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ABSTRACT

This work has been done as part of the effort to plan the National Institute of Education (NIE). The report, one of a series, describes four different management systems used by the Goddard Space Flight Center of NASA, the National Cancer Institute of the National Institutes of Health, and the U.S. Air Force in managing programmatic research and development. Programmatic R&D is defined as activity undertaken to accomplish a specific objective relating to a particular problem. For each agency, the authors present the steps actually taken by managers and researchers in managing research activity, the organization of the agency, and a paradigm that models the essential steps in the R&D management process. Additionally, the document provides an outline of the principles of quantitative models applicable for part of the management process. (Pages 15, 19, 33, 36, and 52 may reproduce poorly.) (Author/DN)

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NATIONAL INSTITUTE OF EDUCATION: METHODS FOR MANAGING PROGRAMMATIC RESEARCH AND DEVELOPMENT

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A WORKING NOTE
prepared for the

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

This Note was prepared to facilitate communication of preliminary research results. Views or conclusions expressed herein may be tentative and do not represent the official opinion of the sponsoring agency.

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PREFACE

This working note contains descriptions of the methods that the Goddard Space Flight Center of NASA, the National Cancer Institute of the National Institutes of Health, and the U.S. Air Force use in managing programmatic research and development. These descriptions were obtained by interviewing managers and other staff personnel in these agencies and interpreting their responses. None of the descriptions have yet been returned to the agencies for their comment or approval. This will be done in the near future. In addition, the section contains an overview of quantitative models used by some industrial companies and governement agencies to evaluate and choose among project proposals.

This work was done as part of the effort to plan the National Institute of Education (NIE). If authorized by the Congress, the NIE would conduct research and development in the field of education. This report is one of a series on the Institute. The others are:

- National Institute of Education: Preliminary Plan for the Proposed Institute (R-657-HEW)
- National Institute of Education: Methods for Managing Fundamental Research (WN-7676)
- National Institute of Education: Methods for Managing Practice-oriented Research and Development (WN-7677)
- National Institute of Education: Organizational and Managerial Alternatives (WN-7679)
- National Institute of Education: Evaluation of Methods for Managing Research and Development (WN-7680)

This report describes methods that the selected agencies use in managing only programmatic R&D; it does not evaluate the relative merits of these methods. A comparative evaluation appears in WN-7680.

Many of the R&D managers interviewed during this study expressed the need for additional study of the methods used in managing non-military R&D in the federal government. This series of reports seeks to provide a basis for research into improved management practices for that entire area. The principal purpose of these reports, however, is to enable the planners of the National Institute of Education to benefit from the experience of other federal R&D agencies in developing the NIE's R&D management procedures.

CONTENTS

I. INTRODUCTION

PURPOSE OF THIS REPORT

This report describes four different management systems that federal agencies use in managing *programmatic research and development.* The first three indicate the procedures used by their respective agency; the last outlines the principles of quantitative models applicable for part of the management process.

For the first three, the format of description will be to treat one agency at a time by (1) presenting the steps that its managers and researchers actually take in managing research activity, and then (2) repeating this presentation for the other agencies. The intention is to present the data on which the interpretive and evaluative statements made in WN-7679 and Wn-7680 are based. This approach was taken because agreement on what people do is easier to get than agreement on the effects of their actions, or what they should do. Agreement on the effects of their actions is lacking because insufficient research on the management of federal R&D has been done. Agreement on what R&D managers should do is difficult because it is ultimately a question of value.

The description for each agency and for the quantitative models will be called a *paradigm,* since not every detail and variant in what is actually done will be described. Each description is meant only as a model that depicts the essential steps in the R&D management process.

A step is deemed essential if changing it would significantly alter an estimate of the basic philosophy underlying the R&D management process being described. By looking at the essential steps, it is easier to infer what the basic underlying philosophy is, and how to project it onto a new situation, such as education R&D. This is, in fact, a meaningful definition of a paradigm; that is, the projection of something which is difficult to describe onto reality, where its consequences are observable and hence describable.

The paradigms that will be treated in this report are listed in Table 1.

Table 1

PARADIGMS DESCRIBED FOR MANAGING PROGRAMMATIC RESEARCH AND DEVELOPMENT

The Management Paradigm used by the Goddard Space Flight Center of the National Aeronautical and Space Administration

The Management Paradigms used by the National Cancer Institute for conducting National Research Programs

The Management Paradigm of the U.S. Air Force for conducting Major Weapon System Development

The Paradigm of Quantitative Models for Project Selection used in Industry and Government Agencies.

METHOD OF RESEARCH

The data used to construct the management paradigms were obtained by interviewing federal R&D managers and reviewing agency documents and literature. For each agency, key personnel and those recommended by key personnel were approached for interview. Altogether 14 managers were interviewed for this one report, some on repeated occasions. A list of the people interviewed will appear in the final version of this report.

The paradigms are a distillation of replies made by managers commenting on the nature and relative importance of their various activities. Necessarily, this approach to research is vulnerable to biases and sometimes produces information that is difficult to verify. Nevertheless, by asking all managers similar questions, and by filtering the responses as objectively as experience made possible, a fair representation of reality is thought to be presented. This approach is within the tradition of naturalistic observation as a method of research.

To gain clarity of exposition, some of the auxiliary mechanisms used by some agencies to overcome shortcomings in their management processes were omitted. Thus, matching the paradigm descriptions, the agencies interviewed, and the paradigm evaluations in WN-7680 to conclude that one agency does a better job of managing research than another agency is not justified. The operations and usefulness of these auxiliary mechanisms are discussed in the evaluation report, WN-7680.

TYPES OF R&D ACTIVITY

This report is limited to the management of programmatic research and development. Methods for managing two other kinds of R&D activity, fundamental research and practice-oriented R&D, appear in WN-7676 and WN-7677 respectively.

In simplest terms, programmatic R&D is activity undertaken to accomplish a specific objective relating to a particular problem. It is usually development oriented, and its success is measured by the accomplishment of a capability or task rather than solely by standards of disciplined inquiry using judgment by scientific peer groups.

Programmatic R&D is goal-oriented rather than conclusion-oriented. It results not in statements of truth but in actions or products or decisions for action.

Another distinguishing characteristic of programmatic R&D is that the component project activities are not ones chosen and directed independently by the researchers themselves, but are activities which fit within a predefined overall program plan, whether formally constructed or informally visualized by program directors. This program plan serves to relate component projects and guide the selection of future work by providing criteria of relevance, logical priority, and program need. For these reasons, programmatic R&D is often funded by contracts rather than grants, stressing control, relation to predefined problem, and attention toward cost/benefit and time considerations as well as technical and scientific excellence as judged by other scientists. This does not mean, however, that ideas of potential high scientific merit yet low relevance to a selected approach are automatically discarded. New approaches to a problem, new technical breakthroughs in surrounding areas of inquiry, and new problems themselves, often redirected efforts of programmatic R&D resulting in new formulations of program plans and new criteria for relevance and benefit.

TYPES OF MANAGEMENT ACTIVITY

To facilitate presentation, the research management process will be broken into three types of activity:

- Program Planning,
- Program Development,
- Program Evaluation.

These categories are deliberately chosen to group together qualitatively similar management activities.

Program Planning management activity is defined to include all the actions taken to foster, detect, and formulate new programs of research and development. Also included are the procedures for deciding which new subprograms will be added to the set of ongoing streams of activity. One example of such a new program is NCI's effort to mount a coherent attack on breast cancer, from detection to treatment, and including virol, chemical, and immunological approaches. The plan for such a program does not merely indicate what research needs to be done, but relates projects together in a logical and time sequenced manner, and identifies the managerial decisions which must be made between all major phases of activity. These characteristics are typical of plans associated with most efforts of programmatic R&D.

Program Development is defined to be the activity of managing the continuous process of refining and elaborating the plan of programmed activity. As a management process, Program Development is typically, though not always, an *iterative and continuing sequence* of stages involving:

- assessment of program progress and needs,
- generation of project ideas,
- selection of projects to support,
- monitoring of project performance,
- evaluation of project outcomes, and
- utilization of project results.

In various management paradigms, these stages are managed in different ways. Sometimes they are done by Program Directors, sometimes by project-specific temporary organizations or boards and sometimes by the overall Agency Director. In most of R&D, and especially when programmatic R&D is being done, action proceeds concurrently in several of the project stages for different projects within the program. This activity is called Program Development because from program management's perspective, programmatic efforts require the combined and integrated results of component projects, selected initially and during the course of a program, to achieve its overall objective.

Program Evaluation is the management activity of assessing what has been accomplished at some point in time by the summation of results from all component projects. The way in which agencies accomplish this management activity is the third topic to be discussed in this paper.

Discussion of management methods will focus on what is done at the *program director's* level, and only occasionally at higher levels. This is necessary because of the decision to describe procedures that managers use in practice. Interactions at the higher levels are more political, and thus subject to greater variation and personality dependencies. Not much insight into ways of allocating a budget between programs of one sort or another is gained by looking at the *procedures* agencies use. The influences surrounding the making of these kinds of decisions is the subject of studies in the policy and political science literature. Attention here will center on what occurs at the interface between the performer and his more immediate managers.

II. PROGRAMMATIC PARADIGM OF NASA/GODDARD SPACE FLIGHT CENTER

OVERVIEW

Goddard's strong linkage between intramural and extramural activities is the result of a major redirection toward programmatic, development projects for what was once a basic research facility. NASA was originally an outgrowth of NACA (National Advisory Committee for Aeronautics) Laboratories. NACA sponsored primarily basic research which was limited to the field of aeronautics. In response to the Sputnik challenge of 1957, NASA was created under the Eisenhower administration to build the nation's competency in aerospace as well as aeronautics.

With the expansion of objectives into aerospace, grants and contracts were given by NASA to universities and industries to supplement the existing facilities of NACA Labs. The old NACA Labs remained relatively intact, but a new extramural branch was established in NASA to manage the extramural work. Both parts operated independently of each other. The arrangement was short-lived.

Goddard came into being in 1959 as the first NASA center devoted strictly to space flight. Personnel were recruited from three sources: (1) the Signal Corp, concerned primarily with meteorlogical programs, (2) the NRL (Naval Research Laboratory), concerned with launching a satellite as part of a world wide effort at the time, and (3) from NACA Labs at Lewis and Ames Research Centers. NASA's original emphasis on basic research, inherited from the former NACA Labs, along with a separate NASA branch for extramural contract management, seemed no longer appropriate for Goddard's well-defined and programmatic objectives for research and development. Though Congress was financially unconstraining at the time, it looked for quick results. To meet its new objectives, Goddard had to meld together its intramural and extramural program activities.

To provide an organizational linkage, Goddard created a matrix form of program management which interweaves intramural researchers from discipline-oriented technology units with project-focused extramural management teams. This form of management has two essential requirements for success: (1) a strong intramural competency for program management, and (2) a diversity of both program interests and capabilities. Both are needed to maintain skills in managing and evaluating extramural programs. These skills are paramount for Goddard's success. Unlike the situation in fundamental research, in which outside scientists are called upon to help make decisions about grants to their fellow scientists, it would be inappropriate for Goddard to rely upon engineers from industry to help in making contract decisions. Consequently, Goddard must have the inhouse competency to make these contract decisions itself. At the program level, however, beyond the immediate realm of contract decisions, outside reviewers are employed to assist in program evaluation.

Goddard is primarily a development organization. With four thousand employees, it currently manages thirty-eight major projects with an average total product cost of about fifty million dollars. Dominating its program development activity is a management procedure emphasizing sequential phases of program planning, committment, and management. Most new projects fit under the broad objectives of relatively stable, large efforts such as the Physics and Astronomy program, Lunar and Planetary program, Communications program, and the Earth Observations program, though some projects may lead to new major programs as well. Small projects are managed by about twenty people, large ones by between forty and fifty people

Flight project R&D constitutes about sixty percent of Goddard's program budget, and most of new project development. The other forty percent is used largely for programs in Tracking and Data Acquisition, which entail operation of world-wide networks for communication and satellite tracking. Since the main focus of this report is on program planning and development rather than on operations, only the Goddard management procedures for conducting flight project R&D will be discussed. Essential features of this management paradigm are:

- *Intramural and extramural* activities are *integrated*, primarily through a *matrix form* of project staffing.

- Project proposals are *reviewed internally* by formal *Source Evaluation Boards.*
- Decisionmaking for project selection follows a *sequential process of study and project phases,* each successive phase representing a higher committment by Goddard to provide full project funding.
- Training and recruitment policies emphasize maintaining a *strong inhouse competence for both research and management.*
- Contracts for projects are awarded mostly to *industrial organizations,* though sometimes awards may be made to individual scientists who then subcontract out to other agencies.
- *Most managerial man-hours are devoted to managing existing contracts,* though a considerable amount of time and effort is directed to *project planning.*

SUMMARY

General Characteristics

Primary output of flight project R&D:	Development of unmanned satellites for research and application.
Mechanisms of support:	Planning and development contracts. Though Goddard contracts are generally performed extramurally, the preparation of technical and management plans, the preliminary research on alternative approaches, the specification of system design, and the actual system development are *all managed intramurally.*
Staffing plan:	Matrix form, in which project management offices frequently cut across discipline-oriented directorates,

though some projects may exist entirely within a single directorate. All managers at the systems level of a project are transferred to the projects office, full-time and co-located. At the subsystems level for small projects, and at the components level, managers stay within their own directorate while working on a project. An administrative officer is assigned full-time to each project, bringing with him a team of administrative service personnel.

Program Planning

Source of new project ideas:

Major programs are relatively broad and stable. Ideas for new programs may stem from project plans or project contracts, managed inhouse. Most new programs originate from ideas of individual intramural researchers, though some may be initiated at the request of NASA Headquarters, or advisory boards consisting mainly of outside scientists.

Mechanisms for planning:

Each year, the NASA Program Administrators review the objectives and overall R&D thrust of the major program areas, and communicate any revisions desired to the appropriate NASA centers. Goddard's short-range (one year) program plans are subsequently prepared by inhouse study groups and approved by the Goddard Management Council.

Coordination:

Program areas are coordinated by the Goddard Management Council which meets together one day every week. Council members are the heads of Goddard directorates.

Program Development

Sources of project ideas:

Inhouse researchers outline objectives for new project possibilities on ideas usually of their own selection. These outlines are essentially proposals of studies for potential projects.

Evaluation of project plans:

In the recent past, project ideas went through four major phases of development and review: Phase A activity (study) requiring approval by the Goddard Center Director; Phase B activity (alternative approaches and system design) requiring approval by the Center Director; Phase C activity (development of the Project Plan) requiring approval by both the Center Director and Management Council; and finally Phase D activity (actual system development) requiring review and approval of the Project Plan by the NASA Director prior to any RFP. Currently, Goddard management is considering collapsing these four phases into three.

Determination of contract type and competition:

The type of contract and degree of contract competition depends primarily on the relevant phase of project activity. Contracts for Phases A and B are fixed price or cost plus fixed fee, and for Phases C and D are incentive types. Contracts may be awarded to single or multiple contractors for alternative approaches, and all involve open competition except for few cases of Phase A work where awards may be made by the Goddard contracting officer on a noncompetitive basis.

Evaluation of project proposals:

For all competitive proposals, review and evaluation is made by a formal Source Evaluation Board constituted separately for each project over one million dollars. Board members include Goddard personnel, representatives from NASA Headquarters, and occasionally outside government consultants. Proposal ratings are made by Technical and Business Management committees operated independently of each other using criteria predefined by the Source Evaluation Board. Board evaluations are presented to a formally appointed "Selecting Official" for final contract decisions. Depending on project cost, this official may be either the NASA Administrator or the Goddard Director.

Monitoring of project performance:

Extramural projects are managed by the Goddard Projects Directorate. Intramural projects are managed by the Goddard Technology Directorate.

Evaluation of projects:

Project evaluations are conducted as an ongoing part of project activities rather than at the completion of the project. Monthly reviews by project managers compare technical performance, cost, and manpower required with benchmark figures indicated on the Project Plan.

Program Evaluation

Mechanisms of evaluation:	Program level reviews are conducted by Goddard Management Council and the NASA Program Administrators. Here again, program evaluations are actually summaries of ongoing project evaluations rather than special efforts conducted at program conclusion.

ACTIVITIES

Program Planning

Annual review of NASA's overall objectives and program thrust provides the central guidelines for Goddard program planning. This NASA review encompasses the programs of all NASA centers. Goddard has made some attempts at long-range planning in the past, but time and resource pressures have kept them to short-range yearly planning.

The yearly revised program plans for Goddard are prepared by the Applications or Science Study Groups consisting of key scientists within the center. These groups propose to the Goddard Management Council what the short range objectives of Goddard should be. Approved program plans are then distributed by the Council to center managers.

Project Initiation

Major programs at Goddard generally develop from individual projects which reveal new areas of interest or new means of research in aerospace. At any time, an individual or team of intramural researchers may initiate a phased process of project development. In the recent past, this process has consisted of four distinct phases:

Phase A: Preliminary Analysis (The Idea Stage)

Phase B: Definition (Alternative Approaches)

Phase C: Design (System Specification and Management Plan)

Phase D: Development/Operations (Hardware Fabrication and Use)

The sequential nature of phased project activity highlights the Goddard philosophy of step-wise increasing committment to an idea. At the end of each phase, the project idea is evaluated and approved for further development by the Center Director, and also by the Management Council for Phases C and D. Between phases, potential projects are evaluated on the following criteria: (1) Timing: Is the time ripe to obtain Congressional support for the project mission? (2) Manpower requirements: Does Goddard possess the needed resources to initiate and manage the required effort? and (3) Attractiveness: Does the potential project complement the Goddard portfolio? Will it maintain diversity of interest and capitalize on Goddard's assets?

Ultimately, the NASA Administrator authorizes all Goddard projects, but the phased project activity process is specific to Goddard management. Historically, passage through all four phases has taken an average of approximately seven years, with a great amount of time consumed by the decision processes between phases. Phases A and B are under the jurisdiction of Goddard's Study Management System. With the approval for Phase C activity, the study takes on a project status. Recently, there is a tendency to combine Phases C and D for new projects. Details of each phase are presented below.

Pre-Phase A activity, consisting of ad hoc, unsolicited formulations of potential projects, is part of Goddard's continual research efforts. This activity is directed toward identification of new objectives or missions, and culminates in Phase A Project Plans, typically from 3-8 pages, submitted to Goddard's Management Council. If the plan calls for less than two man-years of effort in Phase A activity, it may be approved by the division head of the initiating researcher. Otherwise, approval from the Center Director is required.

Approval to conduct Phase A activity is followed by the appointment of a Study Manager, commonly the orginator of the project idea. Phase A activity averages three to six months duration, is generally conducted intramurally, and includes development of a concise statement of mission objectives, identification of research and technical requirements, and assessments of feasibility and desirability of further definition. Sketches of alternative approaches and candidate experiments for fulfilling mission objectives are included. No specific funds at Goddard are allocated toward Phase A work.

Authorization by the Center Director for Phase B activity occurs for only about ten projects per year. Because the planned activity for Phase B is relatively large, usually from six to twelve months time and requiring ten to fifty men, Congress and O.M.B. are often interested. Phase B Project Plans, typically from 20-30 pages, are forwarded to NASA Headquarters and at this time the study is elevated to "new start" project status. Phase B activity is mostly concerned with the development of alternative ways of achieving the mission objectives and the identification of the state-of-the-art constraints. Most activity is conducted intramurally, though for some projects, about half the activity is contracted out. Estimates of development time and total runout costs calculated during this phase become the base figures for any subsequent evaluations. Final Phase B activity is the production of a Phase B Analytical Report and a Phase C Project Plan.

