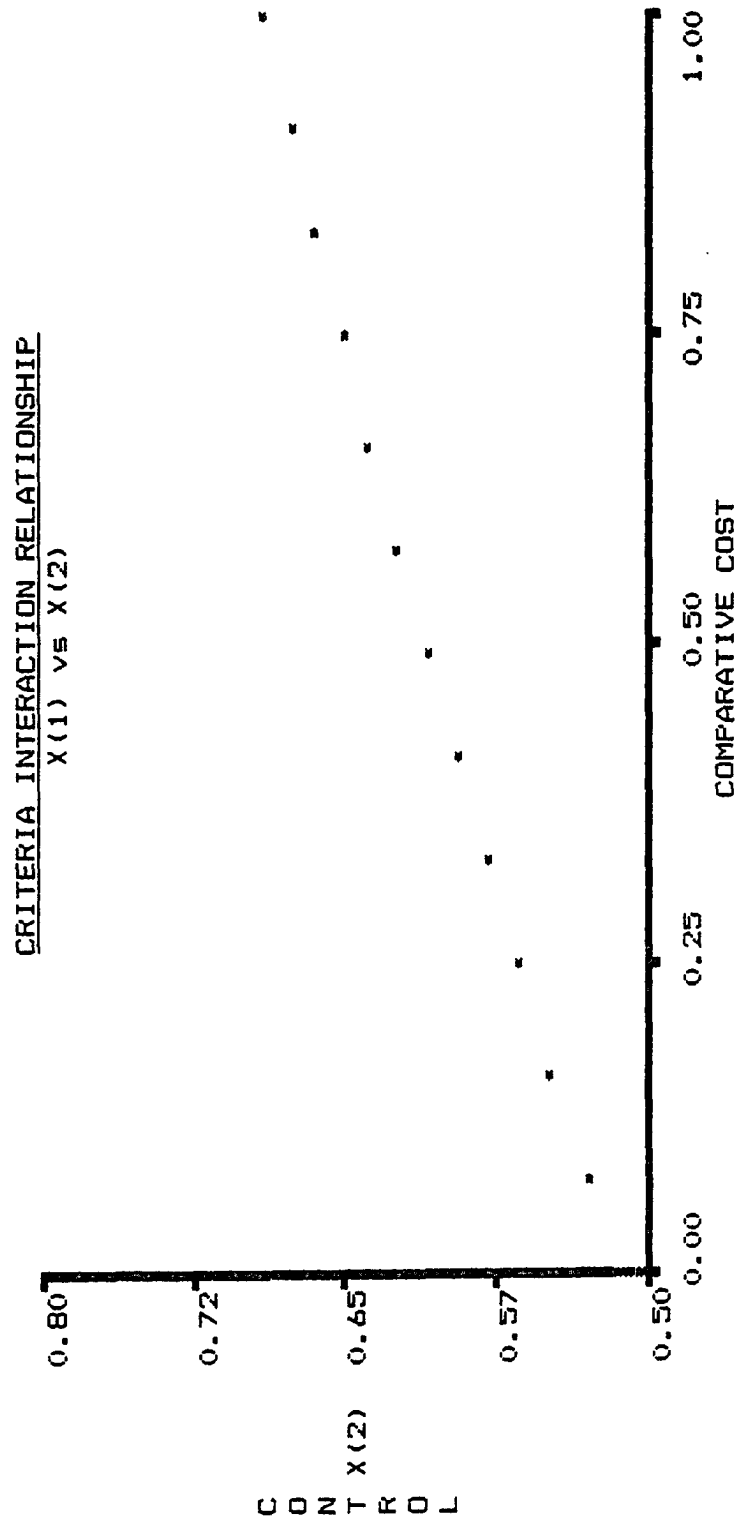


Fig. 24. Determination of $g(X_1, X_2)$.

To transform Equation (5-19) into a joint probability distribution for use in the CF formulation, data points along the function are identified and projected onto the axis of criterion values as was done for the marginal criteria above (e.g., See Figure 21). The data points along the function are determined by the accuracy of the data that the designer-planner has available to model the relationship. For purposes of demonstrating the method by which this transformation takes place ten points will be taken along the function that divide the total length into equal segments, and these points will then be projected onto the criterion value axis.

The total length of the function is determined using the "Length of the Curve" formula as found in Shilov (1973) and others. Equation (5-20) determines the total length of the function between the minimum and maximum values defined for the criterion.

$$L_t = \int_{X_{i\min}}^{X_{i\max}} \sqrt{(1 + [f'(X_i)]^2)} dx \quad \text{Equation (5-20)}$$

The resulting total length value is then divided into ten equal intervals using Equation (5-21) and successive partial integrations on the function to determine values along the function and within the established criterion range.

$$L_p = \int_{X_{n-1}}^{X_n} \sqrt{(1 + [f'(X_i)]^2)} dx \quad \text{Equation (5-21)}$$

where:

$$l_p = L_t/10$$

$$n = 1, \dots, 10$$

$$\begin{aligned} \text{when } X_{n-1} &= 0, \text{ use } X_{i\min} \\ X_n &= 10, \text{ use } X_{i\max} \end{aligned}$$

The resulting points along the function are then projected onto the CDF function line and curve fitting procedures, as described previously for the marginal criteria, are applied to establish a theoretical formulation for each interaction term. Table 13 summarizes the integration, curve fitting and K-S testing that was accomplished to establish the appropriate theoretical function for the representation of the interaction between criteria X_1 and X_2 . Figure 25 shows, graphically, the transformation that is defined in Table 13.

The same procedures are used for each of the remaining criteria interaction terms. Table 14 summarizes the transformation process for criteria interaction x_{23} , Table 15 summarizes the transformation of criteria interaction x_{24} , Table 16 for criteria interaction x_{34} , and Table 17 for criteria interaction x_{234} . Additional information regarding the transformation process is contained in Appendix A.

Applying Criterion Function Model V to the identified relationships yields the general Criterion Function Equation (5-22) which forms the basic equation from which the specific functional relationships, which have been previously developed, will be incorporated so as to evaluate the alternative candidate systems for the case study and identify the optimal candidate system for the relationships which have been defined.

$$\begin{aligned} \text{CF} = & a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 - (a_{12}X_{12} + a_{23}X_{23} + a_{24}X_{24} + a_{34}X_{34}) \\ & + a_{234}X_{234} \end{aligned} \quad \text{Equation (5-22)}$$

The first step is to add the actual relative importance values to Equation (5-22) which yields Equation (5-23).

$$\begin{aligned} \text{CF} = & 0.098X_1 + 0.110X_2 + 0.112X_3 + 0.113X_4 \\ & - (0.096X_{12} + 0.110X_{23} + 0.116X_{24} + 0.127X_{34}) \\ & + 0.118X_{234} \end{aligned} \quad \text{Equation (5-23)}$$

TABLE 13

TRANSFORMATION OF CRITERIA INTERACTION x_{12} ,
 "COMPARATIVE COST / CONTROL" INTO A CDF

n(i)	x(1)	L_p @ n(i)
0	15.0420	40.6761
1	16.4139	45.9575
2	17.7340	51.2388
3	19.0095	56.5202
4	20.2458	61.8015
5	21.4473	67.0830
6	22.6177	72.3644
7	23.7599	77.6458
8	24.8765	82.9271
9	25.9696	88.2086
10	27.0411	93.4899

Total Length = [93.4899 - 40.6761] = 52.8138

value (x1)	F(x1,x2 x1)	S(x)	F(x)-S(x)	X*F(X)	X^2	Value (X1)
15.0420	.0000	-.0216	.0216	.0000	.0000	.0000
16.4139	.1000	.0930	.0070	.0114	.0131	.1143
17.7340	.2000	.2033	.0033	.0449	.0503	.2244
19.0095	.3000	.3098	.0098	.0992	.1093	.3306
20.2458	.4000	.4130	.0130	.1735	.1881	.4337
21.4473	.5000	.5134	.0134	.2669	.2850	.5338
22.6177	.6000	.6111	.0111	.3788	.3986	.6314
23.7599	.7000	.7065	.0065	.5086	.5279	.7265
24.8765	.8000	.7998	.0002	.6557	.6717	.8196
25.9696	.9000	.8911	.0089	.8196	.8294	.9107
27.0411	1.0000	.9806	.0194	1.0000	1.0000	1.0000

234.1570 5.5000 MAX 'D' = .0216 3.9586 4.0734 5.7250
 sig lvl = .0500 CRIT 'D' = .1179
 B = 1.0021 A = -.0216

$Y = -0.0216 + 1.0021 * (X1)$

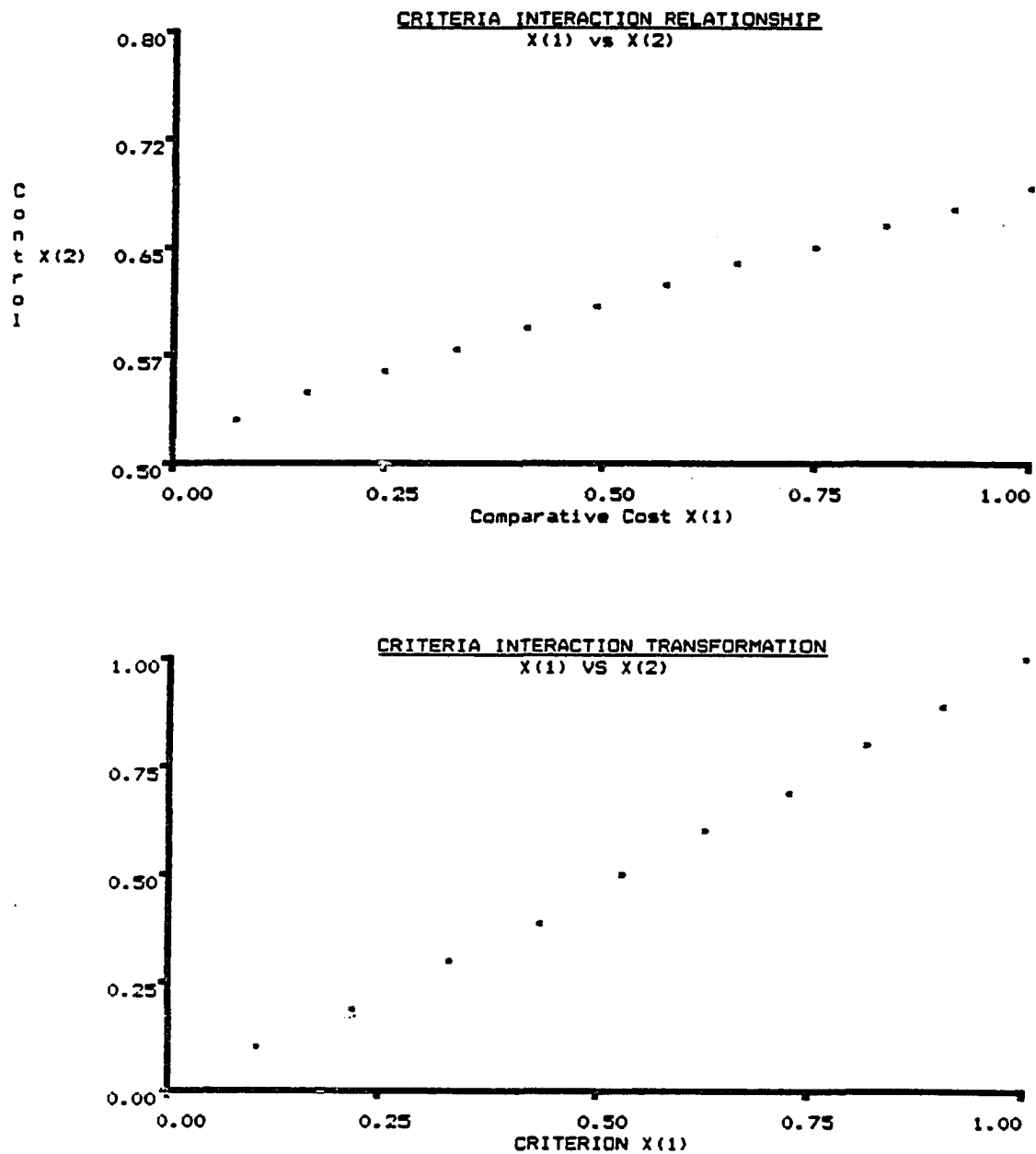


Fig 25. Transformation of Criteria Interaction x_{12} , "Comparative Cost / Control", into a CDF.

TABLE 14

TRANSFORMATION OF CRITERIA INTERACTION x_2, x_3 ,
CONTROL / USER SATISFACTION" INTO A CDF

n(i)	x(3)	$L_p @ n(i)$				
0	.0016	.0022				
1	.1014	.1365				
2	.2012	.2708				
3	.3010	.4051				
4	.4008	.5394				
5	.5006	.6737				
6	.6006	.8083				
7	.7005	.9427				
8	.8003	1.0770				
9	.9001	1.2114				
10	1.0000	1.3458				

Total Length = [1.3458 - 0.0022] = 1.3436						

value (x3)	F(x2,x3 x3)	x*F(x)	x^2	S(x)	F(x)-S(x)	

.0016	.0000	.0000	.0000	.0001	.0001	
.1014	.1000	.0101	.0103	.1001	.0001	
.2012	.2000	.0402	.0405	.2000	.0000	
.3010	.3000	.0903	.0906	.3000	.0000	
.4008	.4000	.1603	.1606	.3999	.0001	
.5006	.5000	.2503	.2506	.4999	.0001	
.6006	.6000	.3604	.3607	.6001	.0001	
.7005	.7000	.4904	.4907	.7001	.0001	
.8003	.8000	.6402	.6405	.8001	.0001	
.9001	.9000	.8101	.8102	.9000	.0000	
1.0000	1.0000	1.0000	1.0000	1.0001	.0001	

5.5081	5.5000	3.8523	3.8547	MAX 'D'	.0001	
				CRIT 'D'	.1179	
B =	1.0016	A =	-.0015	sig lvl = 0.05		

$Y = -.0015 + 1.0016*(x3)$						

TABLE 15

TRANSFORMATION OF CRITERIA INTERACTION x_{24} ,
 "CONTROL / USEFULNESS" INTO A CDF

n(i)	x(4)	L_p @ n(i)
0	.0079	.0107
1	.1070	.1445
2	.2061	.2783
3	.3052	.4121
4	.4043	.5460
5	.5034	.6798
6	.6025	.8136
7	.7016	.9474
8	.8007	1.0813
9	.8998	1.2151
10	.9989	1.3489

Total Length = [1.3489 - 0.0107] = 1.3382

value (x4)	F(x2,x4 x4)	x*F(x)	x^2	S(x)	F(x)-S(x)
.0079	.0000	.0000	.0001	.0000	.0000
.1070	.1000	.0107	.0114	.1000	.0000
.2061	.2000	.0412	.0425	.2000	.0000
.3052	.3000	.0916	.0931	.3000	.0000
.4043	.4000	.1617	.1635	.4000	.0000
.5034	.5000	.2517	.2534	.5000	.0000
.6025	.6000	.3615	.3630	.6000	.0000
.7016	.7000	.4911	.4922	.7000	.0000
.8007	.8000	.6406	.6411	.8000	.0000
.8998	.9000	.8098	.8096	.9000	.0000
.9989	1.0000	.9989	.9978	1.0000	.0000
5.5374	5.5000	3.8588	3.8678	MAX 'D'	.0000
				CRIT 'D'	.1179
				sig lvl = 0.05	
B =	1.0091	A =	-.0080		

$Y = -.0080 + 1.0091*(x)$

TABLE 17

TRANSFORMATION OF CRITERIA INTERACTION x_{234} ,
 "CONTROL / USER SATISFACTION / USEFULNESS" INTO A CDF

n(i)	x(3)	L_p @ n(i)
0	.0016	.3479
1	.1475	.4959
2	.2831	.6439
3	.4048	.7920
4	.5136	.9400
5	.6117	1.0880
6	.7012	1.2359
7	.7836	1.3839
8	.8603	1.5318
9	.9322	1.6797
10	1.0000	1.8276

Total Length = [1.8276 - 0.3479] = 1.4797

value (x3)	F(x ₂₄ , x ₃ x ₃)	S(x)	F(x)-S(x)
.0016	.0000	.0000	.0000
.1475	.1000	.0218	.0782
.2831	.2000	.0804	.1196
.4048	.3000	.1644	.1356
.5136	.4000	.2646	.1354
.6117	.5000	.3753	.1247
.70115	.6000	.4931	.1069
.7836	.7000	.6159	.0841
.8603	.8000	.7423	.0577
.9322	.9000	.8716	.0284
1.00001	1.0000	1.0030	.0030

6.23956 5.5000 Max 'D' = .1356
 Crit 'D' = .1411
 sig lvl = .0100

 $Y = 1.003 * (x_3)^2$

Next, the functional relationships for each criterion and criteria interaction terms are added to create Equation (5-24).

$$\begin{aligned}
 CF = & 0.098F(X_1) + 0.110F(X_2) + 0.112F(X_3) + 0.113F(X_4) \\
 & - (0.096F(X_1, X_2) + 0.110F(X_2, X_3) + 0.116F(X_2, X_4) + \\
 & \quad 0.127F(X_3, X_4)) \\
 & + 0.118F(X_2, X_3, X_4) \qquad \qquad \qquad \text{Equation (5-24)}
 \end{aligned}$$

Next, the criteria interaction terms are updated to reflect the bayesian transformation which enables evaluation of the criteria interaction term, given a value for the appropriate marginal criterion. Equation (5-25) results.

$$\begin{aligned}
 CF = & 0.098F(X_1) + 0.110F(X_2) + 0.112F(X_3) + 0.113F(X_4) \\
 & - (0.096F(X_1, X_2 | X_2) * F(X_2) + 0.110F(X_2, X_3 | X_3) * F(X_3) + \\
 & \quad 0.116F(X_2, X_4 | X_4) * F(X_4) + 0.127F(X_3, X_4 | X_3) * F(X_3)) \\
 & + 0.118F(X_2, X_3, X_4 | X_3) * F(X_3) \qquad \qquad \qquad \text{Equation (5-25)}
 \end{aligned}$$

Finally, the specific functional relationships for each criterion and criteria interaction term are incorporated to complete the Criterion Function model and allow evaluation of each candidate system. Equation (5-26) is the actual Criterion function equation which is used during formal optimization to evaluate each given candidate system.

$$\begin{aligned}
 CF = & 0.098 * (-0.0720 + 1.0752(X_1)) + 0.110 * (1 - e^{-(2.8875 * (X_2))}) \\
 & + 0.112 * (1 - e^{-(8.6625 * (X_3))}) + 0.113 * ((X_4)^9) \\
 & - (0.096 * (-0.0216 + 1.0021(X_1)) * (1 - e^{-(2.8875 * (X_2))}) + \\
 & \quad 0.110 * (-0.0015 + 1.0015(X_3)) * (1 - e^{-(8.6625 * (X_3))}) + \\
 & \quad 0.116 * (-0.0078 + 1.0089(X_4)) * ((X_4)^9) + \\
 & \quad 0.127 * (1.003(X_3)^2) * (1 - e^{-(8.6625 * (X_3))})) \\
 & + 0.118 * (1.003(X_3)^2) * (1 - e^{-(8.6625 * (X_3))}) \qquad \qquad \qquad \text{Equation (5-26)}
 \end{aligned}$$

Formal Optimization

The end product of the criterion function synthesis in the preceding paragraphs is the single mathematical function, Equation (5-26), which yields a performance value for each identified candidate system. This performance value results from the combination of criteria, submodel and parameter definitions, minimum and maximum values for the criterion elements and the synthesis associated with the development of the criterion function. This fact suggests the importance of the procedures and information used by the designer-planner to establish the constraints and value ranges for the parameters, submodels and criteria.

