REPORT ON TECHNOLOGICAL FORECASTING

JOINT
AMC/NMC/AFSC
COMMANDERS

REPORT ON

TECHNOLOGICAL FORECASTING

Prepared by the Interservice
Technological Forecasting Methodology
Study Group

30 June 1967

Department of the Army
Headquarters
United States Army Materiel Command
Washington, D. C. 20315

Department of the Navy
Chief of Naval Material
Naval Material Command
Washington, D. C. 20360

Department of the Air Force
Headquarters, Air Force Systems Command
Andrews Air Force Base, Maryland 20331

ACKNOWLEDGMENT

Technological forecasting as a discipline is in its infancy. However, in the past 5-10 years, efforts in this area have begun to produce the beginnings of a systematic methodology. During informal interservice discussions in the summer of 1966, it was determined that some benefit would result from the assembly and evaluation of the scattered information regarding potential forecasting techniques. The resulting interservice ad hoc study group was chartered on 9 November 1966, by the Joint Secretariat of the Joint AMC/NMC/AFLC/AFSC Commander's Meeting. The support of the above organization is gratefully acknowledged.

The group was formed to assess the state of the art and synthesize available information, not to contribute original research to the field. It has, therefore, drawn heavily upon the work of many investigators in this field. The authors are particularly indebted to the efforts of R. U. Ayres, J. R. Bird, O. Helmer, R. S. Isenson, E. Jantsch, R. C. Lenz, and F. S. Pardee.

INTERSERVICE TECHNOLOGICAL FORECASTING

METHODOLOGY STUDY GROUP

Steering Group:

H. T. Darracott
U. S. Army Materiel Command
Headquarters, Department of the Army
Washington, D. C. 20315

J. W. Sterling (Study Group Executive Secretary)
Office of the Chief of Research and Development
Department of the Army
Washington, D. C. 20310

M. J. Cetron
Headquarters, U. S. Naval Material Command
Washington, D. C. 20360

H. A. Wells
Headquarters, U. S. Air Force Systems Command
Andrews Air Force Base, Maryland 20331

Working Members:

D. B. Keckler
U. S. Army Weapons Command
Rock Island, Illinois 61201

E. Mackiewicz
U. S. Army Tank-Automotive Command
Warren, Michigan 48090

W. A. McKenney
U. S. Naval Weapons Laboratory
Dahlgren, Virginia 22448

T. I. Monahan
U. S. Naval Applied Science Laboratory
Brooklyn, New York 11251

Miss Elma Henderson
U. S. Air Force Systems Command
Andrews Air Force Base, Maryland 20331

DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY MATERIEL COMMAND
WASHINGTON DC, 20315

DEPARTMENT OF THE NAVY
HEADQUARTERS NAVAL MATERIAL COMMAND
WASHINGTON, DC, 20360

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE LOGISTICS COMMAND
WRIGHT-PATTERSON AFB, OHIO 45433

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE SYSTEMS COMMAND
ANDREWS AFB, WASHINGTON, DC, 20331

FOREWORD

1. Technological forecasting is a key input to the Department of Defense planning cycle. Decisions based on such forecasting can be improved by the utilization of more credible forecasting techniques. In recognition of the need to develop advanced methods of technological forecasting for planning military research and development, a joint study was undertaken by representatives of our commands.

2. The Interservice Technological Forecasting Methodology Study Group evaluated alternative methods of forecasting technological progress and results are compiled in this Report. The Report on Technological Forecasting is provided for your information and use as appropriate.

F. S. BESSON, JR.
General, USA
Commanding General,
U. S. Army Materiel Command

I. J. GALANTIN
Admiral, USN
Chief of Naval Material
Naval Material Command

JAMES FERGUSON
General, USAF
Commander,
Air Force Systems Command

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

1.1. Purpose.

The purpose of this report is to promote the utilization of a system of logical analysis which, when applied to pertinent technological data, can result in credible and explicit technological conclusions. To this end, the study group has attempted to evaluate, by survey and literature, possible forecasting techniques and conceptual approaches to technological forecasting. The manual is directed toward scientific or engineering specialists who may be asked to contribute inputs to forecasts but may have only limited understanding of technological forecasting and its possible approaches and problems. It attempts to clarify a complex, controversial subject and recommends increased use of a number of techniques and a synoptic viewpoint that can improve the credibility and utility of forecasts provided by these specialists. The guide may also be of interest to users of such forecasts and, hopefully, will promote greater acceptance by providing an explanation of the rationale and methods of technological forecasting.

1.2. Background.

1.2.1. Utility of Technological Forecasting.

As the cost of research and development projects increases, decision makers become increasingly cautious about approving requests for funds. The time has come to examine new approaches to the problem of gaining support for research and development efforts.

One potential solution to this problem is more credible forecasting for technological advances. Lenz (Ref 95*) has defined a technological forecast as "the prediction, with a level of confidence, of a technological achievement in a given time frame with a specified level of support." The use of a more explicit forecast, based on historical fact and clearly presented, will help to justify proposed program goals and may lead to their approval. Evidence that a goal has been identified and is feasible assists decision makers in evaluating the utility of a proposed program, and it may convince them that resources should be allocated to achieve that goal.

---

* Refers to reference item 95 in bibliography. The bibliography contains those literature references which are repeatedly cited in this report and pertinent background reading material. References that are cited only once and are of only secondary relevance to technological forecasting are noted as footnotes.

In addition, forecasting can aid systems planners by helping them to shorten the time between the achievement of a technological goal and use of the new knowledge in the development of future materiel systems and capabilities. A reliable forecast of the imminent achievement of a technological goal may be reflected in new development plans, in changes to development plans, and in the timely allocation of resources for development and developmental facilities. The forecast may also identify potential problems associated with the achievement of the goal and lead to their timely solution. It should also serve as a vehicle for communication between technical personnel and planners. There is a need for consistency in the manner in which estimates of probable technical performance are prepared and documented. This is particularly important in military applications and for systems engineering personnel, who are required to combine forecasts from a number of technical areas into concepts for future systems.

Forecasting is not a new idea. Most government and private institutions employ some means of predicting future events and expressing the degree of their confidence in the occurrence of these events. In most cases, their methods of forecasting are intuitive, and the forecast is expressed as a hunch or feeling. Although it is not the intention of this report to discount the intuition of responsible experts in a technical field, many of the methods referenced in the report will assist these forecasters in supporting their judgments and in expressing their ideas more clearly. It is hoped that, by the presentation of better methods of forecasting, this report will reduce the number of irresponsible, intuitive guesses in the field of technological forecasting, and will thereby lead to more acceptable forecasting. The rapid, largely haphazard achievement of technological goals in the twentieth century, and the rising complexity and cost of continued technological advancement, have outdistanced the ability of military forecasters to forecast by using only intuitive methods. Better techniques of forecasting will benefit all of the military services.

There are several general areas in which technological forecasting could be improved. First, it must be credible and specific, and should be based on historical facts and realistic trends. The forecast must be comprehensive enough to include all relevant factors and information.

Secondly, the forecast should be useful and meaningful to its intended readers. For example, it should encompass a time span sufficient to cover the long lead time required for the development of a modern weapon system, and the parameters forecast should be relevant to the functions performed by such systems.

The forecast should be explicit. All estimates and predictions concerning future events should be precisely and definitely stated in narrative or graphic form.

In order to be authoritative and convincing to military decision makers, the forecast must be compiled by experts in the technical field being forecast, although the opinions of outside experts may, of course, be included.

Lenz (Ref 95) states that the qualities sought for methods of prediction are explicitness, quantitative expression, reproducibility of results, and derivation on a logical basis. Lenz also provides convincing answers to arguments against explicit forecasting by critically examining the following postulated viewpoints leading to conditions of no forecast:

a. No forecast possible: implies each action taken is unrelated to any past experience, present situation, or future intended action. The resulting error is the assumption that all action is then random.

b. Anything can happen: external influences are viewed as random processes and decisions thus represent a gamble, with some knowledge of the odds and the stakes.

c. The glorious past: assumes continuation of prior circumstances which may no longer exist.

d. Implicit assumption that current circumstances will continue: results in a continual attitude of crisis and abrupt reversals of decisions with each change in external circumstances.

e. Implicit assumption that existing trends of change will continue: fundamental errors arising from uncritical acceptance of such forecasts are usually not recognized because the unrecorded forecast is difficult to reconstruct after changes in circumstances have intervened.

f. Course of action based on an intuitive feeling of future conditions: although implicit intuitive forecasting has been effective in guiding the actions of many successful men, it has the significant weaknesses that it is impossible to teach, expensive to learn, and excludes any process of review.

Lenz concludes that, since some estimate of future conditions is inherent in each managerial decision, the actual question is whether such an estimate should be made unconsciously as an implicit part of the decision or whether it should be arrived at deliberately and stated explicitly.

1.2.2. Conceptual Framework for Technological Forecasting.

The complex subject of technological advance can be better understood by viewing technology as knowledge — knowledge of physical relationships systematically applied to useful arts and transferred through the following eight technology transfer levels:*

---

*This framework was suggested by Harvey Brooks at the Conference on Technology Transfer and Innovation, held 16-17 May 1966 in Washington, D.C. Cited by Jantsch (Ref 90), pp 15-16.

Transfer Level	Example
Impact Levels	
VIII. Society	Implications of communications technology on society
VII. Social systems	Implications of communications technology on defense and other aspects of society
VI. Environments	The communications sector of industry
V. Applications	The market for communications systems
Development Levels	
IV. Functional technological systems	Solid-state communications systems and functional subsystems
III. Elementary technology	Solid-state technology, integrated circuit technology, etc
II. Technological resources	Diffusion techniques, planar techniques, etc
I. Scientific resources	Recognition of natural phenomenon of semiconduction

Within this framework, forecasting can range from very broad predictions of the effects of technology on segments of the economy or society as a whole, to relatively narrow, detailed studies of technological progress in only one technical area, and finally to the initial understanding of how a basic phenomenon can be applied to the solution of a practical problem. Forecasting at levels I through IV predicts the future applications of scientific and technical knowledge to the development of functional systems and is conventionally referred to as state-of-the-art projection, or exploratory forecasting. The prediction of the impact of advancing technology and the consideration/evaluation of possible future worlds (i.e., forecasting at levels V through VIII) can be classified as normative forecasting, using the term developed by Gabor (Ref 69). Normative technological forecasting first assesses future goals, threats, or missions, then considers the impact of the projected technology, and finally works backward to the present.

In this conceptual scheme exploratory forecasting becomes an input to normative forecasting, which in turn becomes the input to a technological plan that can commit resources to the implementation of the desired technology transfer and thereby "invent the future." The area to be treated in this report is exploratory forecasting, i.e., the vertical transfer of technology from levels I to IV.

There is evidence that the rate of technological development has been increasing in recent years. In Technology and the American Economy (Ref 150, pp 3-4), Lynn concluded from a study of 20 major technological innovations that the incubation period — the typical time between a technical discovery and recognition of its commercial potential — has fallen from 30 years before the first world war to 16 years between the wars and to 9 years in the period 1945-1964. The time between this recognition of commercial potential and the initial commercial application, in turn, decreased from about 7 years to about 5 years.

Quinn (Ref 118) has stated that the transfer of technology can be better understood when viewed, not as pieces of hardware, but as knowledge of physical relationships systematically applied to the useful arts. This knowledge can vary over time from the initial concept of how a basic phenomenon can be applied to the solution of practical problems to knowledge applied to system components or complex systems. Quinn notes further that what may appear to be a stepwise function advance in a technology is usually nothing more than the accumulation of small advances not worth noting individually until they additively make a significant change in the total technology. Moreover, a given technology generally includes a variety of competing devices, each with a distinctive balance of performance and economic characteristics. Finally, of course, a specific process or product in a technology may fulfill quite divergent needs and perform very dissimilar functions for its various owners. It is this relative continuity in a technology's technical and economic characteristics and potential applications that makes technological forecasting possible.

This predominantly evolutionary advance by small steps has been pointed out by the studies of Gilfillan (Ref 71, 72, 73) and more recently by DOD Project Hindsight.[1]

Nelson et al,[2] in their analysis of the way in which technical advances occur, developed the following operational concept of technological knowledge.