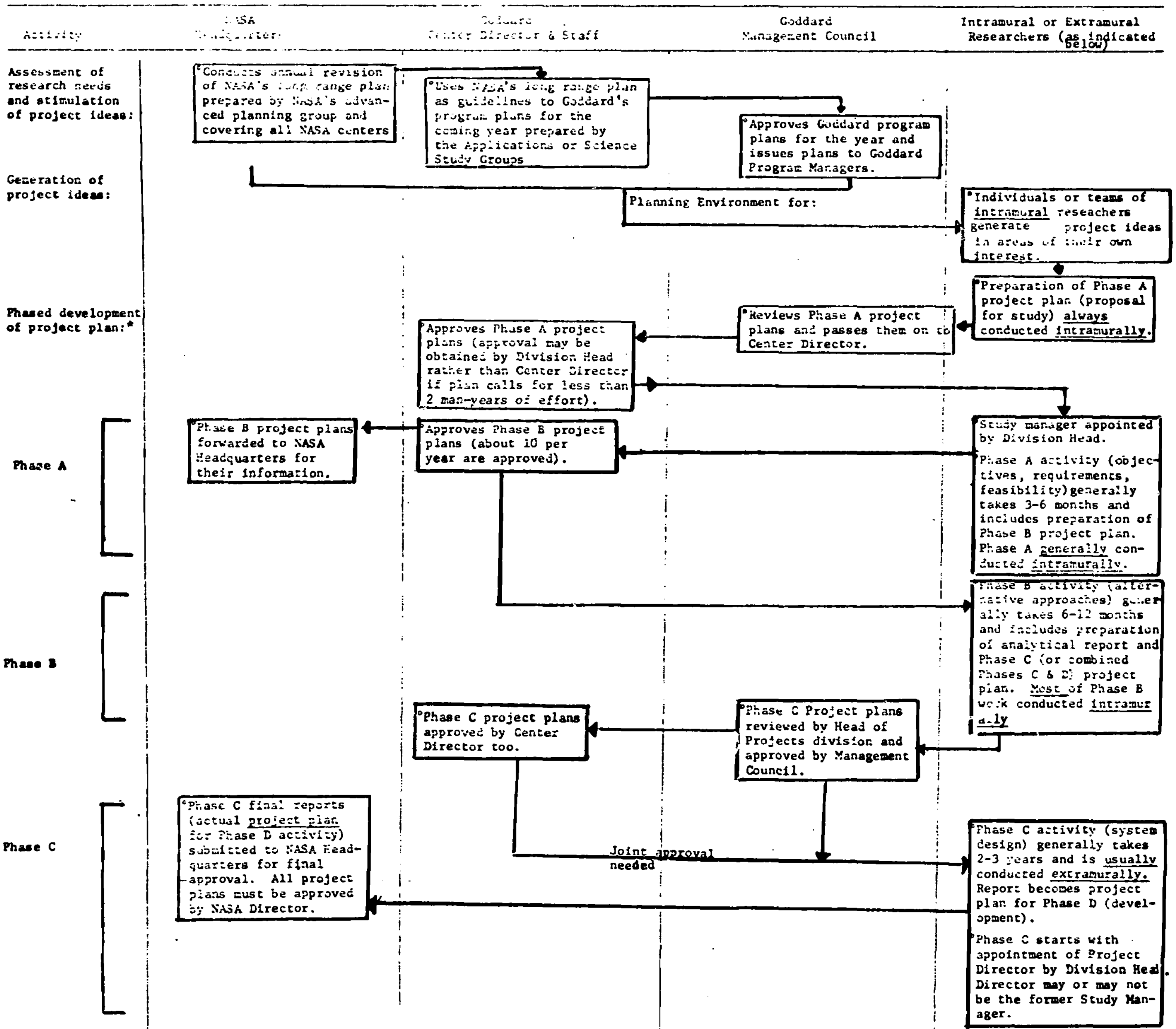
All Phase C Project Plans are reviewed and critiqued by the head of Goddard's Projects Directorate. Approval for Phase C activity by the Center Director and Goddard Management Council elevates the project idea from"study" to "project" status. This phase includes detailed system design, mockups, and identification of backup systems and their development requirements. Generally, all Phase C or Phase D work is contracted out. In specific cases where Goddard managers feel they must develop or maintain a certain competence within an area of interest, Goddard may conduct the entire project totally intramurally.

Typically thirty to forty-eight months are required from the end of Phase B to project completion. Phase C activity averages two to three years. Phase C final reports, submitted to NASA Headquarters, are directed primarily toward recommendations for subsequent actions. An overall description of the project planning process at Goddard appears in Figure 1 .

Contractor Selection

Procedures for the evaluation of external proposals for Goddard contracts vary according to the different activity phases. Descriptions for each phase of (1) the number of contracts written, (2) the

Figure 1: Project Planning Process at NASA/Goddard



nature of contract competition, (3) the type of contract, (4) the use of RFPs, and (5) the responsibility for contractor selection are illustrated in Figure 2. Except for some instances of Phase A work which is awarded on a noncompetitive basis by a Goddard contracting officer, all contracts are competitive based, involve RFPs, and are reviewed for evaluation by a formal Source Evaluation Board constituted separately for each project over one million dollars.

Members of the Source Evaluation Board include Goddard personnel, representatives of NASA Headquarters, and occasionally government consultants. No representatives of potential industrial contractors are included. Prior to the distribution of RFPs, the Board prepares a list of the criteria by which all proposals will be evaluated. When proposals in response to the RFPs come in, they are given to two separate committees of the Board, the Technical Committee and the Business Management Committee, for independent assessments in those respective areas. The two committees use a complex rating system and operate with separated proposal data so that neither committee knows how any single proposal rates in the area of the other committee. Findings of the committees are presented to the Source Evaluation Board which in turn, submits its own evaluations to a "Selecting Official" who has final authority for selection decisions. Generally, if the cost of the project is over five million dollars, the NASA Administrator serves as Selecting Official. For projects of less cost, authorization for selection rests with the Goddard Director.

Depending on practical and funding limitations, contracts for Phases A through C may be awarded to multiple contractors for alternative approaches, and may involve either equal or unequal amounts of funding. Unequal amounts may be awarded because of differing competitive cost positions, or different amounts of work needed to be performed by the different contractors.

For Phase B work, Goddard may allow contractors to submit proposals on either: (a) one or more approaches to be studied, or (b) all approaches to be studied. If there appears to be a lack of contractors capable of performing studies on all approaches,

FIGURE 2 : SUMMARY OF CONTRACTING PROCEDURES

	PHASE A Preliminary Analysis	PHASE B Definition	PHASE C Design	PHASE D Development/Ops.
1. Number of Contracts:	Individual Study Contracts are written for each study area.	Individual Study Contracts are written for each study area.	Two or more contracts	One contract.
2. Competition:	Open competition based on scientific and technical competence in the particular study area (or noncompetitive, including unsolicited proposals).	Open competition (unless noncompetitive justified).	Open competition restriceted to contractors with capability to perform Phase D.	Restricted to Phase C contractors (except for unusual cases).
3. Type of contract:	Fixed Price: Where costs can be realistically estimated. Cost Plus Fixed Fee: Where costs cannot be realistically estimated Funding Levels: a. Amounts depending on contractor's needs. b. Equally funded contracts where expected costs and experience warrant.	Cost Plus Fixed Fee: Where costs cannot be realistically estimated. Fixed Price: Where costs can be realistically estimated. Funding Levels: a. Amounts depending on contractor's needs. b. Equally funded.	Cost Plus Fixed Fee: For large contracts where costs cannot be realistically estimated. Incentive: Phase D contract is motivating factor. Funding Levels: a. Amounts depending on contractor's needs. b. Equally funded.	Incentive types.
4. Requests for Proposals (RFP):	RFP issued where appropriate (may be noncompetitive, including unsolicited proposals).	RFP issued.	RFP issued.	Request revised contractor proposal.
5. Contractor Selection:	Contracting officer selection (unless SEB required).	Source Evaluation Board (SEB)	Use of Phase B SEB desirable.	Use of Phase C SEB desirable.

Goddard contracting officers will probably choose the first alternative. On the other hand, if Goddard officers expect an unwarranted reluctance on the part of contractors to propose on a specific approach, they may choose the second alternative. For both Phase B and A work, contracts are either fixed price or cost plus fixed price.

Generally two, and sometimes more than two, prime contractors are selected for Phase C work. Only those contractors capable of performing through Phase D are considered eligible for Phase C contract awards. In most instances, one of the prime contractors engaged in the Phase C activity will be selected for the Phase D award. Various types of incentive contracts are used for Phase C and D work, though some cost plus fixed fee contracts have been used. Preferably, the same Source Evaluation Board personnel will be used for Phase C and D evaluations. Oftentimes, the Goddard project management personnel are used as consultants to the Board during the evaluation periods, and sometimes selected members of the project management will serve as voting members of the Board. (For more details of the procedures of proposal evaluation, see NASA documents: PR 3.804, parts 1,2, and 3.) See Figure 3 for an overall view.

Project Management

Project teams are assembled from across Goddard's discipline-oriented directorates. Some members are organizationally transferred full-time to the project office and are co-located with the Project Manager. In these cases, the career advancement of the team member is dependent on the Project Manager. Other members are not co-located with the project office and are still organizationally assigned to their parent directorate, though they are responsible for specified project tasks. Usually, managers at the systems level, and also at the subsystem level for projects of high cost, are organizationally assigned to the project office. At the component levels, managers remain within their directorates. Final project responsibility is determined according to the project's span across directorates. If the project lies wholly within a directorate, final responsibility rests with the head of that directorate. More generally, the project will cross directorates so that final responsibility rests with the Program Manager.

Figure 3 : Project Development Process at NASA/Goddard

Activity	Intramural Researchers & Staff	Source Evaluation Board	Project Office
Generation of RFPs:	°Individual Researchers, Study Managers, or Project Managers (depending on the relevant phase) prepare RFP if work is not to be conducted intramurally.	°Source Evaluation Board members include Goddard personnel, representatives of NASA Headquarters, and occasionally government consultants. ° Board prepares list of criteria by which all proposals will be evaluated. ° This list is prepared prior to RFP distribution.	°Extramural projects are managed by Projects Office within Goddards Projects Directorate. (Intramural projects are managed within the Goddard Technology directorate.) °Managers at the system level, and also at the subsystem level depending on cost, are co-located with the Project Office. ° Project Offices are created following contract award for Phase D.
Evaluation & Selection of Proposals:	RFPs issued and proposals received. *This Selecting Official may be from the head of a Goddard division up to the NASA director, depending on the project cost.	° Technical Committee & Business Mgt. Committee independently rate proposals on criteria provided by Board ° Separate evaluations made to Board. ° "Selecting Official" receives evaluations of Board and makes* final contract awards.	
°Management of Project Contracts:			°Monitoring and continual project evaluation is conducted by members of the Project Office. °Monthly reviews are prepared and reviewed by the Goddard Mgt. Council and NASA Program Administrator.

Extramural projects are monitored and managed by the Goddard Projects Directorate. Intramural projects are managed by the Goddard Technology Directorate. Projects in any directorate may receive additional Support Research Technology funds allocated by NASA Program Offices (Office for Manned Space Flight, Office for Space Sciences and Applications, etc.) to build long-range capabilities. Separate Advanced Research Technology funds are awarded directly to Goddard's specialty directorates (directorates other than Projects or Technology). There is no formal committment of these long-range funds continuing, but Goddard has been able to keep them at a level of about ten percent of the center budget.

Performance Evaluation

Project evaluations are conducted as an ongoing part of project activities rather than as separate efforts following project completion. Practices of frequent communication and joint decisionmaking are stressed rather than formal evaluation procedures. During Phase C and D activities, project managers prepare monthly reviews comparing the technical performance, cost, and manpower requirements currently estimated with the benchmark figures indicated in the Project Plan prepared during Phase B. Summaries of these monthly reviews are combined from all projects within a program and are reviewed by the Goddard Management Council and NASA Program Administrator.

ORGANIZATION

Goddard encourages a steady flow of people between intramural research projects and management of extramural projects. Interaction among the two functions is promoted partly by Goddard policies of personnel recruitment and management training, and partly by a matrix form of organizational structure. The latter emphasizes that Goddard does not maintain two separate directorates, one for intramural activity and one for extramural contracts management, each with its own permanent full staff. Instead, the mixing of both activities is induced through the drawing of project personnel from across intramural specialties for temporary assignment to a project office. This matrix form of structure is illustrated in the accompanying organizational chart of Figure 4.

Project Managers

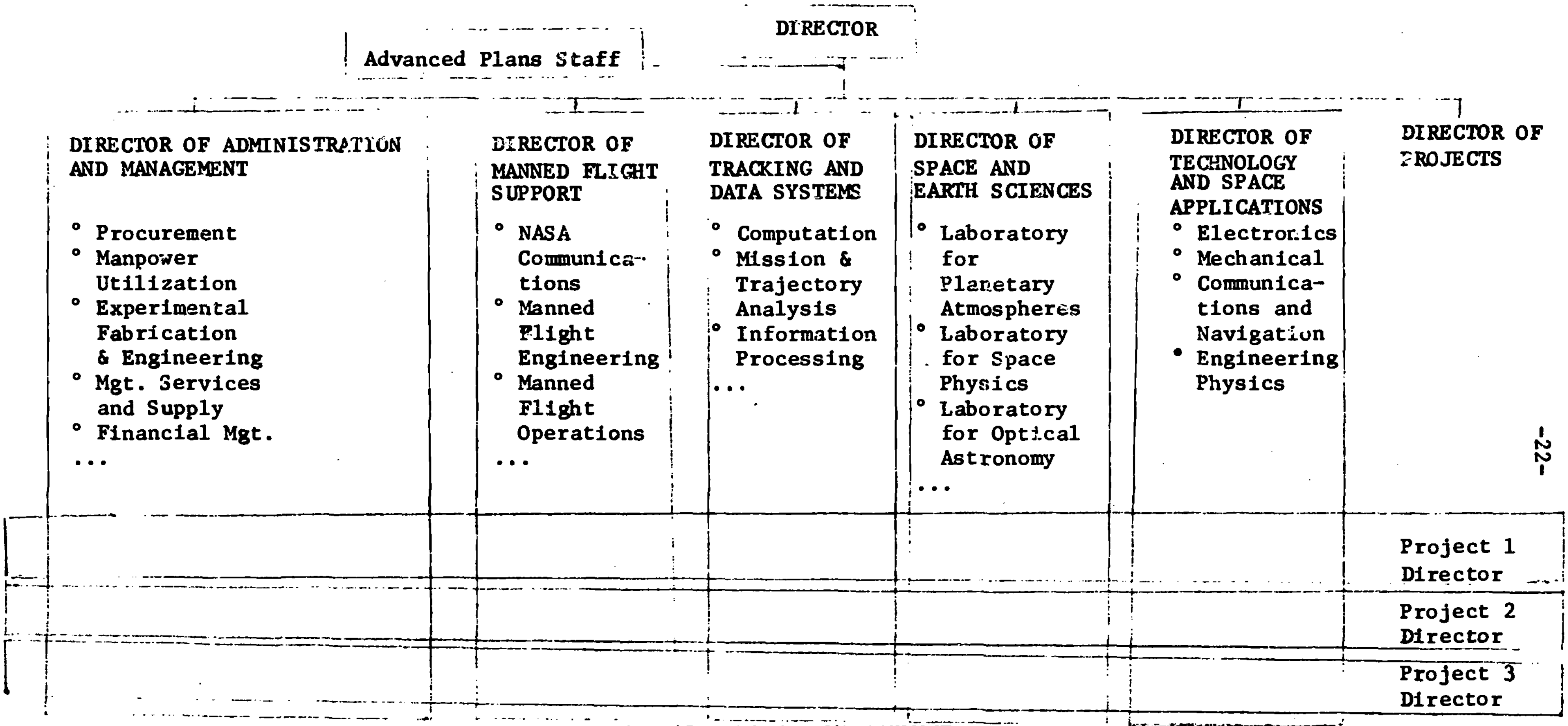
Project Managers are chosen from three sources: (1) Studies Managers of approved studies plans, (2) Project Managers of terminating projects, and (3) Goddard management with the greatest technical competence in the critical technical areas. The primary criterion for selection of Project Manager is technical competence; the second criterion is management experience. If the Project Manager does not have a high degree of competence in the crucial technical areas of the project, then his assistant must.

A Project Manager may or may not be the same person as the Study Manager for the project idea. Directors may or may not have formal management education and training, but invariable will have had some management experience. Many of the project personnel participate in Goddard's management training exercise: GREMEX, a project management simulation. Few tour of duty personnel are ever used as Project Managers.

Attraction of Intramural Researchers onto Projects

Some participation of intramural researchers on project problems is financially induced. Goddard provides its Project Managers with research funds available for supporting R&D back in the discipline-oriented directorates. In this way, Project Manager can encourage good intramural scientists to work on problems whose solutions are vital to the success of the project by providing funds for those problems in particular. In most cases, however, intramural scientists are merely assigned to Project Offices.

FIGURE 4 : ORGANIZATION OF GODDARD SPACE FLIGHT CENTER



GODDARD PROJECT MANAGEMENT

Project Director:	Organizationally assigned to Project Office in Project Dir.
Systems Level Managers:	Organizationally assigned to Project Office in Project Dir.
Subsystems Level Managers:	May or may not remain with parent directorate.
Component Level Managers:	Remain with parent directorate.

III. PROGRAMMATIC PARADIGMS OF THE NATIONAL CANCER INSTITUTE

OVERVIEW

The National Cancer Institute is one of the divisions of the National Institutes of Health, and manages its extramural grant activities largely according to NIH's Dual Review Paradigm described earlier. What makes the Cancer Institute different from the rest of NIH's divisions is that besides conducting grants programs to foster fundamental research, the Institute manages large programmatic activities targeted toward specific diseases or clinical practices. NCI conducts these programmatic activities through various management paradigms different from the Dual Review method. The purpose of this section is to describe these programmatic paradigms. Before these descriptions are made, some background and general information is provided.

In 1937, the National Cancer Institute Act called for the establishment of an institute to foster and coordinate cancer related research, and in 1944, the Cancer Institute was made a division of the National Institutes of Health. In 1971, the Institute operated with a staff of approximately fourteen hundred employees and a budget of over two hundred thirty million dollars. Of last year's staff, about thirty-eight percent were scientific and professional; twenty-five percent were administrative and clerical, and thirty-seven percent were technical and supporting. Of the budget, approximately fifty percent was allocated to extramural grants and training programs, ten percent to intramural research, and forty percent to collaborative studies. Most of the fifty percent allocated to extramural grants was managed according to the conventional NIH Dual Review paradigm. Collaborative and intramural studies constitute the majority of the Institute's programmatic activity and are usually managed separately from the grants programs.

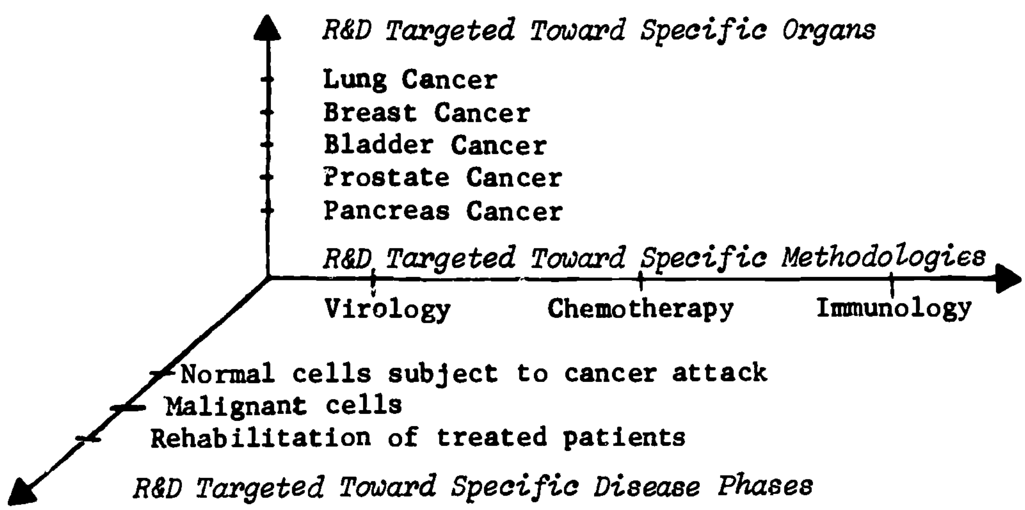
The full range of Institute activities consists of basic research, administered separately within a Directorate of Extramural Activities; practice-and-service-oriented clinical research, administered within a Directorate of General Labs and Clinics; and disease-oriented research, administered by the two directorates of Etiology and Chemotherapy. The *programmatic* activity of NCI resides mainly in the three directorates mentioned last, and all three conduct both intramural and collaborative efforts. One interesting experiment, however, which represents a major departure from traditional, federal R&D management practices, is NCI's recent *programmatic* effort targeted toward Bladder Cancer and managed *extramurally* through the extramural grants program. The management procedures in this experiment will be described along with other practices more normally used by NCI.

In addition to the three main directorates, the Institute has a staff group which participates heavily in developing formal plans for major program activities of the Institute. This Office of Program Planning and Analysis has developed a method called "The Convergence Technique," which is used to formulate rather detailed plans for conducting large research programs. So far, this technique has been used by the Cancer Institute to develop the plans for six major research programs targeted toward special diseases or clinical practices. Details of the convergence technique may be found in Appendix B.

Programmatic activities of NCI encompass three major "research cuts" through the problem of developing preventative measures and clinical treatments of cancer diseases. These three cuts are illustrated in Fig. 5.