To determine the optimal candidate system for the defined criteria and design parameters the criterion function must be exercised. As has been stated previously, the purpose of this research is to demonstrate a method for optimizing the IRM design decision. Figure 26 contains a Supercalc² (Supercalc² is a registered trademark of Sorcim/IUS, San Jose, CA) spreadsheet which evaluates specific candidate systems. The designer-planner can change any of the values of the 34 design parameters and recalculate the associated CF value for that candidate system. In this manner the designer-planner can determine which candidate system, of those evaluated, is the optimal choice for further analysis and implementation. Figure 45, in Appendix B, contains a "contents listing" of the cells in the template shown in Figure 26.

The design space for this particular design case study is a 35-dimensional figure with one dimension for each of the 34 defined parameters and one more dimension for the resulting CF value. It would be an insurmountable task for the designer-planner to evaluate the entire design space and all the associated combinations of parameter values

	A	B	C	D	E	F	G	H
1	Candidate System Evaluation for IRM System Design							
2	-----							
3	PARAMETER values:							
4	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8
5	1356	16	1159	345824	369077	1543	4600	1
6	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16
7	.0059	1	.1	.1	.1	1	.1	1
8	Y17	Y18	Y19	Y20	Y21	Y22	Y23	Y24
9	1	40	1	1	1	5	1	1
10	Y25	Y26	Y27	Y28	Y29	Y30	Y31	Y32
11	1	1	.1	1	.01	160	.05	0
12	Y33	Y34						
13	1	1						
14	-----							
15	SUBMODEL values:							
16	Z21	Z22	Z23					
17	1.0000	.0001	.0004					
18	Z31	Z32	Z33	Z34				
19	.0025	.0005	.0004	.0143				
20	Z41	Z42	Z43	Z44				
21	1.0000	.9979	.9500	1.5000				
22	-----							
23	CRITERION values:							
24	x1	x2	x3	x4				
25	23779000	.0000	.0000	.9807				
26	X1	X2	X3	X4				
27	.7281	.0000	.0000	.9818				
28	-----							
29	FUNCTION values:							
30	F(X1)	F(X2)	F(X3)	F(X4)				
31	.7109	.0000	.0000	.8480				
32	F(X12)	F(X23)	F(X24)	F(X34)				
33	.5034	.0000	.8334	.0000				
34	F(X123)							
35	.0000							
36	-----							
37	CF value:							
38		.0205						
39	-----							

Fig. 26. Supercalc² spreadsheet to evaluate candidate systems.

using the spreadsheet template shown in Figure 26. To demonstrate a method for accomplishing a design space search to locate the optimal candidate system from the set of possible candidate systems, a computer search routine was developed (See Appendix C) which employs a dynamic programming-type search of the 35-dimensional design space and reports to the designer-planner the optimal candidate system, and its associated parameter values, that exists within the defined design space.

To demonstrate the design space search method employed by the computer program a set of five parameter values was analyzed for each parameter. The minimum parameter value, midpoint value, and maximum parameter value were used in the evaluation as well as values halfway between the minimum and midpoint values and halfway between the midpoint and maximum values. In actual application, the designer-planner would select values for the analysis which reflected the level of accuracy of the data being used in the design-planning activity. To reduce the chances of obtaining only a localized maximum CF value the design space search program was accomplished using initial seed parameter values selected according to the same five point scale used in the main body of the program. Here again, data accuracy in an actual application would dictate appropriate initial seed values. Table 18 summarizes the set of parameter values for each of the 34 parameters and the associated CF value for the five best performing candidate systems as determined by the design space search program.

Conclusion

At this point the formal optimization has been completed and an optimal candidate system has been identified from the set of candidate

TABLE 18

SUMMARY OF DESIGN SPACE SEARCH AND
OPTIMAL CANDIDATE SYSTEM IDENTIFICATION

	#1	#2	#3	#4	#5
Y1 -	2045.00	2045.00	2045.00	2045.00	2045.00
Y2 -	187.00	187.00	187.00	187.00	187.00
Y3 -	1635.00	1635.00	1635.00	1635.00	1635.00
Y4 -	348993.00	348993.00	348993.00	348993.00	348993.00
Y5 -	369077.00	369077.00	369077.00	369077.00	369077.00
Y6 -	1543.00	1543.00	1543.00	1543.00	1543.00
Y7 -	7648.00	7648.00	7648.00	7648.00	7648.00
Y8 -	5.00	5.00	5.00	5.00	5.00
Y9 -	13.00	13.00	10.00	13.00	13.00
Y10 -	5.00	5.00	5.00	5.00	5.00
Y11 -	10.00	10.00	10.00	10.00	10.00
Y12 -	10.00	10.00	10.00	10.00	10.00
Y13 -	10.00	10.00	10.00	10.00	10.00
Y14 -	14.00	14.00	14.00	14.00	14.00
Y15 -	10.00	10.00	10.00	10.00	10.00
Y16 -	5.00	5.00	5.00	5.00	4.00
Y17 -	5.00	5.00	5.00	5.00	5.00
Y18 -	3241.00	3241.00	3241.00	3241.00	3241.00
Y19 -	2.50	2.50	2.50	2.50	2.50
Y20 -	5.00	5.00	5.00	5.00	5.00
Y21 -	5.00	5.00	5.00	5.00	5.00
Y22 -	5.00	5.00	5.00	5.00	5.00
Y23 -	5.00	5.00	5.00	5.00	5.00
Y24 -	1.00	1.00	1.00	1.00	1.00
Y25 -	5.00	5.00	5.00	5.00	5.00
Y26 -	1.00	1.00	1.00	1.00	1.00
Y27 -	1.00	3.00	1.00	5.00	1.00
Y28 -	5.00	5.00	5.00	5.00	5.00
Y29 -	1.00	1.00	1.00	1.00	1.00
Y30 -	160.00	160.00	160.00	160.00	160.00
Y31 -	10.00	10.00	10.00	10.00	10.00
Y32 -	1.00	1.00	1.00	1.00	1.00
Y33 -	365.00	365.00	365.00	365.00	365.00
Y34 -	7.00	7.00	7.00	7.00	7.00
CF -	.2134942	.2134623	.2134328	.2134303	.2134021

systems that was evaluated. This is the point at which the Structured Optimization Method, developed in this research project ends. The system life cycle activities must now be continued and the optimal candidate system must be projected onto the operational requirements

that defined the original need to reasonably assure the designer-planner that the selected candidate system will behave as predicted in the earlier analyses. What remains beyond this point, and beyond the scope of this research is to physically test and verify the performance of the selected optimal candidate system prior to beginning implementation in the Production-Consumption Phase of the system's life cycle.

A major advantage of such a structured decision process is that one can formally record all decisions and if the outcome is not satisfactory, reevaluations and changes can be made more quickly and more easily. Additionally, the design-planning methodology attempts to consider the integrated whole requirement and its necessary activities (Ostrowsky, 1977, p 13).

The major strengths of this Information System design methodology are the incorporation of a thorough problem needs description into the design structure by explicitly defining criteria, submodels, parameters, the ranges of values associated with each, and the formal synthesis of these inputs in the criterion function modeling necessary for the evaluation of the alternative solutions.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The aim of Princes and philosophers is to improve.

Gottfried Wilhelm Leibniz, (1702)

Summary

Almost all organizations have experienced a rapidly increasing demand for information processing resources. It has been demonstrated that factories, which are generally thought of as materials transformation systems, are now 75% information handling systems (Skinner, 1985). This increasing demand for information has brought with it a concern that information system implementations within an organization be effective in supporting the organization's goals and objectives. The purpose of this research effort has been to develop and demonstrate the application of a Structured Optimization Method that, when used as an integral part of an information system design life cycle in conjunction with the information requirements determination methods discussed in Chapter Two, will provide the required structure and discipline to consistently support the information resource management needs of the organization while efficiently utilizing the limited resources of the organization.

The Structured Optimization Method for Information Resource Management developed in this research supports the four general requirements of a design tool as defined in Chapter Four (Bubenko and Kallhammar, 1971). First, the Structured Optimization Method presents an organized problem solving procedure which is not dependent on a specific solution

procedure. This allows the Method to be easily tailored to the appropriate level within the organization as well as accommodating the organization's particular method of operation. Second, the Method is fully capable of utilizing new methods of analysis within the structured format of the solution procedure. Finally, the Criterion Function modeling procedure, an integral part of the Structured Optimization Method, directly accommodates both quantitative and qualitative data.

A Multiple Criteria Decision Making framework was used to develop the Structured Optimization Method that describes alternative candidate systems of a proposed Information Resource Management system and permits the identification of the optimal design for the proposed organizational information requirements. The structured method was demonstrated using case study data from an organization within the USAF Ballistic Missile Office. The purpose of the case study data was not to solve an existing IRM design problem, but rather, to demonstrate the application of the method using data similar to that which the designer-planner would have available in an actual design problem.

Conclusion Number 1

The power of the optimization structure lies in its ability to identify constraints and limits on each criterion element. The designer-planner establishes these criterion element values based on the information available at the time the criterion model is created. When additional information becomes available, the structured optimization method developed in this research provides the means for the designer-planner to apply the principle of iteration and reaccomplish previous steps in the method and incorporate new information into the model.

Contributions

Conclusion Number 2

The application of the Structured Optimization Method is a practical way to describe the performance of alternative versions of a proposed Information Resource Management system. The systematic procedure developed in this research study makes a major contribution to information system design activities by providing:

- 1) A Structured Optimization Method that is capable of developing and evaluating candidate system designs, and identifying an optimal information system design that will support organizational requirements, with the minimum necessary expenditure of design-planning resources.
- 2) A formal criterion function modeling procedure that evaluates alternative candidate systems through explicit analysis of both qualitative and quantitative criteria and identifies the optimal system from among those systems studied.

Limitations

It may be appropriate, in some cases, to collect additional data which would allow the submodel and criterion relationships to be developed from more quantitative functional relationships. Not having this additional data may limit the direct applicability of the calculated results of this research, but it does not limit the applicability of the procedures themselves.

Conclusion Number 3

The computer routines used to demonstrate the structured optimization method, while complete in their theory of operation, are not integrated into a "user friendly" set of routines which guide the designer-planner through the application of the steps in the method. An integrated bank of computer routines would allow the criterion modeling activities to be accomplished more easily. Additionally, the criterion function analysis is currently accomplished using a five-point data interval in an effort to demonstrate the proposed method. Future applications of this model require that the data interval be established as a result of the accuracy of the data available to the designer-planner.

Conclusion Number 4

Also, the demonstration of the structured optimization method does not demonstrate all of the advantages of using a structured method such as the one presented in this research. It is only through the application of this method to an actual IRM system design problem that a comprehensive understanding of the advantages of such a structured approach will manifest themselves.

Potential for Future Research

There are several areas that provide rich potential for future research into the application and use of the Structured Optimization Method which has been developed in this research study.

- 1) The purpose of this research was to demonstrate a method for evaluating and identifying IRM candidate systems and not applying the method in the field. Therefore, future work is

indicated which would apply the methods described in this work to a field problem in IRM system design.

- 2) The structured nature of the method, and the reliance upon knowledge of the designer-planner suggest the development of an Expert System to build upon the experiences of the designer-planner and improve the overall design-planning process. The proper application of expert systems is in situations involving a limited number of choices arrived at by weighing judgments about complicated alternatives (Alexander, 1984). The IRM system design application is just this kind of situation.
- 3) Additional Expert System development is also suggested for the entire system life cycle of activities not just the Structured Optimization Method activities.
- 4) New computer programming capabilities such as Conceptual Modeling Languages are another area for possible research and improved application of the Structured Optimization Method.

APPENDIX A

MODELS FOR CRITERION FUNCTION SYNTHESIS

Introduction

In the optimization process what is needed is, not only an understanding of the decision processes that must be implemented, but also the kinds of decision making models that are involved and what information is required to implement those models. The models themselves, however, represent only the optimization analysis. They do not do anything to help in defining what decisions have to be made to get to the optimization activity except as it relates to the mechanics of the Structured Optimization Method itself. The parameters, submodels and criteria that are modeled must be defined by the designer-planner under each design situation.

This appendix describes, in detail, the eight Criterion Function Models defined by Ostrofsky (1983). All design-planning optimization using the Structured Optimization Method developed in this research occurs within the framework of one of these eight models. With experience, the designer-planner develops the understanding needed to identify the best model to apply to each given design problem. Figure 27 depicts the relationships which are characteristic of each of the eight models. Figure 27 indicates that a criteria set, $\{X_i\}$, can be defined which displays no interaction between members of the defined set. That is, a change in the value of one criterion will not affect

CHARACTERISTICS OF CRITERIA

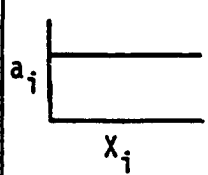
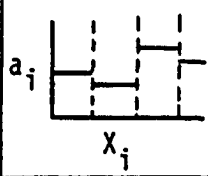
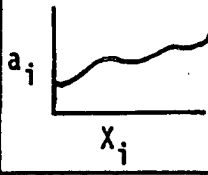
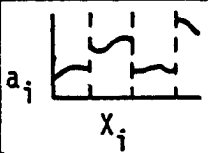
NATURE OF RELATIVE WEIGHT		INDEPENDENT	WITH INTERACTION	GRAPHIC REPRESENTATION OF RELATIVE WEIGHTS
	CONSTANT	I	V	
	INTERVAL	II	VI	
	VARIABLE	III	VII	
	VARIABLE WITH DISCONTINUITIES	IV	VIII	

Fig. 27. Characteristics of the Eight Criterion Function Models.

the value of any other criterion in the set. These are Models I, II, III, and IV and are termed the "Independent Models." Additionally, a criteria set can be defined in which there is interaction between members of the defined set. In this case, a change in the value of one criterion will affect the value of one or more of the remaining criteria in the set. Figure 27 labels Models V, VI, VII, and VIII "Interdependent Models."

Further, the defined criterion relative importance for a criterion can exist in one of four relationships to each criterion or criterion interaction. In Models I and V, the relative importance value exists as a constant value throughout the established range of values for the criterion or criterion interaction. In Models II and VI, the relative importance value is a constant within a number of intervals defined within the range of each criterion or criterion interaction. Models III and VII define a continuously variable value for the relative importance throughout the range of values for the criterion or criterion interaction. Finally, Models IV and VIII address the occurrence of continuously variable relative importance values for each criterion or criterion interaction with the added dimension of discontinuities in the range of values. Each of these models is discussed in detail and examples are developed.

Independent Models

The first four models to be discussed are those whose criteria exist independent of each other. A change in the value of one criterion is assumed not to affect the values of the other criteria in the model.

Model I

This model, or one similar to it, is used in almost 95% of the optimization activities (Ostrowsky, 1983). It assumes independence of criteria and a constant relative importance value throughout the range of values for each criterion or criterion interaction. The model is generally defined to be:

$$CF = \sum a_i X_i; \quad i = 1, \dots, n \quad \text{Equation (A-1)}$$

where:

a_i = the relative importance of the i th criterion, and

$$\sum a_i = 1.0$$

X_i = a normalized function of the performance measure of the i th criterion

$$= (x_i - x_{imin}) / (x_{imax} - x_{imin})$$

The advantages of this model include the ability to readily transform criteria into utility values through the normalization process and the relative ease of handling criteria with different units of measure. The disadvantages include the assumption of criteria independence, the need to have consistent units to add together, and the need to account for varying degrees of sensitivity in the units of measure among the criteria in the model.