The operational part of the body of technological knowledge is a set of techniques, each defined as a set of actions and decision rules guiding their

1. Chalmers W. Sherwin and Raymond S. Isenson, "Project Hindsight," Science, vol 156, 23 June 1967, pp 1571-77.

2. Richard R. Nelson, Merton J. Peck, and Edward D. Kalachek, Technology, Economic Growth and Public Policy, Washington, Brookings Institution, 1967.

sequential application, that man has learned will generally lead to a predictable outcome under certain specified circumstances. The stock of known techniques for achieving practical results is only part of the richer and deeper body of human knowledge, which includes, as well, a comprehension of the properties of things under various conditions, relationships among and between objects and properties, and broad frameworks of interpretation.

In many cases, techniques can be derived from the general body of understanding. In other cases, the technique is almost completely empirical, i.e., it works in a predictable way but it is not known why.

At any given time the stock of known techniques defines the set of products that can be made, and the known broad processes (and the range of variation within these processes) for making them. There are four principal constraints on the kinds and quantities of goods that an economy can produce per worker:

a. The stock of technological knowledge, which limits the kinds of products man knows how to produce, and the various processes he knows for producing them.

b. The education, training, and experience of the work force, which determines the extent to which this knowledge is embodied in people.

c. The organization of firms and of the economy as a whole, which determines the effectiveness with which this knowledge can be used.

d. The stock of physical capital and the availability of natural resources.

Within these limits, and given time to permit human material resources to be reallocated, there is a considerable range of choice concerning what and how much can be produced. Technological advances take the form of new product designs or new process routines. Examples of the first are the jet engine and penicillin; of the second, the oxygen process for steel making and the arc welding technique. Technological advances in the broader sense also include improved management techniques, such as statistical quality control or production control programming, and new concepts of organizing economic activity. At any given time technological knowledge exists to produce a considerably wider range of products or use a larger set of processes than, in fact, are being supplied or employed. Some of these have been well tested but have been made obsolete by newer technologies. Others have not been operationally tested but are sufficiently close that a satisfactory program for their use could easily be specified, given the incentive to do so; the job would be considered routine engineering. Like the obsolete technologies, these are not in use because they are not economic under existing conditions of demand and supply.

In addition to the stock of presently operational techniques, at any time there is a considerable store of ideas reasonably well worked out but still short of operational, and an almost infinite stock of partial or embryonic ideas that are not even close to operational. Technology advances as these ideas are developed into operational form.

The quantity of resources required to make a design idea operational depends upon three key variables:

a. The magnitude of the advance sought over existing comparable products.

b. The nature of the product field, in particular the size and complexity of the system.

c. The stock of relevant knowledge that permits new techniques to be derived or deduced, as well as the stock of available materials and components with which designers can work. At any particular moment, in almost all fields, a number of efforts are in progress aimed at creating new or improved products and processes. Some are aimed at various dimensions of product performance, others at reducing cost. Some reach for major advances, some for minor improvements. As a result, technology seldom is stagnant in any field. The pace of technological advance, however, varies strikingly from one product field to another, and from time to time.

Two broad factors lie behind the differing and changing rates of technological progress. First, there are differences and changes in the rewards for particular kinds of technological advance — demand factors that stimulate or repress efforts aimed at achieving them. Second, there are differences and changes in the stock of relevant components and materials and of knowledge, and in the number of people who possess the relevant knowledge — supply factors which permit or restrict certain kinds of advances. When only marginal modifications in a product or process are sought, the knowledge required need not extend much beyond existing technology. When the advances sought are greater, the inventor must see existing techniques within a significantly larger and perhaps a quite different context. Scientific knowledge has often been the key to that larger context.

The science-based technologies and industries have a great advantage in achieving major advances in products and processes. Research aimed at opening up new possibilities has substituted both for chance development in the relevant sciences and for the classical major inventive effort aimed at cracking open a problem through direct attack. The post-World War II explosion of major advances in electronics, aircraft, missiles, chemicals, and medicines reflects the maturing of the science base in these industries as well as the large volume of resources they employ to advance technology.

James Bright, of the Harvard Business School (Ref 41), has noted seven important tides of technological change. These are:

a. Increased transportation capability.

b. Increased mastery of energy.

c. Extension and control of life.

d. Increased ability to alter the characteristics of materials.

e. Extension of sensory capabilities.

f. Mechanization of physical activities.

g. Mechanization of intellectual activities.

To summarize, the evolution of knowledge in the various technology areas yields perceivable patterns of steady but piecemeal improvements in design, based on experience and exploitation of new materials and components and spiced by an occasional major advance. It is the analysis of these patterns that makes technological forecasting possible.

1.3. Scope of Effort and Orientation of Report.

As stated above in 1.2.2., this report addresses itself primarily to exploratory forecasting, or state-of-the-art projection, as applied to technology transfer levels I through IV. Misunderstanding regarding the purpose of the report and technological forecasting in general can be minimized if (1) the type and purpose of the forecast is clearly defined and (2) a clear distinction is maintained between exploratory forecasting, normative forecasting, and long-range planning.

Technological forecasting can mean different things to different people. The following classification system is proposed in order to provide a structure for further definition of the type of forecast envisioned:

a. Technology transfer levels involved.

b. Nature of forecast.

(1) Exploratory.

(2) Normative.

(3) Combined forecast and plan.

c. Field of forecast.

(1) Military.

(2) Industrial.

(3) Society as a whole.

d. Orientation of forecast.

(1) Describes future scientific and technological opportunities which can become available if selected by planners.

(2) Forecasts scientific and technological capabilities or events (choice by planners not included as a contingency).

(3) Forecasts impact of application of such capabilities.

e. Breadth of forecast — may range from either projections of the major forces of science and technology to projections of narrowly defined specific design parameters such as horsepower per pound of power plant.

f. Method of gathering inputs.

(1) Permanent in-house function assigned to pertinent field departments or laboratories but assembled by central group.

(2) Central "think" group (e.g., GE Tempo, RAND Corporation).

(3) Technical panel (in-house or supplemented by outside sources).

(4) Forecasting institute or consulting firm.

(5) Staff analysis group.

(6) Ad hoc study group.

(7) Scientific adviser.

(8) Research committee.

g. Predominant forecasting technique utilized (see Chapter 4).

(1) Intuitive.

(2) Statistical.

(3) Cause and effect analysis.

(4) Analogy.

(5) Models and conceptual schemes.

(6) Others.

h. Extent of "self-fulfilling" nature of forecast (i.e., degree to which forecast can stimulate action and thereby create the forecast effect).

If military R&D planning is viewed in the conceptual framework outlined in Paragraph 1.2 and the previous classification scheme, exploratory forecasting can be viewed as the presentation of future technological opportunities and threats, while normative forecasting might be considered as the goal-setting portion of long-range planning. The long-range plan then becomes a statement of goals and objectives and the proposed approaches to achieving these goals. The program is the final commitment of the organization to put its resources into the approaches outlined in the technical plan.

The above steps can be combined in a single operation or carried out separately.

The U.S. Air Force's technological forecasting efforts (described in Paragraph 2.3) have varied from separate exploratory forecasting, as in Technology For Tomorrow (Ref 1), to the broader approach taken in Project Forecast (Ref 2), which also considered cost factors, systems analysis, and military policy.

In the current approach to the preparation of the Army Long Range Technological Forecast (ALRTF) (and in the proposed Navy Forecast), only the first step is involved. That is, the ALRTF is not a plan nor is it a statement of what necessarily will occur. Rather it is a statement of the opportunities presented by the growth of our scientific and technical knowledge, which can be available if selected and supported by orderly programs of research and development. This broad forecast of opportunities is possible and desirable because military technology embraces a wide spectrum: ordnance, logistics, protection, communications, medicine, toxics, detection, surveillance, environment, and human factors, to mention but a few major areas. The basic and applied sciences feeding into these military technologies are even broader, perhaps as broad as almost all of science and engineering. Research in power sources, for example, could change the essential configuration of ordnance systems as well as of transportation systems. Research in immunology could change communications systems and/or antipersonnel weapons. Micrometeorological research for chemical warfare applies also to surveillance, and so on.

In organization of narrower scope, a combined forecast/plan approach, such as the Battelle Design Method (described in Ref 43, pp 58-67), may be more appropriate. However, in military forecasting, the breadth of the forecast area and the usual separation of producers and users of technology (described in Chapter 2) makes the separate exploratory forecast an appropriate tool whereby the technology producers can make known the opportunities available to the users.

In line with the previous discussion, this guide does not address itself directly to those techniques pertinent to the technology selection process. It does recognize that the exploratory forecast must be compatible with, and capable of being integrated into, the subsequent planning process and discusses this problem in Chapter 3 (Parameter Selection), Chapter 4 (Forecasting Aids), and Chapter 6 (Presentation).

CHAPTER 2

THE ROLE OF TECHNOLOGICAL FORECASTING IN THE MILITARY PLANNING CYCLE

2. 1. Introduction.

The pace and direction of technological change greatly affects the short- and long-term environment and with it strategic planning in the Department of Defense (DOD). It is obvious that a need exists for a comprehensive look into the future to forecast what the force structure of the services might look like in ten to twenty years.

The expansive growth of technology in the mid-20th century has posed a dilemma to the military planner which is well stated in the Rockefeller Fund report: [1]

> "Four factors — the importance of a growing industrial base, the crucial role of lead-times, the increasing significance of forces in being, and the necessity of a versatile military establishment — impose on policy makers an unparalleled problem of choice. It is further complicated by the explosive rapidity with which technology is developing... Moreover, each new weapon system costs more than double its predecessor which it replaces at shorter and shorter intervals.
>
> "This technological race places an extraordinary premium on the ability to assess developing trends correctly... "

The purpose of a military technological forecast is to help in resolving the above dilemma by making technological trends more explicit to planning personnel in the operational and technical communities.

RDT&E within the military services is characteristically conducted as a dialogue between the user's interest, represented by the operational side of the house, and the producer's interest, represented by the technical side of the house. Plans are the result of "negotiations" between the two interests. The planning process is facilitated by an iterative interchange on a frequent, if not continuous, basis. Trade-offs resulting from this process should provide the operating forces with the maximum military capability possible within the limits of available resources.

If the military is to meet its operational needs in the future, early decisions are vital: it takes from four to twenty years to get today's technical developments into the operational inventory. A technological forecast that identifies,

1. The Rockefeller Fund, National Security — The Military Aspect, January 1958.

in terms of military relevance, future opportunities arising from advances in science and technology will provide one element on which the necessary dialogue can be structured.

A meaningful forecast can assist in the projection of military policy and force structures to meet anticipated enemy threats. It can be extensively used in:

a. Projecting U. S. technological capabilities during the forecast period. It can identify technologies which would enhance the operational capability and effectiveness of the military.

b. Making better postulations of the enemy threat during the forecast period by identifying technological capabilities which can be attained by the U. S. and which may be assumed, a priori, to be within an enemy's potential. Confirmation and interpretation of the threat are considered to be outside the responsibility of a technological forecast.

c. Providing the necessary input into a technology/capability matrix to define goals for exploratory development and system configurations to meet and/or exceed the projected enemy threat. Scientific and technological areas which have high payoffs not directly responsive to the projected threat can be identified intuitively.

d. Serving senior management by presenting strengths and capabilities of military scientific and technical efforts.