Figure 5

NCI's Programmatic Research Attacks on Cancer



The management of programmatic R&D targeted toward specific methodologies resides predominantly in the Directorates of Etiology and Chemotherapy. Organ-centered programmatic R&D is managed within the Directorate of General Labs and Clinics, with the one exception of the Bladder Cancer Program, to be managed on an experimental basis within the Directorate of Extramural Activities. Procedures for the management of each type of programmatic activity differ in some respects and are common in others. These comparisions are outlined below.

Because the Dual Review paradigm by which the National Cancer Institute conducts most of its extramural grants activity has already been described in an earlier report, this section will highlight the essential features of the management paradigms used by the Cancer Institute in conducting its programmatic activity only. These features are:

For *all* programmatic R&D activity at NCI:

- Major *ideas for programs* arise intramurally or through interactions between the science and medical communities and the NCI advisory groups.
- Ideas presented to and approved by the National Advisory Council on Cancer are developed into formal programs, often by a *formal planning procedure* (The Convergence Technique) used to help derive the required R&D content to meet program goals.

For programmatic R&D activity *managed intramurally* within the *Directorates of Etilology and Chemotherapy*:

- A *matrix form of program management* is used, intersecting discipline-oriented organizational "branches" of the Institute with special problem-focused organizational "segments."
- *Segments* are the administrative units of NCI collaborative research, and segment members include both intramural and outside scientists.
- *Segment Chairmen*, all intramural scientists, assume responsibility for program management and have greatest influence on decisions of project selection.

- Evaluation of project proposals is conducted through a *variant of the dual review process* using full segments and segment chairmen as reviewers.
- A major emphasis is placed on the *directed and integrated use of intramural and collaborative research.*

For programmatic R&D activity also *managed intramurally*, but within the *Directorate of General Labs and Clinics*:

- *Task forces* are assigned by the National Advisory Council to assume responsibility for overall program planning and management.
- These task forces provide the basis for another *matrix form of program management* paralleling that of Etiology and Chemotherapy. In General Labs and Clinics, research members of NCI discipline-oriented "branches" also serve on these programmatic task forces.
- Task forces include both intramural and outside scientists, as do segments.
- An *NCI Steering Committee*, usually composed of the intramural members of the task force, has greatest influence in decisions of project selection, as do the segment chairmen.
- Evaluation of project proposals is conducted through a *similar variant of the dual review process* using Task Force Subcommittees, including both intramural and outside scientists, and the Task Force Steering Committee reviewers.
- A similar emphasis is placed on the *directed and integrated use of intramural and collaborative research.*

For programmatic R&D activity *managed extramurally* and supported by the grants program of the *Directorate of Extramural Activities*:

- *One large grant* is awarded for the management of a major programmatic effort. (This is not standard procedure for NCI, but is being conducted on an experimental basis.)

- o The grant will be awarded upon approval by the National Advisory Council of a program plan (prepared according to the Convergence Technique) presented to the Council.
- o The award will probably be given to one of the intramural scientists who participated on the planning cadre which prepared the program plan.
- o This grantee will then assume all responsibility and authority for awarding subgrants on all the R&D activities specified in the plan.

SUMMARY

General Characteristics

Primary output:	Preventative measures and clinical treatments for cancer.
Mechanisms of support:	For all programmatic R&D managed intramurally, contracts for studies are let on a one-year cycle; each contractor must submit a new proposal each year even though his project covers many years' work. For NCI's experiment with extramural management of programmatic R&D, support is provided by one overall grant for each program.
Managerial emphasis:	Monitoring of projects receives more managerial effort than any other management activity, for programs managed intramurally.
Staffing plan:	Predominantly *matrix form*. In two directorates, problem-focused organizational *segments*, which are the administrative units of collaborative,

contracted research, cut across discipline-oriented Institute *branches*, which are the administrative units of intramural research. Practically all intramural staff serve on at least one problem-focused segment. Intramural branch chiefs often also serve as segment chairman managing collaborative research. In a third directorate, similar Institute *branches* intersect with problem-focused *task forces* which are constituted similarly to segments.

Program Planning

Sources of new program ideas:

Ideas for Institute programs come from outside peer-directed research, from deans of medical schools, hospitals, the American Cancer Society and other cancer-related associations, and mostly from current intramural research. All new ideas are presented to the National Cancer Advisory Council for comments.

Mechanisms for planning:

If program ideas do not fit into current program plans, additional plans are prepared often by the Office of Program Planning and Analysis, together with a director appointed to the new program. They use the *Convergence Technique*, a formal planning procedure, to determine intermediate program objectives, major decision points, the necessary projects, and data requirements.

Coordination: Within each major program, a "working group" of all segment chairmen or intramural task force members, depending on the directorate, meets regularly to review overall progress, reassign priorities, and modify any program plans as necessary. Across-program coordination is the responsibility of the NCI Director.

Program Development

Sources of project ideas: For R&D programs managed intramurally, ideas for *contracts* within a program are generated both intramurally and from the scientific and medical communities. Most project contracts are derived logically from the data requirements outlined on the relevant program plans.

Means of proposal review: Contract proposals are usually reviewed first for *technical excellence* by both intramural and outside members of the program management team, and second for *relevance, need, and logical priority* by selected intramural members of the same team. In two NCI directorates, these groups are the program segments and segment chairmen, respectively. In a third directorate, they are the Task Force Subcommittee and NCI Steering Committee, respectively.

Allocation of budget: The Institute awards contracts within a program from among the set of proposals acceptable to the first review group on the grounds of technical excellence, and in the order determined by the scores of the second group, regarding relevance, need, and logical priority.

Monitoring of performance: Monitoring for all contracts is conducted by project officers, who may oversee several related contracts and conduct periodic site visits. Quarterly progress reports, and annual resubmission of contract proposals are required.

Evaluation of outcomes: No formal procedures of evaluation are used. Instead, projects are evaluated continually in terms of their progress in supplying the data required by the overall program plans.

Program Evaluation

Mechanism of evaluation: Again, no formal procedures are used. Overall program evaluation is measured by progress through the program plan.

ACTIVITIES

Program Planning

Programs in the Cancer Institute are both relatively large and stable. For example, the three major programs of the Directorate of Etiology include: Cardinogenesis, with twenty million dollars spread across fourteen contracts; Viral Oncology, with forty-four million dollars and approximately forty contracts; and Demography, with ten million dollars and about eight contracts. Program planning usually is associated with the initiation of a program revision or addition linked strongly to an already existing program and reflective of recent breakthroughs.

The specific roles and management procedures for program planning used for programs to be managed *intramurally* differ in many ways from those used for programs to be managed *extramurally*. In the former case, if a program revision or addition cannot be incorporated within existing program plans or is so large that a whole new plan is needed, a program director, to whom responsibility has been assigned for the additional work, coordinates with the Office of Program Planning and Analysis in generating a new program plan. This planning team, often with the help of outside scientists, develops program objectives and strategies, a list of initial project areas, decides whether or not the projects within an area will be done intramurally or outside, generates requests for proposals, and oversees the development of the subprogram throughout its lifetime. The program plan,prepared by the planning team and presented to the National Advisory Council, is called a *Convergence Chart* at NCI because of its role in the Convergence Technique. Details of the Convergence Technique are described in the appendix.

In the case of programs to be managed *extramurally*, a greater participating role is taken by the National Advisory Council. In the former case, the Council merely reviews plans initiated intramurally and supported by the NCI Director. A major program example of this is the Special Virus Cancer Program, managed intramurally within the Directorate of Etiology. Much greater participation by the Council was taken in the initiation of the Bladder Cancer Program, managed extramurally and supported by the Directorate of Extramural Activities.

Interest in pursuing a Bladder Cancer Program started within the Council in response to high incidence rates and a feeling, supported by the American Cancer Society, that a major programmatic effort aimed at bladder cancer was feasible at the current time. The Council commissioned a task force of intramural and extramural scientists to prepare a program plan, and with the help of the Office of Program Planning and Analysis, a detailed Convergence Chart was developed. The plan was presented to the Council, and if it is approved, one of the intramural scientists on the planning task force will probably be designated Program Manager and be given a single, large grant to manage the entire program.

Whether new NCI programs are to be managed intramurally or extramurally, the program plan, or Convergence Chart, plays a key role in defining exactly what R&D activities will be conducted. In addition, the chart illustrates the desired major thrusts of R&D efforts and is used both to acquaint outside scientists with current NCI activity and to encourage the submission of relevant proposals. As a management tool, the charts indicate to NCI managers how newly planned activity ties in with existing NCI work, what gap areas are left, and where program priorities should be placed. Finally, the Convergence Charts form the basis for individual work statements and are used as overall guides to both project and program evaluation. Because of the importance of these charts, or program plans, to NCI management, formal procedures for their development have been devised and tested. Through application of those procedures, plans have been prepared for programs in all four NCI directorates. Those plans are listed below, and an abstract example is presented in the appendix.

Program Plan (Convergence Chart)	NCI Directorates
Special virus cancer	Etiology
Chemo-Carcinogenesis	Etiology
Chemotherapy	Chemotherapy
Breast Cancer	General Labs and Clinics
Rectal Colon Cancer	Extramural
Bladder Cancer	Extramural

For additional information describing the theory and practice of the Convergence Technique , see Appendix A.

Overall differences in the planning procedures for programs managed intramurally and extramurally are highlighted in Fig. 6. In both cases, the Office of Program Planning and Analysis may contribute substantially to the preparation of the program plan. Their participation, however, is neither mandatory nor typical for all programs. Frequently, the reactions of scientists toward any approach which attempts to control or manage science is negative. Consequently, the planning staff view their operations as managerial

Figure 6: Program Planning Participants and Roles at NCI

Activity	Cancer Institute Director and National Advisory Council on Cancer	Science Directors for Program Areas (Etiology and Chemotherapy, General Labs and Clinics)	Program planning teams appointed by Science Directors or Council	Program Manager assigned by Science Director for Intramural Mgt. or by Council for Extramural Mgt.
Assessment of Research needs and stimulation of new programs	•Both the NCI Director and the National Advisory Council interact with the research and medical communities, the cancer associations, and consider cancer incident statistics to determine research needs and potentially fruitful new directions.	•Contribute ideas for new programs arising from breakthroughs in current programs managed intramurally.	•For programs to be managed extramurally, the program planning teams consist of about half intramural and half extramural scientists. •For programs to be managed internally, the teams consist of the assigned Program Manager, intramural scientists, and if requested, representatives from the NCI Director's Office of Program Planning and Analysis.	Planning for intramural management (Top half of chart)
Assignment of responsibility for Program Planning:	•Planning efforts for research programs to be managed intramurally are authorized by the NCI Director. •NCI Director assigns overall responsibility to the Science Director of the relevant program area. (Head of Directorate)	•Assigns a planning team and Program Manager to participate in the planning and to manage the program once planned.		•Participating in the program planning as part of planning team.
Preparation of Program Plan:			•Prepares the Program Plan of ten with the aid of the Office of Program Planning and Analysis which uses the Convergence Technique of Program Planning.	
Approval of Program Plan:	•Program Plan presented to council for comments. •Actual authorization for intramural programs is given by NCI Director.			•Sets up intramural management procedures for accomplishing the Program Plan.
		INTRAMURAL MANAGEMENT EXTRAMURAL MANAGEMENT		
Assignment of Responsibility and Preparation of Program Plan:	•Planning efforts for research programs to be managed extramurally, are authorized by the National Advisory Council. •Council appoints a planning team of both intramural and extramural scientists.		•Prepares the Program Plan with the aid of the Office of Program Planning and Analysis which uses the Convergence Technique.	Planning for extramural management (Bottom half of chart)
Approval of Program Plan:	•Program Plan presented to Council for approval. •If approved, Council awards grant to extramural member of planning team.			•Sets up extramural management procedures for accomplishing the Program Plan.

resources for those program managers who wish to use them. However, for many initial skeptics, even brief participation in planning exercises has converted them toward favoring the Convergence Technique as a useful planning tool, and the concept of planning itself as a useful approach in meeting priority objectives.

Program Development

Program additions or revisions are managed in one of two ways. In some cases, the constituent projects correspond to components of already existing program plans and Institute structures, and are developed along with other existing programs. This means that no new problem-oriented Institute *segments* or task forces are established as separate administrative units of the new program activity. In other cases, new administrative structures are created. Within the Directorates of Etiology and Chemotherapy, each of the programs is divided into *segments*, typically five to ten segments per program, where each segment represents a block of projects similar enough to be managed as a total package. Projects are often collected into segments with the interests of the assigned segment chairman in mind, so that the chairmen tend to remain with the program for its duration. Segment chairmen are all intramural scientists, and approximately half the members of a segment come from outside the Institute.

Even within the programmatic R&D activities of the Cancer Institute, program development is largely evolutionary. Program plans are often rewritten, especially when an area of the program starts producing consistently negative results. Redirection of effort is then made accordingly. On the positive side, consistently negative results within an area often indicate program progress. For example, thirty-two adenal viruses were eliminated as cancer agents in the first year of an Institute program. Many of these viruses had been postulated for fifteen years as being cancer producing.

Ideas for projects within a program are generated continually both intramurally, outside, and at project review committee meetings. For ideas generated intramurally, the scientist proposing the project meets with his branch chief to decide if the project is too big to be worked out by the individual scientist. If it is too big, the idea is taken to the segment chairmen. They and the branch chiefs then decide if (1) the idea fits into an existing program plan, and (2) whether there is sufficient money to support the project.

If enough money is available, the scientists write an RFP, and the same group as above reviews the request prior to its distribution. Proposals coming into the Institute in response to the RFP are reviewed by the two types of groups mentioned earlier; the first consisting of both intramural and outside scientists, and the second consisting of only intramural members. If the second review group, rating proposals on relevance, need, and logical priority, cannot decide whether or not to fund a proposed project, or cannot choose between alternative competing projects, they may select an ad hoc team to make site visits and make the final choice. This happens especially if one of the competing proposals is relatively overpriced.

Contracts are let in one year cycles. Proposals must indicate required levels of support for the current and subsequent years. All are resubmitted for review annually.

The management of funded contracts is done by *segments* or *task forces*, depending on whether the program is conducted within the Directorates of Etiology and Chemotherapy or General Labs and Clinics. Both forms are similarly constituted and have similar roles. A single segment chairman or task force member may be running several related contracts. Monitoring of performance is done by project officers who oversee related contracts and conduct site visits. All contracts are visited a minimum of once per year. Some get up to twelve visits per year. Typically, contracts range from one hundred thousand to two hundred thousand dollars, and a single contract officer may handle four or five of them simultaneously.

Contractors must submit progress reports three times per year. The project officer summarizes these reports and circulates the summary among the rest of his segment or task force. All projects are continually assessed in terms of their progress in providing the data required by the program plan. No other formal evaluation procedures are used. However, a contractor's overall performance is usually recorded for reference in ranking future proposals.

Figure 7: Program Development Procedures for NCI for Intramural Management

Activity	Planning Team appointed by NCI Director or Council	Segment Chairmen and Task Force Steering Committee	Proposal Review Committees
Generation of project ideas:	°Planning Team develops <u>initial</u> list of project areas for the program, and decides whether to do the individual projects within an area either intramurally or extramurally. Also develops RFPs for initial list of projects.	°Segment Chairmen are responsible for management of all funded projects managed intramurally within the Directorates of Etilogy and Chemotherapy. °Task Force Steering Committees are responsible for management of all funded projects managed intramurally within the Directorate of General Labs and Clinics.	°In Etilogy and Chemotherapy Directorates, the first review committee includes both intramural and extramural members of the program segments. The second review committee consists only of the intramural Segment Chairmen. °In General Labs and Clinics, the parallel first review is by a Task Force Subcommittee also of intramural and outside scientists, and the second review by a Task Force Steering Committee of intramural task force members.
	Ideas for new projects coming into the loop. Ideas may come from Segment Chairmen, Program Manager, Review Committee discussions, or directly from the program plan.	°Review of RFPs prior to distribution.	
Evaluation of Project Proposals:			°Proposals are reviewed by first committee for <u>technical excellence</u>.
Supporting and Monitoring ongoing projects:		°In Etiology and Chemotherapy approved projects are allocated to already existing program segments, or new segments are formed specifically for the new program revision or addition. °In General Labs and Clinics new task forces are built to manage the additional work.	°Proposals are subsequently reviewed by second committee for <u>relevance</u>, <u>need</u> and <u>logical priority</u>.
Evaluation of projects and programs:	°National Advisory Council conducts total program reviews using indications of progress through program plans.	°Segment Chairmen and Task Force Steering Committees evaluate projects in terms of producing data required by the program plan.	°Ad hoc evaluation teams may be used for site visits and guidance to Technical Review Committee

A description of the program development processes appears in Fig. 7.

The above description focuses on program development within a program. Here, procedures for proposal review and contract management are relatively straightforward. The more critical problems of program development at NCI occur between programs and concern the allocation of responsibility for particular program pieces necessary for more than one program. For example, work on certain viruses may be common to the requirements of both the Special Virus Program of the Directorate of Etiology and the Breast Cancer Program of General Labs and Clinics. Since both programs operate with relatively separate funds and management teams, there may be some conflicts over the allocation of work. These problems may even magnify with the inclusion of additional programmatic R&D managed extramurally within the grants program. Though no formal procedures of resolution have been evolved, NCI management has become sensitive to this issue in program development.

Program Evaluation

At the program level, evaluation is associated with progress through the program plans. No formal evaluation procedures are used.

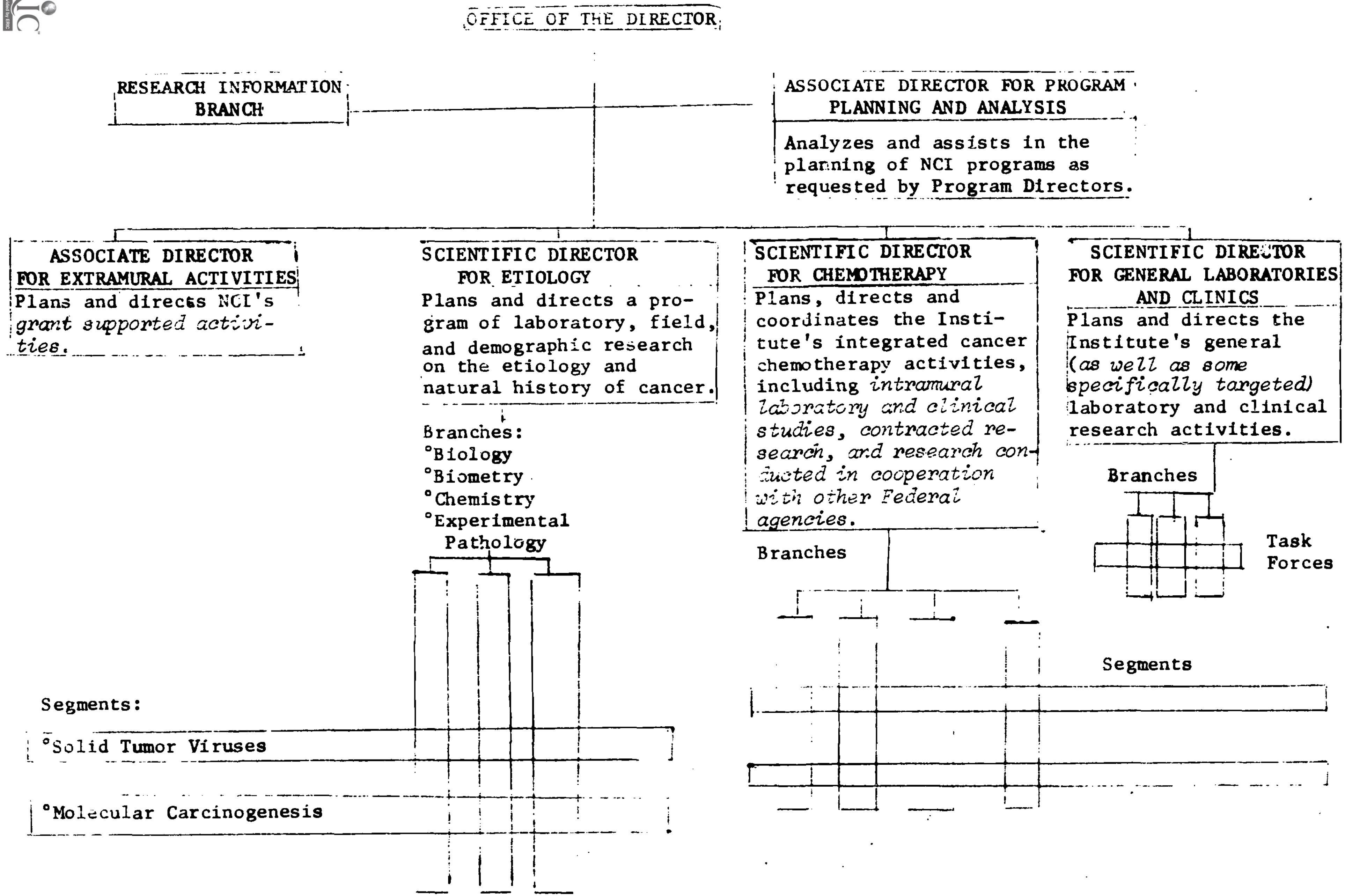
ORGANIZATION

Structure

The accompanying chart indicates the four major divisions of the Cancer Institute. Etiology, General Labs and Clinics, and Chemotherapy do both intramural and collaborative research. The Extramural Division does only extramural grants management.