Model II

This model has the same conditions placed on it as did Model I except that now the relative importance value, a_i , is constant for an interval of criterion values, but there is more than one interval within the range of criterion or criterion interaction values. The lengths of the intervals for each criterion do not have to be equal, nor do they have to align. Model II does require that each criterion have the same

number of intervals. If the number of intervals is not initially the same the designer-planner must create additional intervals to insure each criterion has the same number. Equation (A-2) depicts Model II.

$$CF = \sum a_i \beta X_i \beta; i = 1, \dots, n \quad \text{Equation (A-2)}$$

where:

a_i = the relative importance of the i th criterion, and

$\sum a_i = 1.0$ for each of the β intervals

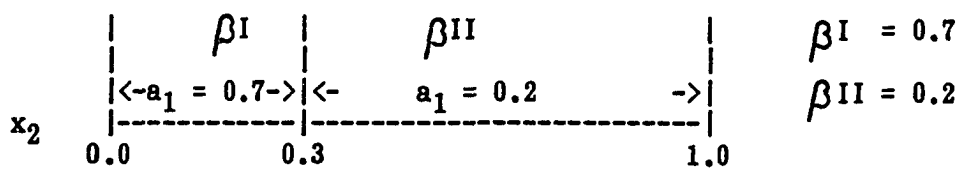
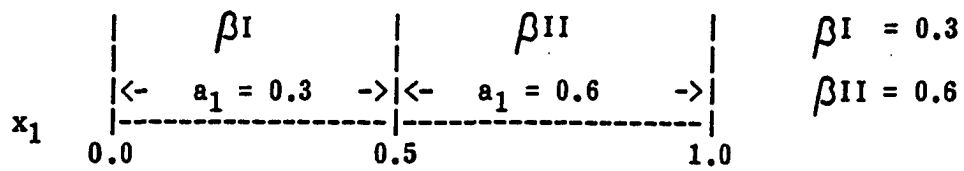
X_i = a normalized function of the performance measure of the i th criterion

$$= \frac{(x_i - x_{imin})}{(x_{imax} - x_{imin})}$$

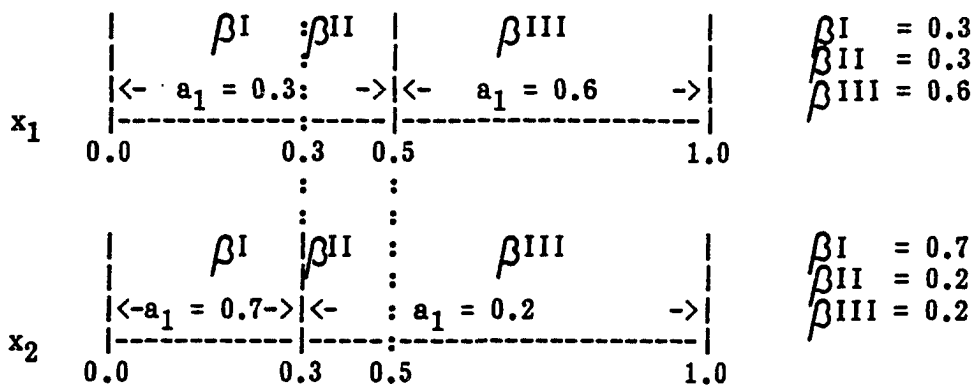
β = the interval number

An example of interval alignment is shown in Figure 28. Initially, Figure 28a shows that criterion x_1 is defined to have two ranges of relative importance. When x_1 is less than 0.5, $a_1 = 0.3$ and when x_1 is equal to or greater than 0.5, $a_1 = 0.6$. Similarly, criterion x_2 is defined to also have two ranges or relative importance values. When x_2 is less than 0.3, $a_2 = 0.7$ and when x_2 is greater than or equal to 0.3, $a_2 = 0.2$. To implement Model II an additional relative importance range is created to satisfy the requirement that each criteria has an equal number of intervals and that their ranges are identical. Figure 28b illustrates the addition of a third interval ($\beta = 3$) for each criterion. These new values are used in Model II.

The advantage of Model II is that it handles changing relative importance values within the range of values for each criterion. Two disadvantages are the difficulty in acquiring the relative importance data from the decision maker, and the complexity of CF value comparison.



a. Initial relative importance intervals for two criteria.



b. Adjusted relative importance intervals for two criteria.

Fig. 28. Relative Importance Intervals for Model II.

Model III

Model III also assumes the criteria are independent; however, it also assumes that the relative importance values are dependent on the value of the criterion within its range of values. This model results when the number of intervals, as defined in Model II, within the range of the criterion or criterion interaction approaches infinity. In this model, the value of the relative importance becomes a function of where one is in the range of values for x_i . Equation (A-3) depicts Model III.

$$CF = \sum a_i X_i; \quad i = 1, \dots, n \quad \text{Equation (A-3)}$$

where:

$$\lim_{\beta \rightarrow \infty} [a_i^{\beta} X_i^{\beta}] \Rightarrow [a_i = g_i(X_i)]$$

X_i = a normalized function of the performance measure of the i th criterion

$$= (x_i - x_{i\min}) / (x_{i\max} - x_{i\min})$$

therefore Equation (A-3) becomes:

$$CF = \sum g_i(X_i) X_i; \quad i = 1, \dots, n \quad \text{Equation (A-4)}$$

The advantage of Model III is that it handles continuously changing relative importance values within the range of values for each criterion. Two disadvantages are the difficulty in acquiring the relative importance data from the decision maker, in determining the functional relationship that exists between the relative importance values and the criterion, and the complexity of CF value comparison.

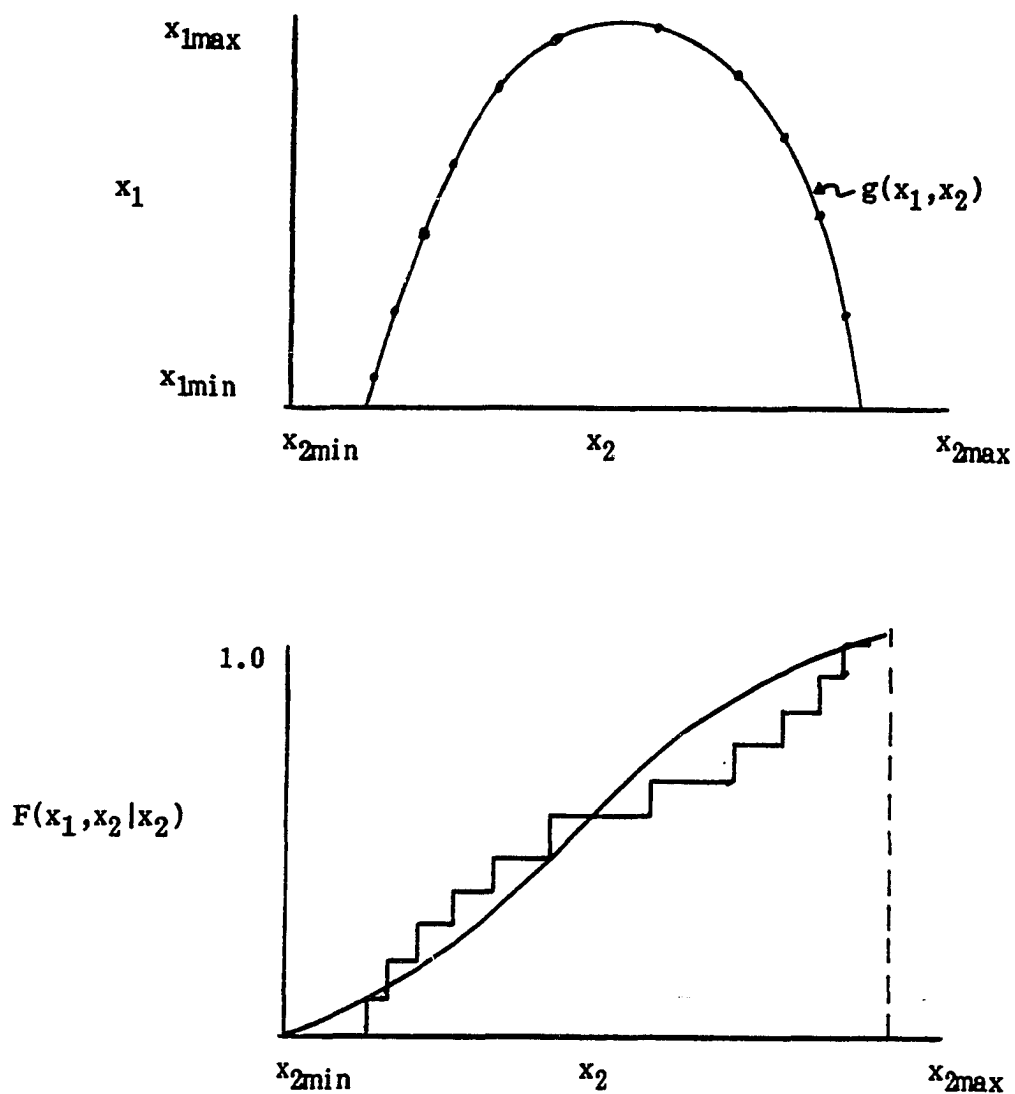
Model IV

Model IV is an extension of Model III except that it accounts for discontinuities in the functional relationship between the relative importance value and the criterion value.

Interdependent Models

Next, the four independent models discussed previously will be reexamined after the introduction of the concept of interaction. This interaction, or interdependence involves the criteria and not the relative importance values. This is, in large part, because the relative importance values are treated in terms of subjective evaluations, whereas the criteria are physical and their inputs are objectively measured and evaluated.

The occurrence of an interaction in a Boolean or Borel field is an event and it is evaluated in the same manner as the marginal criteria with their associated relative importance values. An interaction between two criteria is referred to as a First Order Interaction and deals with the paired overlap of these two criteria. A Second Order Interaction deals with the overlap of three criteria, and so on. An interaction effect between two criteria is a physical relationship that exists such that a change in one criterion value will affect the value of the second criterion. Figure 29 depicts the process that transforms the physical relationship between criteria into a probability relationship that can be used in the Criterion Function modeling process. In Figure 29a, data points are plotted along the functional relationship that has been defined to exist between two (or more) criteria. The distance between the data points is dependent on the accuracy of the available data. These data points are then mapped into a Cumulative Distribution Function, Figure 29b, whose relationship is then used to transform the conditional probability statement into a functional relationship of the joint probability of the criteria interaction. This



From Conditional Probabilities:

$$F(x_1, x_2 | x_2) = \frac{F(x_1, x_2)}{F(x_2)}$$

Therefore: $F(x_1, x_2) = F(x_1, x_2 | x_2) * F(x_2)$

Fig. 29. Transformation of $g(x_1, x_2)$ to $F(x_1, x_2 | x_2)$.

is done using the standard Bayesian Probability Statement (Ostrofsky, 1977). Similar activities are accomplished for second, and higher, order interactions.

Model V

This criterion function model is identical to Model I except that it no longer assumes independence among criteria. In this case the model becomes:

$$CF = P(U \Theta_i); i = 1, \dots, n \quad \text{Equation (A-5)}$$

where:

$$\Theta_i = a_i X_i$$

therefore Equation (A-5) can be transformed to:

$$CF = \sum_i \delta_i \Theta_i - \sum_i \sum_j \delta_{ij} \Theta_{ij} \\ + \sum_i \sum_j \sum_k \dots \\ \pm \sum_i \sum_j \sum_k \dots \sum_{j+1} \delta_{ijk, \dots, j+1} \Theta_{ijk, \dots, j+1} \\ J \neq J + 1$$

$$\delta = 0, \text{ when } \Theta \text{ does not exist, and } 1, \text{ when } \Theta \text{ exists.}$$

The advantage of this model, and the other interaction model, is that it explicitly treats and evaluates the interaction effect that exists between criteria. The disadvantage comes in the difficulties in defining the relationship that exists between criteria and in obtaining accurate data that will facilitate the modeling activities.

Model VI

This model is similar to Model II in its use and computations except that criteria interactions have been added. Each interaction term is treated in the total criterion function in the same manner as the marginal criterion is treated in Model II.

Model VII

This model is similar to Model III in its use and computations except that criteria interactions have been added. Each interaction term is treated in the total criterion function in the same manner as the marginal criterion is treated in Model III.

Model VIII

This model is similar to Model IV in its use and computations except that criteria interactions have been added. Each interaction term is treated in the total criterion function in the same manner as the marginal criterion is treated in Model IV.

APPENDIX B

COMPUTER SUBROUTINES

The following subroutines contained in Figures 30 through 44 are those that were used to establish minimum and maximum value ranges for the submodels and criteria that were used in the modeling of the IRM system design case study. They are presented here to comprise a compact listing of routines used in the modeling activity. Figure 45 is a contents listing of the SuperCalc² Criterion Function Model Template.

```

C      ***** Z-21 'RELIABILITY OF DATA' *****
C      ***** Subroutine to Define Criterion 'CONTROL' *****
C      Y27 = Source of Data
C      Y29 = Intended Accuracy
C      Y33 = Interval Between Reports
C      ASSUMPTIONS:
C      1. Source of Data is the percent of External Data used.
C      2. Intended Accuracy is measured as a percent of Error.
C      3. Interval Between Reports (in days) as described by BMO
C          org's: 1, 2, 3, 5, 7, 10, 12, 14, 15, 22, 25, 30, 45,
C              60, 90, 120, 180, 365.
C
C      SUBROUTINE RELY21
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      DO 1 I27=1,10
C          Y27=FLOAT(I27)
C      DO 1 I29=1,25
C          Y29=FLOAT(I29)
C      DO 1 I33=1,18
C          IF (I33.EQ.1)   Y33 = 1
C          IF (I33.EQ.2)   Y33 = 2
C          IF (I33.EQ.3)   Y33 = 3
C          IF (I33.EQ.4)   Y33 = 5
C          IF (I33.EQ.5)   Y33 = 7
C          IF (I33.EQ.6)   Y33 = 10
C          IF (I33.EQ.7)   Y33 = 12
C          IF (I33.EQ.8)   Y33 = 14
C          IF (I33.EQ.9)   Y33 = 15
C          IF (I33.EQ.10)  Y33 = 22
C          IF (I33.EQ.11)  Y33 = 25
C          IF (I33.EQ.12)  Y33 = 30
C          IF (I33.EQ.13)  Y33 = 45
C          IF (I33.EQ.14)  Y33 = 60
C          IF (I33.EQ.15)  Y33 = 90
C          IF (I33.EQ.16)  Y33 = 120
C          IF (I33.EQ.17)  Y33 = 180
C          IF (I33.EQ.18)  Y33 = 365
C      Z21 = (EXP(-((Y27/10)*(Y29/100)*(Y33/365))))
21     IF (Z21.LT.FMIN) GO TO 20
20     IF (Z21.GT.FMAX) GO TO 30
21     GOTO 1
20     FMIN = Z21
21     GOTO 21
30     FMAX = Z21
1     CONTINUE
51     WRITE (6,51)FMAX,FMIN
51     FORMAT(1H0,'Z21 MAX = ',E12.5,5X,'Z21 MIN = ',E12.5)
RETURN
END

```

Fig. 30. Computer Printout of Submodel Reliability, z_{21} .

```

C      ***** Z-22 'SUPPORT FOR STANDARDS' *****
C      ***** Subroutine to Define Criterion 'CONTROL' *****
C
C      Y8 = Output Quality Rating
C      Y13 = # Applications with Common Data
C      Y14 = # Functions Served by the Application
C      Y15 = Proportion of Data in Shared Files
C
C      SUBROUTINE SUPPRT
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      DO 1 I8=1,5
C          Y8=FLOAT(I8)
C      DO 1 I13=1,10
C          Y13=FLOAT(I13)
C      DO 1 I14=1,14
C          Y14=FLOAT(I14)
C      DO 1 I15=1,10
C          Y15=FLOAT(I15)
C
C      Z22 = (Y8/5 * Y13/10 * Y14/14 * Y15/10)
C
C      IF (Z22.LT.FMIN) GO TO 20
C      IF (Z22.GT.FMAX) GO TO 30
C      GOTO 1
C      20  FMIN = Z22
C          GOTO 21
C      30  FMAX = Z22
C      1   CONTINUE
C      WRITE (6,51)FMAX,FMIN
C      51  FORMAT(1H0,'Z22 MAX = ',E12.5,5X,'Z22 MIN = ',E12.5)
C      RETURN
C      END

```

Fig. 31. Computer Printout of Submodel Support for Standards, z_{22} .

```

C      ***** Z-23 'INTEGRITY' *****
C      ***** Subroutine to Define Criterion 'CONTROL' *****
C
C      Y10 = Error Checking
C      Y11 = Security
C      Y12 = System Backup
C      Y28 = Influence of Information of Organization
C
C      ASSUMPTIONS:
C      1. Security is the percentage of the system requiring a
C         clearance or password.
C      2. System backup is the percentage of information that
C         requires backup of data or alternate means of processing.
C
C      SUBROUTINE INTEG
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      DO 1 I10=1,5
C         Y10=FLOAT(I10)
C      DO 1 I11=1,10
C         Y11=FLOAT(I11)
C      DO 1 I12=1,10
C         Y12=FLOAT(I12)
C      DO 1 I28=1,5
C         Y28=FLOAT(I28)
C
C      Z23 = (((Y10/5) * (Y28/5)) * Y11/10 * Y12/10)
C
C      IF (Z23.LT.FMIN) GO TO 20
C      IF (Z23.GT.FMAX) GO TO 30
C      GOTO 1
C      20  FMIN = Z23
C         GOTO 21
C      30  FMAX = Z23
C      1   CONTINUE
C      WRITE (6,51)FMAX,FMIN
C      51  FORMAT(1H0,'Z23 MAX = ',E12.5,5X,'Z23 MIN = ',E12.5)
C      RETURN
C      END