By formalizing the inputs from the technical community to the definition of long-range military capabilities, a forecast can be used in preparing the following documents:

a. Joint Long Range Strategic Study (JLRSS)

b. Joint Strategic Operations Plan (JSOP)

c. Joint Research and Development Objectives Document (JRDOD)

d. Army Combat Development Objectives Guide (CDOG)

e. Army Operational Capability Objectives (OCO)

f. Army Qualitative Materiel Development Objectives (QMDO)

g. Basic Army Strategic Estimate (BASE)

h. Army Strategic Plan (ASP)

i. Army Force Development Plan (AFDP)

j. Navy Long Range Strategic Study (NLRSS)

k. Marine Corps Long Range Plan (MCLRP)

l. Navy Mid-Range Study (NMS)

m. Navy Mid-Range Objectives (NMRO)

n. Marine Corps Mid-Range Objectives (MCMRO)

o. Navy, Marine Corps, and Air Force General Operational Requirements (GOR)

p. Navy, Marine Corps, and Air Force Tentative Specific Operational Requirements (TSOR)

q. Navy, Marine Corps, and Air Force Advanced Development Objectives (ADO)

r. Navy, Marine Corps, and Air Force Specific Operational Requirements (SOR)

s. Navy and Marine Corps Exploratory Development Requirements (EDR)

t. Navy Goals for Technology in Exploratory Development (EDG's)

u. AFSC Planning Activity Report

v. Air Force Technical Objective Documents (TOD's)

w. Doctrinal and tactical studies

A formal forecast can provide inputs to feasibility studies at all levels of the military's operational and technical communities. The forecast can make available to laboratories and technical offices projections of the state of the art in supporting areas outside their immediate scientific or technical expertise. It can identify technological areas which have high potential for sensitive developments, for example, a moderate improvement in some technologies could have a high impact on operational effectiveness. A large technical gain in other areas, however, may not improve an operational capability. The forecast can also identify the extent of interdependence of the various technical disciplines and areas in which component developments are compatible, or augment one another. When more than one functional capability contributes to an end-item development, a reasonable prognostication can determine the relative burden on the projected state of the art in each contributing area.

A forecast, generated by laboratory personnel, will strengthen the laboratory's planning functions by encouraging longer range projections of scientific and technical capabilities and will provide more communication with higher echelon planners.

2.2. Technological Forecasting in the U. S. Army.

The Army Long Range Technological Forecast (ALRTF) is prepared by the U. S. Army Materiel Command under staff supervision of the Chief of Research and Development. It is intended to describe knowledge, capabilities, and materiel which science and technology can be expected to produce if supported by orderly programs of research and development. The document is used by operational and organizational planners, the combat development system, and long-range research and development planners in the Department of the Army in formulating new concepts, requirements, and plans.

The Army Long Range Technological Forecast is currently published in three volumes, as follows:

a. Volume One, "Scientific Opportunities," discusses the opportunities and limitations in both nonmateriel- and materiel-oriented research that will affect the future technical capabilities of the Army. The research activities needed for a selected scientific area and its related technical requirements are among the opportunities identified.

b. Volume Two, "Technological Capabilities," describes the technological capabilities which are foreseen as achievable in areas vital to the provision of future high-performance materiel.

c. Volume Three, "Advanced System Concepts," includes examples of materiel systems that might be provided if the capabilities described in Volume Two are achieved.

The Commanding General, U. S. Army Materiel Command, formally compiles and consolidates Army-wide critiques and contributions to this Forecast with the close cooperation of the Army Research Office on behalf of the Chief, Research and Development. The relationship of the Army Long Range Technological Forecast to Army planning documents is shown in Figure 2.1. The Forecast is one input to the "Basic Army Strategic Estimate." It is used by the Combat Developments Command in the preparation of doctrinal studies, Qualitative Materiel Development Objectives, and Qualitative Materiel Requirements cited in the Combat Development Objectives Guide (CDOG).

In addition to the ALRTF, the Army conducts a series of Forecasts-in-Depth intended to provide an insight into specific technological fields, for use by persons within and outside the Department of the Army who have need for such background information. A Forecast-in-Depth (FID) is primarily an encyclopedic summary of the current knowledge, a projection of the expected technological

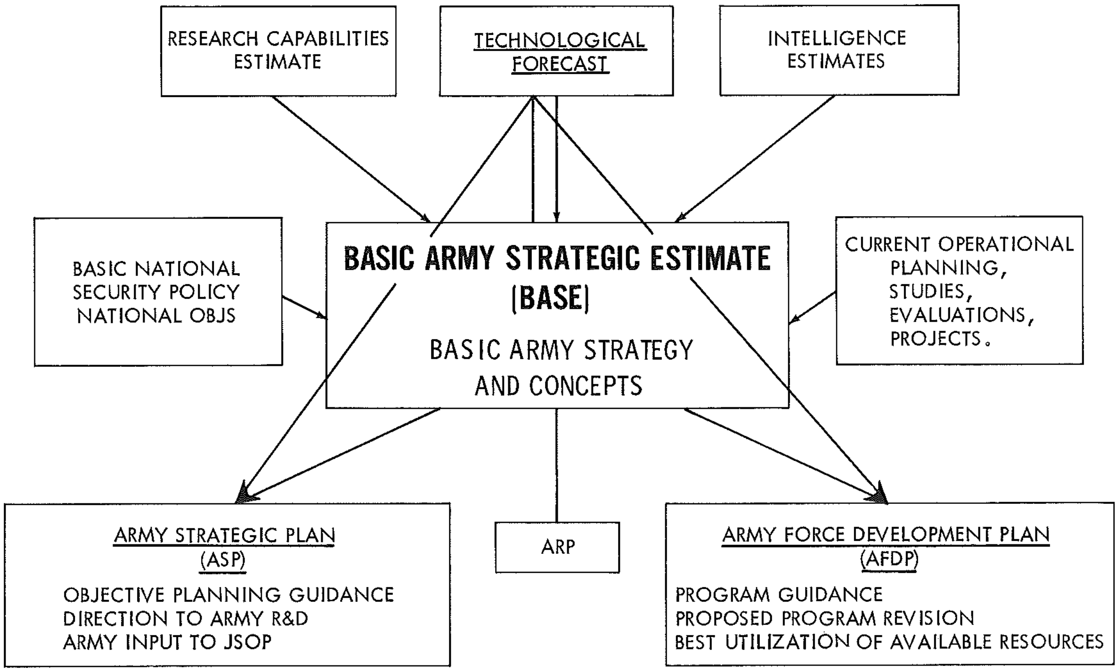


Figure 2.1. Role of Forecast in Army Planning

environment during the next 20 years, and an analysis of the research effort required to attain the most promising materiel aspects. Its purpose is to enable scientists and technically and operationally oriented individuals to communicate relevant ideas and learn of potentialities in a given field.

A Forecast-in-Depth, while generally comprehensive, is not exhaustive. Hence, the treatment may properly be considered an overall introduction to the current state of the art and a 20-year extrapolation of the technological environment. An extensive bibliography is included.

2.3. Technological Forecasting in the U. S. Air Force.

In the Air Force it has become a tradition to prepare technological forecasts by periodically convening large groups of scientists and engineers from government laboratories and from the scientific and industrial community. Such groups have been assembled in an approximately five-year cycle for periods of concentrated study extending over several months. The two most recent technological forecasting studies conducted by the Air Force were the Woods Hole Studies of 1957/58 and Project Forecast in 1963. Both of these were broad-scope studies involving many fields of technology of interest to the Air Force. Both produced a series of reports which contained technological forecasts for periods ten to fifteen years into the future.

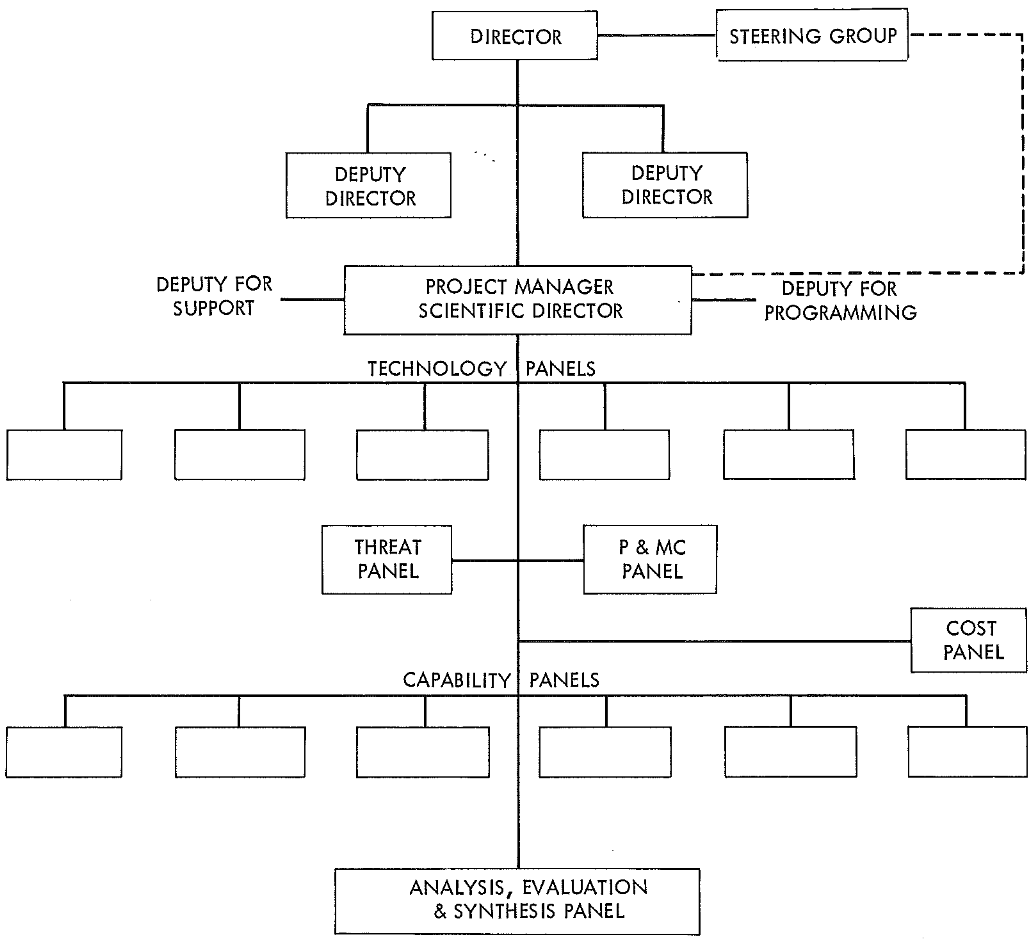


Figure 2. 2. Organization of Project Forecast Group

Figure 2. 2 shows the organization of the latest major Air Force effort, Project Forecast. The forecasting of technology was done by the Technology Panels identified on the chart. The project organization was used as a mechanism for relating the forecast to military capabilities, the threat, and national policy considerations, through specific panels established for this purpose.

In the interim period between formal technological forecasting studies, the panel reports are distributed throughout the Air Force, where they are used as reference material in Air Force planning documents such as the following:

a. Office of Aerospace Research Five-Year Plan. The Office of Aerospace Research (OAR) is responsible for the Air Force research program. Since OAR tasks are generally of a long-term nature, its goals must be forecast against relatively uncertain visions of the future. Nevertheless, in the interest of maximum economy and effectiveness in the use of our national resources, the OAR intends to proceed along carefully plotted courses of action. This year's (1967) Five Year Plan sets forth organizational and research objectives for FY 1968 through FY 1972, describes courses of action for their accomplishment, and presents studied estimates of the requisite resources.

b. AFSC Planning Activity Report. The Air Force Systems Command's Planning Activity Report is the principal document for reporting on development planning activities under the control of Headquarters, Air Force Systems Command. It provides descriptions, funding, schedules, and pertinent progress milestones for development planning activities that (1) lead to the development of a new system or new equipment for the operational inventory, (2) lead to the submission of a Proposal for an Advanced Development Program to demonstrate the technical feasibility of a subsystem or building block and/or to establish the confidence level in an experimental system or equipment which may be incorporated into the operational inventory, (3) examine an operational mission or function in depth to identify system concepts that may improve the operational capability to perform the mission, and (4) examine specific technological advancements to determine their potential applications to the various Air Force missions or functions.

c. RTD Long Range Plan. This plan, prepared by the Air Force Directorate of Laboratories (DOL), formerly the Research and Technology Division (RTD), considers the management of Air Force Exploratory and Advanced Development programs. It is prepared by scientists and engineers in the Air Force laboratories. It is an attainable plan in that it describes how DOL will allocate the resources that it may realistically expect to have available over the next decade. The plan is oriented toward achieving the level of technology required to attain future Air Force capabilities, many of which were identified by Project Forecast. It also recognizes that a major objective of the Directorate is to build and maintain a strong in-house technical capability in the Air Force laboratories. DOL's plan is not unalterable; breakthroughs will occur and efforts that prove unfruitful will be terminated. On the whole, however, the plan represents a coordinated picture of where DOL is going in the next decade.