In the Etiology Division, there are three major programs, each headed by an associate director. Each program is further broken into branches, each headed by a branch chief. These branches tend to be discipline-oriented; e.g., Biometry, Biology, Chemistry, and Experimental Rathology. The branches are the administrative units for intramural research activity. Alongside component branches are

Figure 8: ORGANIZATION OF THE NATIONAL CANCER INSTITUTE



program segments, each headed by a segment chairman. These segments tend to be problem-oriented; e.g., Solid Tumor Viruses, Immunology, Molecular Carcinogenesis, Bioassay, Lung and Information and Research. The segments are the administrative units for collaborative (contracted) research within the Directorates of Etiology and Chemotherapy. A segment is composed of between five and ten people serving as program officers for a few contracts. In general, these members perform two roles: as intramural researchers within a branch, and as program officers within a segment. Segment chairmen commonly play double roles, serving as branch chiefs as well.

Within Etiology, the Carcinogenesis program has eight segments, the Viral Oncology program has nine segments, and the Demography program has seven. A few segments are nearly vertical, drawing most of their members from a single branch. Most are horizontal, cutting across many branches. Ninety percent of the intramural staff serves on at least one segment.

A similar matrix form of program management exists in the Directorate of General Labs and Clinics. Rather than being called segments, the problem-focused administrative units of collaborative research are called task forces, and are headed by a Task Force Steering Committee of intramural members. Intramural task force members similarly serve also in discipline-oriented branches of General Labs and Clinics. Included are branches of surgery, radiology, immunology, endicrinology, dermatology, and metabolics.

The Cancer Institute tries to maintain organizational stability on one hand, and on the other, to be responsive through organizational changes, to major breakthroughs. Most organizational changes are incremental, though some have been major. For example, the Etiology Division did not exist in 1965, yet now has three major programs within it. Also, if the idea of host change as a means of cancer prevention and cure gains Institute support, immunology may gain divisional status as well.

Staffing Policies

Program managers almost always come from a research background, and get some staff experience before assuming program responsibility. Earlier institute experiences with trying to train good administrators to be good science managers failed because of their lack of technical background. Typically, each program manager handles projects whose budgets total between thirty-five and forty million dollars.

IV. AIR FORCE MANAGEMENT PARADIGM FOR WEAPONS SYSTEM DEVELOPMENT

OVERVIEW

Within Air Force programs concerned with overall strategic and tactical forces are many projects of weapon system development. These projects are often so large, in budget and complexity, as to require their own systems for planning, contract selection, and contract management. Much of the management activities of the Air Force focuses down at this project level. Temporary management organizations and often procedures themselves are project-specific. For these reasons, this section dealing with Air Force R&D management methods will emphasize project initiation, contractor selection, and contract management, and will focus on projects of major weapon systems development.*

Procedures for all military system development and procurement, more than procedures for R&D management in non-defense sectors, reflect underlying processes of advocacy; with profit-making developers competing for contracts from the services, and the services requesting funding from Congress. Consequently, the management of these military R&D projects emphasizes balancing among needs and interests, and controlling potentially overzealous developers. This differs greatly from the situation in which R&D projects must be stimulated in areas of need, which is the prime management task in some of the other R&D agencies discussed earlier.

Decisions first by private contractors, concerning which unsolicited project ideas to promote and to which RFPs to respond, and second, by the services, concerning which proposed systems merit Air Force advocacy for funding, are influenced by a wide variety of intelligence systems, sensitivities to technological advances, clues of Congressional attitude,

*A major project is defined as one having either an estimated RDT&E cost in excess of $50 million, or an estimated production cost in excess of $200 million.

and formal military planning documents. The management of system development reflects this sensitivity as to what might be approved, as well as strict compliance to a large number of formal procedures for initiating, directing, approving, monitoring, and controlling major extramural projects.

A detailed and complete description of the entire process of program planning and development for any of the armed services would require volumes. Instead, this section attempts to convey the broad features of the managerial procedures used specifically by the Air Force throughout most of the last decade in developing major systems. It highlights both project initiation and control. More formal and complex descriptions of the flow of decisions and documentation in this management process may be found in the instructions and guides listed in the past Air Force Regulations concerning system development. (sce AFR-57-1, AFR 375 series, and DOD 4100.35)

In July, 1971, the Air Force issued a new regulation for program management (AFR 800-2) which supercedes much of the procedural requirements used in the past, and attempts to reduce formal management and review activities by delegating more responsibility to the final program user (implementing command) and to the designated Program Manager. Details of this regulation have just begun to evolve. Consequently, this section will describe those procedures used over the last 8 years, and will conclude with highlights of the new procedures implied by AFR 800-2.

In the past, Air Force project development consisted of three phases, each ending with a requirement of approval by the Office of the Secretary of Defense (OSD) for continuation. The *Conceptual Phase* traced the system from its perceived need in any of the Air Force operating divisions, stated as a Required Operational Capability or ROC; through review panels and supplementary studies administered by Air Force Headquarters; to OSD approval of the technical development plan for the project. The *Validation Phase* included the establishment of a Systems Project Office (SPO) to manage the proposed development; additional trade-off studies, technical feasibility studies, and mission analyses as required; the development of RFPs; and OSD approval for development. Finally, the *Development Phase* consisted of contracted development under close management of the SPO according to detailed Air Force Regulations.

For this last phase, a System Project Office (SPO) was established as a temporary organization, existing only during the development lifetime of the project. Once the system was produced and operational, this organization was disbanded. Even within the temporary SPOs, turnover of managerial personnel was high, particularly among the military participating as part of their tour of duty. SPO size ranged from about fifty, as in the contemporary Maverick and SRAM missile projects, to as high as four hundred fifty, as in the Minuteman missile project.

The essential features of the former management paradigm for Air Force system development projects were:

- Major *project ideas* were initiated from any of the Air Force operating divisions, such as the Strategic Air Command, Tactical Air Command, and Systems Command, and were stated as a "perceived military need" or Required Operational Capability (ROC). (No change under AFR 800-2)
- The *development and evaluation of project ideas* (ROCs) were managed within Air Force Headquarters by area-focused panels of officers prior to any position of Air Force advocacy for funding. (No change under AFR 800-2)
- Approval for each individual project had to be obtained from Air Force Headquarters, the Office of the Secretary of Defense, and Congress. (No change under AFR 800-2)
- All major development projects were conducted *extramurally*, under close management of a System Project Office (SPO) of finite life and subject to *detailed formalized management procedures*. (Under AFR 800-2, SPOs are eliminated and a new emphasis placed on single Program Managers and a reduction of formalized procedures.)
- Major managerial emphasis is placed first on *selection and justification of project ideas* prior to positions of advocacy and preparation of any RFP, and second, on *control* of extramural project development subsequent to contract award. (No

change under AFR 800-2)

- Contract proposals are reviewed and selected by temporary, formal *Source Selection Boards*, established specifically for each major project, and awards are made to industrial organizations rather than individual scientists. (Under AFR 800-2, most of the cumbersome features of formal contract selection are eliminated, and the number of people participating is greatly reduced. See details in the text.)

SUMMARY

General Characteristics

Relevant project output:	Development of major weapon systems.
Mechanism of support:	Detailed development contracts awarded to outside private aerospace organizations. Contracts may be fixed fee, cost plus fee, or incentive type contracts.
Staffing plan:	Following contract award, temporary System Project Offices were established inhouse to direct the overall management of the development projects. (Under AFR 800-2, these large SPOs will be replaced by much smaller Program Offices assisting the Program Manager.)

Program Planning

Sources of new program ideas:	Sources for new program ideas involving projects of weapon system development may be any of the many intelligence documents utilized by Air Force or the many formal

	planning documents produced by them.
Mechanisms for planning:	Formal planning documents are prepared by the Joint Chief of Staff, by Air Force Headquarters, and by Systems Command.
Coordination:	Coordination among project plans is promoted by frequent meetings of the Air Force Council made up of the Deputy Chiefs of Staff of all the functionally oriented divisions, and of the Air Staff Board made up of the heads of the departments under the Deputy Chiefs of Staff. A major concern of these groups is in determining the set of potential projects which can best meet the needs of Air Force programs.

<u>Program Development</u>

Sources of new project ideas:	Project ideas may arise from any general officer in any of the operating divisions such as Strategic Air Command or Systems Command, or may be suggested by any potential contractor.
Development of project ideas:	A project idea, stated as a Required Operational Capability (ROC) is first coordinated with all other divisions to prevent

duplication and foster joint benefits. It is then reviewed by the Air Force Council and by an inhouse area-focused panel maintained continuously by the Deputy Chief of Staff for R&D. Following subsequent studies required by the panel and the development of a Concept Formulation Package/Technical Development Plan (CFP/TDP) the project idea was reviewed by the Air Staff Board, again by the Air Force Council, and finally by OSD and Congress. (Under AFR 800-2, the CFP is replaced by the documents already prepared during program advocacy, and the TDP and many other formal documents are replaced by the single Program Management Plan.)

Preparation of the RFP: Following approval for funding, a Systems Project Office (SPO) was established within Systems Command to prepare the RFP for the project contract. (Under AFR 800-2, SPOs are eliminated and responsibility is delegated to a single Program Manager.)

Selection of external contractors: Proposals were reviewed and contracts were awarded by formal *Source Selection Boards* established solely to review proposals for an individual project. Each Board had its own advisory council which determined criteria for selection, and its own set of technical committees to score proposals in their particular area. All were disbanded following contract award. (Under AFR 800-2, the Board and technical committees are all replaced by a small single committee of 10-15 personnel.)

Monitoring of performance: Contractor performance in the development of a new system was monitored closely by the System Project Office throughout development. The SPO was assisted in monitoring contractor compliance to Air Force regulations by an outside Air Force Plant Representative Office. (Elimination of SPOs under AFR 800-2.)

Mechanism of project evaluation: No formal procedures are used within the Air Force. However, other government agencies such as the Government Accounting Office (GAO) often conduct unsolicited project evaluations in situations of potential underachievement in performance, cost, or time.

ACTIVITIES

Within Air Force Headquarters, project management activities for weapon system development are directed largely toward initiation of potential projects for submission to Congress for funding. Subsequent to funding approval, major managerial efforts are directed to contractor selection procedures. Because many industrial organizations often compete for Air Force project contracts, and because the amount of money in any contract is often quite high, detailed and formal procedures must be followed by temporary project-specific selection groups in awarding contracts fairly, and in accordance with pre-defined standards. Following contract award, project management activities emphasize control, and in the past, responsibility was directed to temporary, project-specific System Project Offices for constant monitoring and communication with the contractors selected.

Initiation of Potential Projects

The perceived need giving rise to a major project idea may originate from a number of intelligence and planning sources. Some are the logical consequences of new threats. Others are spawned from technological breakthroughs permitting new military capabilities. Most are products of the continual interchange of ideas between the Air Force with its perception of its own strengths and weaknesses, and industry and its perceptions of possible new products and capability advances.

On the military side, commanders of the Air Force operating divisions receive continual intelligence reports about the capabilities of potential adversaries and are provided with a host of planning documents indicating anticipated events and desired future capabilities. Some of the formal, annually revised, planning documents related to the needs and desires of new systems are listed below:

Prepared by the Joint Chiefs of Staff:

JIEP -- Joint Intelligence Estimate for Planning

JSCP -- Joint Strategic Capabilities Plan
(1 fiscal year into the future)

JLRSS - Joint Long-Range Strategic Study
(10-20 years into the future)

JSOP -- Joint Strategic Objectives Plan
(2-10 years into the future)

JRDOD -- Joint Research and Development Document
(Broad capabilities desired for systems and material in period covered by JSOP, and technological accomplishments desired for period of JLRSS)

Prepared by Air Force Headquarters:

USAF Planning Concepts -- Conceptual foundations for desired capabilities. Revised annually by the Directorate of Doctrine, Concepts, and Objectives, under the Deputy Chief of Staff for R&D.

Technological Horizons Document -- Revised annually by the Directorate of Operations Requirements and Development Plans, under the same Deputy Chief of Staff.

Prepared by the Air Force Operating Commands:

Technological Objectives Plan -- Prepared by Air Force Systems Command.

The initiation of a specific proposed project, stated as a Required Operational Capability (ROC), involves a complex procedure of coordination and multiple review, includes the generation of many supplementary studies of feasibility and justification, and culminated in the production of a Concept Formulation Package/Technical Development Plan (CFP/TDP) which outlined the entire system design, management plan, and time schedule of development activities. (This document and others, have been replaced by a single Program Management Plan.) An abstracted, pictorial description of this process is presented in Appendix C. Only the relevant portions of the Air Force hierarchy are shown. Each page illustrates a single step in the generalized procedures of project planning. The procedures illustrated end with the preparation of the project plan, conducted extramurally and under the overall management of the System Project Offices formerly used by the Air Force.

Contractor Selection

In the past, for each RFP, a Source Selection Authority and a Source Selection Evaluation Board were specially appointed by the Secretary of the Air Force, and included representatives of Systems Command, Logistics Command, and the system's using command. The Board usually had about five to ten generals and perhaps a few senior civilians such as the Assistant Secretary. A separate Source Selection Advisory Council was set up to determine the criteria to be used in rating proposals. In addition, each Board maintained five committees to rank proposal independently of each other on their particular aspect. These included a Technical Committee (responsible for assessments of engineering capabilities and plans), a Management and Production Committee (assessing production capabilities), a Logistics Committee, a Cost Committee, and a Cost/Effectiveness Committee. Committees had about twenty-five members each, with technical backgrounds appropriate to their aspect of the project.

The evaluation techniques used by the Air Force were designed to prevent presentation to the Source Selection Authority of reports which simply compared one proposal to another. Instead, the techniques emphasized the development of a set of *standards* prior to proposal review and against which companies' approaches could be measured. For each of the committees mentioned above, the Advisory Council prepared a list of *items*, fairly broad in scope, for which an evaluation was made on all proposals. An example of an item involving development of an aircraft is "Cabin Environment." Each of the committees then subdivided items further into *factors*. A factor under the item Cabin Environment is "Soundproofing." Standards were then prepared for each factor. Generally, standards did not exceed that which was specified as minimally acceptable in the RFP and did not address subject matter not specified in the RFP.

Each committee indicated for their *factors* whether the companies' proposals exceeded minimum requirements, met minimum requirements, or failed to meet minimum requirements. They then developed an overall score for each *item* based on the component *factor* rankings. Item scores were from 0 as unacceptable to 10 as exceptional. If a company's proposals met all requirements within an item, but did not exceed them, the item was ranked 5. If the company's proposal offered some unique device, process or approach which, for example, saved time, material, or reduced risk, then it was scored 6,7, or 8. If the company showed evidence of a rare solution which was exceptional in all aspects, then it was scored 9 or 10 on that item. Failure to meet minimum requirements of an item was scored 4 through 1 depending on the importance of the deficiency, what must be done to correct it, and the impact the correction will have.*

*"The Source Selection Process" - a Preliminary Draft ASD Manual, 15 June 1969.

Weights applied to indicate the importance of the different items in coming up with an overall evaluation were determined by the Selection Advisory Council and were not made known to the evaluators serving on the committees during the evaluation period. Consequently, individual evaluators could not determine during the course of the evaluation which of the companies achieved the highest overall ranking.

Following item scoring, committee heads coordinated their findings so that the inter-item interfaces and relationships would be fully explored and that deficiences found in the technical evaluations were made known to the Cost and Cost/Effectiveness committees.

An ad hoc super-committee then applied the item weightings determined by the Advisory Council, rank ordered all proposals on the basis of an overall score, and briefed the Source Selection Evaluation Board on the relative rankings. Decisions of contract award were then made by the Board and reviewed by the Secretary of the Air Force. (For further details of this past source selection procedures, see DOD 3200.9, DOD 4105.62, AFR 80-20, and AFR70-15.)

Under the new Air Force regulation (AFR 800-2), most of this process has changed. The new procedures call for only a single committee of ten to fifteen people to advise the Source Selection Authority on contract proposals. This represents a major policy change, the implications of which are still unknown. Though past procedures were more cumbersome and costly, they did provide effective means for fair, comprehensive review of highly complex programs.

Contract Management

Under the former system, once a contract had been awarded, the full responsibility for the management of the project was given to the System Project Office. This office maintained constant contact with the contractor (either a single prime contractor who subcontracted for required components and systems, or a number of associate contractors each responsible for a major portion of the project) and participated in some of the technical decision making. The SPO received monthly formal progress reports and cost performance reports from the contractor, and maintained surveillance for compliance with Air Force regulations with the assistance

Figure 9: Project Management for Air Force Weapon System Development; Former System

Activity	Using Command (Operating Division which will use the system to be developed)	Area-Focused Panels Maintained by the Deputy Chief of Staff for R&D	Air Force Council and Air Staff Board	Systems Command	System Project Office (SPO) Within Systems Command	Source Selection Advisory Council	5 Committees of the Source Selection Evaluation Board
Sources of project ideas	o Any General Officer may submit a project idea in the form of a required operational capability (ROC). o ROCs must be approved by *Head of Division* (Commander) before sent to headquarters.	o Reviews all ROCS and orders Systems Command to do supporting studies of technical feasibility and mission analysis		o Prepares supporting studies (often by contract to extramural agencies).			
Preparation of project plan:		o Prepares position paper on ROC for approval by Air Force Council and Board	o *Reviews ROCs* for approval as projects for which Air Force will request funds from OSD and Congress. o Orders Systems Command to prepare project plan.	o Sets up Systems Project Office (SPO) within Systems Command, and appoints Project Director.	o Issues RFP to prepare the project plan by extramural contract. o Reviews proposal and selects contractor to produce plan. o Submits completed project plan to Air Force Council.		
Evaluation of project plan:			o Approves project plan and requests funds for project from OSD and Congress.				
Evaluation of proposals and selection of project contractor:			if funded:	o Orders RFPs for project (Systems Development) o Proposals sent to a special Source Selection Authority appointed by the Secretary of the Air Force specifically for evaluating project proposals.		o Develops list of items on which all proposals must be evaluated. o Determines relative weightings of importance for each item. o Combines item scores, using relative weighting of importance, into overall proposal score. o Rank orders all proposals on basis of overall scores, and submits findings to Source Selection Authority which awards contract with concurrence of the Secretary of the Air Force.	o Subdivides items into factors and indicates whether proposals meet or exceed minimum requirements on each factor. o Determines scores for each item.
Monitoring and supporting ongoing project:	o Representatives of Using Command and Training Command participate in SPO during system development.				o SPO assumes responsibility for overall management of systems development. o SPO assisted in contractor monitoring by on-site Air Force Plant Representative Office. o Prepares monthly cost-progress report and quarterly acquisition report to Air Force Headquarters, Systems Command, and Using Command.		
Implementation of project results:	o Using Command assumes control of developed system with maintenance support from Air Material Areas (AMAs) within Logistics Command.	System developed and produced, SPO disbanded.				Contract awarded, Source Selection, Authority, Council and Board disbanded.	

of an Air Force Plant Representative Office at the contractor's plant.

The managerial emphasis of the SPO was on controlling the contractor to keep abreast of the time schedule of development activities as detailed in the Technical Development Plan, to stay within the appropriated budgets, and to meet the development deadline for initial operating capability. SPO engineers maintained continuous contact with contractor engineers for these purposes. At the conclusion of flight testing and production, the SPO was disbanded. Responsibility for the maintenance of operating systems was then assumed by the appropriate Air Material Area (AMA) under the jurisdiction of Air Force Logistics Command.

A description of the entire process of project planning and development under the former Air Force system is provided in Figure 9.