```

Fig. 32. Computer Printout of Submodel Integrity, z_{23} .

```

C      ***** Z-31 'QUALITY OF THE SYSTEM' *****
C      Subroutine to Define Criterion 'USER SATISFACTION'
C
C      Y8 = Output Quality Rating
C      Y16 = Input Quality Rating
C      Y17 = Online Performance Rating
C      Y18 = Capacity
C      Y19 = Response Time
C
C      ASSUMPTIONS:
C      1. Workload volumes from case study analysis are 40, 103,
C          140, 241, 263, 395, 608, 1957, 2240, 2661, and 3241.
C      2. Response time shall be evaluated from 1 second to
C          3 seconds, in half-second intervals.
C
C      SUBROUTINE QUAL
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      DO 1 I16=1,5
C          Y16=FLOAT(I16)
C      DO 1 I8=1,5
C          Y8=FLOAT(I8)
C      DO 1 I17=1,5
C          Y17=FLOAT(I17)
C      DO 1 I18=1,11
C          IF (I18.EQ.1) Y18= 40
C          IF (I18.EQ.2) Y18= 103
C          IF (I18.EQ.3) Y18= 140
C          IF (I18.EQ.4) Y18= 241
C          IF (I18.EQ.5) Y18= 263
C          IF (I18.EQ.6) Y18= 395
C          IF (I18.EQ.7) Y18= 608
C          IF (I18.EQ.8) Y18=1957
C          IF (I18.EQ.9) Y18=2240
C          IF (I18.EQ.10) Y18=2661
C          IF (I18.EQ.11) Y18=3241
C      DO 1 I19=10,30,5
C          Y19=FLOAT(I19)
C      Z31 = (((Y16 + Y8 + Y17)/15) * (1/(Y19/10)) * (Y18/3241))
21      IF (Z31.LT.FMIN) GO TO 20
C      IF (Z31.GT.FMAX) GO TO 30
C      GOTO 1
20      FMIN = Z31
C      GOTO 21
30      FMAX = Z31
1      CONTINUE
C      WRITE (6,51)FMAX,FMIN
51      FORMAT(1H0,'Z31 MAX = ',E12.5,5X,'Z31 MIN = ',E12.5)
C      RETURN
C      END

```

Fig. 33. Computer Printout of Submodel Quality of the System, Z₃₁.


```

C          ***** Z-32 'ATTITUDES & PERCEPTIONS' *****
C          Subroutine to Define Criterion 'USER SATISFACTION'
C
C          Y8 = Output Quality Rating
C          Y17 = Online Performance Rating
C          Y20 = Management Support
C          Y21 = Model Simplicity
C          Z31 = Quality of the System
C
C          SUBROUTINE ATT
C
C          FMIN=10.0**10
C          FMAX=-10.0**9
C          DO 1 I31=2,10,2
C             Z31=FLOAT(I31)
C          DO 1 I8=1,5
C             Y8=FLOAT(I8)
C          DO 1 I17=1,5
C             Y17=FLOAT(I17)
C          DO 1 I20=1,5
C             Y20=FLOAT(I20)
C          DO 1 I21=1,5
C             Y21=FLOAT(I21)
C
C          Z32 = (((Y8 + Y17 + Y20 + Y21)/20) * (Z31/10))
C
C          IF (Z32.LT.FMIN) GO TO 20
C          IF (Z32.GT.FMAX) GO TO 30
C          GOTO 1
C          20  FMIN = Z32
C             GOTO 21
C          30  FMAX = Z32
C          1   CONTINUE
C          WRITE (6,51)FMAX,FMIN
C          51  FORMAT(1H0,'Z32 MAX = ',E12.5,5X,'Z32 MIN = ',E12.5)
C          RETURN
C          END

```

Fig. 34. Computer Printout of Submodel Attitudes and Perceptions, z_{32} .

```

C          ***** Z-33 'DECISION STYLE' *****
C          Subroutine to Define Criterion 'USER SATISFACTION'
C
C          Y22 = Number of Inquiries
C          Y23 = User's Technical Orientation
C          Z32 = Attitudes & Perceptions
C
C          ASSUMPTIONS:
C
C          1. The number of inquiries will be within the range 1 -> 20.
C          2. User's Technical Orientation ranges from "High Analytic"
C             (1) to "Low Analytic" (5).
C          3. The assumption is made that the decision maker will make
C             no more than 4 times the 'User's Technical Orientation
C             value' system inquiries.
C
C          SUBROUTINE STYLE
C
C          FMIN=10.0**10
C          FMAX=-10.0**9
C          DO 1 I22=1,20
C             Y22=FLOAT(I22)
C          DO 1 I23=1,5
C             Y23=FLOAT(I23)
C          DO 1 I32=2,10,2
C             Z32=FLOAT(I32)
C
C          IF (4*Y23.GT.Y22) GO TO 1
C
C          Z33 = ((Z32/10) * ((4*Y23)/Y22))
C
C          IF (Z33.LT.FMIN) GO TO 20
C          IF (Z33.GT.FMAX) GO TO 30
C          GOTO 1
C          20 FMIN = Z33
C             GOTO 21
C          30 FMAX = Z33
C             1 CONTINUE
C          WRITE (6,51)FMAX,FMIN
C          51 FORMAT(1H0,'Z33 MAX = ',E12.5,5X,'Z33 MIN = ',E12.5)
C          RETURN
C          END

```

Fig. 35. Computer Printout of Submodel Decision Style, z₃₃.

```

C          ***** Z-34 'SITUATIONAL FACTORS' *****
C          Subroutine to Define Criterion 'USER SATISFACTION'
C
C          Y14 = Number of Functions Served by an Application
C          Y24 = User's Time in the Job
C          Y25 = User's Education Level
C          Y26 = User's Age
C
C          SUBROUTINE FACTOR
C
C          FMIN=10.0**10
C          FMAX=-10.0**9
C          DO 1 I14=1,14
C             Y14=FLOAT(I14)
C          DO 1 I24=1,5
C             Y24=FLOAT(I24)
C          DO 1 I25=1,5
C             Y25=FLOAT(I25)
C          DO 1 I26=1,5
C             Y26=FLOAT(I26)
C
C          Z34 = ((1/Y24) * (Y25/5) * (1/Y26) * (Y14/14))
C
C          IF (Z34.LT.FMIN) GO TO 20
C          IF (Z34.GT.FMAX) GO TO 30
C          GOTO 1
C          20  FMIN = Z34
C             GOTO 21
C          30  FMAX = Z34
C          1   CONTINUE
C          WRITE (6,51)FMAX,FMIN
C          51  FORMAT(1H0,'Z34 MAX = ',E12.5,5X,'Z34 MIN = ',E12.5)
C          RETURN
C          END

```

Fig. 36. Computer Printout of Submodel Situational Factors, z_{34} .

```

C      ***** Z-41 'RELIABILITY OF DATA' *****
C      **** Subroutine to Define Criterion 'USEFULNESS' ****
C      Y27 = Source of Data
C      Y29 = Intended Accuracy
C      Y33 = Interval Between Reports
C      ASSUMPTIONS:
C      1. Source of Data is the percent of External Data used.
C      2. Intended Accuracy is measured as a percent of Error.
C         (Data interval is 0.2)
C      3. Interval Between Reports (in days) as described by BMD
C         org's: 1, 2, 3, 5, 7, 10, 12, 14, 15, 22, 25, 30, 45,
C         60, 90, 120, 180, 365.
C
SUBROUTINE RELY4
FMIN=10.0**10
FMAX=-10.0**9
DO 1 I27=1,10
  Y27=FLOAT(I27)
DO 1 I29=1,25,2
  Y29=FLOAT(I29)
DO 1 I33=1,18
  IF (I33.EQ.1) Y33 = 1
  IF (I33.EQ.2) Y33 = 2
  IF (I33.EQ.3) Y33 = 3
  IF (I33.EQ.4) Y33 = 5
  IF (I33.EQ.5) Y33 = 7
  IF (I33.EQ.6) Y33 = 10
  IF (I33.EQ.7) Y33 = 12
  IF (I33.EQ.8) Y33 = 14
  IF (I33.EQ.9) Y33 = 15
  IF (I33.EQ.10) Y33 = 22
  IF (I33.EQ.11) Y33 = 25
  IF (I33.EQ.12) Y33 = 30
  IF (I33.EQ.13) Y33 = 45
  IF (I33.EQ.14) Y33 = 60
  IF (I33.EQ.15) Y33 = 90
  IF (I33.EQ.16) Y33 = 120
  IF (I33.EQ.17) Y33 = 180
  IF (I33.EQ.18) Y33 = 365
Z41 = (EXP(-(Y27/10) * (Y29/100) * (Y33/365)))
IF (Z41.LT.FMIN) GO TO 20
21 IF (Z41.GT.FMAX) GO TO 30
  GOTO 1
20 FMIN = Z41
  GOTO 21
30 FMAX = Z41
1 CONTINUE
WRITE (6,51)FMAX,FMIN
51 FORMAT(1H0,'Z41 MAX = ',E12.5,5X,'Z41 MIN = ',E12.5)
RETURN
END

```

Fig. 37. Computer Printout of Submodel Reliability ,z₄₁.

```

C          ***** Z-42 'FLEXIBILITY' *****
C          **** Subroutine to Define Criterion 'USEFULNESS' ****
C
C          Y9 = Activity Time Allocation
C          Y14 = # of Functions Served by the Application
C          Y17 = Online Performance Rating
C
C          ASSUMPTIONS:
C          1. Activity Time Allocation is percent of the day a
C             manager spends on a particular function.
C          2. # of Functions Served is the number of managerial
C             activities directly supported by the IRM system.
C
C          SUBROUTINE FLEX
C
C          FMIN=10.0**10
C          FMAX=-10.0**9
C          DO 1 I9=1,12
C             Y9=FLOAT(I9)
C          DO 1 I14=1,14
C             Y14=FLOAT(I14)
C          DO 1 I17=1,5
C             Y17=FLOAT(I17)
C
C          Z42 = (EXP(-(((Y9/100) * (Y14/14)) / (Y17/5))))
C
C          IF (Z42.LT.FMIN) GO TO 20
C          IF (Z42.GT.FMAX) GO TO 30
C          GOTO 1
C          20  FMIN = Z42
C             GOTO 21
C          30  FMAX = Z42
C          1   CONTINUE
C          WRITE (6,51)FMAX,FMIN
C          51  FORMAT(1H0,'Z42 MAX = ',E12.5,5X,'Z42 MIN = ',E12.5)
C          RETURN
C          END

```

Fig. 38. Computer Printout of Submodel Flexibility, z_{42} .

```

C      ***** Z-43 'AVAILABILITY' *****
C      **** Subroutine to Define Criterion 'USEFULNESS' ****
C
C      Y30 = Total Time
C      Y31 = Downtime
C
C      ASSUMPTIONS:
C      1. Total system time during a month = 160 hours.
C      2. Downtime is a percentage of Total time which includes;
C         a.) Routine Preventive Maintenance, and
C         b.) Unscheduled Maintenance and Repairs.
C
C      SUBROUTINE AVAIL
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      Y30=160.0
C      DO 1 I31=5,25
C         Y31=FLOAT(I31)
C
C      Z43 = ((Y30 - (Y31/100)) / Y30)
C
C      IF (Z43.LT.FMIN) GO TO 20
C      IF (Z43.GT.FMAX) GO TO 30
C      GOTO 1
C      20  FMIN = Z43
C         GOTO 21
C      30  FMAX = Z43
C      1   CONTINUE
C      WRITE (6,51)FMAX,FMIN
C      51  FORMAT(1H0,'Z43 MAX = ',E12.5,5X,'Z43 MIN = ',E12.5)
C      RETURN
C      END

```

Fig. 39. Computer Printout of Submodel Availability, z_{43} .

```

C      ***** Z-44 'AVERAGE AGE OF INFORMATION' *****
C      ***** Subroutine to Define Criterion 'USEFULNESS' ***
C
C      Y32 = Type of Data (Condition or Operating) [0 or 1]
C      Y33 = Interval Between Reports [Days]
C              (per case study data - 1, 2, 3, 5, 7, 10, 12, 14, 15,
C              22, 25, 30, 45, 60, 90, 120, 180, and 365 days.)
C      Y34 = Processing Delay [Days]
C
C      SUBROUTINE AGE
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      DO 1 I32=0,1
C          Y32=FLOAT(I32)
C      DO 1 I33=1,18
C          IF (I33.EQ.1) Y33 = 1
C          IF (I33.EQ.2) Y33 = 2
C          IF (I33.EQ.3) Y33 = 3
C          IF (I33.EQ.4) Y33 = 5
C          IF (I33.EQ.5) Y33 = 7
C          IF (I33.EQ.6) Y33 = 10
C          IF (I33.EQ.7) Y33 = 12
C          IF (I33.EQ.8) Y33 = 14
C          IF (I33.EQ.9) Y33 = 15
C          IF (I33.EQ.10) Y33 = 22
C          IF (I33.EQ.11) Y33 = 25
C          IF (I33.EQ.12) Y33 = 30
C          IF (I33.EQ.13) Y33 = 45
C          IF (I33.EQ.14) Y33 = 60
C          IF (I33.EQ.15) Y33 = 90
C          IF (I33.EQ.16) Y33 = 120
C          IF (I33.EQ.17) Y33 = 180
C          IF (I33.EQ.18) Y33 = 365
C      DO 1 I34=1,7
C          Y35=FLOAT(I34)
C
C      Z44 = (Y34 + ((Y32 * Y33/2) + Y33/2))
C
C      IF (Z44.LT.FMIN) GO TO 20
C      IF (Z44.GT.FMAX) GO TO 30
C      GOTO 1
C      20  FMIN = Z44
C          GOTO 21
C      30  FMAX = Z44
C      1   CONTINUE
C      WRITE (6,51)FMAX,FMIN
C      51  FORMAT(1H0,'Z44 MAX = ',E12.5,5X,'Z44 MIN = ',E12.5)
C      RETURN
C      END

```

Fig. 40. Computer Printout for Submodel Average Age of Information, z_{44} .

```

C      ***** X-1 COMPARATIVE COSTS *****
C      * Subroutine to Define Criterion 'COMPARATIVE COST' *
C      Y1 = New Equipment & Software Costs
C      Y2 = Installation Costs
C      Y3 = Recurring Maintenance Costs
C      Y4 = Baseline Cost with IRM
C      Y5 = Baseline Cost without IRM
C      Y6 = Recurring Supply Costs
C      Y7 = Productivity Gain Estimate
C
C      SUBROUTINE COST
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      DO 1 I1=1,3
C          IF (I1.EQ.1) Y1=1142
C          IF (I1.EQ.2) Y1=1356
C          IF (I1.EQ.3) Y1=2045
C      DO 1 I2=1,2
C          IF (I2.EQ.1) Y2=16
C          IF (I2.EQ.2) Y2=187
C      DO 1 I3=1,3
C          IF (I3.EQ.1) Y3=1159
C          IF (I3.EQ.2) Y3=1174
C          IF (I3.EQ.3) Y3=1635
C      DO 1 I4=1,3
C          IF (I4.EQ.1) Y4=348993
C          IF (I4.EQ.2) Y4=352876
C          IF (I4.EQ.3) Y4=345824
C      Y5=369077
C      DO 1 I6=1,2
C          IF (I6.EQ.1) Y6=1543
C          IF (I6.EQ.2) Y6=1892
C      DO 1 I7=1,3
C          IF (I7.EQ.1) Y7=4600
C          IF (I7.EQ.2) Y7=6560
C          IF (I7.EQ.3) Y7=7648
C      X1 = (Y5 - (Y1 + Y2 + Y3 + Y4 + Y6 - Y7)) * 1000
C      WRITE (6,50)X1
50     FORMAT(1H0,E12.5)
C      IF (X1.LT.FMIN) GO TO 20
21     IF (X1.GT.FMAX) GO TO 30
C      GOTO 1
20     FMIN = X1
C      GOTO 21
30     FMAX = X1
1      CONTINUE
C      WRITE (6,51)FMAX,FMIN
51     FORMAT(1H0,'X1 MAX = ',E12.5,5X,'X1 MIN = ',E12.5)
C      RETURN
C      END

```

Fig. 41. Computer Printout of Criterion Comparative Cost, x_1 .


```

C      ***** X-2 'CONTROL' *****
C      **** Subroutine to Calculate Criterion 'CONTROL' ****
C
C      This subroutine combines Submodels Z21, Z22, and Z23
C      to determine Min and Max values for the Criterion
C      CONTROL (X2).
C
C      ASSUMPTIONS:
C      1. The multiplicative combination of submodels Z21, Z22,
C         and Z23 adequately represents the criterion 'Control.'
C      2. The submodels are independent.
C
C      SUBROUTINE CONTRL
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      DO 1 I21=78,100,2
C         Z21=FLOAT(I21)
C      DO 1 I22=0,10,2
C         Z22=FLOAT(I22)
C      DO 1 I23=0,10,2
C         Z23=FLOAT(I23)
C
C      X2 = (Z21/100 * Z22/10 * Z23/10)
C
C      IF (X2.LT.FMIN) GO TO 20
C      IF (X2.GT.FMAX) GO TO 30
C      GOTO 1
C      20  FMIN = X2
C         GOTO 21
C      30  FMAX = X2
C      1   CONTINUE
C      51  WRITE (6,51)FMAX,FMIN
C      FORMAT(1H0,'X2 MAX = ',E12.5,5X,'X2 MIN = ',E12.5)
C      RETURN
C      END

```

Fig. 42. Computer Printout of Criterion Control, x_2 .

```

C      ***** X-3 'USER SATISFACTION' *****
C      Subroutine to Calculate Criterion 'User Satisfaction'
C
C      This subroutine combines Submodels Z31, Z32, Z33, and Z34
C      to determine Min and Max values for the Criterion X3.
C
C      ASSUMPTIONS:
C      1. The multiplicative combination of submodels Z31, Z32,
C          Z33, and Z34 adequately represents the criterion 'User
C          Satisfaction.'
C      2. The submodels are independent.
C
C      SUBROUTINE USAT
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      DO 1 I31=2,10,2
C          Z31=FLOAT(I31)
C      DO 1 I32=2,10,2
C          Z32=FLOAT(I32)
C      DO 1 I33=2,10,2
C          Z33=FLOAT(I33)
C      DO 1 I34=2,10,2
C          Z34=FLOAT(I34)
C
C      X3 = ((Z31/10) * (Z32/10) * (Z33/10) * ( Z34/10))
C
C      IF (X3.LT.FMIN) GO TO 20
C      IF (X3.GT.FMAX) GO TO 30
C      GOTO 1
C      20  FMIN = X3
C          GOTO 21
C      30  FMAX = X3
C      1   CONTINUE
C          WRITE (6,51)FMAX,FMIN
C      51  FORMAT(1H0,'X3 MAX = ',E12.5,5X,'X3 MIN = ',E12.5)
C          RETURN
C          END