d. Technical Objectives Documents. These are prepared by the Research and Technology Division, AFSC, to provide means of communicating with science and industry and to describe the Air Force's objectives in each of 36 different technical areas. As is the case in any selective grouping of science and technology, it is difficult to draw sharp boundaries between areas and thus overlaps occur within the documents.

e. Technology for Tomorrow. The fifth and latest edition of this document was published by the Aeronautical Systems Division, AFSC, in

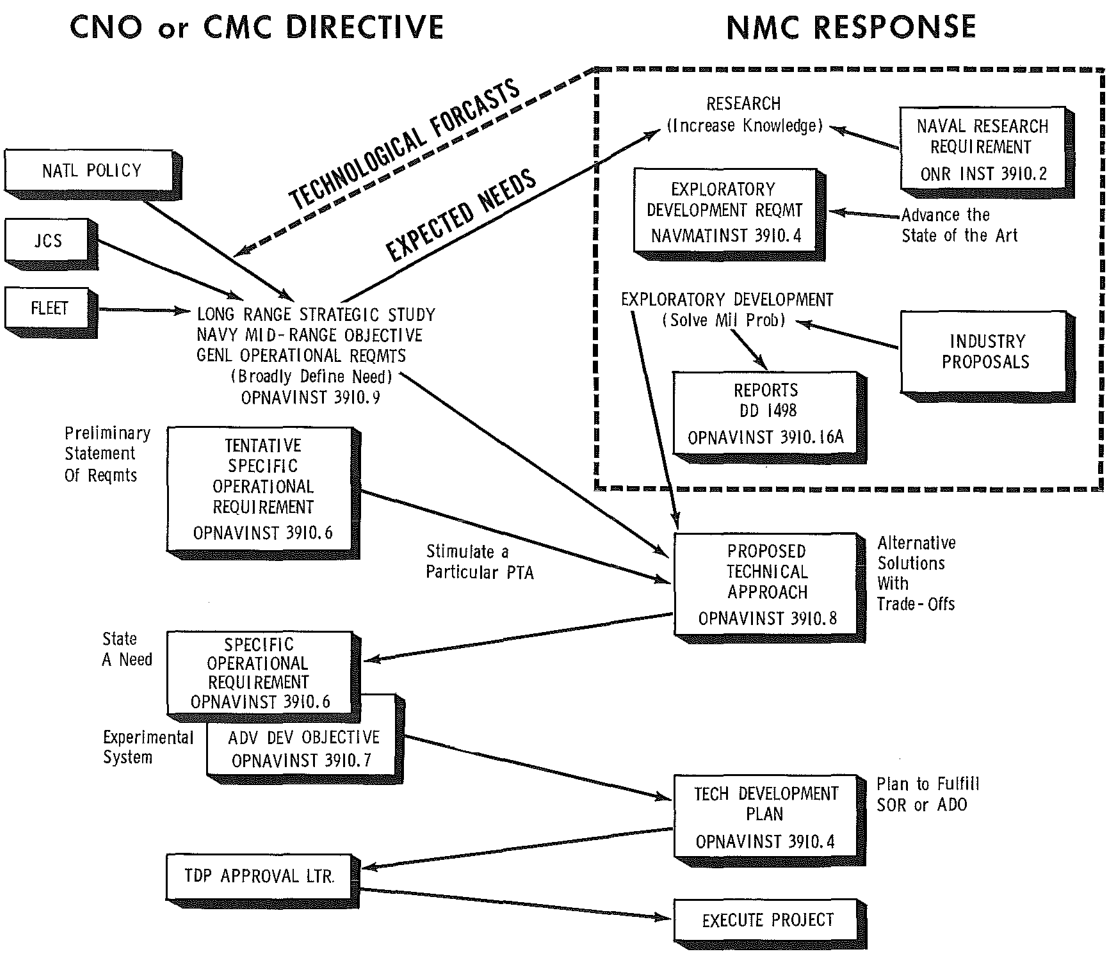


Figure 2.3. Technological Forecasting's Position in Navy Planning (Source: OPNAV Instruction 3900.8C)

1962. (At present only a reference document, it may be reinstated by the Research and Technology Division, AFSC.) It was a presentation of motivational concepts outlining the approach to an optimum plan. It was a guide to the organization and selective application of resources and capabilities for aggressive support of the Air Force's long-range technical mission. The contents and organization of the document reflected the fact that a cohesive detailed plan existed collectively in the minds of the engineers, scientists, and management personnel who have contributed to its formulation.

2.4. Technological Forecasting in the U. S. Navy.

Informal prediction of technological capability is common in the normal planning activity of the Navy's technical community, which is shown in Figure 2.3. The figure shows the functional status of the technological forecast within the flow sequence of planning documents. It is shown that requirements are assessed against feasibilities as referenced to time, with two important planning criteria outputs:

a. Technological constraints or limits imposed which serve to define feasible performance in relation to desired performance.

b. Implications for shifts in orientation or emphasis in defined areas of research and development.

A formalized, coordinated Navy Technological Forecast has been proposed (Ref 20) by a study group drawn from several in-house laboratories and working under a charter by the Chief of Naval Development to study the utility, techniques, and implementation of formal technological forecasting. The recommendations of the study group have been accepted, and the Navy Technological Forecast will be prepared under the direction of the Chief of Naval Development.

The proposed Navy Technological Forecast (NTF) would consist of a loose-leaf document in three parts containing individual prognostications of pertinent advances, capabilities, limitations, or developments which the naval scientific and technological community can be predictably assured of having available during a forthcoming 20-year period. This document would describe scientific knowledge, capabilities in technology, and examples of subsystems, components, or systems which science and technology should expect to produce during this period. The NTF would be divided into three parts for convenience of the user.

Part I — Scientific Opportunities: Should describe significant projections of research in the physical, engineering, environmental, and life sciences normally associated with the RDT&E 6.1 research category. The advances and limitations in scientific research defined in Naval Requirements which are relevant to future technological capabilities of the Navy would be discussed.

Part II — Technological Capabilities: Should contain the significant projections of applied research and development which normally are included in the RDT&E 6.2 research category. This section of the forecast would cover a broad spectrum of research and development ranging from basic technologies (e.g. Power Conversion) to functional capabilities (e.g., Deep Ocean Technology).

Part III — Probable Systems Options: Should rely heavily on the first two parts to suggest examples of subsystems or systems which could be developed if the capabilities described in Parts I and II are achieved. The examples to be included should be supportable by realistic projected capabilities.

2.5. Technological Forecasting in the U. S. Marine Corps.

The Marine Corps presently employs the Army Long Range Technological Forecast, interpreting it in terms of specific Marine Corps applications. In addition, under Marine Corps sponsorship, the Syracuse University Research Corporation engaged in a study (Project 1985) in 1963-1964, entitled, "The United States and the World in the 1985 Era" (Ref 141), which examined "projected national objectives and policies, the international and domestic military, economic, and technological factors affecting the United States in the 1985 era." It is anticipated that the Army Long Range Technological Forecast will continue to be used in areas in which Marine Corps interests parallel those of the Army and that the Navy Technological Forecast, when published, will meet the needs of the Marine Corps in most other technical areas. In the interim period, the Syracuse study will be updated as required.

2.6. Conclusion.

There is need for effective communication between the operational and technical communities within the military. The scientific community proposes technological capabilities while the operational community disposes to fulfill strategic and tactical needs. If the Forecast is good, it can be a repository of avenues of technical approaches from which choices can be made in developing goals.

Figures 2.4, 2.5, and 2.6, respectively, illustrate the functional status of the technological forecasts in the Army, Air Force, and Navy long-range planning framework. The forecast functions and utilizations are seen to be analogous for all three services.

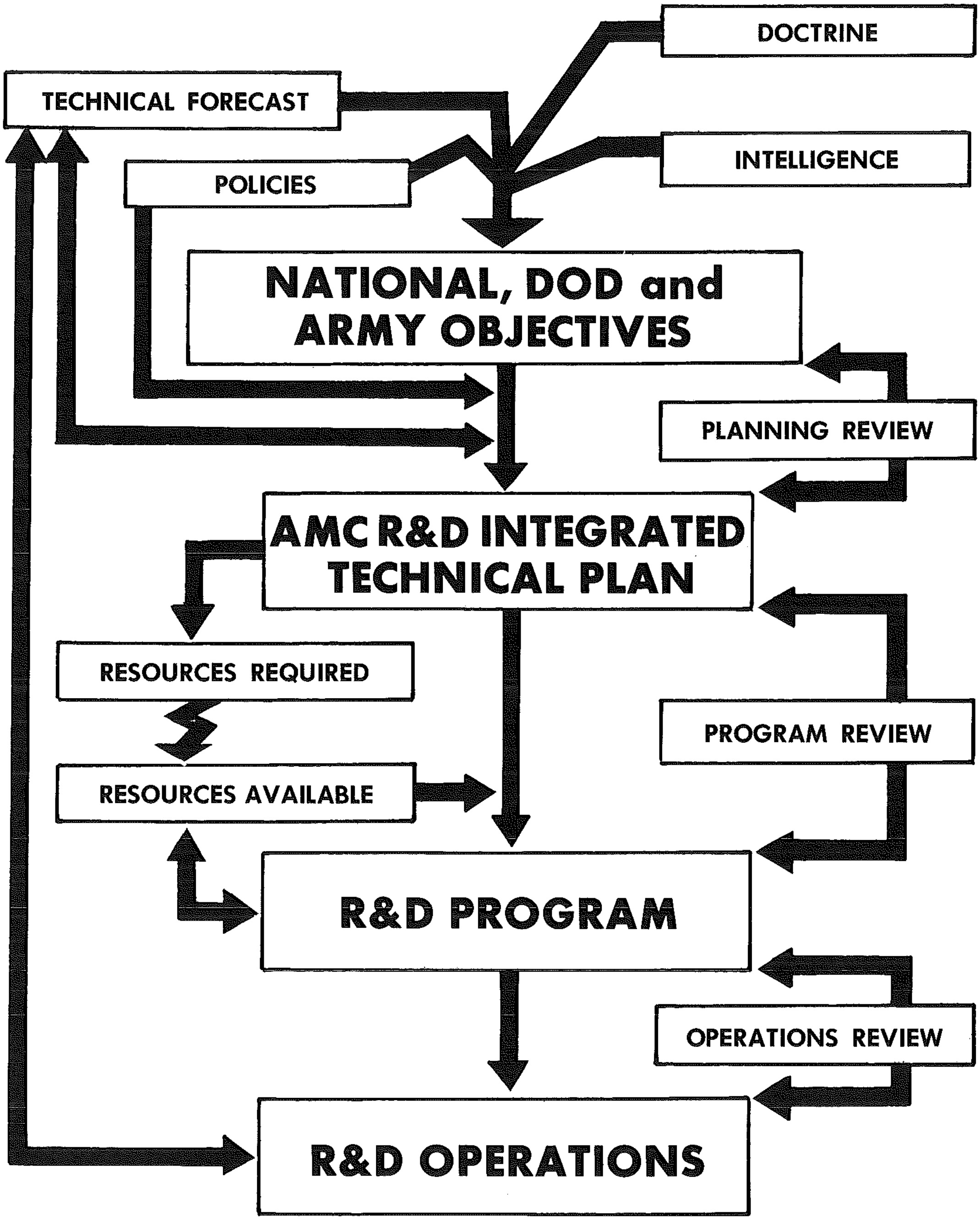


Figure 2.4. R&D Planning Interrelationships in the Army
(Source: AMC Pamphlet 705-1, Volume 1, January 1966)