FORMER ORGANIZATION

Structural Relationships

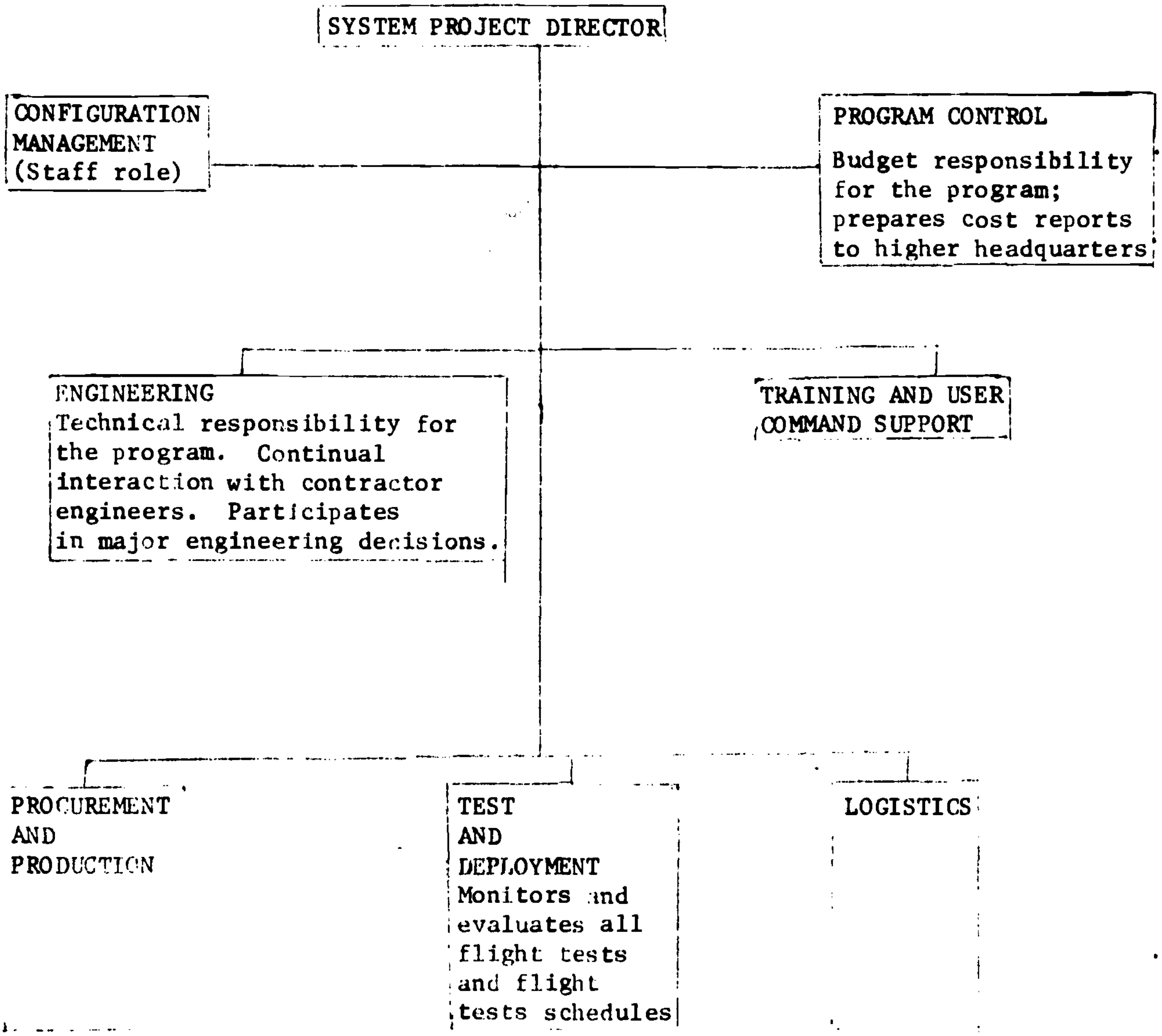
A typical organization structure for System Project Offices which existed as part of the Air Force system for program development over the last 8 years is shown on page 54. The organization of the entire Air Force Department is abstracted in the figures of Appendix C. None of this latter structure has been changed by the new regulation for program management.

Project Directors and Staff

Most SPOs contained mixes of military and civilian personnel. Turnover among System Project Directors and among their staffs had sometimes led to confusion in the management of development projects, and efforts toward extending the tour-of-duty of project directors and providing more civilians in the SPO were being taken by the Air Force.

Project directors were almost always full colonels, and had extensive backgrounds in procurement management. They generally had advanced degrees, but not necessarily in technical fields. Many were graduates of Air Force Schools and so had some formal training in engineering.

Figure 10: STANDARD STRUCTURE OF THE SYSTEM PROJECT OFFICE UNDER THE FORMER REGULATIONS FOR PROGRAM MANAGEMENT



User Representation within the SPO

Included within the Systems Project Office responsible for the *development* of new Air Force projects under the old system, were representatives of the training and using Commands who were responsible for project *implementation and utilization* following development. Early participation by users was included to minimize unanticipated obstacles to project use later on, and ensure development of systems containing features desired by project users.

This last feature became one of the fundamental principles of program management under the new regulation issued in July, 1971. The concept of user participation in development was extended to user responsibility and control. Headquarters participation was reduced and the concept of a large System Project Office was supplanted by the concept of a single Program Manager appointed by the implementing command rather than by Systems Command.

Additional changes in program management initiated by AFR 800-2 are described below.

NEW PROGRAM MANAGEMENT PROCEDURES EFFECTIVE 27 JULY 1971 UNDER AFR 800-2

The following description highlights and paraphrases the new procedures designated in AFR 800-2. Where appropriate, major changes are indicated.

General Philosophy

The regulation delegates maximum authority and responsibility to the implementing command and the designated Program Manager for the conduct of a program within approved performance, schedule, and funding parameters. Decentralized management principles are emphasized and the single manager concept is to be employed to the extent practicable.

Allocation of Responsibility

a. USAF Headquarters:

(1) Establishes and verifies requirements.

(2) Conducts program advocacy.

(3) Issues program management directives (PMDs) which:

(a) Initiate, approve, change, modify, or terminate programs.

(b) Designate the implementing command for programs, define the task, and delegate the program management task to that command.

(c) Designate participating commands and their responsibilities.

b. The Implementing Command:

(1) Is responsible for the program task as defined in the PMD. (This is a major change. Formerly, program development was the responsibility of Air Force Systems Command, and participation of the implementing command was limited to representation in the SPO.)

(2) Appoints the Program Manager and appropriately staffs a program office. For major programs, this should be sufficiently early in the conceptual phase to allow the Program Manager to participate in program advocacy. (Again, a major change. Previously, Program Managers (SPO Directors) were appointed by Systems Command.)

(3) Delegates maximum authority and responsibility to the Program Manager.

c. The Program Manager:

(1) Organizes, plans, directs, and controls the program, utilizing the advice and recommendations of the participating organizations.

(2) Tailors the organization of the program office and the selection and application of management systems to the needs of the particular program within the constraints specified by the PMD and implementing command supplements.

(3) Makes technical and business management decisions within the approved program to accomplish program objectives.

(4) Establishes the need, scope, costs, and schedule for all program related effort.

(5) Assesses and documents the impact of proposed changes which alter approved performance, schedule, and cost objectives.

(6) Prepares and issues a program management plan (PMP) in consonance with the PMD and implementing command supplements. The PMP is tailored to the needs of the program and will not require higher headquarters approval unless such approval is specifically required in the PMD.

(7) Maintains a continuous assessment of his program's

progress and performance versus requirements, threat, schedule, and costs, and informs higher headquarters of recommended changes.

Communications

Program Managers are charged with promptly reporting appropriate problems to the proper level for timely resolution. To do so, a direct channel of communications, called the BLUE LINE is applied to programs specified by USAF headquarters. This provides direct communication from the Program Manager to the Commander (implementing command), Chief of Staff, and the Secretary of the Air Force. The participating personnel included in this BLUE LINE channel are indicated in the following illustration. (Again, a major change. Under former procedures, communications between a System Project Director and AF Headquarters were severely restricted, each successively high layer requiring detailed, formal review before critical information could be passed up the chain of command.)

Overall, one can see a major change in Air Force program management emphasis toward decentralization, reduced formality in procedure, and redirection of development control to the implementing command. Actual effects of these policy changes have yet to be realized.

AIR FORCE BLUE LINE CHANNEL OF COMMUNICATION FOR PROGRAM MANAGEMENT

Secretary of the Air Force

Chief of Staff — Staff

Commander Implementing Command — Staff

Commander Participating Commands — Staff

Program Manager | Program Manager | Program Manager

V. QUANTITATIVE MODELS FOR PROJECT SELECTION

INTRODUCTORY VERSE:

Title:
"The Company President's Completely Perfect and
Absolutely Quantitative Method of Evaluating His
R&D Program"

by Ned Landon
GE's Corporate R&D Center

I multiply your projects by the words I can't pronounce,
And weigh your published papers to the nearest half an ounce;
I add a big fat bonus for research that's really pure.
(And if it's also useful, your job will be secure!)

I integrate your patent rate upon a monthly basis;
Compute just what your place in the race to conquer space is;
Your scientific stature I assay upon some scales
Whose final calibration is the Company net-to-sales.

And thus I create numbers where there were none before;
I have lots of facts and figures -- and formulae galore --
And these quantitative studies make the whole thing crystal clear;
Our research should cost exactly what we've budgeted this year.

OVERVIEW

In this final section on Models for R&D Project Selection, the style of presentation changes from one of detailed description of management methods by sample agencies to one of general overview and current state-of-the-art. This change occurs primarily because of the great diversity among government agencies and industries in their use of quantitative models for project selection. To examine only a few cases and leave the impression that this typifies the formulation, use, and reliance on quantitative models would be less accurate than a general overview of the kinds of models existing, the overall advantages and requirements of model use, and the general attitude of uses toward the appropriate role of models in R&D decisionmaking. Consequently, this final section adopts the latter strategy and uses as its information source the published literature on the subject rather than interviews with members of selected agencies.

This overview deals with five managerial questions concerning quantitative models for R&D project selection:

(1) Are Project Selection Models totally quantitative, as the introductory verse implies?

(2) In general, what are the advantages and limitations of using quantitative models for project selection?

(3) In practice, are project selection decisions actually made by computerized models, or do the models serve only as one source of input to human decisionmakers?

(4) Are computerized R&D Project Selection Models widespread among industries and government agencies?

(5) What are some examples of different Project Selection Models?

As a management paradigm, Project Selection Models focus on only *one* aspect of a highly diverse management process. This differs considerably from the three agency management paradigms presented earlier. Consequently, the content of this final section should not be construed as an alternative approach to total management, but rather as a supplementary management tool, applicable in concert with each of the agency management paradigms described earlier.

In general, the essential features and focus of Project Selection Models are:

- In preparing information inputs for model use, *groups of technical advisors* provide quantitative assessments according to specified criteria, for each project or research area.
- Assessments are combined according to some *mathematical model* by which projects or areas may be compared or budgets allocated.
- Recommended budget allocations are made *all at once* according to the current model solution, usually in relation to a fixed budget cycle.

SUMMARY

General Characteristics

Primary output:	Allocation of fixed budget to candidate projects or project areas.
Mechanisms of support:	Not relevant to paradigm.
Managerial emphasis:	Program planning only. Monitoring and control are not considered.
Staffing plan:	Requirement of sources of technical assessments.
Coordination:	Coordination in project planning is provided by some models in terms of systematic consideration of project interactions. Other models provide no consideration for coordination.
Sources of project ideas:	Provided by certain models through the identification of technological areas in which R&D is desired. Considered by most models as given inputs.
Allocation of budget:	Determined, in part, by application of the specific model used. Some review and modification according to managerial judgment almost always occurs.
Evaluation:	Some evaluation occurs as a by product of recommendations for project renewal. Even here, the intent of model application is strictly toward what to do next rather than how well have we done.

CRITICAL ISSUES

Are Project Selection Models Absolutely Quantitative, as the Introductory Verse Implies?

If by "absolutely quantitative" one means uninfluenced by human judgment, the answer to this question is definitely no. Because of the uncertainties regarding technical success, time and cost, effectiveness and value, all project selection models use human judgment as their basic input. These judgments are, however, expressed in terms of numerical values. Accordingly, the models using them are quantitative. But placing numbers on judgments does not change the fact that judgments are the fundamental ingredient, and whether expressed as numbers or sentences, are still judgments.

Why then bother with translating judgments into numbers at all? With judgments expressed in numerical values, one can formalize a set of decision criteria and assign numerical values to their relative importance. These weights can then be *applied consistently* to a large number of potential candidate projects. When projects must be compared on the basis of multiple criteria and when the rating of each project along each criterion is complex, it is extremely difficult if not impossible to treat all projects consistently unless some numerical characterization is used in place of lengthy statements of judgment.

In General, What are the Apparent and Actual Advantages and Limitations of Using Quantitative Models for Project Selection?

If quantitative models for project selection are still only applications of human judgment, what are the apparent attractions of models to some R&D managers, and what are the actual advantages and limitations that result from their use? In answer to the first part, the idea that there is a quantitative basis for a difficult managerial task is generally appealing. In most R&D organizations, the setting for project selection decisions is as follows:

(1) The organization has an annual cycle for project selection and budgeting.

(2) Competition exists for support among several candidate projects.

(3) The total budget for the projects is less than the sum of the candidate project budgets.

To economists and management scientists, this is an example of a classical resource allocation problem of the kind for which quantitative solutions have been developed. However, the quality of any mathematical solution is no better than the quality of the input provided, and in practically all R&D scoring models currently available, the quality of at least half the input is severely limited. The more certain, and predictable half is that concerned with project cost, although even here large uncertainties are present. But few projects are selected on the basis of cost alone. Most selection decisions are concerned with comparisons of:

- *Cost and Economic Benefit:* Project costs are compared to an economic valuation of all the benefits (direct and sometimes also indirect) derived from the project.
- *Cost and Effectiveness:* Project costs are compared to an index of project impact or effectiveness in achieving specified objectives. Effectiveness itself is a multidimensional characteristic. The comparisons below indicate specific components of an effectiveness measure.
- *Cost and Relevance:* Project costs are compared to an index of relevance toward a specified objective or program field.
- *Cost and Estimated Success:* Project costs are compared to estimates of the probability of technical success.
- *Cost and Progress:* Project costs are compared to an index of how far the success of the project would move the parent program through a series of milestones.
- Combinations of these factors.

Estimation of the second half of these inputs is subject to far more uncertainty than estimates of costs.

In the selection models, measures of benefit, effectiveness, relevance, probability of success, consequent progress, or similar criteria are usually made by groups of technical advisors through discussions and debate. They proceed in the same way as the peer panels of other agencies who decide directly on project selection. The difference between selection models and direct panel review is that panel reviews provide judgments of each project in all its aspects in competition with other projects, while the technical groups used in project selection models provide judgments only of each aspect of a project, one at a time, separate from both other aspects of the same project and from other projects. Judgments in this latter approach are combined through one of the selection models to form a comprehensive assessment of a specific project and a subsequent comparison among all projects.

The selection model's advantages of additional objectivity through explicit treatment of multiple criteria and consistent combination of technical assessments must be balanced against the user's perceptions of how completely and how accurately the model's rules conform to his own desired selection criteria. Frequently, subtle indications of the quality of the investigator or his institution, or complex issues of potential inter-project relationships and balance among all the projects in an organization's R&D portfolio do not enter into a model, yet equally frequently, they are quite important to the decisionmaker.

In Practice, Are Project Selection Decisions Actually Made by Computerized Models Without Additional Human Intervention?

Throughout the literature on project selection models, concerning both methodology and usage, is the impression that the results of model application serve as input to human review of budget allocation. Often, reference is made to model use in producing alternative sets of candidate projects which satisfy different criterion weightings of importance. For example, the models may be used to answer questions such as: What if we valued this criterion more than this one? Or what if we decreased the total budget available by ten percent? Nowhere in the literature did we encounter a situation described as one in which the selections are made directly from application of a decision model without any subsequent review by committee or manager. Most descriptions of use emphasize the model recommendations as a basis for further deliberation.

At a recent conference on the administration of research, one company president was quoted as saying: "My job begins where the numbers leave off ...(but) I prefer to leave off from good numbers!" The numbers provided by quantitative models are "good" only in that they provide the final decisionmaker with a fairly consistent application of the same criteria to all candidate projects and a consistent combination of all assessments to facilitate comparisons among projects. Whether or not the numbers are "good" in terms of the technical assessments of measures of benefit, relevance, or whatever, is independent of the quantitative model and dependent instead on the competence and degree of effort given by the staff in preparing inputs for the model.

Are Computerized R&D Project Selection Models Widespread Among Industry and Government Agencies?

Surveys on the use of quantitative models in practice conducted within the last decade have concluded that though interest in project selection models have been high, and the proliferation of various models has been following an exponential growth curve, the actual use of models in practice has been both infrequent and limited in scope. The first major survey published in 1964 by Baker and Pound (6) stated:

> Although the literature, interviews, and seminar data are not conclusive on the matter, it does suggest that there has been little thorough testing and only scattered use of the proposed methods.

The authors do mention, however, that earlier surveys by Harrel and Quinn show that "many laboratories use some sort of quantitative technique part of the time."

In late 1966, Albert Rubenstein (7) published a second survey of theory and practice of R&D evaluation which concluded:

> The practice of project selection in industry and government is dominated by ... methods depending heavily upon individual or group judgment and using very little quantitative analysis. The use of cost and return estimates is common, but very few organizations employ any formal mathematical model for combining these estimates and generating optimal project portfolios.

Rubenstein continues:

> In following the field closely since 1950, one detects very little increase in the use by operating R&D organizations of

> the more quantitative methods ... There are some clearly evident reasons for this; the complexity of many of the formulations, the requirements for data that is not generally available, the omission from some formulations in dealing with the diverse kinds of selection decisions that arise in R&D.

No indications in the literature exist that widespread use of quantitative models has occurred subsequent to these surveys, or that the problems described as reasons for their lack of general use have been solved.

What Are the Underlying Principles in Different Project Selection Models?

All quantitative models for project selection are derived from some or all of three basic concepts:

(1) The concept of using "relative weightings of importance" in combining assessments among different dimensions or criteria. For example, a manager may indicate that measures of the probability of success are twice as important as measures of the expected time to completion and should therefore receive twice as much "weight" in determining whether one project should be selected over another.

(2) The concept of "discounting" streams of income and expense to produce comparable valuations of money flows. This procedure indicates to a manager that in situations of excess funds, cash at the current time may be more valuable than the same amount of cash at a later time because of the opportunity of earning interest in alternative investments.

(3) The concept of "maximization" of some criterion function subject to prespecified constraints. For example, maximizing rate of return on investment, subject to the budget constraint and the constraint that no more than some specified percent of the budget can be spent on R&D in any single field.

Different kinds of quantitative models for project selection are formulated on different combinations of these three principles. Models based on the first concept are called "Multiple-Criteria Scoring Models." Models based primarily on the second concept are called "Economic Models." Models using the third concept are called

"Models of Constrained Optimization." Each of these basic models are described below. Combinations are frequent. For example, maximization along one dimension may be only one selection criterion among many; each with its own relative weighting. The value of discounted moneys may be another criterion, used either in a scoring model or within a maximization procedure. Furthermore, different models may be used for different purposes; the Scoring Model for selection among candidate projects for fundamental research, the Economic Model or Maximization Model for advanced engineering or development projects. The complexity of each may vary according to the demands of the user and the complexity of the candidate projects. Each kind of quantitative model has its own underlying procedure, however, and its own set of advantages and limitations.

Scoring Models

Scoring models provide the most simple framework for comparative evaluation among candidate projects. Each project is rated on different criteria, with rating scores associated with different levels or ranges along the relevant criteria. For example, Criterion 1 may be "Probability of Technical Success." If a project is judged to have a probability of technical success lying within the range .00 to .01, it may receive a score of 1 along that criterion. Similar procedures occur for other ranges and other criteria forming the following abstract illustration:

Criterion 1: *Probability of Technical Success*

Range 1: (.00 to .01)	Score 1
Range 2: (.01 to .02)	Score 2
...	
Range 10: (... to ...)	Score 10

Criterion 2: *Expected Time to Completion*

Range 1: (1 month to 1 year)	Score 10
Range 2: (1 year to 2 years)	Score 9
...	
Range 10: (... to ...)	Score 1

Criterion 3: ....

Each criterion may also have a "relative weighting of importance" which allows individual scores along separate criteria to be combined into an overall project score. If the relative weighting of Criterion 1 is 2, and the relative weighting of Criterion 2 is 1, this indicates that the score of a project along Criterion 1 is twice as important as the score along Criterion 2. Considering only these two criteria, the total project score may be determined according to the overall formula:

Project Score = (Score on Criterion 1) times 2 + Score on Criterion 2

A different formulation of the overall project score involves *multiplying* component scores rather than *adding* them. Differences resulting from these two procedures are investigated by Moore and Baker in (1).

To apply the Scoring Model approach, simply compute an overall project score for each candidate project, reorder the list of candidate projects on the basis of decreasing project score, and allocate funds for the entire planning horizon to the candidate projects starting from the top of the list.