```

Fig. 43. Computer Printout of Criterion User Satisfaction, x_3 .

```

C      ***** X-4 'USEFULNESS' *****
C      *** Subroutine to Calculate Criterion 'USEFULNESS' **
C
C      This subroutine combines Parameter, Y8, and Submodels,
C      Z41, Z42, Z43, and Z44 to determine Min and Max values
C      for the Criterion X4.
C
C      A "Sequential Optimization" procedure is used to derive X4min
C      and X4max.
C
C      ASSUMPTIONS:
C      1. The multiplicative combination of parameter Y8 and
C          submodels Z41, Z42, Z43 and Z44 adequately represents
C          the criterion 'Usefulness.'
C      2. The submodels and parameter Y8 are independent.
C
C      SUBROUTINE USEFUL
C
C      FMIN=10.0**10
C      FMAX=-10.0**9
C      Y8=1
C      Z41=78
C      Z42=55
C      Z43=75
C      DO 1 I35=0,1
C          Y35=FLOAT(I35)
C      DO 1 I36=1,18
C          IF (I36.EQ.1) Y36=1
C          IF (I36.EQ.2) Y36=2
C          IF (I36.EQ.3) Y36=3
C          IF (I36.EQ.4) Y36=5
C          IF (I36.EQ.5) Y36=7
C          IF (I36.EQ.6) Y36=10
C          IF (I36.EQ.7) Y36=12
C          IF (I36.EQ.8) Y36=14
C          IF (I36.EQ.9) Y36=15
C          IF (I36.EQ.10) Y36=22
C          IF (I36.EQ.11) Y36=25
C          IF (I36.EQ.12) Y36=30
C          IF (I36.EQ.13) Y36=45
C          IF (I36.EQ.14) Y36=60
C          IF (I36.EQ.15) Y36=90
C          IF (I36.EQ.16) Y36=120
C          IF (I36.EQ.17) Y36=180
C          IF (I36.EQ.18) Y36=365
C      DO 1 I37=1,7
C          Y37=FLOAT(I37)
C
C      Z44 = (Y37 + ((Y35 * Y36/2) + Y36/2))
C

```

Fig. 44. Computer Printout of Criterion Usefulness, x_4 .

```

      X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))
C
      IF (X4.LT.FMIN) GO TO 120
121     IF (X4.GT.FMAX) GO TO 130
      GOTO 1
120     FMIN = X4
      Z44MIN = Z44
      GOTO 121
130     FMAX = X4
Z44MAX = Z44
1     CONTINUE
      Z44 = Z44MIN
      DO 2 I43=75,95,5
        Z43=FLOAT(I43)
C
      X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))
C
      IF (X4.LT.FMIN) GO TO 220
221     IF (X4.GT.FMAX) GO TO 230
      GOTO 2
220     FMIN = X4
      Z43MIN = Z43
      GOTO 221
230     FMAX = X4
      Z43MAX = Z43
2     CONTINUE
      Z43=Z43MIN
      DO 3 I42=55,100,5
        Z42=FLOAT(I42)
C
      X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))
C
      IF (X4.LT.FMIN) GO TO 320
321     IF (X4.GT.FMAX) GO TO 330
      GOTO 3
320     FMIN = X4
      Z42MIN = Z42
      GOTO 321
330     FMAX = X4
      Z42MAX = Z42
3     CONTINUE
      Z42=Z42MIN
      DO 4 I41=78,100,2
        Z41=FLOAT(I41)
C
      X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))

```

Fig. 44. Computer Printout of Criterion Usefulness, x_4 (cont.).

```

C
  IF (X4.LT.FMIN) GO TO 420
421  IF (X4.GT.FMAX) GO TO 430
      GOTO 4
420  FMIN = X4
      Z41MIN = Z41
      GOTO 421
430  FMAX = X4
      Z41MAX = Z41
4     CONTINUE
      Z41=Z41MIN
      DO 5 I8=1,5
          Y8=FLOAT(I8)
C
      X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))
C
  IF (X4.LT.FMIN) GO TO 520
521  IF (X4.GT.FMAX) GO TO 530
      GOTO 5
520  FMIN = X4
      Y8MIN = Y8
      GOTO 521
530  FMAX = X4
      Y8MAX = Y8
5     CONTINUE
C
C     START FMAX CALCULATIONS
C
      Y8=Y8MAX
      Z41=Z41MAX
      Z42=Z42MAX
      Z44=Z44MAX
      DO 6 I43=75,95,5
          Z43=FLOAT(I43)
C
      X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))
C
  IF (X4.LT.FMIN) GO TO 620
621  IF (X4.GT.FMAX) GO TO 630
      GOTO 6
620  FMIN = X4
      Z43MIN = Z43
      GOTO 621
630  FMAX = X4
      Z43MAX = Z43
6     CONTINUE
      Z43=Z43MAX

```

Fig. 44. Computer Printout of Criterion Usefulness, x_4 (cont.).

```

DO 7 I42=55,100,5
  Z42=FLOAT(I42)
C
  X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))
C
  IF (X4.LT.FMIN) GO TO 720
721  IF (X4.GT.FMAX) GO TO 730
      GOTO 7
720  FMIN = X4
      Z42MIN = Z42
      GOTO 721
730  FMAX = X4
      Z42MAX = Z42
7     CONTINUE
      Z42=Z42MAX
      DO 8 I41=78,100,2
        Z41=FLOAT(I41)
C
        X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))
C
        IF (X4.LT.FMIN) GO TO 820
821  IF (X4.GT.FMAX) GO TO 830
      GOTO 8
820  FMIN = X4
      Z41MIN = Z41
      GOTO 821
830  FMAX = X4
      Z41MAX = Z41
8     CONTINUE
      Z41=Z41MAX
      DO 9 I8=1,5
        Y8=FLOAT(I8)
C
        X4=(EXP(-(((Z41/100) * Z42/100 *
# Z43/100*(Z44/365))/(Y8/5))))
C
        IF (X4.LT.FMIN) GO TO 920
921  IF (X4.GT.FMAX) GO TO 930
      GOTO 9
920  FMIN = X4
      Y8MIN = Y8
      GOTO 921
930  FMAX = X4
      Y8MAX = Y8
9     CONTINUE
      WRITE (6,51)FMAX,FMIN
51    FORMAT(1H0,'X4 MAX = ',E12.5,5X,'X4 MIN = ',E12.5)
      RETURN
      END

```

Fig. 44. Computer Printout of Criterion Usefulness, x_4 (cont.).

```

PARAMETER values:
A1      = "PARAMETER values:
A2      = "      Y1
B2      = "      Y2
C2      = "      Y3
D2      = "      Y4
E2      = "      Y5
F2      = "      Y6
G2      = "      Y7
H2      = "      Y8
A3      = 1356
B3      = 16
C3      = 1159
D3      = 345824
E3      = 369077
F3      = 1543
G3      = 4600
H3      = 1
A4      = "      Y9
B4      = "      Y10
C4      = "      Y11
D4      = "      Y12
E4      = "      Y13
F4      = "      Y14
G4      = "      Y15
H4      = "      Y16
A5      = .0059
B5      = 1
C5      = .1
D5      = .1
E5      = .1
F5      = 1
G5      = .1
H5      = 1
A6      = "      Y17
B6      = "      Y18
C6      = "      Y19
D6      = "      Y20
E6      = "      Y21
F6      = "      Y22
G6      = "      Y23
H6      = "      Y24
A7      = 1
B7      = 40
C7      = 1
D7      = 1
E7      = 1
F7      = 5
G7      = 1
H7      = 1

```

Fig. 45. SuperCalc² Contents Listing for Criterion Function Model.

```

A8      = "      Y25
B8      = "      Y26
C8      = "      Y27
D8      = "      Y28
E8      = "      Y29
F8      = "      Y30
G8      = "      Y31
H8      = "      Y32
A9      = 1
B9      = 1
C9      = .1
D9      = 1
E9      = .01
F9      = 160
G9      = .05
H9      = 0
A10     = "      Y33
B10     = "      Y34
A11     = 1
B11     = 1
A12     = "-----
B12     = "-----
C12     = "-----
D12     = "-----
E12     = "-----
F12     = "-----
G12     = "-----
H12     = "-----
A13     = "SUBMODEL values:
A14     = "      Z21
B14     = "      Z22
C14     = "      Z23
A15 1   = 2.71828^(-((C9)*(E9)*(A11/365)))
B15 1   = (H3/5)*(E5)*(F5/14)*(G5)
C15 1   = (((B5/5)*(D9/5))*C5*D5)
D15 1   =
A16 1   = "      Z31
B16 1   = "      Z32
C16 1   = "      Z33
D16 1   = "      Z34
A17 1   = (((H5+H3+A7)/15)*(1/C7)*(B7/3241))
B17 1   = (((H3+A7+D7+E7)/20)*(A17))
C17 1   = IF(4*G7>F7,9999999999,(B17*((4*G7)/F7)))
D17 1   = ((1/H7)*(A9/5)*(1/B9)*(F5/14))
A18 1   = "      Z41
B18 1   = "      Z42
C18 1   = "      Z43
D18 1   = "      Z44

```

Fig. 45. SuperCalc² Contents Listing for Criterion Function Model (cont.).


```

A19 1      = 2.71828^(-((C9)*(E9)*(A11/365)))
B19 1      = (2.71828^(-(((A5)*(F5/14))/(A7/5))))
C19 1      = ((F9-(G9*F9))/F9)
D19 1      = (B11+((H9*A11/2)+A11/2))
A20 1      = "-----
B20 1      = "-----
C20 1      = "-----
D20 1      = "-----
E20        = "-----
F20        = "-----
G20        = "-----
H20        = "-----
A21        = "CRITERION values:
A22        = "      x1
B22        = "      x2
C22        = "      x3
D22        = "      x4
A23 I      = (E3-(A3+B3+C3+D3+F3-G3))*1000
B23 1      = (A15)*(B15)*(C15)
C23 1      = A17*B17*C17*D17
D23 1      = (2.71828^(-((A19*B19*C19*(D19/365))/(H3/5))))
A24        = "      X1
B24        = "      X2
C24        = "      X3
D24        = "      X4
A25 1      = ((E3-(A3+B3+C3+D3+F3-G3))-15042)/(27041-15042)
B25 1      = IF(B23<.1008,0,((A15)*(B15)*(C15)-.1008)
            /(1.0-.1008))
C25 1      = IF(C23<.0016,0,((A17*B17*C17*D17)-.0016)
            /(1.0-.0016))
D25 1      = ((2.71828^(-((A19*B19*C19*(D19/365)
            /(H3/5))))-.0079)/(.9987-.0079)
A26        = "-----
B26        = "-----
C26        = "-----
D26        = "-----
E26        = "-----
F26        = "-----
G26        = "-----
H26        = "-----
A27        = "FUNCTION values:
A28        = "  F(X1)
B28        = "  F(X2)
C28        = "  F(X3)
D28        = "  F(X4)
A29 1      = -0.0720+1.0752*A25
B29 1      = 1-2.71828^(-(2.8875*B25))
C29 1      = 1-2.71828^(-(8.6625*C25))
D29 1      = IF(D25>.9223,D25^9,(-.007+.421*D25))

```

Fig. 45. SuperCalc² Contents Listing for Criterion Function Model (cont.).

```

A30 1      = " F(X12)
B30 1      = " F(X23)
C30 1      = " F(X24)
D30 1      = " F(X34)
A31 1      = (-0.0216+1.0021*A25)*A29
B31 1      = (-.0015+1.0015*C25)*C29
C31 1      = (-.0078+1.0089*D25)*D29
D31 1      = (1.003*(C25)^2)*C29
A32 1      = " F(X123)
B32 1      =
C32 1      =
D32 1      =
A33 1      = (1.003*(C25)^2)*C29
B33 1      =
C33 1      =
D33 1      =
A34        = "-----
B34        = "-----
C34        = "-----
D34        = "-----
E34        = "-----
F34        = "-----
G34        = "-----
H34        = "-----
A35        = "CF value:
B36 1      = .098*A29+.11*B29+.112*C29+.113*D29-.096*A31
           - .11*B31-.116*C31-.127*D31+.118*A33
A37        = "-----
B37        = "-----
C37        = "-----
D37        = "-----
E37        = "-----
F37        = "-----
G37        = "-----
H37        = "-----

```

Fig. 45. SuperCalc² Contents Listing for Criterion Function Model (cont.).

APPENDIX C

CRITERION FUNCTION OPTIMIZATION PROGRAM

Introduction

The purpose of this research is to develop a Structured Optimization Method that is applicable to Information Resource Management System design. The following FORTRAN program implements the Criterion Function Modeling procedure by searching the 35-dimensional design space of the sample problem and tabulates the parameter values for each of the top five performing candidate systems. The program is initialized with starting values for each of the first 33 parameters. These values are used in conjunction with a set of values for the 34th parameter to calculate a value for the Criterion Function (CF) using Equation (5-26). The calculations are accomplished in the subroutine "CALCS." The resulting CF value is compared to CF values in a table containing the five "best" CF values using subroutine "BEST5."

To demonstrate method, five data values for each of the 34 defined parameters were used. These values were taken at the established Minimum and Maximum parameter values and at defined values 25%, 50%, and 75% of the range from minimum to maximum. In an actual application of this structured optimization method the designer-planner would use parameter values that are appropriate for the accuracy of the data available.

The first iteration of the program calculates CF values from the initial values of the first 33 parameters and the five values for parameter 34. These five values are stored in the "BEST5" table. The second iteration then combines the five values for parameter 33 with the five values for parameter 34 and the initial values for parameters 1 through 32. Again, a CF value is calculated for each pairing of values from parameters 33 and 34. The five "best" Criterion Function values are stored in the table along with the parameter values that generated those values. The third iteration then combines the five values for parameter 32 with the five parameter 33 and 34 pairs of values to generate new CF values. Again, the five "best" CF values are saved.

At each step through the 34 parameters from bottom to top the five groupings of parameter values which generated the "best" CF values are saved and used at the next iteration. A tabulated listing is made after all 34 parameters have been evaluated which identifies the five "best" candidate systems and the parameter values associated with each.