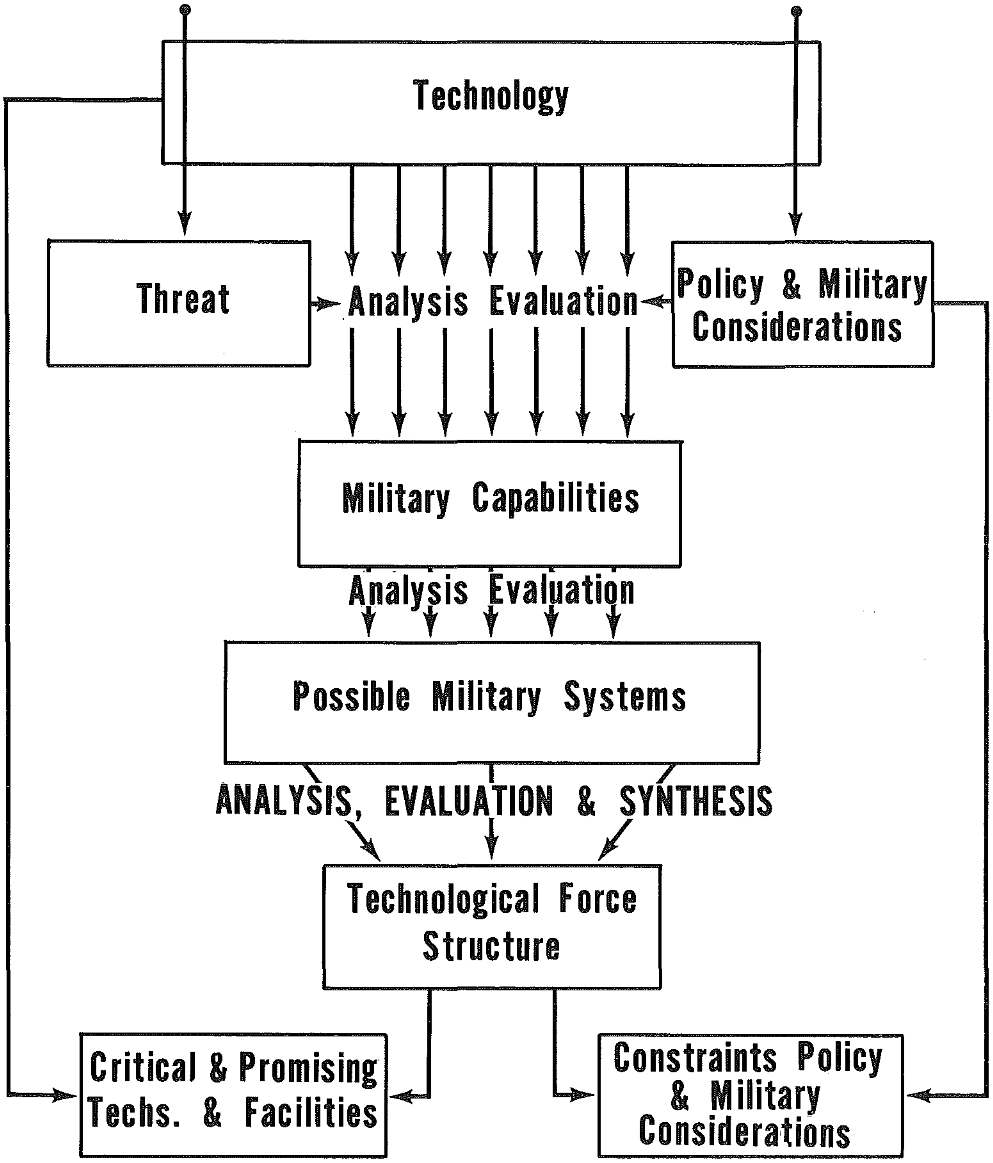


Figure 2.5. Project Forecast Flow
(Source: Air Force Project Instruction Manual, 1963)

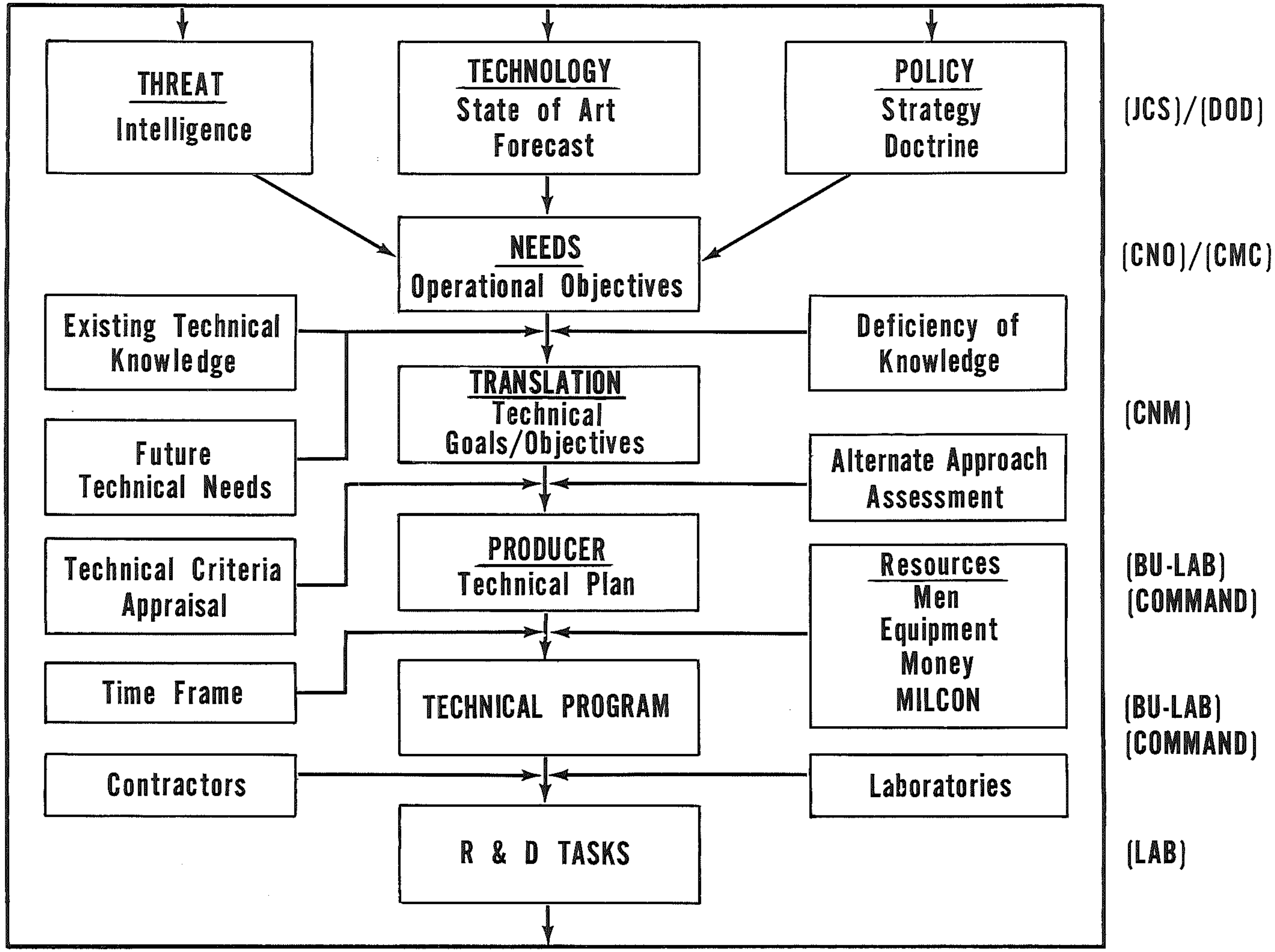


Figure 2.6. R&D Planning Sequence in the Navy

CHAPTER 3

SELECTION OF PARAMETERS OR FACTORS TO FORECAST

3.1. Introduction.

The decision regarding what should be forecast may be the critical step in determining the ultimate utility of a forecast. It is somewhat analogous to the important problem formulation step in problem solving. Swager (Ref 137) has advanced the thesis that technological forecasting will have a greater impact when more attention is addressed to the question "What should be forecast?" and somewhat less to "What methods should be used for forecasting?"

Parameter selection and forecast presentation (see Chapter 6) is also analogous to the effectiveness problem in information retrieval, as commonly expressed by the following equation:

$$\frac{\text{\% of relevant material available actually retrieved}}{\text{\% of material retrieved which is found irrelevant}} = \begin{array}{c}\text{effectiveness}\\ \text{of}\\ \text{retrieval}\end{array}$$

That is, the forecaster must be selective by forecasting those parameters which best indicate progress in a particular science or technology without dissipating his efforts and the attention of the reader on excessive irrelevant data. The parameters selected can be single-valued such as "pounds of thrust" of rocket engines, dual-valued such as "signal-to-noise ratio" of an infrared detector, an overall figure of merit composed of several parameters such as the "flutter index" plotted as a function of Mach number, or even a very subjective factor such as trends in the predictability of various nuclear weapon effects. In many cases, it is necessary to forecast several parameters in order to adequately describe the progress in a given field.

3.2. Classification of Forecast Data.

The types of forecast data can be grouped in the following categories, depending upon the technology transfer level involved and the orientation of the forecast:

a. Scientific and technical findings in which the relationship to functional capabilities has not yet been established. These are generally data that accrue outside the application of technology to the achievement of functional capability.

b. Functional capabilities which are independent of any specific technology, although in fact being based on all applicable ones; the end result as opposed to the means.

c. Technical parameters for specific techniques which enable the functional capabilities to be accomplished.

d. Performance parameters which describe a physical property or capability of an item of hardware, such as a gun, vehicle, ship, or airplane.

e. Systems concepts which show possible systems resulting from the combination of functional capabilities.

The nature of the interrelationships among the classes of forecast data may be illustrated by the following example. A system may have several critical performance parameters which, when measured against mission requirements, determine the effectiveness of the system. Overall mission accomplishment may be dependent upon the successful attainment of certain functional capabilities in several task areas. In turn, the functional capability may be attainable through several different techniques or by the combination of a number of "building block" components, which are in turn limited by the materials, skills, and scientific base. For example, the performance parameter called burnout speed (of a rocket) is uniquely determined by two technical parameters which we might call state-of-the-art parameters. These are the ratio of fuel weight to gross weight and the ratio of energy release to annihilation energy. These, in turn, are dependent upon such limiting factors as high-temperature materials and methods of producing fuels as well as the facilities and manpower required to produce necessary research information, fabrication techniques, etc.

Ayres (Ref 32) suggests that, in the choice of appropriate parameters, one should determine whether the predominant constraints are internal or external, and that progress should be expressed accordingly in "intensive" or "extensive" parameters. Generally, intensive parameters can be expected to become more predominant for a system as inherent limits are approached. Ayres' example of intensive parameters include:

a. Ratios of input to output, eventually approaching unity (e.g., energy conversion efficiency).

b. Functional capabilities, eventually approaching absolute (natural) limits (e.g., speed, low pressure).

c. Functional capabilities, eventually approaching practical or tolerence limits due to human limitations or characteristics of the earth (e.g., acceleration of passenger transport devices, maximum velocity in atmosphere).

Extensive variables would include all other variables with parametic constraints, such as cost, magnitude, intensity, strength, temperature, and so on.

Another basic characteristic of forecast data is the degree of quantifiability of the subject area. Certain subjects (e.g., "soft sciences") are too inexact to be quantified. In other cases, the subject area may contain many interrelated quantifiable and nonquantifiable factors, and attempts to reduce the subject to several quantitative parameters may result in oversimplification. Such subjects may benefit from the use of the analytical tools described in Paragraph 4.3. Fortunately, in many areas of science and technology, the subject can be reduced to one or several parameters that accurately represent progress in that area. An interesting example can be found in a recent issue of Space/Aeronautics,[1] in which twenty critical parameters of aerospace research and development are identified and forecast for the period 1965-1975.

3.3. Criteria for Choice of Parameters.

Pardee (Ref 114) states that the initial step in developing a quantitative projection of potential advance in state of the art is to select a performance characteristic or combination of characteristics which will provide a satisfactorily comprehensive measure of the state of the art in a given technical area. This presupposes that actions such as the following have been taken:

a. The breadth or scope of each technical area has been clearly defined.

b. A comprehensive and nonoverlapping structure of all major technical areas has been developed and detailed as to the content of each individual area.

c. The technical areas as well as major projects within technical areas have been identified.

d. A review system for tracking progress against projection should be in existence so that any narrowing, branching, or other changes in the structure can be readily identified on a historical basis.