Economic Models

The second model form simply "discounts" the expected streams of incomes and expenses for each candidate project and compares them according to their computed economic value. In the abstract, the model form is:

$$\text{Project Score} = \frac{\text{Discounted Expected Income}}{\text{Discounted Expected Expenses}}$$

If this ratio is less than 1, this indicates that considering all the flows of income and expenses coming from a particular candidate project, the overall value of the project at the time of initiation is negative. Consequently, on economic grounds, no candidate project whose project score is less than 1 should be funded. All candidate projects with scores greater than 1 represent investments of positive economic value, and the greater the score, the greater the value. Mathematically, the formula for determining this ratio is:

$$\text{Project Score} = \frac{\sum_{K=1}^{N} (I_t \cdot (1+r)^{-t})}{\sum_{K=1}^{N} (C_t \cdot (1+r)^{-t})}$$

where I_t = Income (money gained or costs saved from the project in the year t)

C_t = Cost of the project in the year t

r = the discount rate applied to future money

N = Project lifetime, or number of years into the future used in project planning

t = year (1.....N)

To apply the Economic Model, use the same procedure as before: simply compute an overall project score for each candidate project, reorder the list of candidate projects on the basis of decreasing project score, and allocate funds for the entire planning horizon to candidate projects starting from the top of the list.

The Economic Model above scores candidate projects on the basis of their "present economic value" considering the flows of all future income and expenses. This same model may be rewritten in an alternative form which scores candidate projects on the basis of their rate of return per dollar invested in the project, or "internal rate of return." To calculate project scores using this alternative form of the Economic Model, rewrite the above equation so that the ratio is preset to zero, and for each candidate project, calculate the resulting rediscount rate r.

Apply this form of the model in the following way. Suppose that the R&D organization which will be funding candidate projects could always reinvest its funds in the bond market at 5% instead of allocating its funds to candidate R&D projects. Consequently, if any candidate project has an "internal rate of return" calculated by the second form of the Economic Model which is less than 5%, then this project has less economic value than simply putting the same amount of money in the bond market. Similarly, if any R&D organization establishes a minimum level for rate of return below which it wants to fund no projects, this second form of the Economic Model will indicate which candidate projects meet that constraint. Projects which do have calculated rates of return higher than this minimum may then be funded starting from the project with the greatest rate of return.

Models of Constrained Optimization

The third basic model uses the principles of linear programming to maximize some specific criterion function subject to multiple constraints. Both the criterion and the constraints may be economic in nature or may refer to any other measure of relevance or benefit. The main difference in concept between the first two models and this third one is that in the first two, project scores are independently determined for each candidate project and the total set of selected projects is determined subsequent to the application of the model. In this third approach, the model itself selects the best set of projects by considering simultaneously all candidate projects. In this case, the model assigns a project score of either 1 or 0 depending on whether it includes a project in the set to be funded or in the set to be discarded. One example of this model in the abstract is the following:

maximize the function $\sum_{i=1}^{N} V_i \cdot x_i$

subject to the constraint $\sum_{i=1}^{N} C_{i,t} \cdot x_i \leq b_t$

for each $t = 1,2,\ldots n$

where V_i = Some measure for candidate project i representing the degree to which the project accomplishes the prespecified criterion. This criterion may be the expected economic value, the probability of technical success, or any other R&D criterion to be maximized.

x_i = Project score for candidate project i, determined by the model to be either:
1 if the project is selected for funding
or
0 if the project is not selected for funding

$C_{i,t}$ = Cost of candidate project i in year t

b_t = Maximum budget for all projects in year t

N = Number of candidate projects

n = Number of years in time horizon for project planning

To apply this third model for project selection, choose the criterion to be maximized and rate each candidate project according to the criterion.

These ratings are the values V_i. Supply the additional required information on candidate project costs and maximum budget levels for the future years and use the procedure of linear programming to perform the model calculations. The output of the model will be a list of x_i, one for each candidate project. If the value of x_i is 1, then select candidate project i for funding. If the value of x_i is 0, then discard the candidate project i from consideration for the current planning period.

Overall Comparison of the Three Model Forms

Of all three models, only the Economic Model has a focus limited usually to considerations of economic value. For financial organizations and R&D institutions concerned strictly with economic gain from candidate projects, this model may be very appropriate. For most federal agencies sponsoring R&D, however, cost and economic gain are only a part of a much larger set of criteria used in project selection. In these cases, variations of the Scoring Model and Constrained Optimization Model are more appropriate. The advantages of the Scoring Model are that it is simple and it may not require a computer for the necessary calculations. The main advantage of the third approach is that it can handle multiple constraints and thus consider different budget levels for each year in the planning horizon. To show how the Scoring Model and Constrained Optimization Model may be focused on criteria other than economic ones, and example of each is provided below.

PATTERN: A Scoring Model based on Relevance

The name PATTERN is an accronym for Planning Assistance Through Technical Evaluation of Relevance Numbers. The technique was developed by Honeywell, Inc. and is now being tested for application by the U.S. Bureau of Mines. The output of the PATTERN Model is not a list of candidate projects to be funded, but rather a form of roadmap indicating which technological deficiencies are most important or cost-effective in terms of meeting various overall objectives and goals of the R&D organization. By being able to trace the relations between technological deficiences in different areas and organizational goals, R&D managers can determine in which project areas it would be most advantageous to invest.

The PATTERN Model begins with a formulation of overall objectives provided by a planning team. These overall objectives form the top level of what is called a "relevance tree." All the lower levels contain elements which, if accomplished, would contribute to those elements above. In the Honeywell version of PATTERN, described by Sigford and Parvin (2), the fifth level of the tree outlines various operational systems which, if built, would contribute to the accomplishment of higher missions and objectives. At the final, eighth level of the relevance tree are listed the critical technological deficiencies which must be accomplished in order to develop the operational systems above. Elements throughout the relevance tree are developed by a group of technical experts who discuss whether required advances are achievable in the current state-of-the-art, or conceiveable in the near future, and how objectives and subgoals would be advanced with improvements in various technological areas.

To illustrate the kinds of elements which may be considered, the following diagram lists samples of elements from different levels of the relevance tree used as an example in (2).

Top Level:	Overall Objective	...	Scientific Preeminence
Level 2:		...	Exploration
Level 3:		...	Space (or Earth)
Level 4:		...	Solar System (or Lunar)
Level 5:	Operational System	...	Unmanned Orbiter (or Solar Probe)
Level 6:	Functional Subsystem	...	Navigation (or Power)
Level 7:		...	Range and Direction Instruments
Level 8:	Technology Deficiency	...	Unreliability of Equipment after long shutdown in space

After the relevance tree has been completed, relating technological deficiencies to objectives and goals, the technical group assigns "relevance numbers" to each element according to criteria specified for each level of the tree. According to Sigford and Parvin (2), example criteria at the levelof operational systems may be *Cost*

Effectiveness, *Political Implication*, and *Scientific Implication*, each evaluated in terms of component characteristics and benefits. At the level of technological deficiencies, criteria used may be in terms of *Feasibility* of achieving a solution, *Effort* needed to solve the deficiency, and relative *Subsystem Performance Improvement* achievable per unit of effort spent in advancing a given technology. Multiplication of all relevance numbers from any one technological deficiency up the entire relevance tree produces the total relevance number for the deficiency.

The output of relevance numbers can then be used by R&D managers to determine the relative merits of postulated operational systems. These merits are in terms of the anticipated contributions of the systems toward overall objectives. Additionally, the relevance numbers allow managers to compare the relative merits of investing in different technological deficiencies, in terms of the importance of a deficiency in contributing toward the successful development of the postulated systems.

The PATTERN Technique is a Scoring Model in the sense that numbers are assigned to project areas in terms of their ratings along stated criteria. The total relevance numbers, or total project area scores, are determined by multiplying component ratings up through the relevance tree. The main difference between the PATTERN Model and the abstract Scoring Model presented earlier is that criteria in PATTERN are arranged hierarchically, and the weight given to any criterion is dependent upon the ratings of all the elements at higher levels on the tree.

One feature provided by the PATTERN Technique and usually absent in Scoring Models is a way of measuring cross project impact. Reference to the relevance tree in PATTERN will indicate to an R&D manager how advances in one area of technological deficiency will effect advances required in other areas of deficiency.

TORQUE: A Constrained Optimization Model based on Utility of Effort

The name TORQUE is an accronym for Technology Or Research Quantitative Utility Evaluation. The technique was developed in the late 1960's by an interservice team for the Department of Defense, and has been tested by the Air Force as a management tool for allocating an R&D budget among alternative project areas. A more detailed description of the TORQUE Model is presented by Nutt in (3).

TORQUE uses the same reasoning found in PATTERN to outline overall objectives and determine technological advances required. It goes beyond the results of PATTERN, however, in determining the level of funds which should be allocated to each area of technological deficiency in order to maximize the overall "utility" from all the areas funded.

Like PATTERN, TORQUE begins with a listing of overall objectives. The selection of objectives and their rankings in order of importance to the R&D organization are provided by planning teams. Other interdisciplinary teams of technical experts develop alternative approaches to realizing the objectives, and identify the technological advances required. In a procedure analogous to providing "relevance numbers," TORQUE planners assign ratings on the criticality of a technology area to the approach or system which it supports.

The next steps extend the scope of TORQUE into the area of resource allocation. The first task is for the teams of technical experts to sort technological areas into related groups and divide the groups into sequential levels of difficulty. Next, the technology teams determine the resources required to achieve the various technologies identified. The final step is to determine the best allocation of funds in support of different Levels of Difficulty (LOD) for each technology area.

To determine the best use of funds, the TORQUE Model calculates, for each Level of Difficulty for a technology area, a utility score, defined as:

$$U = \sum_{i=1}^{N} C_i \cdot W_i \cdot Cf \cdot t_i$$

where U = "Utility" of achieving a particular Level of Difficulty for a particular technology area

N = Number of systems or approaches supported by the Level of Difficulty

C_i = "Criticality" of the Level of Difficulty to the i^{th} system or approach supported. (Criticality ratings range from 0 as "no contribution" to 1.0 as "absolutely essential.")

provide an indication of the variety of management systems possible in conducting large scale efforts in programmatic R&D.

SELECTED REFERENCES FOR QUANTITATIVE MODELS OF PROJECT SELECTION

(1) Moore and Baker, "Computational Analysis of Scoring Models for R&D Project Selection," Management Science, Vol. 16, No. 4, December, 1969.

(2) Sigford and Parvin, "Project PATTERN: A Methodology for Determining Relevance in Complex Decision-Making," IEEE Transactions on Engineering Management, Vol. EM-12, March, 1965.

(3) Nutt, "Testing TORQUE - A Quantitative R&D Resource - Allocation System," IEEE Transactions on Engineering Management, Vol. EM-16, November, 1969.

(4) Schroder, "R&D Project Evaluation and Selection Models for Development: A Survey of the State of the Art," Socio-Economic Planning Science, Vol. 5, 1971. Pergamon Press. Printed in Great Britian.

(5) Rosen and Souder, " A Method for Allocating R&D Expenditures," IEEE Transactions and Engineering Management, Vol. EM-12, September, 1965.

(6) Baker and Pound, "R&D Project Selection: Where We Stand," IEEE Transactions on Engineering Management, Vol. EM-11, December, 1964.

(7) Rubenstein, "Economic Evaluation of Research and Development: A Brief Survey of Theory and Practice," The Journal of Industrial Engineering, Vol. XVII, No. 11, November, 1966.

(8) Roberts and Schmitt, "Creativity Versus Planning - You CAN Have Both," Innovation, Number 19, March, 1971.

will be running the program after ir starts. At NCI this man is called a Science Manager. Other men on the planning team should be specialists in relevant technical fields. Their fields may or may not overlap, and the men may be either intramural or extramural scientists. The last person on the planning team should be from the systems analysis staff. His role is one of synthesizer and as such he must be experienced in the planning technique.

According to Mr. Carrese, some important informal rules in bringing together this team are: Never have more than seven on the team. Take notes at the first few sessions, but do not produce a transcript.

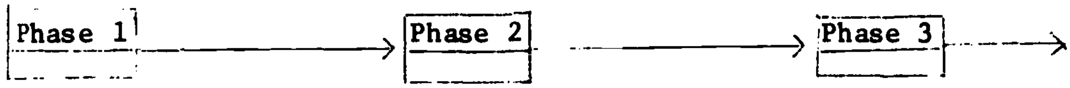
The first job is to set down an operational objective which, if achieved, will clearly end the program. An example of an unoperational objective is: Cure leukemia. An example of an operational objective is: Develop a vaccine for acute early childhood leukemia. Typically, formulating the program objective takes from one to five days, but sometimes takes much more time. One common impulse in beginning program planning is to survey the literature. At all costs, suggests Mr. Carrese, this must be avoided. First layout the overall program objectives. Then do the literature search.

For the next three to five weeks; lay out the intermediate objectives, decision pionts, and steps. (These are defined below.) The attitude in these meetings must be a willingness to forget about resource constraints. During this time, the systems analysis staff should help the team build the program plan (called a "Convergence Chart") and keep them on a productive track. After a plan is prepared, invite a lot of experts in the field to criticize and help modify it. Encourage constructive revision. The end product is a program plan to be used by the program manager and his segment chairman.

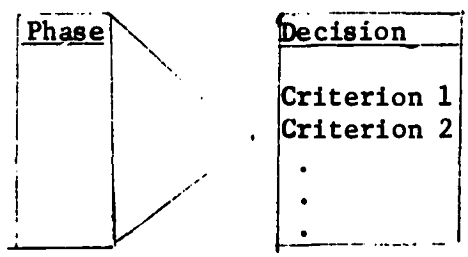
THEORY OF THE CONVERGENCE TECHNIQUE

The logical process by which a convergence chart is made is backward directed, from end goal to present state. To reach the end goal, several intermediate goals will have to be reached. Each intermediate goal is the title of a program phase. Together, the intermediate goals indicate the "minimum critical work needed to achieve the program objective."

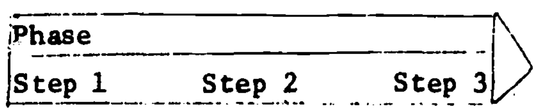
It takes a great deal of discussion and analysis in the planning meetings to reach this point.



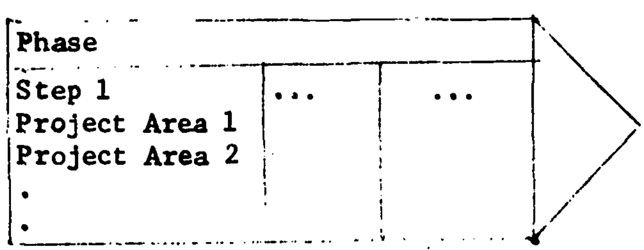
The next logical question is: "How will we know when an intermediate goal has been reached?" Determining the accomplishment of an intermediate goal is defined as a program <u>decision</u> and has associated with it a set of minimum acceptable criteria that will be used in making that decision.



The criteria indicate what data will be needed in order to make a particular program decision. In turn, data requirements and intermediate goals provide clues to the research steps that must be undertaken.



Knowing these steps, it is usually possible to formulate the project areas in which work is required for each step.



The logical sequence of these boxes is called *The Linear Array*. The primary reason for doing research along a linear array is to obtain data required to meet criteria for making a program decision. Together, these program decisions direct research activity toward the predefined program goals. Using this framework of planning, "managing" simply means ensuring the acquisition of data needed to make program decisions. Accordingly, managers need "data progress" reports rather than project status or change reports, since neither of the latter relate directly to program decisions.

A second planning array (presented below the linear array on a convergence chart) is of *Concurrent Research*. This is a set of program-related research areas, not required in the program logic, but which may yield important insights. In allocating the program budget, projects in these areas have second priority.

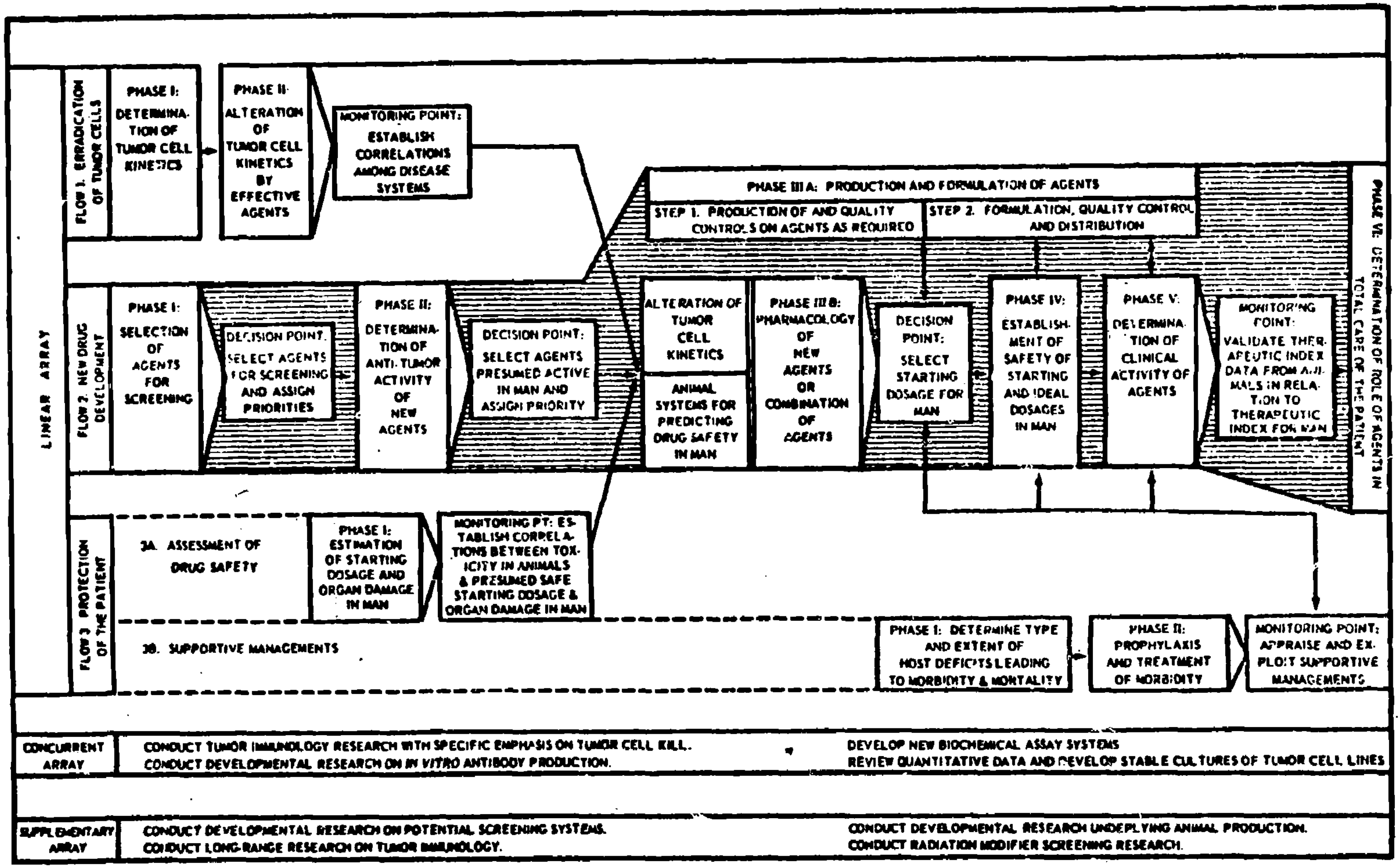
A third array (below the second) is the *Supplementary Array*, which includes "blue sky" project areas that may have big impacts, but with low probability. Many of these projects in these areas are funded as grants in the normal NIH manner.

Next to each project area described for a program step in the linear array is an open circle if work is required to be done, and a solid dot if substantial work is underway or completed. This provides an efficient way of exposing the program manager to his current and future needs. Work in open circle project areas must eventually be conducted because all project areas on the linear array have been identified as among the minimal acceptable set of project activity to be completed, according to the team of experts who have developed the linear array.

The final planning step is to "cluster" related project areas into "segments" for the purpose of efficient program management. Segments may be constructed according to methodology, field, equipment requirements, or focus. Many will cut across organizational branches of the division.