The program is run five times, setting the initial parameter values to each of their respective values from minimum to maximum. Again, it should be noted that the designer-planner would use that interval of data values that is appropriate for the accuracy of the data being used to generate the Criterion Function values.

```

C   IRM Design Optimization Program
C   Parameter values taken at Min, 25%, 50%, 75%, and Max values
#   DIMENSION Y(34),YA(34),YB(34),YC(34),YD(34),YE(34),
#       YAT(34),YBT(34),YCT(34),YDT(34),YET(34)
C   CFMAX=-1.0
C   INITIAL PARAMETER VALUES ESTABLISHED
Y(1)=2045
Y(2)=187
Y(3)=1174
Y(4)=352876
Y(5)=369077
Y(6)=1892
Y(7)=7648
Y(8)=5
Y(9)=13
Y(10)=5
Y(11)=10
Y(12)=10
Y(13)=10
Y(14)=14
Y(15)=10
Y(16)=5
Y(17)=5
Y(18)=3241
Y(19)=3
Y(20)=5
Y(21)=5
Y(22)=20
Y(23)=5
Y(24)=5
Y(25)=5
Y(26)=5
Y(27)=10
Y(28)=5
Y(29)=25
Y(30)=160
Y(31)=25
Y(32)=1
Y(33)=365
CFT1=0
CFT2=0
CFT3=0
CFT4=0
CFT5=0
C   > START CALCULATIONS WITH Y34 <
DO 1 I34=1,5
  IF (I34.EQ.1) Y(34) = 1
  IF (I34.EQ.2) Y(34) = 3
  IF (I34.EQ.3) Y(34) = 4
  IF (I34.EQ.4) Y(34) = 5
  IF (I34.EQ.5) Y(34) = 7
CALL CALCS (Y,I,CF)
101 CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,

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#          YB,I,YC,I,YD,I,YE,I)
1  CONTINUE
C  > CALCULATIONS TO INCLUDE Y33 <
   DO 111 I=34,34
   YAT(I) = YA(I)
   YBT(I) = YB(I)
   YCT(I) = YC(I)
   YDT(I) = YD(I)
   YET(I) = YE(I)
111 CONTINUE
   DO 2 I33=1,5
     IF (I33.EQ.1) Y(33) = 1
     IF (I33.EQ.2) Y(33) = 7
     IF (I33.EQ.3) Y(33) = 15
     IF (I33.EQ.4) Y(33) = 60
     IF (I33.EQ.5) Y(33) = 365
   DO 2 I34=1,5
     IF (I34.EQ.1) Y(34) = YAT(34)
     IF (I34.EQ.2) Y(34) = YBT(34)
     IF (I34.EQ.3) Y(34) = YCT(34)
     IF (I34.EQ.4) Y(34) = YDT(34)
     IF (I34.EQ.5) Y(34) = YET(34)
   CALL CALCS (Y,I,CF)
201 CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#          YB,I,YC,I,YD,I,YE,I)
2  CONTINUE
C  > CALCULATIONS TO INCLUDE Y32 <
   DO 112 I=33,34
   YAT(I) = YA(I)
   YBT(I) = YB(I)
   YCT(I) = YC(I)
   YDT(I) = YD(I)
   YET(I) = YE(I)
112 CONTINUE
   DO 3 I32=1,2
     IF (I32.EQ.1) Y(32) = 0
     IF (I32.EQ.2) Y(32) = 1
   DO 3 J=1,5
     IF (J.EQ.1) GO TO 151
     IF (J.EQ.2) GO TO 152
     IF (J.EQ.3) GO TO 153
     IF (J.EQ.4) GO TO 154
     IF (J.EQ.5) GO TO 155
150 CALL CALCS (Y,I,CF)
   GO TO 170
151 DO 161 I=33,34
   Y(I)=YAT(I)
161 CONTINUE
   GO TO 150
152 DO 162 I=33,34
   Y(I)=YBT(I)
162 CONTINUE
   GO TO 150

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153      DO 163 I=33,34
          Y(I)=YCT(I)
163      CONTINUE
          GO TO 150
154      DO 164 I=33,34
          Y(I)=YDT(I)
164      CONTINUE
          GO TO 150
155      DO 165 I=33,34
          Y(I)=YET(I)
165      CONTINUE
          GO TO 150
170      CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#          YB,I,YC,I,YD,I,YE,I)
3      CONTINUE
C      > CALCULATIONS TO INCLUDE Y31 <
          DO 113 I=32,34
              YAT(I) = YA(I)
              YBT(I) = YB(I)
              YCT(I) = YC(I)
              YDT(I) = YD(I)
              YET(I) = YE(I)
113      CONTINUE
          DO 4 I31=1,5
              Y(31) = I31*5
          DO 4 J=1,5
              IF (J.EQ.1) GO TO 251
              IF (J.EQ.2) GO TO 252
              IF (J.EQ.3) GO TO 253
              IF (J.EQ.4) GO TO 254
              IF (J.EQ.5) GO TO 255
250      CALL CALCS (Y,I,CF)
          GO TO 270
251      DO 261 I=32,34
          Y(I)=YAT(I)
261      CONTINUE
          GO TO 250
252      DO 262 I=32,34
          Y(I)=YBT(I)
262      CONTINUE
          GO TO 250
253      DO 263 I=32,34
          Y(I)=YCT(I)
263      CONTINUE
          GO TO 250
254      DO 264 I=32,34
          Y(I)=YDT(I)
264      CONTINUE
          GO TO 250
255      DO 265 I=32,34
          Y(I)=YET(I)
265      CONTINUE
          GO TO 250

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270     CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#         YB, I, YC, I, YD, I, YE, I)
4     CONTINUE
C   > Y30 IS A CONSTANT <
      DO 114 I=31, 34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
114    CONTINUE
      Y(30) = 160
      DO 5 J=1, 5
          IF (J.EQ.1) GO TO 351
          IF (J.EQ.2) GO TO 352
          IF (J.EQ.3) GO TO 353
          IF (J.EQ.4) GO TO 354
          IF (J.EQ.5) GO TO 355
350    CALL CALCS (Y, I, CF)
      GO TO 370
351    DO 361 I=31, 34
      Y(I)=YAT(I)
361    CONTINUE
      GO TO 350
352    DO 362 I=31, 34
      Y(I)=YBT(I)
362    CONTINUE
      GO TO 350
353    DO 363 I=31, 34
      Y(I)=YCT(I)
363    CONTINUE
      GO TO 350
354    DO 364 I=31, 34
      Y(I)=YDT(I)
364    CONTINUE
      GO TO 350
355    DO 365 I=31, 34
      Y(I)=YET(I)
365    CONTINUE
      GO TO 350
370    CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#         YB, I, YC, I, YD, I, YE, I)
5     CONTINUE
C   > CALCULATIONS TO INCLUDE Y29 <
      DO 115 I=30, 34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
115    CONTINUE
      DO 6 I29=1, 5
          IF (I29.EQ.1) Y(29) = 1

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      IF (I29.EQ.2) Y(29) = 7
      IF (I29.EQ.3) Y(29) = 13
      IF (I29.EQ.4) Y(29) = 19
      IF (I29.EQ.5) Y(29) = 25

      DO 6 J=1,5
        IF (J.EQ.1) GO TO 451
        IF (J.EQ.2) GO TO 452
        IF (J.EQ.3) GO TO 453
        IF (J.EQ.4) GO TO 454
        IF (J.EQ.5) GO TO 455
450    CALL CALCS (Y, I, CF)
        GO TO 470
451    DO 461 I=30,34
        Y(I)=YAT(I)
461    CONTINUE
        GO TO 450
452    DO 462 I=30,34
        Y(I)=YBT(I)
462    CONTINUE
        GO TO 450
453    DO 463 I=30,34
        Y(I)=YCT(I)
463    CONTINUE
        GO TO 450
454    DO 464 I=30,34
        Y(I)=YDT(I)
464    CONTINUE
        GO TO 450
455    DO 465 I=30,34
        Y(I)=YET(I)
465    CONTINUE
        GO TO 450
470    CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#          YB, I, YC, I, YD, I, YE, I)
6      CONTINUE
C    > CALCULATIONS TO INCLUDE Y28 <
      DO 116 I=29,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
116    CONTINUE
      DO 7 I28=1,5
        Y(28) = I28

      DO 7 J=1,5
        IF (J.EQ.1) GO TO 551
        IF (J.EQ.2) GO TO 552
        IF (J.EQ.3) GO TO 553
        IF (J.EQ.4) GO TO 554
        IF (J.EQ.5) GO TO 555

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550     CALL CALCS (Y,I,CF)
C
      GO TO 570
551     DO 561 I=29,34
      Y(I)=YAT(I)
561     CONTINUE
      GO TO 550
552     DO 562 I=29,34
      Y(I)=YBT(I)
562     CONTINUE
      GO TO 550
553     DO 563 I=29,34
      Y(I)=YCT(I)
563     CONTINUE
      GO TO 550
554     DO 564 I=29,34
      Y(I)=YDT(I)
564     CONTINUE
      GO TO 550
555     DO 565 I=29,34
      Y(I)=YET(I)
565     CONTINUE
      GO TO 550
570     CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#         YB,I,YC,I,YD,I,YE,I)
7       CONTINUE
C > CALCULATIONS TO INCLUDE Y27 <
      DO 117 I=28,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
117     CONTINUE
      DO 8 I27=1,5
      IF (I27.EQ.1) Y(27) = 1
      IF (I27.EQ.2) Y(27) = 3
      IF (I27.EQ.3) Y(27) = 5
      IF (I27.EQ.4) Y(27) = 7
      IF (I27.EQ.5) Y(27) = 10
      DO 8 J=1,5
      IF (J.EQ.1) GO TO 651
      IF (J.EQ.2) GO TO 652
      IF (J.EQ.3) GO TO 653
      IF (J.EQ.4) GO TO 654
      IF (J.EQ.5) GO TO 655
650     CALL CALCS (Y,I,CF)
      GO TO 670
651     DO 661 I=28,34
      Y(I)=YAT(I)
661     CONTINUE
      GO TO 650
652     DO 662 I=28,34

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        Y(I)=YBT(I)
662    CONTINUE
        GO TO 650
663    DO 663 I=28,34
        Y(I)=YCT(I)
663    CONTINUE
        GO TO 650
664    DO 664 I=28,34
        Y(I)=YDT(I)
664    CONTINUE
        GO TO 650
665    DO 665 I=28,34
        Y(I)=YET(I)
665    CONTINUE
        GO TO 650
670    CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#       YB,I,YC,I,YD,I,YE,I)
8      CONTINUE
C    > CALCULATIONS TO INCLUDE Y26 <
        DO 118 I=27,34
        YAT(I) = YA(I)
        YBT(I) = YB(I)
        YCT(I) = YC(I)
        YDT(I) = YD(I)
        YET(I) = YE(I)
118    CONTINUE
        DO 9 I26=1,5
        Y(26) = I26
        DO 9 J=1,5
        IF (J.EQ.1) GO TO 751
        IF (J.EQ.2) GO TO 752
        IF (J.EQ.3) GO TO 753
        IF (J.EQ.4) GO TO 754
        IF (J.EQ.5) GO TO 755
750    CALL CALCS (Y,I,CF)
        GO TO 770
751    DO 761 I=27,34
        Y(I)=YAT(I)
761    CONTINUE
        GO TO 750
752    DO 762 I=27,34
        Y(I)=YBT(I)
762    CONTINUE
        GO TO 750
753    DO 763 I=27,34
        Y(I)=YCT(I)
763    CONTINUE
        GO TO 750
754    DO 764 I=27,34
        Y(I)=YDT(I)
764    CONTINUE
        GO TO 750
755    DO 765 I=27,34

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          Y(I)=YET(I)
765      CONTINUE
          GO TO 750
770      CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#          YB, I, YC, I, YD, I, YE, I)
9        CONTINUE
C      > CALCULATIONS TO INCLUDE Y25 <
          DO 119 I=26, 34
          YAT(I) = YA(I)
          YBT(I) = YB(I)
          YCT(I) = YC(I)
          YDT(I) = YD(I)
          YET(I) = YE(I)
119      CONTINUE
          DO 10 I25=1, 5
          Y(25) = I25
          DO 10 J=1, 5
          IF (J.EQ.1) GO TO 851
          IF (J.EQ.2) GO TO 852
          IF (J.EQ.3) GO TO 853
          IF (J.EQ.4) GO TO 854
          IF (J.EQ.5) GO TO 855
850      CALL CALCS (Y, I, CF)
          GO TO 870
851      DO 861 I=26, 34
          Y(I)=YAT(I)
861      CONTINUE
          GO TO 850
852      DO 862 I=26, 34
          Y(I)=YBT(I)
862      CONTINUE
          GO TO 850
853      DO 863 I=26, 34
          Y(I)=YCT(I)
863      CONTINUE
          GO TO 850
854      DO 864 I=26, 34
          Y(I)=YDT(I)
864      CONTINUE
          GO TO 850
855      DO 865 I=26, 34
          Y(I)=YET(I)
865      CONTINUE
          GO TO 850
870      CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#          YB, I, YC, I, YD, I, YE, I)
10       CONTINUE
C      > CALCULATIONS TO INCLUDE Y24<
          DO 120 I=25, 34
          YAT(I) = YA(I)
          YBT(I) = YB(I)
          YCT(I) = YC(I)
          YDT(I) = YD(I)

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      YET(I) = YE(I)
120  CONTINUE
      DO 11 I24=1,5
          Y(24) = I24
      DO 11 J=1,5
          IF (J.EQ.1) GO TO 951
          IF (J.EQ.2) GO TO 952
          IF (J.EQ.3) GO TO 953
          IF (J.EQ.4) GO TO 954
          IF (J.EQ.5) GO TO 955
950  CALL CALCS (Y,I,CF)
      GO TO 970
951  DO 961 I=25,34
      Y(I)=YAT(I)
961  CONTINUE
      GO TO 950
952  DO 962 I=25,34
      Y(I)=YBT(I)
962  CONTINUE
      GO TO 950
953  DO 963 I=25,34
      Y(I)=YCT(I)
963  CONTINUE
      GO TO 950
954  DO 964 I=25,34
      Y(I)=YDT(I)
964  CONTINUE
      GO TO 950
955  DO 965 I=25,34
      Y(I)=YET(I)
965  CONTINUE
      GO TO 950
970  CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#      YB,I,YC,I,YD,I,YE,I)
11  CONTINUE
C  > CALCULATIONS TO INCLUDE Y23 <
      DO 121 I=24,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
121  CONTINUE
      DO 12 I23=1,5
          Y(23) = I23
      DO 12 J=1,5
          IF (J.EQ.1) GO TO 1051
          IF (J.EQ.2) GO TO 1052
          IF (J.EQ.3) GO TO 1053
          IF (J.EQ.4) GO TO 1054
          IF (J.EQ.5) GO TO 1055
1050 CALL CALCS (Y,I,CF)
      GO TO 1070

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1051 DO 1061 I=24,34
      Y(I)=YAT(I)
1061 CONTINUE
      GO TO 1050
1052 DO 1062 I=24,34
      Y(I)=YBT(I)
1062 CONTINUE
      GO TO 1050
1053 DO 1063 I=24,34
      Y(I)=YCT(I)
1063 CONTINUE
      GO TO 1050
1054 DO 1064 I=24,34
      Y(I)=YDT(I)
1064 CONTINUE
      GO TO 1050
1055 DO 1065 I=24,34
      Y(I)=YET(I)
1065 CONTINUE
      GO TO 1050
1070 CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#       YB,I,YC,I,YD,I,YE,I)
12    CONTINUE
C    > CALCULATIONS TO INCLUDE Y22<
      DO 122 I=23,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
122   CONTINUE
      DO 13 I22=1,4
      IF (I22.EQ.1) Y(22) = 5
      IF (I22.EQ.2) Y(22) = 10
      IF (I22.EQ.3) Y(22) = 15
      IF (I22.EQ.4) Y(22) = 20
      DO 13 J=1,5
      IF (J.EQ.1) GO TO 1151
      IF (J.EQ.2) GO TO 1152
      IF (J.EQ.3) GO TO 1153
      IF (J.EQ.4) GO TO 1154
      IF (J.EQ.5) GO TO 1155
1150 CALL CALCS (Y,I,CF)
      GO TO 1170
1151 DO 1161 I=23,34
      Y(I)=YAT(I)
1161 CONTINUE
      GO TO 1150
1152 DO 1162 I=23,34
      Y(I)=YBT(I)
1162 CONTINUE
      GO TO 1150
1153 DO 1163 I=23,34

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      Y(I)=YCT(I)
1163  CONTINUE
      GO TO 1150
1154  DO 1164 I=23,34
      Y(I)=YDT(I)
1164  CONTINUE
      GO TO 1150
1155  DO 1165 I=23,34
      Y(I)=YET(I)
1165  CONTINUE
      GO TO 1150
1170  CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#      YB,I,YC,I,YD,I,YE,I)
13    CONTINUE
C    > CALCULATIONS TO INCLUDE Y21 <
      DO 123 I=22,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
123  CONTINUE
      DO 14 I21=1,5
      Y(21) = I21
      DO 14 J=1,5
      IF (J.EQ.1) GO TO 1251
      IF (J.EQ.2) GO TO 1252
      IF (J.EQ.3) GO TO 1253
      IF (J.EQ.4) GO TO 1254
      IF (J.EQ.5) GO TO 1255
1250  CALL CALCS (Y,I,CF)
      GO TO 1270
1251  DO 1261 I=22,34
      Y(I)=YAT(I)
1261  CONTINUE
      GO TO 1250
1252  DO 1262 I=22,34
      Y(I)=YBT(I)
1262  CONTINUE
      GO TO 1250
1253  DO 1263 I=22,34
      Y(I)=YCT(I)
1263  CONTINUE
      GO TO 1250
1254  DO 1264 I=22,34
      Y(I)=YDT(I)
1264  CONTINUE
      GO TO 1250
1255  DO 1265 I=22,34
      Y(I)=YET(I)
1265  CONTINUE
      GO TO 1250
1270  CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,

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#          YB, I, YC, I, YD, I, YE, I)
14  CONTINUE
C  > CALCULATIONS TO INCLUDE Y20 <
    DO 124 I=21,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
124  CONTINUE
    DO 15 I20=1,5
      Y(20) = I20
    DO 15 J=1,5
      IF (J.EQ.1) GO TO 1351
      IF (J.EQ.2) GO TO 1352
      IF (J.EQ.3) GO TO 1353
      IF (J.EQ.4) GO TO 1354
      IF (J.EQ.5) GO TO 1355
1350  CALL CALCS (Y, I, CF)
      GO TO 1370
1351  DO 1361 I=21,34
      Y(I)=YAT(I)
1361  CONTINUE
      GO TO 1350
1352  DO 1362 I=21,34
      Y(I)=YBT(I)
1362  CONTINUE
      GO TO 1350
1353  DO 1363 I=21,34
      Y(I)=YCT(I)
1363  CONTINUE
      GO TO 1350
1354  DO 1364 I=21,34
      Y(I)=YDT(I)
1364  CONTINUE
      GO TO 1350
1355  DO 1365 I=21,34
      Y(I)=YET(I)
1365  CONTINUE
      GO TO 1350
1370  CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#          YB, I, YC, I, YD, I, YE, I)
15  CONTINUE
C  > CALCULATIONS TO INCLUDE Y19 <
    DO 125 I=20,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
125  CONTINUE
    DO 16 I19=1,5
      IF (I19.EQ.1) Y(19) = 1.0

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        IF (I19.EQ.2) Y(19) = 1.5
        IF (I19.EQ.3) Y(19) = 2.0
        IF (I19.EQ.4) Y(19) = 2.5
        IF (I19.EQ.5) Y(19) = 3.0
    DO 16 J=1,5
        IF (J.EQ.1) GO TO 1451
        IF (J.EQ.2) GO TO 1452
        IF (J.EQ.3) GO TO 1453
        IF (J.EQ.4) GO TO 1454
        IF (J.EQ.5) GO TO 1455
1450    CALL CALCS (Y,I,CF)
        GO TO 1470
1451    DO 1461 I=20,34
        Y(I)=YAT(I)
1461    CONTINUE
        GO TO 1450
1452    DO 1462 I=20,34
        Y(I)=YBT(I)
1462    CONTINUE
        GO TO 1450
1453    DO 1463 I=20,34
        Y(I)=YCT(I)
1463    CONTINUE
        GO TO 1450
1454    DO 1464 I=20,34
        Y(I)=YDT(I)
1464    CONTINUE
        GO TO 1450
1455    DO 1465 I=20,34
        Y(I)=YET(I)
1465    CONTINUE
        GO TO 1450
1470    CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
        #           YB,I,YC,I,YD,I,YE,I)
16     CONTINUE
C     > CALCULATIONS TO INCLUDE Y18 <
        DO 126 I=19,34
        YAT(I) = YA(I)
        YBT(I) = YB(I)
        YCT(I) = YC(I)
        YDT(I) = YD(I)
        YET(I) = YE(I)
126    CONTINUE
        DO 17 I18=1,5
        IF (I18.EQ.1) Y(18) = 40
        IF (I18.EQ.2) Y(18) = 241
        IF (I18.EQ.3) Y(18) = 395
        IF (I18.EQ.4) Y(18) = 2240
        IF (I18.EQ.5) Y(18) = 3241
    DO 17 J=1,5
        IF (J.EQ.1) GO TO 1551
        IF (J.EQ.2) GO TO 1552
        IF (J.EQ.3) GO TO 1553

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        IF (J.EQ.4) GO TO 1554
        IF (J.EQ.5) GO TO 1555
1550    CALL CALCS (Y,I,CF)
        GO TO 1570
1551    DO 1561 I=19,34
        Y(I)=YAT(I)
1561    CONTINUE
        GO TO 1550
1552    DO 1562 I=19,34
        Y(I)=YBT(I)
1562    CONTINUE
        GO TO 1550
1553    DO 1563 I=19,34
        Y(I)=YCT(I)
1563    CONTINUE
        GO TO 1550
1554    DO 1564 I=19,34
        Y(I)=YDT(I)
1564    CONTINUE
        GO TO 1550
1555    DO 1565 I=19,34
        Y(I)=YET(I)
1565    CONTINUE
        GO TO 1550
1570    CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#         YB,I,YC,I,YD,I,YE,I)
17     CONTINUE
C    > CALCULATIONS TO INCLUDE Y17 <
        DO 127 I=18,34
        YAT(I) = YA(I)
        YBT(I) = YB(I)
        YCT(I) = YC(I)
        YDT(I) = YD(I)
        YET(I) = YE(I)
127    CONTINUE
        DO 18 I17=1,5
        Y(17) = I17

        DO 18 J=1,5
        IF (J.EQ.1) GO TO 1651
        IF (J.EQ.2) GO TO 1652
        IF (J.EQ.3) GO TO 1653
        IF (J.EQ.4) GO TO 1654
        IF (J.EQ.5) GO TO 1655
1650    CALL CALCS (Y,I,CF)
        GO TO 1670
1651    DO 1661 I=18,34
        Y(I)=YAT(I)
1661    CONTINUE
        GO TO 1650
1652    DO 1662 I=18,34
        Y(I)=YBT(I)
1662    CONTINUE

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      GO TO 1650
1653  DO 1663 I=18,34
      Y(I)=YCT(I)
1663  CONTINUE
      GO TO 1650
1654  DO 1664 I=18,34
      Y(I)=YDT(I)
1664  CONTINUE
      GO TO 1650
1655  DO 1665 I=18,34
      Y(I)=YET(I)
1665  CONTINUE
      GO TO 1650
1670  CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#      YB,I,YC,I,YD,I,YE,I)
18    CONTINUE
C    > CALCULATIONS TO INCLUDE Y16 <
      DO 128 I=17,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
128   CONTINUE
      DO 19 I16=1,5
      IF (I16.EQ.1) Y(16) = 1
      IF (I16.EQ.2) Y(16) = 2
      IF (I16.EQ.3) Y(16) = 3
      IF (I16.EQ.4) Y(16) = 4
      IF (I16.EQ.5) Y(16) = 5
      DO 19 J=1,5
      IF (J.EQ.1) GO TO 1751
      IF (J.EQ.2) GO TO 1752
      IF (J.EQ.3) GO TO 1753
      IF (J.EQ.4) GO TO 1754
      IF (J.EQ.5) GO TO 1755
1750  CALL CALCS (Y,I,CF)
      GO TO 1770
1751  DO 1761 I=17,34
      Y(I)=YAT(I)
1761  CONTINUE
      GO TO 1750
1752  DO 1762 I=17,34
      Y(I)=YBT(I)
1762  CONTINUE
      GO TO 1750
1753  DO 1763 I=17,34
      Y(I)=YCT(I)
1763  CONTINUE
      GO TO 1750
1754  DO 1764 I=17,34
      Y(I)=YDT(I)
1764  CONTINUE

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      GO TO 1750
1755  DO 1765 I=17,34
      Y(I)=YET(I)
1765  CONTINUE
      GO TO 1750
1770  CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#      YB,I,YC,I,YD,I,YE,I)
19    CONTINUE
C    > CALCULATIONS TO INCLUDE Y15 <
      DO 129 I=16,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
129   CONTINUE
      DO 20 I15=1,5
      IF (I15.EQ.1) Y(15) = 1.0
      IF (I15.EQ.2) Y(15) = 2.5
      IF (I15.EQ.3) Y(15) = 5.0
      IF (I15.EQ.4) Y(15) = 7.5
      IF (I15.EQ.5) Y(15) = 10.0
      DO 20 J=1,5
      IF (J.EQ.1) GO TO 1851
      IF (J.EQ.2) GO TO 1852
      IF (J.EQ.3) GO TO 1853
      IF (J.EQ.4) GO TO 1854
      IF (J.EQ.5) GO TO 1855
1850  CALL CALCS (Y,I,CF)
      GO TO 1870
1851  DO 1861 I=16,34
      Y(I)=YAT(I)
1861  CONTINUE
      GO TO 1850
1852  DO 1862 I=16,34
      Y(I)=YBT(I)
1862  CONTINUE
      GO TO 1850
1853  DO 1863 I=16,34
      Y(I)=YCT(I)
1863  CONTINUE
      GO TO 1850
1854  DO 1864 I=16,34