Assuming that such an overall technical area structure has been adequately formulated, then the search for characteristics suitable for quantification can begin. The following illustrative listing of guidelines, or criteria, developed by Pardee (Ref 114), may serve as an aid in the selection of acceptable (hopefully quantifiable) measures of performance capability:

a. Comprehensiveness. Obviously, a single variable would be preferable if it could be made to adequately represent progress in the area. As a practical matter, the number of variables selected usually should not exceed three or four. Nevertheless, the characteristic or

1. Space/Aeronautics, Special Research and Development Issue, Conover-Mast Publications Inc, Mid-July 1966, p 78.

combination of characteristics selected should incorporate a high portion of the approaches, and quantitatively identifiable objectives within these approaches, which are likely to be derived from research in the technical area during the time period covered by the forecast.

b. Operational Significance. Preferably, the characteristic or characteristics selected should bear a direct relationship to a military need, for example, a major design specification or military characteristic. The most obvious of these are: range, speed, accuracy, and payload. Methods for assessment of operational significance include a narrative statement, a qualitative rating scale, and formal quantitative factors.

c. Ease of Measurement. Consideration should be given to the ease with which projected parameters can be measured for determining degree of accomplishment. Likely sources for such data include research activities which involve the use of mathematical simulation of the operating characteristics of the future military hardware; partial-scale or partial-duration tests, including breadboards and mock-ups; or full-scale and full-duration testing.

d. Probable Accuracy. This criterion might be evaluated by using informal checks for reasonableness, formal tests of statistical validity, or some intermediary means.

e. Identification and Measurement of Interdependencies. In some instances a pacing characteristic can be identified and other variables related to it in a fixed fashion. However, this is frequently difficult since the pacing item may change as performance levels move from one portion of the range to another. For example, in aircraft design, propulsion developments — measured by acceleration or thrust levels — may be the pacing item at one part of the speed regime, whereas at higher levels, heat-resistant material — measured by temperature — is the pacing parameter.

In the design of an artillery weapon, a system could be optimized for weight, length of service life, stability, maximum range, etc. To some extent, however, these objectives are contradictory, and as a result a projection of future artillery systems must consider some type of trade-off analysis between parameters. The result could very well provide an optimum system with none of the critical parameters designed at its optimum point. Another example, at a lower level of hierarchical development, would be a prediction for only a small part of a system, such as a gun tube. Gun tubes can be designed for long life, high muzzle velocity, weight reduction, etc. To project the future of gun tube technology, one would have to select one of the following opposing assumptions: (1) that the need for lightweight, highly mobile artillery was of prime importance and that the military would consider reducing tube life if necessary to effect a substantial reduction in weight, thereby facilitating handling and increasing mobility, or (2), conversely, that an improved tube weight could not be gained at the expense of tube life.

The key factor, then, is to make the determination of parameters which are important, perhaps even critical, to the system, subsystem, or whatever level is being forecast; seek out the dominant relationships between them, and express them as simply and explicitly as possible. This will very likely necessitate ignoring the noncritical or lesser interdependencies.

Pardee (Ref 114) suggests a series of alternative possible approaches to incorporating interdependencies into projections. Each one in the series represents a somewhat increased level of sophistication:

> "(1) The use of narrative indicating that the major performance characteristics are related but not specifying the precise nature of the relationship.
>
> "(2) Plotting separately each of the three or four major characteristics which are interrelated but placing the charts in juxtaposition and accompanying them with a set of common underlying assumptions.
>
> "(3) Selection from a small series of (3 to 10) prespecified forms in which the characteristics might be related. Visualized here are 'black box' or 'plug in' relationships from which the estimator would choose the one which most closely approximates his view of the potential real world situation.
>
> "(4) Plotting of the specific relationships among each set of characteristics as best they can be determined."

Pardee states that approach one is most widespread today, whereas approach two can be implemented currently, and approaches three and four are essentially proposals which deserve further study.

CHAPTER 4

FORECASTING METHODOLOGY

4.1. Introduction.

4.1.1. Forecasting Techniques.

At present, there are at least five definable categories of technological forecasting techniques. The classification system chosen is somewhat arbitrary; however, it does provide a means of grouping related methods and a structure for more meaningful discussion. In general, the more effective techniques are based on a careful analysis of past results combined with the insights of knowledgeable and imaginative people. These methods require interpretation of the underlying data, consideration of causal forces and trends, interactions with other technologies, and probable limitations or barriers.

The available techniques are listed as follows:

a. Intuitive Forecasting.

(1) Individual or "genius" forecasting.

(2) Consensus.

(a) Polls.

(b) Panels.

(c) Delphi.

b. Trend Extrapolation.

(1) Simple extrapolation.

(2) Curve fitting with judgment modifications.

(3) Systematic curve fitting.

(4) Trend curves.

c. Trend Correlation.

(1) Precursor events.

(2) Correlation analysis.

(3) Correlation coefficient.

d. Analogy.

(1) Growth analogy.

(2) Historical analogy.

e. Predictive Models.

4.1.2. Forecasting Aids.

In addition, a number of forecasting aids have been found to have utility, mainly through their ability to structure the information so that patterns can be perceived and causal relationships can be considered. These aids include new techniques unique to forecasting, as well as more general analytical tools which can be adapted to technological forecasting. Some of the more promising aids are grouped as follows:

a. Matrices.

b. Contextual Mapping.

c. Morphological Research.

d. Network Construction.

(1) Relevance trees.

(2) Mission networks and functional analysis.

(3) Graphic models.

(4) Decision trees.

e. Systems Analysis.

f. Demand Assessment.

g. Analysis of Theoretical Limits and Barriers.

h. Prediction of Technological Changeover Points.

4.2. Discussion of Forecasting Methods.

4.2.1. Intuitive Methods.

One of the most direct and, at the present time, widely used methods of generating a forecast is to sample the opinions of one or more persons knowledgeable in the specific technology or technical area under consideration. When more than one forecaster is involved, the forecast is based on a consensus or on a composite of estimates.

Past experience has shown the record of intuitive forecasting to be rather spotty. The experts are often right, but also often wrong, and critical evaluation of such forecasts is difficult in the absence of explicit statements regarding the logic involved and assumptions made.

4.2.1.1. Individual or "Genius" Forecasting.

If the previous caveats are observed, there can be considerable merit in a forecast made by a single individual who is expert in his special area and knowledgeable in related scientific disciplines or technologies. He also should be capable of taking a synoptical view of the functional area to which his expertise has direct application.

4.2.1.2. Polls.

To overcome the difficulty inherent in a single estimate, which may be a poor one, it may be well to combine the judgments of several individuals who are active in the field. It is presumed that a realistic forecast can be obtained by canceling out the errors of individual predictions, but this is not necessarily the case, especially if the sample is poorly drawn. It has been shown that a forecast arrived at by polling a group of scientists or engineers may lack the imaginativeness demanded of such forecasts, which may be obtained in one prepared by a highly informed individual. On the other hand, the technique of polling individuals has the advantage of providing an indication of the direction in which an emerging technology may develop.

4.2.1.3. Panels.

The panel approach to technological forecasting, in which individual experts are brought together, provides for a desirable interaction among their several opinions. Project Forecast of the Air Force and Project Seabed of the Navy are two interesting examples of successful panel operations. The method, if not handled properly, suffers from the possibility of generating a "bandwagon" majority opinion. In addition, there is a tendency among some specialists to be unwilling to abandon previously expressed opinions.

4.2.1.4. Delphi Technique.

The Delphi technique is directed to the systematic solicitation of expert opinion. Instead of using the traditional approach toward achieving a consensus through open discussion, this technique "eliminates committee activity altogether, thus . . . reducing the influence of certain psychological factors, such as specious persuasion, unwillingness to abandon publicly expressed opinions, and the bandwagon effect of majority opinion." It replaces direct debate by a carefully designed program of sequential individual interrogations (best conducted by questionnaires), interspersed with information and opinion feedback derived by computed consensus from the earlier parts of the program. Some of the questions directed to the respondents, may, for instance, inquire into the reasons for previously expressed opinions, and a collection of such reasons may then be presented to each respondent in the group, together with an invitation to reconsider and possibly revise his earlier estimates. Both the inquiry into the reasons and the subsequent feedback of the reasons adduced by others may serve to stimulate the experts into taking into due account considerations they might through inadvertence have neglected and into giving due weight to factors they were inclined to dismiss as unimportant on first thought. The technique has been described by Helmer (Ref 81), and the results of one broad Delphi study have been reported by Gordon and Helmer (Ref 75).

4.2.2. Trend Extrapolation.

An obvious method of technological forecasting is to assume that whatever has happened in the past will continue to happen in the future, provided there are no major disturbances. The extrapolation of time-series-related trends can vary from a simple continuation of an existing trend, to the use of mathematical methods of curve fitting, and finally to trend extrapolation with judgment modification based on consideration of causative factors.

For all forms of trend extrapolation certain basic characteristics need to be established. First, the trend under study should be capable of quantification in order that it can be portrayed numerically. The trend parameter should have a significant effect or impact in the forecast technological area or scientific discipline. Another important prerequisite is that an adequate data base should exist on which to establish a reliable trend line. For this purpose, data points should be plotted as far back into time as possible. As a rule of thumb, the trend should be plotted as far back in time as the forecast will be projected into the future.

4.2.2.1. Simple Extrapolation.

This method is simply the extension on a visual best-fit basis of some form of time series on the theory that existing trends will continue. It does not consider the causative factors for the trend pattern or possible constraints, such as physical limits. While this method has the advantage of objectivity and simplicity, it is not a very accurate method and can lead to horrendous errors if major perturbations occur or if unforeseen limits retard progress. Most intuitive forecasts of progress are based on subconscious versions of this technique.

Two basic assumptions must be made to use this method:

a. That those forces which created the prior pattern of progress will more likely continue than change.

b. That the combined effect of these forces is more likely to extend the previous pattern of progress than it is to produce a different pattern.

The further the forecast extends into the future, the greater the probability that one of these assumptions will become invalid.

The method is applicable to forecasting functional capabilities. If the field of interest to the forecast centers on man's ability to communicate, appropriate data sets might be "frequency spectrum exploitable" or "number of intelligence bits per hour per mile of separation between communicators." Such a set of data does not explicitly concern itself with whether the desired function is to be accomplished by cable, microwave, teletype, or a Telstar satellite. One or more of these techniques must be implicitly involved. The growth is considered in terms of cumulative time or calendar year. A plot of functional capability versus time may display a linear growth but more typically an exponential growth (Figure 4.1). Three lines are shown in the figure: the upper and lower ranges of the reasonably probable future rate of progress, and a line between these limits indicating the most likely trend. Examples of simple extrapolations of trends are given in Chapter 6.

If no restrictive limits are approached in the time period under consideration, an acceptable approximation can be quickly obtained by this method.

4.2.2.2. Curve Fitting with Judgment Modification.

Technological progress, as it is presently occurring, more than likely proceeds in an exponential manner similar to acceleration under the influence of gravitational forces or to the phenomenon of biological growth. Initial advance is exponential, followed by a diminution of the rate of advance as "maturity" is approached. The synthesis of several fields of progress, each occurring at different intervals, may result in an exponential advance for a functional capability.

Consider trends of specific techniques which enable a functional capability to be achieved. In the communications field, one set might consider the historical growth of a bandwidth capability of microwave links. This class of data, which we have called "specific technique," follows a characteristic curve (Figure 4.2). Initially the technique tends to experience a period of slow growth. It might well be hidden in a laboratory at this time or buried in the patent office. Finally, its potential is recognized, money and work are poured in, problems are solved, and an accelerated growth occurs. Eventually, limiting factors are encountered, the growth rate decelerates, and the curve asymptotically approaches some upper value, which should be definable when the limiting factor is known.