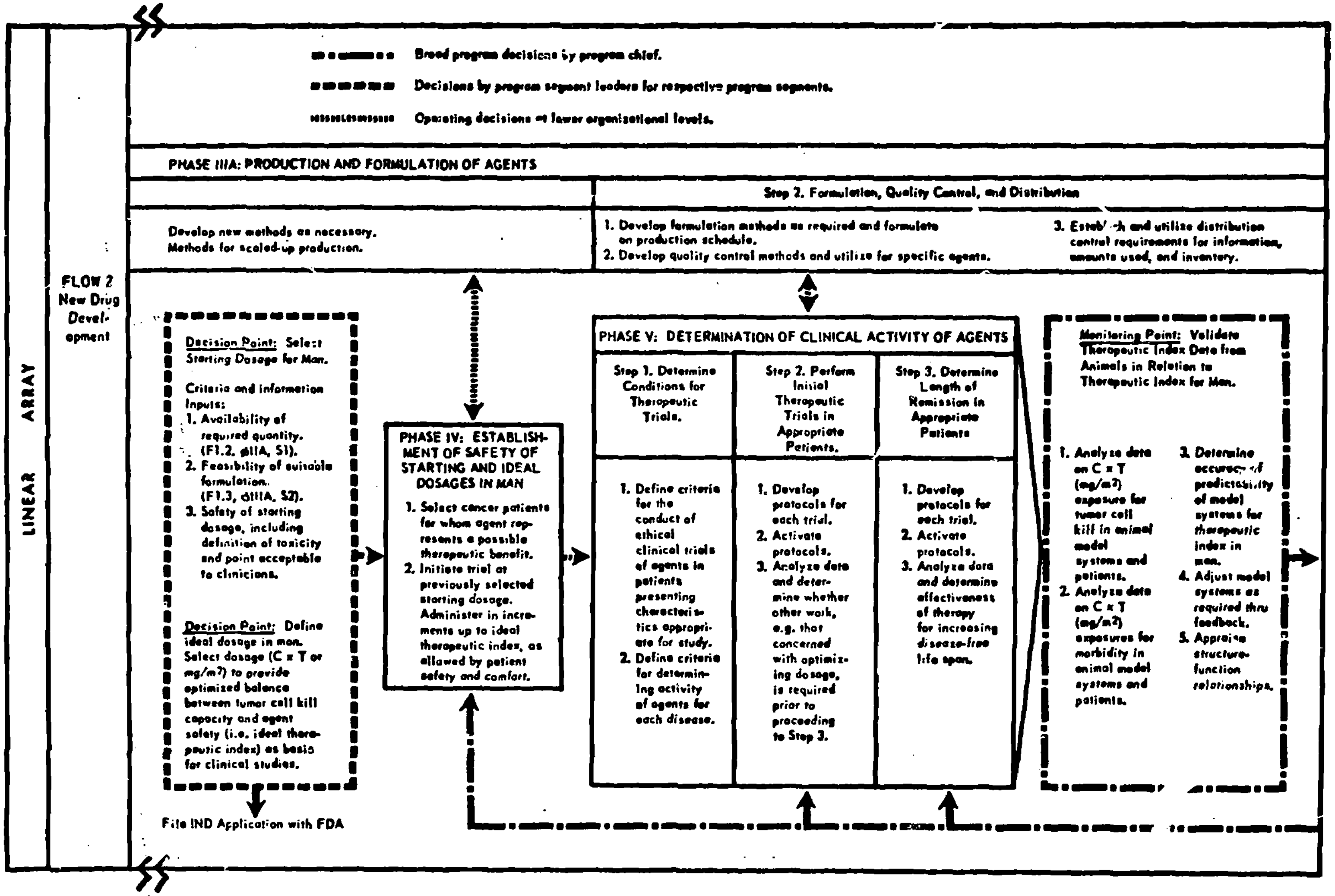
An abstract of the program plan ("Convergence Chart") prepared for the Cancer Chemotherapy Program (CCP) is illustrated in the following figure. A more detailed view of part of this Chart is presented in the subsequent figure. This second figure provides an example of criteria specified for a particular program decision (surrounded by an evenly dotted line) as well as the flow of program activity determined by more broad program decisions by the Program Director.

Figure 11 : Abstracted Program Plan for the Cancer Chemotherapy Program*



*Reprinted in Management Science, Vol. 13, No. 8, April, 1967, page 427.

Figure 12: Details of Program Phases and Steps in the Abstracted Program Plan for the Cancer Chemotherapy Program*



*Reprinted in Management Science, Vol. 13, No. 8, April, 1967, page 428.

APPENDIX B

ABSTRACT DESCRIPTION OF THE AIR FORCE PROCESS OF PROJECT INITIATION AND PLANNING

INTRODUCTION

The following eight diagrams illustrate the various steps and flow of documentation usually involved in the initiation and planning of any new Air Force major weapon development project, under both the old regulations and the new. These steps and flow are superimposed on a partial chart of the Air Force organizational structure which highlights the relevant portions participating in the processes.

Materials from which this description is drawn include Air Force Regulations AFR-57-1, the past AFR-375 series now superceded by AFR 800-2, Department of Defense Directives 3200 and 5010, and interviews with Major Thomas Tierney, RAND Air Force liason officer, and with the System Project Director and members of his staff for the SRAM Missile Development Project.

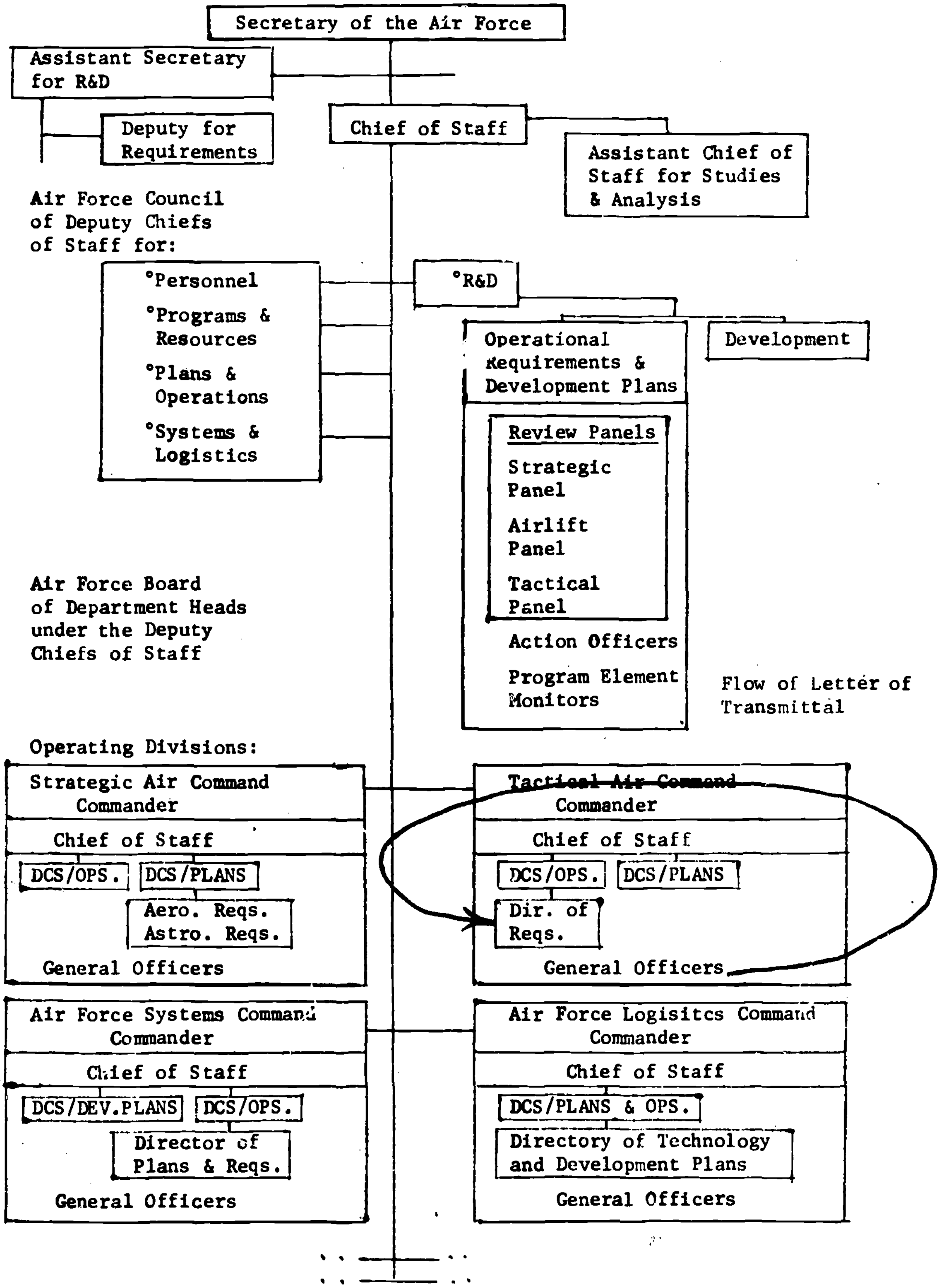
Not all Air Force projects follow these procedural steps. Depending on the importance of the project idea and on its relevance to other already existing projects, some of the steps may be eliminated or significantly shortened. The entire description, however, provides a general picture of the typical initiation and planning steps required in project management under the system used by the Air Force over most of the last decade, and emphasizes the use of hierarchical tiers of multiple review. Where appropriate, major revisions consistent with the new regulations are indicated.

DESCRIPTION OF THE TYPICAL STEPS

STEP 1: PREPARATION OF ROC

A perceived military need or deficiency is stated on a "Letter of Transmittal" from any general officer within the Air Force operating divisions, such as the Strategic Air Command or the Tactical Air Command, to the officer's Commander. This letter is forwarded to the Commander's

Figure 13:
Step 1: ROC Prepared



Director of Requirements who prepares a statement of the project idea in the form of a Required Operational Capability (ROC). See Figure 13.

STEP 2: COORDINATION OF ROC

The Director of Requirements located within the operating division of ROC origin sends the ROC to the Directors of Requirement of all the other divisions in order to prevent duplication of efforts and to foster joint benefits among all proposed projects. See Figure 14.

STEP 3: ROC APPROVAL

Following return of the comments from all the Directors of Requirement, the ROC is sent to the Commander of the originating division for approval. See Figure 15.

STEP 4: PREPARATION OF POSITION PAPER UNDER THE OLD SYSTEM

If the Commander chose to approve the ROC as a project idea worthy of subsequent action, the ROC was sent to Air Force Headquarters and was received by the division of Operational Requirements and Development Plans (AFRDQ) located under the Deputy Chief of Staff of R&D. Here it was assigned to an Action Officer responsible for review management.

The Action Officer first sent the ROC in its current form to all the Deputy Chiefs of Staff and to the appropriate formally constituted review panel maintained continuously within AFRDQ. One of these panels existed for each of the Strategic, Tactical, and Airlift program areas of the Air Force. Preliminary comments from these personnel were then returned to the Action Officer who synthesized their ideas and evaluations into a Position Paper. Both the ROC and its associated Position Paper were then redistributed to the same reviewers for statements of concurrence or non-concurrence with the Position Paper as written. See Figure 16. (Details of the new program management procedures are not yet defined.)

STEP 5: FIRST MAJOR HEADQUARTER REVIEW UNDER THE OLD SYSTEM

The Position Paper along with all the responses to it by the Deputy Chiefs of Staff were forwarded to the same area-focused panel

Figure 14:
Step 2: Coordination of ROC

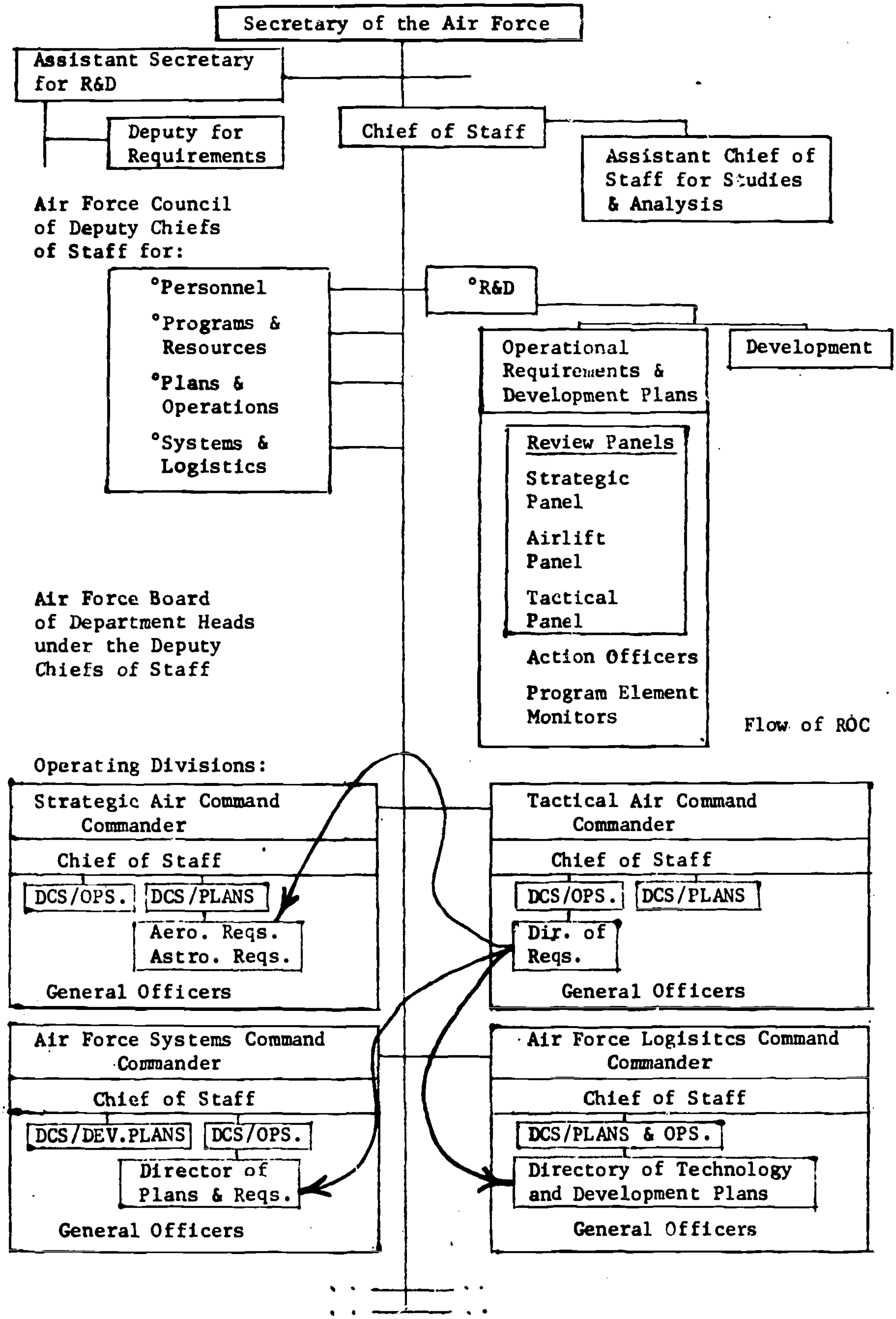


Figure 15:
Step 3: ROC Approval

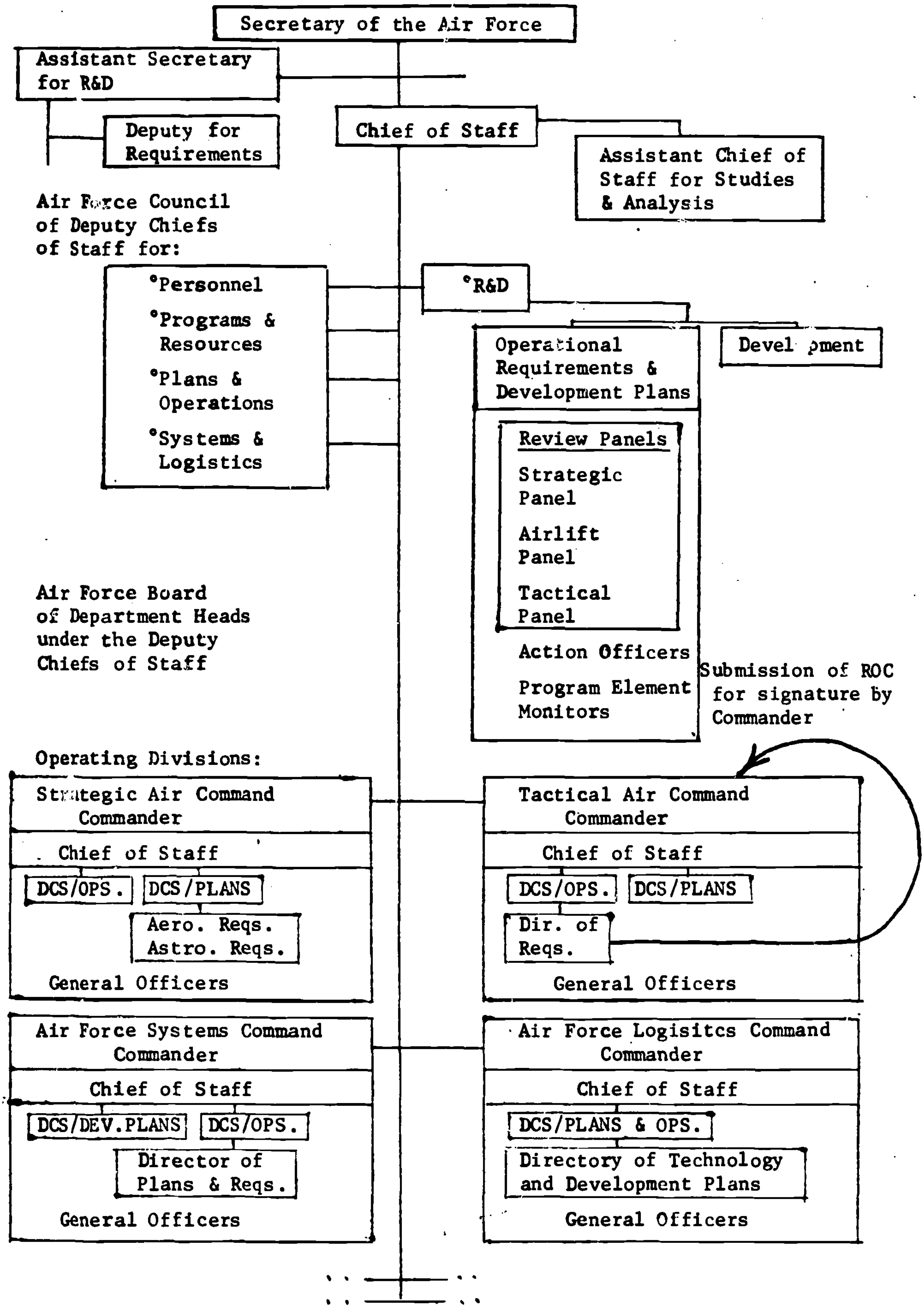
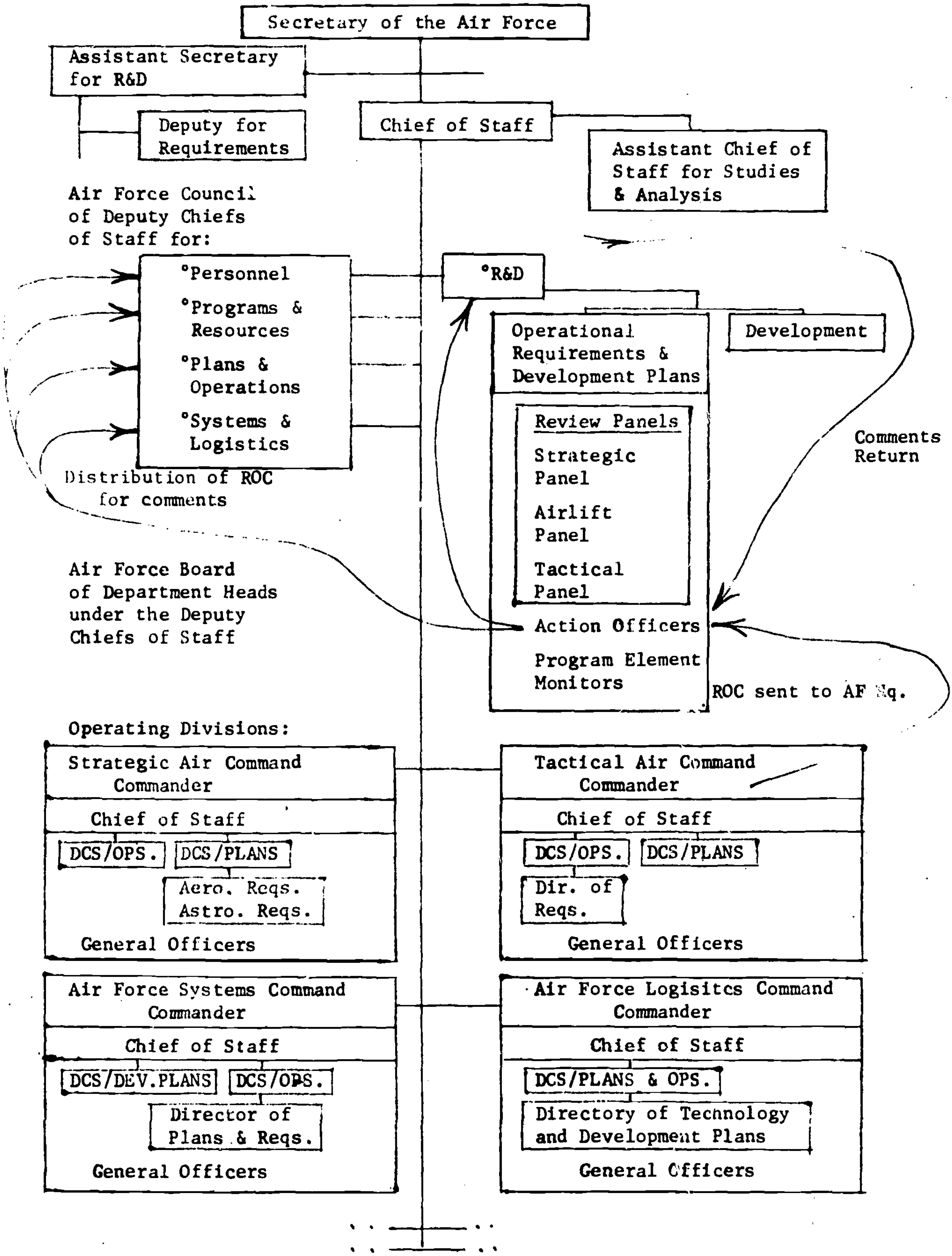


Figure 16:
Step 4: Preparation of Position Paper under the Old System



within AFRDQ for the first major headquarter review. See Figure 17.