      Y(I)=YDT(I)
1864  CONTINUE
      GO TO 1850
1855  DO 1865 I=16,34
      Y(I)=YET(I)
1865  CONTINUE
      GO TO 1850
1870  CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#      YB,I,YC,I,YD,I,YE,I)
20    CONTINUE

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C   > CALCULATIONS TO INCLUDE Y14 <
      DO 130 I=15,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
130  CONTINUE
      DO 21 I14=1,5
      IF (I14.EQ.1) Y(14) = 1
      IF (I14.EQ.2) Y(14) = 3
      IF (I14.EQ.3) Y(14) = 7
      IF (I14.EQ.4) Y(14) = 11
      IF (I14.EQ.5) Y(14) = 14
      DO 21 J=1,5
      IF (J.EQ.1) GO TO 1951
      IF (J.EQ.2) GO TO 1952
      IF (J.EQ.3) GO TO 1953
      IF (J.EQ.4) GO TO 1954
      IF (J.EQ.5) GO TO 1955
1950  CALL CALCS (Y,I,CF)
      GO TO 1970
1951  DO 1961 I=15,34
      Y(I)=YAT(I)
1961  CONTINUE
      GO TO 1950
1952  DO 1962 I=15,34
      Y(I)=YBT(I)
1962  CONTINUE
      GO TO 1950
1953  DO 1963 I=15,34
      Y(I)=YCT(I)
1963  CONTINUE
      GO TO 1950
1954  DO 1964 I=15,34
      Y(I)=YDT(I)
1964  CONTINUE
      GO TO 1950
1955  DO 1965 I=15,34
      Y(I)=YET(I)
1965  CONTINUE
      GO TO 1950
1970  # CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
      YB,I,YC,I,YD,I,YE,I)
21    CONTINUE
C   > CALCULATIONS TO INCLUDE Y13 <
      DO 131 I=14,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
131  CONTINUE

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DO 22 I13=1,5
  IF (I13.EQ.1) Y(13) = 1
  IF (I13.EQ.2) Y(13) = 3
  IF (I13.EQ.3) Y(13) = 5
  IF (I13.EQ.4) Y(13) = 7
  IF (I13.EQ.5) Y(13) = 10
DO 22 J=1,5
  IF (J.EQ.1) GO TO 2051
  IF (J.EQ.2) GO TO 2052
  IF (J.EQ.3) GO TO 2053
  IF (J.EQ.4) GO TO 2054
  IF (J.EQ.5) GO TO 2055
2050 CALL CALCS (Y,I,CF)
      GO TO 2070
2051 DO 2061 I=14,34
      Y(I)=YAT(I)
2061 CONTINUE
      GO TO 2050
2052 DO 2062 I=14,34
      Y(I)=YBT(I)
2062 CONTINUE
      GO TO 2050
2053 DO 2063 I=14,34
      Y(I)=YCT(I)
2063 CONTINUE
      GO TO 2050
2054 DO 2064 I=14,34
      Y(I)=YDT(I)
2064 CONTINUE
      GO TO 2050
2055 DO 2065 I=14,34
      Y(I)=YET(I)
2065 CONTINUE
      GO TO 2050
2070 CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#       YB,I,YC,I,YD,I,YE,I)
22 CONTINUE
C > CALCULATIONS TO INCLUDE Y12 <
DO 132 I=13,34
  YAT(I) = YA(I)
  YBT(I) = YB(I)
  YCT(I) = YC(I)
  YDT(I) = YD(I)
  YET(I) = YE(I)
132 CONTINUE
DO 23 I12=1,5
  IF (I12.EQ.1) Y(12) = 1
  IF (I12.EQ.2) Y(12) = 3
  IF (I12.EQ.3) Y(12) = 5
  IF (I12.EQ.4) Y(12) = 7
  IF (I12.EQ.5) Y(12) = 10
DO 23 J=1,5
  IF (J.EQ.1) GO TO 2151

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        IF (J.EQ.2) GO TO 2152
        IF (J.EQ.3) GO TO 2153
        IF (J.EQ.4) GO TO 2154
        IF (J.EQ.5) GO TO 2155
2150   CALL CALCS (Y,I,CF)
        GO TO 2170
2151   DO 2161 I=13,34
        Y(I)=YAT(I)
2161   CONTINUE
        GO TO 2150
2152   DO 2162 I=13,34
        Y(I)=YBT(I)
2162   CONTINUE
        GO TO 2150
2153   DO 2163 I=13,34
        Y(I)=YCT(I)
2163   CONTINUE
        GO TO 2150
2154   DO 2164 I=13,34
        Y(I)=YDT(I)
2164   CONTINUE
        GO TO 2150
2155   DO 2165 I=13,34
        Y(I)=YET(I)
2165   CONTINUE
        GO TO 2150
2170   CALL BEST5 (Y, I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA, I,
#       YB, I, YC, I, YD, I, YE, I)
23     CONTINUE
C   > CALCULATIONS TO INCLUDE Y11 <
        DO 133 I=12,34
        YAT(I) = YA(I)
        YBT(I) = YB(I)
        YCT(I) = YC(I)
        YDT(I) = YD(I)
        YET(I) = YE(I)
133   CONTINUE
        DO 24 I11=1,5
        IF (I11.EQ.1) Y(11) = 1
        IF (I11.EQ.2) Y(11) = 3
        IF (I11.EQ.3) Y(11) = 5
        IF (I11.EQ.4) Y(11) = 7
        IF (I11.EQ.5) Y(11) = 10
        DO 24 J=1,5
        IF (J.EQ.1) GO TO 2251
        IF (J.EQ.2) GO TO 2252
        IF (J.EQ.3) GO TO 2253
        IF (J.EQ.4) GO TO 2254
        IF (J.EQ.5) GO TO 2255
2250   CALL CALCS (Y, I,CF)
        GO TO 2270
2251   DO 2261 I=12,34
        Y(I)=YAT(I)

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2261 CONTINUE
      GO TO 2250
2252 DO 2262 I=12,34
      Y(I)=YBT(I)
2262 CONTINUE
      GO TO 2250
2253 DO 2263 I=12,34
      Y(I)=YCT(I)
2263 CONTINUE
      GO TO 2250
2254 DO 2264 I=12,34
      Y(I)=YDT(I)
2264 CONTINUE
      GO TO 2250
2255 DO 2265 I=12,34
      Y(I)=YET(I)
2265 CONTINUE
      GO TO 2250
2270 CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#       YB,I,YC,I,YD,I,YE,I)
24 CONTINUE
C > CALCULATIONS TO INCLUDE Y10 <
      DO 134 I=11,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
134 CONTINUE
      DO 25 I10=1,5
      Y(10) = I10
      DO 25 J=1,5
      IF (J.EQ.1) GO TO 2351
      IF (J.EQ.2) GO TO 2352
      IF (J.EQ.3) GO TO 2353
      IF (J.EQ.4) GO TO 2354
      IF (J.EQ.5) GO TO 2355
2350 CALL CALCS (Y,I,CF)
      GO TO 2370
2351 DO 2361 I=11,34
      Y(I)=YAT(I)
2361 CONTINUE
      GO TO 2350
2352 DO 2362 I=11,34
      Y(I)=YBT(I)
2362 CONTINUE
      GO TO 2350
2353 DO 2363 I=11,34
      Y(I)=YCT(I)
2363 CONTINUE
      GO TO 2350
2354 DO 2364 I=11,34
      Y(I)=YDT(I)

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2364 CONTINUE
      GO TO 2350
2355 DO 2365 I=11,34
      Y(I)=YET(I)
2365 CONTINUE
      GO TO 2350
2370 CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#          YB, I, YC, I, YD, I, YE, I)
25 CONTINUE
C > CALCULATIONS TO INCLUDE Y9 <
      DO 135 I=10,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
135 CONTINUE
      DO 26 I9=1,5
        IF (I9.EQ.1) Y(9) = 1
        IF (I9.EQ.2) Y(9) = 4
        IF (I9.EQ.3) Y(9) = 7
        IF (I9.EQ.4) Y(9) = 10
        IF (I9.EQ.5) Y(9) = 13
      DO 26 J=1,5
        IF (J.EQ.1) GO TO 2451
        IF (J.EQ.2) GO TO 2452
        IF (J.EQ.3) GO TO 2453
        IF (J.EQ.4) GO TO 2454
        IF (J.EQ.5) GO TO 2455
2450 CALL CALCS (Y, I, CF)
      GO TO 2470
2451 DO 2461 I=10,34
      Y(I)=YAT(I)
2461 CONTINUE
      GO TO 2450
2452 DO 2462 I=10,34
      Y(I)=YBT(I)
2462 CONTINUE
      GO TO 2450
2453 DO 2463 I=10,34
      Y(I)=YCT(I)
2463 CONTINUE
      GO TO 2450
2454 DO 2464 I=10,34
      Y(I)=YDT(I)
2464 CONTINUE
      GO TO 2450
2455 DO 2465 I=10,34
      Y(I)=YET(I)
2465 CONTINUE
      GO TO 2450
2470 CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#          YB, I, YC, I, YD, I, YE, I)

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26      CONTINUE
C  > CALCULATIONS TO INCLUDE Y8 <
      DO 136 I=9,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
136     CONTINUE
      DO 27 I8=1,5
      IF (I8.EQ.1) Y(8) = 1
      IF (I8.EQ.2) Y(8) = 2
      IF (I8.EQ.3) Y(8) = 3
      IF (I8.EQ.4) Y(8) = 4
      IF (I8.EQ.5) Y(8) = 5
      DO 27 J=1,5
      IF (J.EQ.1) GO TO 2551
      IF (J.EQ.2) GO TO 2552
      IF (J.EQ.3) GO TO 2553
      IF (J.EQ.4) GO TO 2554
      IF (J.EQ.5) GO TO 2555
2550    CALL CALCS (Y, I, CF)
      GO TO 2570
2551    DO 2561 I=9,34
      Y(I)=YAT(I)
2561    CONTINUE
      GO TO 2550
2552    DO 2562 I=9,34
      Y(I)=YBT(I)
2562    CONTINUE
      GO TO 2550
2553    DO 2563 I=9,34
      Y(I)=YCT(I)
2563    CONTINUE
      GO TO 2550
2554    DO 2564 I=9,34
      Y(I)=YDT(I)
2564    CONTINUE
      GO TO 2550
2555    DO 2565 I=9,34
      Y(I)=YET(I)
2565    CONTINUE
      GO TO 2550
2570    CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#          YB, I, YC, I, YD, I, YE, I)
27      CONTINUE
C  > CALCULATIONS TO INCLUDE Y7 <
      DO 137 I=8,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)

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137      CONTINUE
        DO 28 I7=1,3
          IF (I7.EQ.1) Y(7) = 4600
          IF (I7.EQ.2) Y(7) = 6560
          IF (I7.EQ.3) Y(7) = 7648
        DO 28 J=1,5
          IF (J.EQ.1) GO TO 2651
          IF (J.EQ.2) GO TO 2652
          IF (J.EQ.3) GO TO 2653
          IF (J.EQ.4) GO TO 2654
          IF (J.EQ.5) GO TO 2655
2650     CALL CALCS (Y,I,CF)
        GO TO 2670
2651     DO 2661 I=8,34
        Y(I)=YAT(I)
2661     CONTINUE
        GO TO 2650
2652     DO 2662 I=8,34
        Y(I)=YBT(I)
2662     CONTINUE
        GO TO 2650
2653     DO 2663 I=8,34
        Y(I)=YCT(I)
2663     CONTINUE
        GO TO 2650
2654     DO 2664 I=8,34
        Y(I)=YDT(I)
2664     CONTINUE
        GO TO 2650
2655     DO 2665 I=8,34
        Y(I)=YET(I)
2665     CONTINUE
        GO TO 2650
2670     CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#          YB,I,YC,I,YD,I,YE,I)
28      CONTINUE
C    > CALCULATIONS TO INCLUDE Y6 <
        DO 138 I=7,34
        YAT(I) = YA(I)
        YBT(I) = YB(I)
        YCT(I) = YC(I)
        YDT(I) = YD(I)
        YET(I) = YE(I)
138     CONTINUE
        DO 29 I6=1,2
          IF (I6.EQ.1) Y(6) = 1543
          IF (I6.EQ.2) Y(6) = 1892
        DO 29 J=1,5
          IF (J.EQ.1) GO TO 2751
          IF (J.EQ.2) GO TO 2752
          IF (J.EQ.3) GO TO 2753
          IF (J.EQ.4) GO TO 2754
          IF (J.EQ.5) GO TO 2755

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2750 CALL CALCS (Y,I,CF)
      GO TO 2770
2751 DO 2761 I=7,34
      Y(I)=YAT(I)
2761 CONTINUE
      GO TO 2750
2752 DO 2762 I=7,34
      Y(I)=YBT(I)
2762 CONTINUE
      GO TO 2750
2753 DO 2763 I=7,34
      Y(I)=YCT(I)
2763 CONTINUE
      GO TO 2750
2754 DO 2764 I=7,34
      Y(I)=YDT(I)
2764 CONTINUE
      GO TO 2750
2755 DO 2765 I=7,34
      Y(I)=YET(I)
2765 CONTINUE
      GO TO 2750
2770 CALL BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,YA,I,
#      YB,I,YC,I,YD,I,YE,I)
29   CONTINUE
C   > CALCULATIONS TO INCLUDE Y5 <
      DO 139 I=6,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
139  CONTINUE
      Y(5) = 369077
      DO 30 J=1,5
      IF (J.EQ.1) GO TO 2851
      IF (J.EQ.2) GO TO 2852
      IF (J.EQ.3) GO TO 2853
      IF (J.EQ.4) GO TO 2854
      IF (J.EQ.5) GO TO 2855
2850 CALL CALCS (Y,I,CF)
      GO TO 2870
2851 DO 2861 I=6,34
      Y(I)=YAT(I)
2861 CONTINUE
      GO TO 2850
2852 DO 2862 I=6,34
      Y(I)=YBT(I)
2862 CONTINUE
      GO TO 2850
2853 DO 2863 I=6,34
      Y(I)=YCT(I)
2863 CONTINUE

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GO TO 2850
2854 DO 2864 I=6,34
      Y(I)=YDT(I)
2864 CONTINUE
      GO TO 2850
2855 DO 2865 I=6,34
      Y(I)=YET(I)
2865 CONTINUE
      GO TO 2850
2870 CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#       YB, I, YC, I, YD, I, YE, I)
30   # CONTINUE
C   > CALCULATIONS TO INCLUDE Y4 <
      DO 140 I=5,34
        YAT(I) = YA(I)
        YBT(I) = YB(I)
        YCT(I) = YC(I)
        YDT(I) = YD(I)
        YET(I) = YE(I)
140  CONTINUE
      DO 31 I4=1,3
        IF (I4.EQ.1) Y(4) = 348993
        IF (I4.EQ.2) Y(4) = 352876
        IF (I4.EQ.3) Y(4) = 345824
      DO 31 J=1,5
        IF (J.EQ.1) GO TO 2951
        IF (J.EQ.2) GO TO 2952
        IF (J.EQ.3) GO TO 2953
        IF (J.EQ.4) GO TO 2954
        IF (J.EQ.5) GO TO 2955
2950 CALL CALCS (Y, I, CF)
      GO TO 2970
2951 DO 2961 I=5,34
      Y(I)=YAT(I)
2961 CONTINUE
      GO TO 2950
2952 DO 2962 I=5,34
      Y(I)=YBT(I)
2962 CONTINUE
      GO TO 2950
2953 DO 2963 I=5,34
      Y(I)=YCT(I)
2963 CONTINUE
      GO TO 2950
2954 DO 2964 I=5,34
      Y(I)=YDT(I)
2964 CONTINUE
      GO TO 2950
2955 DO 2965 I=5,34
      Y(I)=YET(I)
2965 CONTINUE
      GO TO 2950
2970 CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,

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#          YB, I, YC, I, YD, I, YE, I)
31  CONTINUE
C  > CALCULATIONS TO INCLUDE Y3 <
    DO 141 I=4,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
141  CONTINUE
    DO 32 I3=1,3
      IF (I3.EQ.1) Y(3) = 1159
      IF (I3.EQ.2) Y(3) = 1174
      IF (I3.EQ.3) Y(3) = 1635
    DO 32 J=1,5
      IF (J.EQ.1) GO TO 3051
      IF (J.EQ.2) GO TO 3052
      IF (J.EQ.3) GO TO 3053
      IF (J.EQ.4) GO TO 3054
      IF (J.EQ.5) GO TO 3055
3050  CALL CALCS (Y,I,CF)
      GO TO 3070
3051  DO 3061 I=4,34
      Y(I)=YAT(I)
3061  CONTINUE
      GO TO 3050
3052  DO 3062 I=4,34
      Y(I)=YBT(I)
3062  CONTINUE
      GO TO 3050
3053  DO 3063 I=4,34
      Y(I)=YCT(I)
3063  CONTINUE
      GO TO 3050
3054  DO 3064 I=4,34
      Y(I)=YDT(I)
3064  CONTINUE
      GO TO 3050
3055  DO 3065 I=4,34
      Y(I)=YET(I)
3065  CONTINUE
      GO TO 3050
3070  CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#          YB, I, YC, I, YD, I, YE, I)
32  CONTINUE
C  > CALCULATIONS TO INCLUDE Y2 <
    DO 142 I=3,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
142  CONTINUE

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DO 33 I2=1,2
  IF (I2.EQ.1) Y(2) = 16
  IF (I2.EQ.2) Y(2) = 187
DO 33 J=1,5
  IF (J.EQ.1) GO TO 3151
  IF (J.EQ.2) GO TO 3152
  IF (J.EQ.3) GO TO 3153
  IF (J.EQ.4) GO TO 3154
  IF (J.EQ.5) GO TO 3155
3150 CALL CALCS (Y,I,CF)
      GO TO 3170
3151 DO 3161 I=3,34
      Y(I)=YAT(I)
3161 CONTINUE
      GO TO 3150
3152 DO 3162 I=3,34
      Y(I)=YBT(I)
3162 CONTINUE
      GO TO 3150
3153 DO 3163 I=3,34
      Y(I)=YCT(I)
3163 CONTINUE
      GO TO 3150
3154 DO 3164 I=3,34
      Y(I)=YDT(I)
3164 CONTINUE
      GO TO 3150
3155 DO 3165 I=3,34
      Y(I)=YET(I)
3165 CONTINUE
      GO TO 3150
3170 CALL BEST5 (Y, I,CF,CFT1,CFT2,CFT3,CFT4,CFT5, YA, I,
#       YB, I, YC, I, YD, I, YE, I)
33   CONTINUE
C   > CALCULATIONS TO INCLUDE Y1 <
      DO 143 I=2,34
      YAT(I) = YA(I)
      YBT(I) = YB(I)
      YCT(I) = YC(I)
      YDT(I) = YD(I)
      YET(I) = YE(I)
143  CONTINUE
      DO 34 I1=1,3
      IF (I1.EQ.1) Y(1) = 1142
      IF (I1.EQ.2) Y(1) = 1356
      IF (I1.EQ.3) Y(1) = 2045
DO 34 J=1,5
  IF (J.EQ.1) GO TO 3251
  IF (J.EQ.2) GO TO 3252
  IF (J.EQ.3) GO TO 3253
  IF (J.EQ.4) GO TO 3254
  IF (J.EQ.5) GO TO 3255
3250 CALL CALCS (Y, I,CF)

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GO TO 3270
3251 DO 3261 I=2,34
      Y(I)=YAT(I)
3261 CONTINUE
      GO TO 3250
3252 DO 3262 I=2,34
      Y(I)=YBT(I)
3262 CONTINUE
      GO TO 3250
3253 DO 3263 I=2,34
      Y(I)=YCT(I)
3263 CONTINUE
      GO TO 3250
3254 DO 3264 I=2,34
      Y(I)=YDT(I)
3264 CONTINUE
      GO TO 3250
3255 DO 3265 I=2,34
      Y(I)=YET(I)
3265 CONTINUE
      GO TO 3250
3270 CALL BEST5 (Y, I, CF, CFT1, CFT2, CFT3, CFT4, CFT5, YA, I,
#      YB, I, YC, I, YD, I, YE, I)
34 CONTINUE
WRITE (6,55)YA(1),YB(1),YC(1),YD(1),YE(1)
WRITE (6,55)YA(2),YB(2),YC(2),YD(2),YE(2)
WRITE (6,55)YA(3),YB(3),YC(3),YD(3),YE(3)
WRITE (6,55)YA(4),YB(4),YC(4),YD(4),YE(4)
WRITE (6,55)YA(5),YB(5),YC(5),YD(5),YE(5)
WRITE (6,55)YA(6),YB(6),YC(6),YD(6),YE(6)
WRITE (6,55)YA(7),YB(7),YC(7),YD(7),YE(7)
WRITE (6,55)YA(8),YB(8),YC(8),YD(8),YE(8)
WRITE (6,55)YA(9),YB(9),YC(9),YD(9),YE(9)
WRITE (6,55)YA(10),YB(10),YC(10),YD(10),YE(10)
WRITE (6,55)YA(11),YB(11),YC(11),YD(11),YE(11)
WRITE (6,55)YA(12),YB(12),YC(12),YD(12),YE(12)
WRITE (6,55)YA(13),YB(13),YC(13),YD(13),YE(13)
WRITE (6,55)YA(14),YB(14),YC(14),YD(14),YE(14)
WRITE (6,55)YA(15),YB(15),YC(15),YD(15),YE(15)
WRITE (6,55)YA(16),YB(16),YC(16),YD(16),YE(16)
WRITE (6,55)YA(17),YB(17),YC(17),YD(17),YE(17)
WRITE (6,55)YA(18),YB(18),YC(18),YD(18),YE(18)
WRITE (6,55)YA(19),YB(19),YC(19),YD(19),YE(19)
WRITE (6,55)YA(20),YB(20),YC(20),YD(20),YE(20)
WRITE (6,55)YA(21),YB(21),YC(21),YD(21),YE(21)
WRITE (6,55)YA(22),YB(22),YC(22),YD(22),YE(22)
WRITE (6,55)YA(23),YB(23),YC(23),YD(23),YE(23)
WRITE (6,55)YA(24),YB(24),YC(24),YD(24),YE(24)
WRITE (6,55)YA(25),YB(25),YC(25),YD(25),YE(25)
WRITE (6,55)YA(26),YB(26),YC(26),YD(26),YE(26)
WRITE (6,55)YA(27),YB(27),YC(27),YD(27),YE(27)
WRITE (6,55)YA(28),YB(28),YC(28),YD(28),YE(28)
WRITE (6,55)YA(29),YB(29),YC(29),YD(29),YE(29)

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WRITE (6,55)YA(30),YB(30),YC(30),YD(30),YE(30)
WRITE (6,55)YA(31),YB(31),YC(31),YD(31),YE(31)
WRITE (6,55)YA(32),YB(32),YC(32),YD(32),YE(32)
WRITE (6,55)YA(33),YB(33),YC(33),YD(33),YE(33)
WRITE (6,55)YA(34),YB(34),YC(34),YD(34),YE(34)
WRITE (6,65)CFT1,CFT2,CFT3,CFT4,CFT5
C   * OUTPUT FORMATS *
51  FORMAT (1(F9.2,8X))
52  FORMAT (2(F9.2,8X))
53  FORMAT (3(F9.2,8X))
54  FORMAT (4(F9.2,8X))
55  FORMAT (5(F9.2,8X))
56  FORMAT (6(F9.2,8X))
57  FORMAT (7(F9.2,8X))
58  FORMAT (8(F9.2,8X))
59  FORMAT (9(F9.2,8X))
65  FORMAT (5(F14.12,3X))
    STOP
    END
C
SUBROUTINE CALCS (Y,I,CF)
DIMENSION Y(34)
Z21= (EXP(-((Y(27)/10*(Y(29)/100)*(Y(33)/365))))
Z22= ((Y(8)/5)*(Y(13)/10)*(Y(14)/14)*(Y(15)/10))
Z23= (((Y(10)/5)*(Y(28)/5))*(Y(11)/10)*(Y(12)/10))
Z31= (((Y(16)+Y(8)+Y(17))/15)*(1/(Y(19))))
#   *(Y(18)/3241))
Z32= (((Y(8)+Y(17)+Y(20)+Y(21))/20)*(Z31))
Z33= ((Z32)*((4*Y(23))/Y(22)))
Z34= ((1/Y(24))*(Y(25)/5)*(1/Y(26))*(Y(14)/14))
Z41= (EXP(-((Y(27)/10*(Y(29)/100)*(Y(33)/365))))
Z42= (EXP(-(((Y(9)/100)*(Y(14)/14))/(Y(17)/5))))
Z43= ((Y(30)-(Y(30)*Y(31)/100))/Y(30))
Z44= (Y(34)+((Y(32)*Y(33)/2)+Y(33)/2))
X1  = (Y(5)-(Y(1)+Y(2)+Y(3)+Y(4)+Y(6)-Y(7)))
X1N = (X1 - 15042) / 11999
X2N = (Z21 * Z22 * Z23)
X3N = (Z31 * Z32 * Z33 * Z34)
X4  = (EXP(-((Z41*Z42*Z43*(Z44/365))/(Y(8)/5))))
X4N = (X4 - 0.0079)/0.9908
FX1  = -0.0720 + 1.0752 * X1N
FX2  = 1 - (EXP(-(2.8875 * X2N)))
FX3  = 1 - (EXP(-(8.6625 * X3N)))
IF (X4N.GT.0.9223) GO TO 9
FX4  = -0.007 + (0.421 * X4N)
GO TO 8
9    FX4  = X4N**9
8    FX12 = (-0.0216 + 1.0021 * X1N) * FX1
    FX23 = (-0.0015 + 1.0015 * X3N) * FX3
    FX24 = (-0.0078 + 1.0089 * X4N) * FX4
    FX34 = (1.003 * (X3N)**2) * FX3
    FX123= (1.003 * (X3N)**2) * FX3
CF= (0.098*FX1)+(0.11*FX2)+(0.112*FX3)+(0.113*FX4)

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#      -((0.096*FX12)+(0.11*FX23)+(0.116*FX24)
#      +(0.127*FX34))+(0.118 * FX123)
RETURN
END
C
SUBROUTINE BEST5 (Y,I,CF,CFT1,CFT2,CFT3,CFT4,CFT5,
#              YA,I,YB,I,YC,I,YD,I,YE,I)
DIMENSION Y(34),YA(34),YB(34),YC(34),YD(34),YE(34)
IF (CF.GT.CFT1) GO TO 510
IF ((CF.GT.CFT2).AND.(CF.NE.CFT1)) GO TO 550
IF ((CF.GT.CFT3).AND.(CF.NE.CFT1).AND.(CF.NE.CFT2))
#   GO TO 570
IF ((CF.GT.CFT4).AND.(CF.NE.CFT1).AND.(CF.NE.CFT2)
#   .AND.(CF.NE.CFT3)) GO TO 580
IF ((CF.GT.CFT5).AND.(CF.NE.CFT1).AND.(CF.NE.CFT2)
#   .AND.(CF.NE.CFT3).AND.(CF.NE.CFT4)) GO TO 590
RETURN
510  CFTH1 = CFT1
     IF (CFT1.GT.CFT2) GO TO 512
     CFT1 = CF
     DO 511 I=1,34
511  YA(I) = Y(I)
     CONTINUE
     RETURN
512  CFT1 = CF
     IF (CFTH1.GT.CFT2) GO TO 515
     RETURN
515  CFTH2 = CFT2
     CFT2 = CFTH1
     IF (CFTH2.GT.CFT3) GO TO 520
     DO 516 I=1,34
516  YB(I) = YA(I)
     YA(I) = Y(I)
     CONTINUE
     RETURN
520  CFTH3 = CFT3
     CFT3 = CFTH2
     IF (CFTH3.GT.CFT4) GO TO 522
     DO 521 I=1,34
521  YC(I) = YB(I)
     YB(I) = YA(I)
     YA(I) = Y(I)
     CONTINUE
     RETURN
522  CFTH4 = CFT4
     CFT4 = CFTH3
     IF (CFTH4.GT.CFT5) GO TO 525
     DO 523 I=1,34
523  YD(I) = YC(I)
     YC(I) = YB(I)
     YB(I) = YA(I)
     YA(I) = Y(I)
     CONTINUE

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```
RETURN
525  CFT5 = CFTH4
      DO 526 I=1,34
      YE(I) = YD(I)
      YD(I) = YC(I)
      YC(I) = YB(I)
      YB(I) = YA(I)
      YA(I) = Y(I)
526  CONTINUE
      RETURN
550  IF (CFT2.GT.CFT3) GO TO 552
      IF (CFT2.GT.CFT4) GO TO 554
      IF (CFT2.GT.CFT5) GO TO 556
      CFT2 = CF
      DO 551 I=1,34
      YB(I) = Y(I)
551  CONTINUE
      RETURN
552  CFTH3 = CFT3
      IF (CFT3.GT.CFT4) GO TO 558
      CFT3 = CFT2
      DO 553 I=1,34
      YC(I) = YB(I)
553  CONTINUE
      RETURN
554  IF (CFT4.GT.CFT5) GO TO 562
      CFT4 = CFT2
      CFT2 = CF
      DO 555 I=1,34
      YD(I) = YB(I)
      YB(I) = Y(I)
555  CONTINUE
      RETURN
556  CFT5 = CFT2
      CFT2 = CF
      DO 557 I=1,34
      YE(I) = YB(I)
      YB(I) = Y(I)
557  CONTINUE
      RETURN
558  IF (CFT4.GT.CFT5) GO TO 559
      RETURN
559  CFT5 = CFT4
      CFT4 = CFT3
      CFT3 = CFT2
      CFT2 = CF
      DO 560 I=1,34
      YE(I) = YD(I)
      YD(I) = YC(I)
      YC(I) = YB(I)
      YB(I) = Y(I)
560  CONTINUE
      RETURN
```