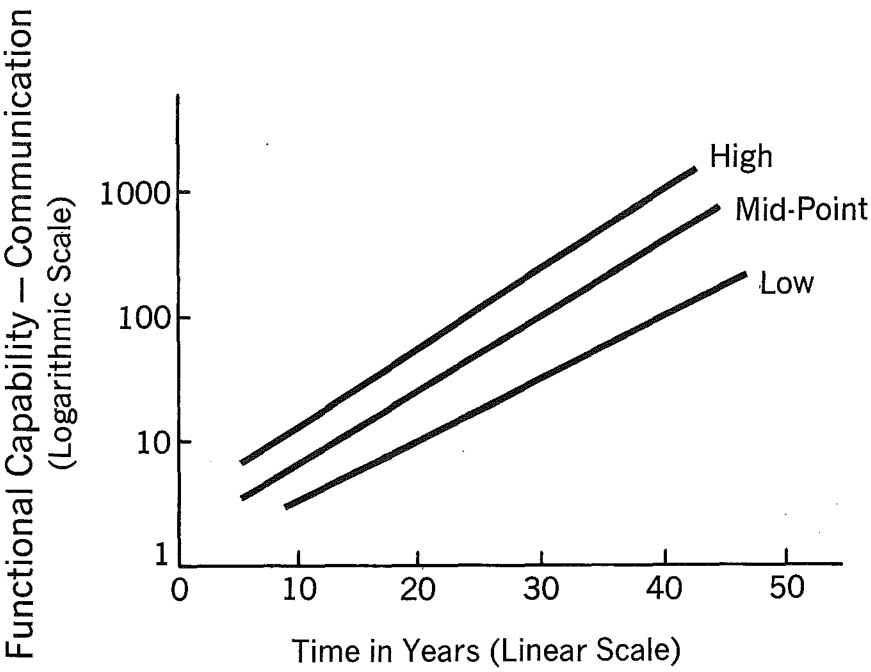


Figure 4. 1. Typical Functional Capability — Time History

A detailed study of historical growth in terms of the demonstrated functional capability would not reveal the deliberate day-to-day enhancement suggested, for example, by the chart in Figure 4. 3, which shows the almost precisely exponential increase of energy conversion efficiency (lumens per watt) in illumination technology from the paraffin candle to the gallium arsenide diode. In fact, a continuing series of perturbations, of steplike advances and plateaus, would be seen, and properly so. If the trend line is an indication of the potential upward limit of a functional capability at each point in time, the limit is realized only when a decision is made to exploit all of the available pertinent knowledge. Where nothing new and better is made, a plateau results.

The possibility always exists that physical or natural limits may be approached in certain technological areas. When this situation occurs, one can only terminate the curve at the limiting point and suitably annotate the chart. Such information is clearly useful in avoiding undertaking what the forecaster recognizes to be a theoretical impossibility.

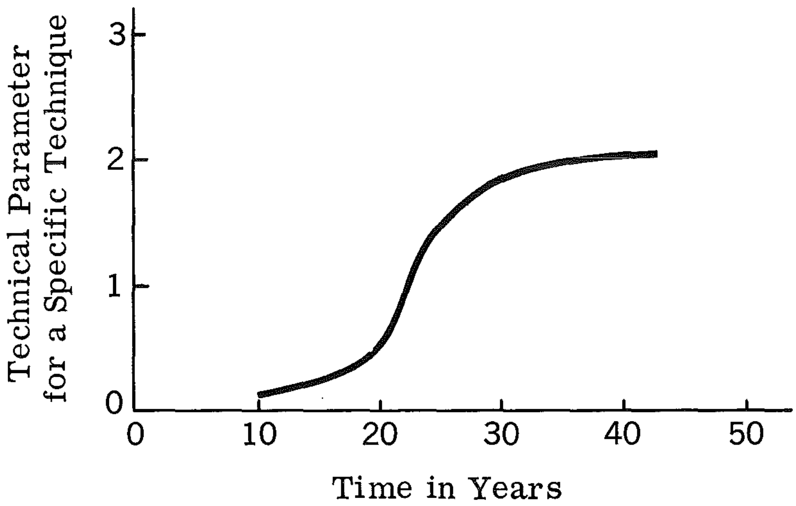


Figure 4. 2. Trends in Technique
Contributing to Functional Capability

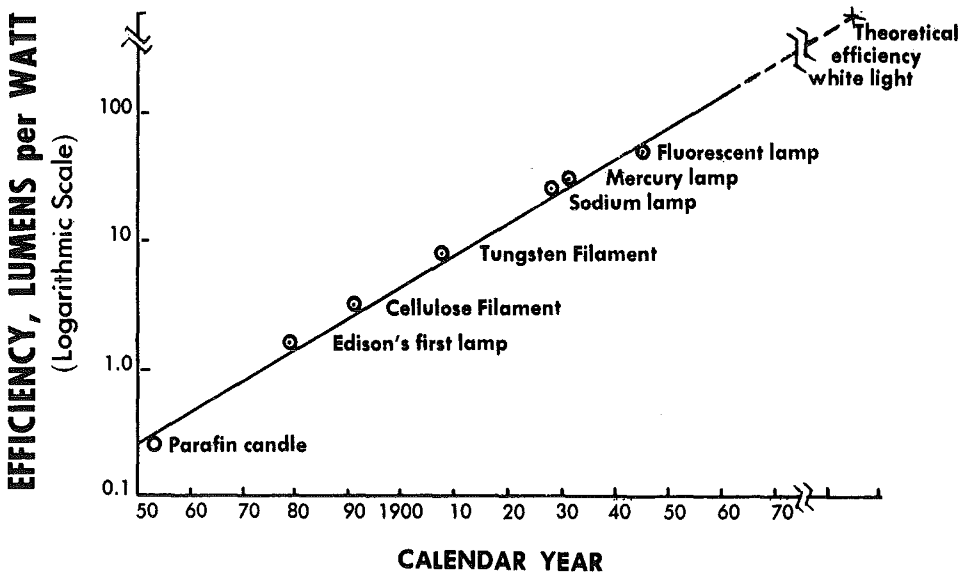


Figure 4. 3. Functional Capability Trend — Illumination

The data points in Figure 4.3 address themselves to particular techniques which are the current basis for the functional capability described in the associated trend curve, luminous efficiency. Figure 4.4 is a plot of the growth curve of the conventional incandescent bulb and the fluorescent lamp, both current techniques for converting electric power to illumination. Growth points are identified to indicate the manner in which the plot has been prepared. The shape of the curve shows a rather limited growth during the early experimental years of the technology, then literally an explosion in the increased efficiency, and finally, a tapering off as the growth curve appears to approach an asymptote. The relationship between this plot of technological advance and that of functional capability is apparent. Each specific technology contributes a small portion to the overall functional capability growth. At best, each offers only a few data points to the long-term technological growth curve and assists in understanding or interpreting the capability curve. Thus, the functional capability forecast is biased by, but not dependent upon, any particular technology.

Functional capabilities that can be achieved by various techniques or parameters of a general nature represent a "system" of a higher order characterized by a succession of innovations at a constant or changing rate. According to Ayres (Ref 32), a good model of the system whose performance is to be analyzed lies in the past performance of the system, that is, the system simulates itself, so long as it is not affected by outside factors. When envelope curves are extrapolated beyond the current state of the art, a continuation of the rate of invention (and perhaps the rate of change) which has characterized the system in the past is assumed. This then may fail to take into account the effects of unusual breakthroughs, but the consequence of a continuous process of ordinary innovation would presumably be taken into account.

Envelope curves can be used to inclose the individual S-shaped curves and then to extrapolate a projected range of the capability rather than a single-valued projection. An example cited by Ayres (Ref 32) is that of the trend of operating energy of particle accelerators, shown in Figure 4.5. Proponents of this approach have stated that envelope curves can yield more reliable forecasts than those approaches based mainly upon consideration of the projected capabilities of specific techniques. The logic here is that if the forecaster, say in 1950, looked closely at the capabilities of known techniques for particle accelerators, their limits or barriers would be fairly visible but the future innovations, the breakthroughs, would be more difficult or impossible to see. The result would, most likely, be an overly conservative forecast showing an incorrect leveling off. In envelope extrapolation the burden of proof is shifted and the forecaster assumes that progress will continue within the envelope range unless a definite limit or perturbation can be identified. He asks what might force the curve down, not what detailed hardware or technique will be required to keep it up. The technique of envelope-curve extrapolation presents an interesting thesis which can cause forecasters to change their approach to the analysis of a forecast area. It leads to a broader viewpoint that forces an analysis of limits (natural or otherwise) and promotes an analysis of causal factors acting upon the system.