STEP 6: PREPARATION OF VARIOUS RADs UNDER THE OLD SYSTEM

Panel approval of the ROC was followed by a succession of Required Action Directives (RADs) which called for supplementary studies involving either mission analyses, technical feasibility of the project idea, or analyses of current technology for possible application to the project idea. The majority of these studies were performed extramurally under the management of Air Force Systems Command. At this point, overall management of the project idea review was given to a Program Element Monitor who monitored the execution of all RADs and kept the Panel informed of study progress. See Figure 18. (Under the new program managerment regulations, RADs and other headquarter directive documents are replaced by the single Program Management Directive.)

STEP 7: SECOND AND THIRD HEADQUARTER REVIEWS UNDER THE OLD SYSTEM

Previously, RADs issued by ARFDQ have kept some project ideas within the study stage for a number of years. Following execution of all RADs ordered by the Panel, the original ROC plus all its supporting studies received two more headquarter reviews, one by the Air Staff Board, consisting of all the department heads under the Deputy Chiefs of Staff, and one by the Air Force Council, consisting of the Deputy Chiefs themselves.

Approval by both groups was required for the project to proceed. If it were granted, a final RAD was issued by the Panel to Systems Command for the preparation of the project plan. This plan, called the Concept Formulation Package/Technical Development Plan, was prepared extramurally under the management of Systems Command. See Figure 19. (In the new system, the same two groups hold project reviews, but the scope of the project plan is substantially reduced and responsibility for plan preparation is given to the Program Manager appointed by the implementing command rather than by Systems Command.)

STEP 8: PREPARATION OF THE PROJECT PLAN

To help prepare the former project plan (CFP/TDP), Systems Command

Figure 17:
Step 5: First Major Headquarter Review under the Old System

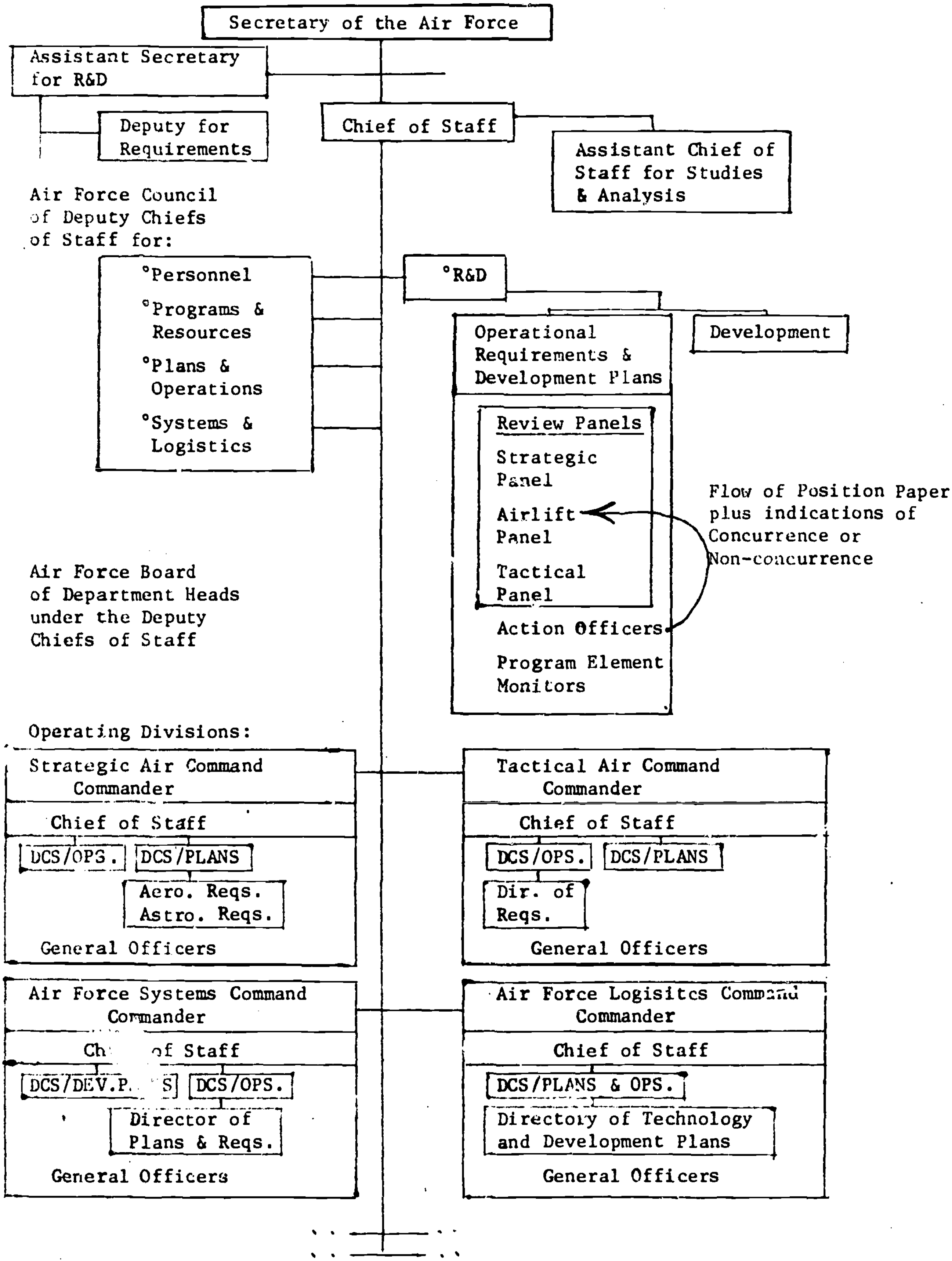


Figure 18:

Step 6: Preparation and Execution of RADs for Supplementary Studies under the Old System

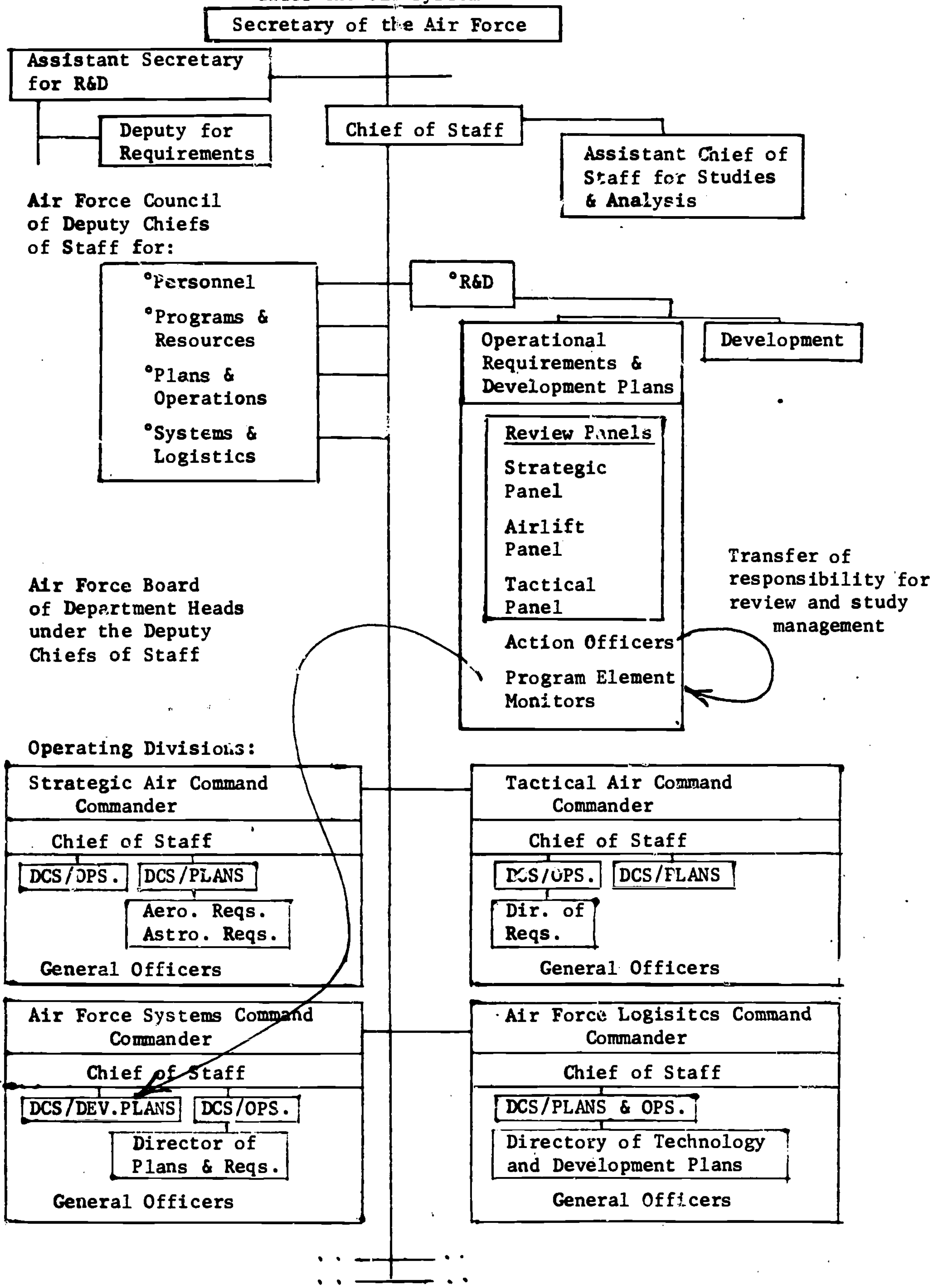
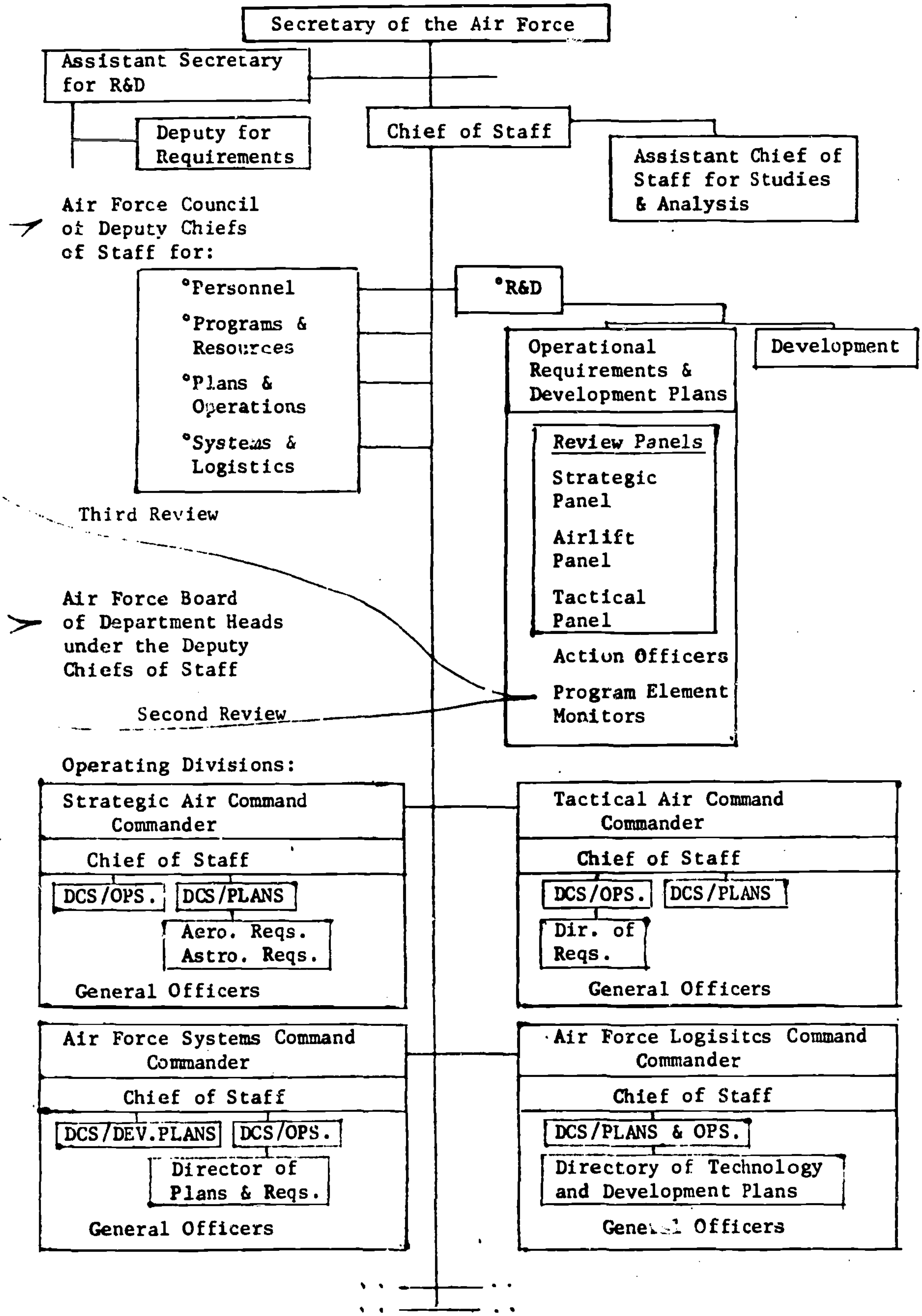


Figure 19:

Step 7: Second and Third Headquarter Reviews under the Old System



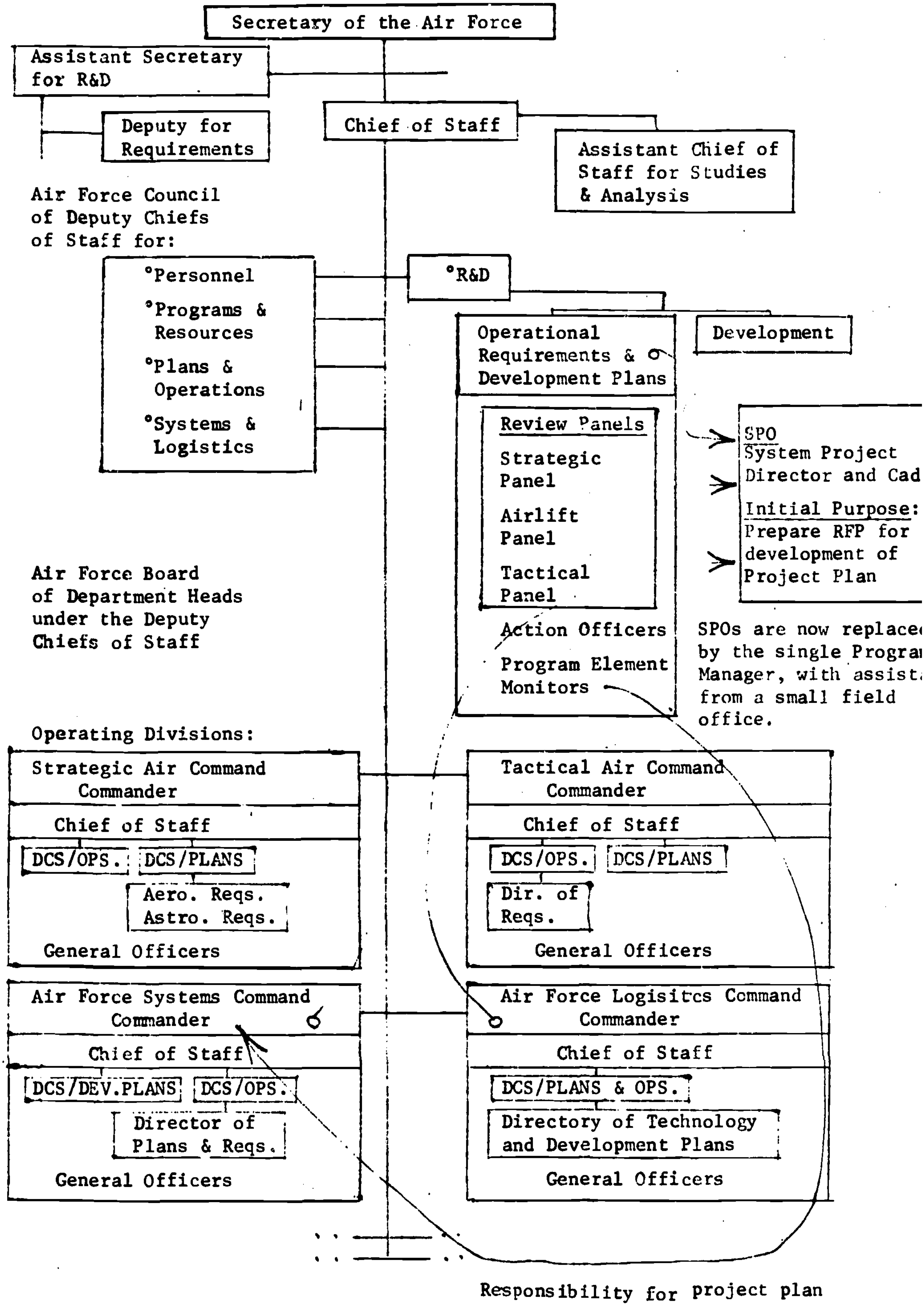
appointed a System Project Director and a cadre of five or six personnel to form the core of a System Project Office (SPO). This SPO prepared the RFPs for the extramural development of the project plan (and if the project was funded by Congress, also managed the overall extramural system development). Representatives from AFRDQ and Logistics Command were included in the SPO team to help prepare the RFPs for the project plan. See Figure 20. (Preparation under the new regulation is the responsibility of the Program Manager only.)

In the former system, following preparation of the Concept Formulation Package/Technical Development Plan were additional reviews by the Air Staff, Air Force Council, and the Office of the Secretary of Defense. Approval by each, and authorization for funding by Congress did not, however, end the overall planning process. Prior to development and distribution of RFPs, evaluation of proposals, and awarding of contracts for actual system development was the production of volumes of detailed specifications of design and management procedures which made up the actual contract content.

Contract terminology was omitted in a more operational planning document of General Specifications for Performance and Design Requirements which was used by the system developer as a manual of minimal tasks and capabilities which must be achieved to fulfill the contract agreements. These General Specifications included both minimum operational requirements and minimum proceudres of testing and analysis to determine whether the requirements were achieved.

From the viewpoint of the contractor, all operational requirements and procedures of quality assurance stated in the General Specifications Plan were contractual commitments. In no way was he free to change that plan. Even the System Project Director responsible for the overall management of the project was unable to change the plan. Any changes in either the minimum levels of operational performances required, in the overall cost of the project, or in the time stipulated for development or production phases had to be approved by most of the participant groups involved in the original project planning process. Consequently, approvals for changes of these kinds involved lengthy procedures of additional multiple reviews and were sought only if it became clear that

Figure 20:
Step 8: Preparation of the Project Plan under the Old System



minimum requirements would not be achieved within the time and cost constraints. Minor specifications of design, however, which did not adversely affect either time, cost, or performance levels could be enacted by the System Project Director as a result of communication and joint decisionmaking between his staff of engineers within the System Project Office and the engineers of the development contractor.

Under the new regulation of July, 1971, much of these procedures are retained. Though greater responsibility for project development is given to the Program Manager, he must still gain higher approval for any changes effecting overall cost, time, or performance beyond the stated requirements.