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562   CFT5 = CFT4
      CFT4 = CFT2
      CFT2 = CF
      DO 563 I=1,34
      YE(I) = YD(I)
      YD(I) = YB(I)
      YB(I) = Y(I)
563   CONTINUE
      RETURN
570   IF (CFT3.GT.CFT4) GO TO 572
      IF (CFT3.GT.CFT5) GO TO 578
      CFT3 = CF
      DO 571 I=1,34
      YC(I) = Y(I)
571   CONTINUE
      RETURN
572   IF (CFT4.GT.CFT5) GO TO 573
575   CFT4 = CFT3
      CFT3 = CF
      DO 576 I=1,34
      YD(I) = YC(I)
      YC(I) = Y(I)
576   CONTINUE
      RETURN
573   CFT5 = CFT4
      DO 574 I=1,34
      YE(I) = YD(I)
574   CONTINUE
      GO TO 575
578   CFT5 = CFT3
      CFT3 = CF
      DO 579 I=1,34
      YE(I) = YC(I)
      YC(I) = Y(I)
579   CONTINUE
      RETURN
580   IF (CFT4.GT.CFT5) GO TO 582
583   CFT4 = CF
      DO 585 I=1,34
      YD(I) = Y(I)
585   CONTINUE
      RETURN
582   CFT5 = CFT4
      DO 584 I=1,34
      YE(I) = YD(I)
584   CONTINUE
      GO TO 583
590   CFT5 = CF
      DO 591 I=1,34
      YE(I) = Y(I)
591   CONTINUE
      RETURN
      END
```

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