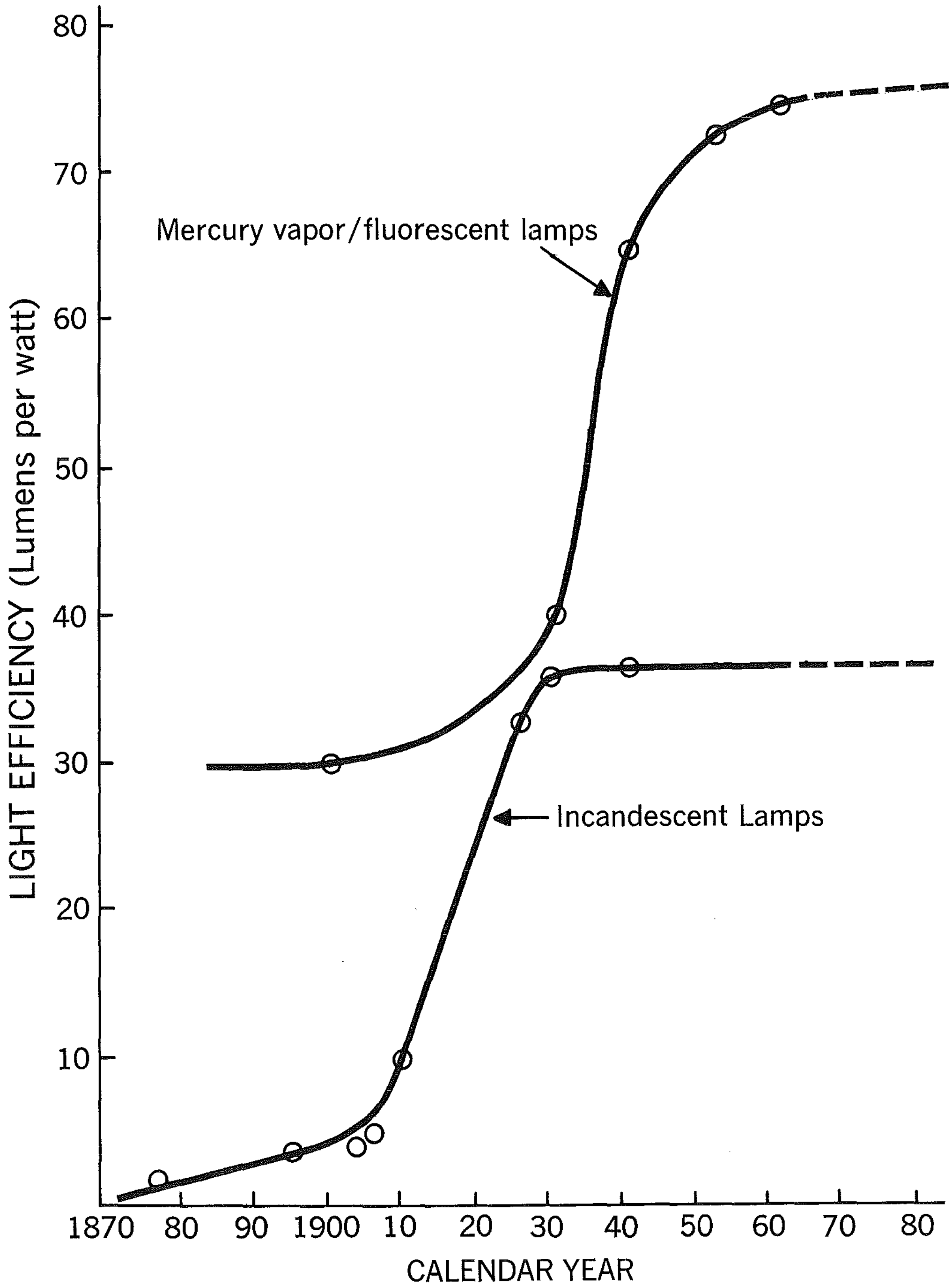


Figure 4.4. Specific Techniques — Illumination

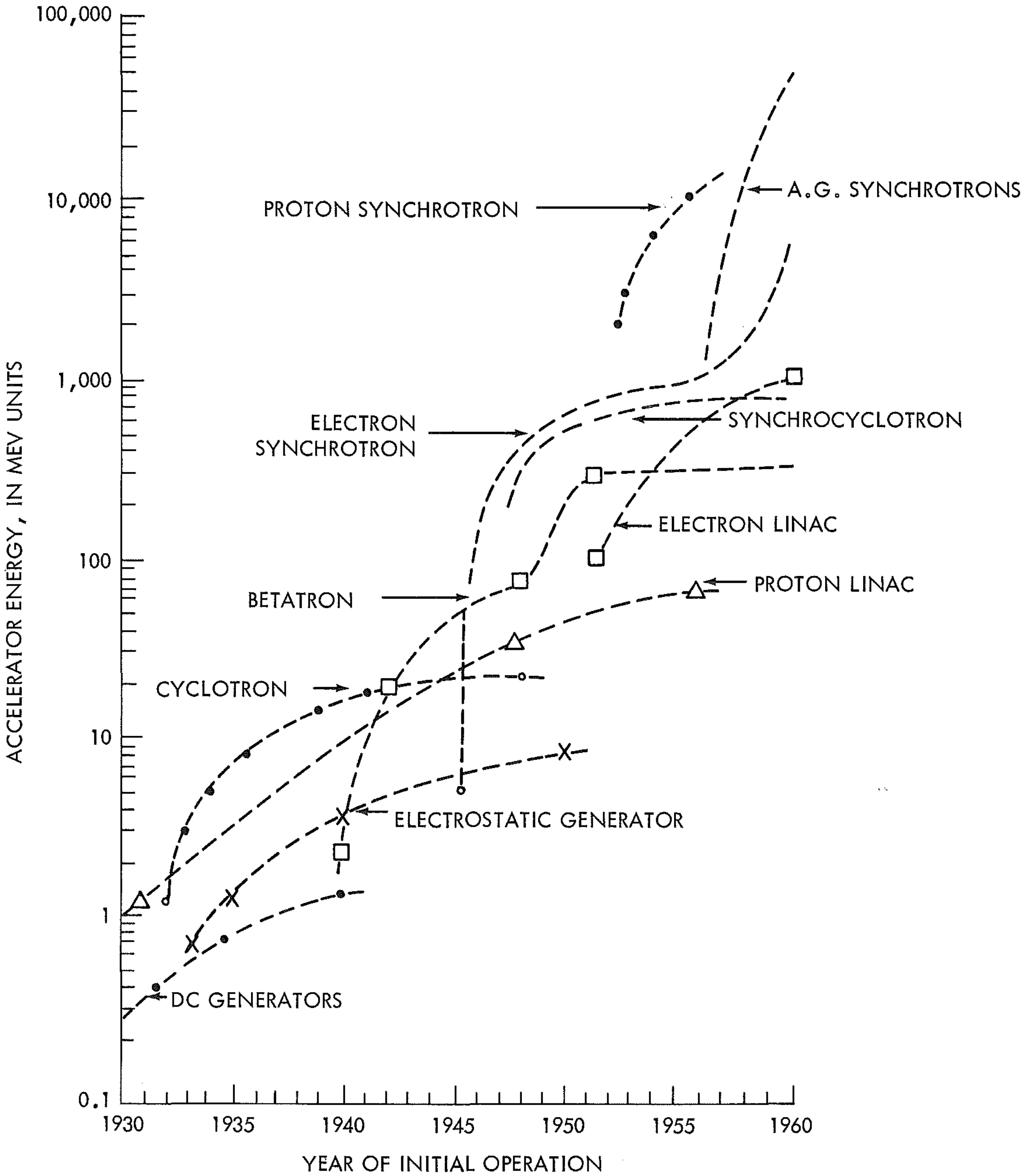


Figure 4.5. Typical Envelope Curve —
Rate of Increase of Operating Energy in Particle Accelerators

4.2.2.3. Systematic Curve Fitting.

To calculate and project trends quantitatively, one may use one or more empirical equations:

a. Straight line or first degree polynomial, in instances in which growth is characterized by a linear increase or decrease:

$$y = a + bx \tag{4.1}$$

b. Parabola or second degree polynomial, in instances in which growth is characterized by one bend, either upward or downward:

$$y = a + bx + cx^2 \tag{4.2}$$

c. Exponential, in which growth is a geometric function with respect to time (or other controlling parameter):

$$y = ae^{bx} \tag{4.3}$$

If the empirical data to be used in making the projection are reliable, equations (4.1), (4.2), or (4.3) may be used, together with the technique of least squares, to project future values of significant parameters.

4.2.2.3.1. Method of Least Squares.

This method of fitting a straight line, parabola, or higher degree polynomial to a given set of data specifies that the best fit for a polynomial of a given degree results when R, the sum of the squares of the residuals, is a minimum. It is assumed that values of x_i, the independent variable, are error free, and the residuals are defined as the distances between observed y_i's and the corresponding y values of the curve being fitted, measured parallel to the y-axis.

To determine the parameters (constants) of the desired polynomial a set of "normal" equations is derived by a squaring and minimizing process. If a polynomial of best fit of a given degree is to be found for a set of n data points, then

$$R = \sum_{i=1}^{i=n} (y-y_i)^2 = \text{minimum} \tag{4.4}$$

where $y = f(x) = a + bx + cx^2 + \ldots$

If f(x) is a straight line, y = a + bx. The ordinates of the straight line being fitted are a + bx, and the summation becomes

$$R = \sum_{i=1}^{i=n} [(a + bx_i) - y_i]^2 \tag{4.5}$$

Taking derivatives with respect to the parameters a and b, and setting the derivatives equal to zero yields:

$$\frac{dR}{da} = 2 \sum_{i=1}^{i=n} [(a + bx_i) - y_i] = 0 \qquad (4.6)$$

$$\frac{dR}{db} = 2 \sum_{i=1}^{i=n} x_i [(a + bx_i) - y_i] = 0 \qquad (4.7)$$

from which

$$\sum_{i=1}^{i=n} y_i = an + b \sum_{i=1}^{i=n} x_i \qquad (4.8)$$

$$\sum_{i=1}^{i=n} x_i y_i = a \sum_{i=1}^{i=n} x_i + b \sum_{i=1}^{i=n} (x_i)^2 \qquad (4.9)$$

Solution of these two simultaneous linear equations gives the values of a and b, parameters of the equation $y = a + bx$, the straight line that best fits the given data points by the criterion of least squares.

Before an exponential trend curve such as equation (4.3) can be used, it must be transformed into the straight line form

$$\log y = \log a + (b \log e)x, \qquad (4.10)$$

for which we can write $Y = A + BX$

in which
$Y = \log y,$
$A = \log a,$
$B = b \log e,$
$X = x$

If N is the number of points to be considered,

$$A = \frac{\Sigma Y}{N} - \frac{B \Sigma X}{N} \qquad (4.11)$$

$$B = \frac{N \Sigma (XY) - \Sigma X \Sigma Y}{N \Sigma (X^2) - (\Sigma X)^2} \qquad (4.12)$$

from which a and b are readily computed.

These calculations are readily performed using a computer.

4.2.2.3.2. Regression Analysis.

In regression analysis, an algebraic relationship between the dependent variable, y, and the independent variable, x, is sought, telling what y will be, on the average, for any specific value of x. For linear regression, this can be represented geometrically by a straight line. The formula for the maximum likelihood or least-squares estimator of the slope is

$$b = \frac{\Sigma (x - \bar{x})(y - \bar{y})}{\Sigma (x - \bar{x})^2} \qquad (4.13)$$

which may be written in the following form, more convenient for computations:

$$b = \frac{\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}} \qquad (4.14)$$

Once the estimated slope, b, is known, the estimated intercept, a, is easy to compute:

$$a = \bar{y} - b\bar{x} = \frac{\Sigma y}{n} - \frac{b \Sigma x}{n} \qquad (4.15)$$

4.2.2.4 Trend Curves.

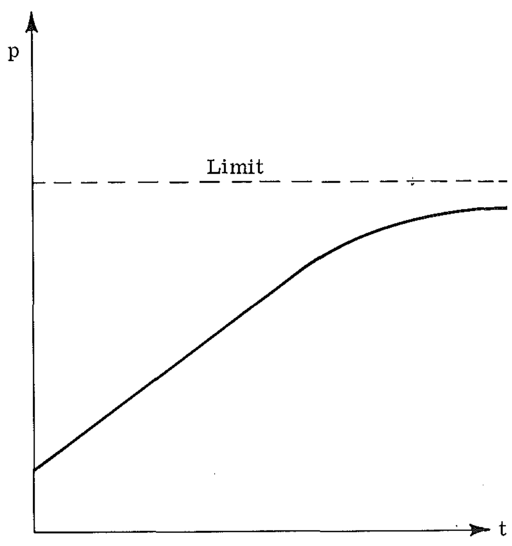


Figure 4.6. Linear Increase with Flattening

Several types of trend curves which describe a relationship between a parameter p and time t have been presented by Jantsch (Ref 90).

a. Linear increase with flattening (Figure 4.6). The efficiency of thermal power plants exhibits these characteristics. The mechanization of human work as expressed in terms of decrease in annual working hours per man has been linear over the past 75 years.

b. Exponential increase with no limit in the considered time frame (Figure 4.7). These characteristics are exhibited by a number of functional capabilities; for example, maximum combat aircraft speed, or maximum transport aircraft speed (up to the planned operational capability of the

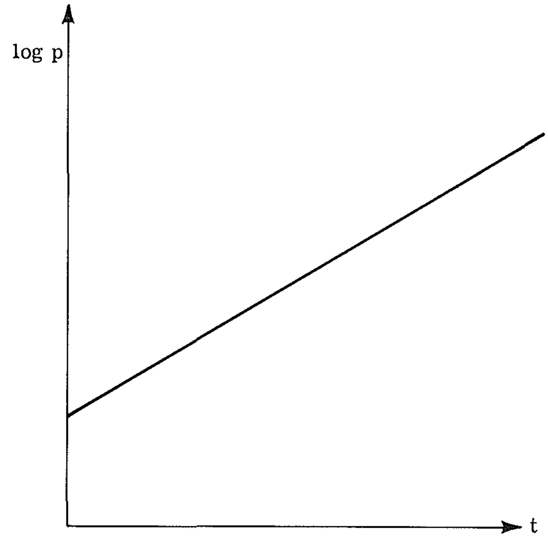


Figure 4.7. Exponential Increase

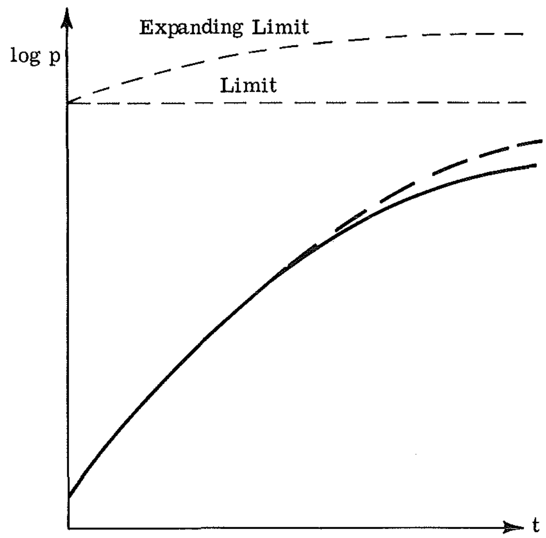


Figure 4.8. S-Shaped Curve

SST). The almost precisely exponential increase of energy conversion efficiency (lumens per watt) in illumination technology from the paraffin candle to the gallium arsenide diode (Paragraph 4.2.2.2) seems to suggest that a functional capability can follow such a trend until it abruptly hits a limit — the gallium arsenide diode's efficiency is close to one.

c. S-shaped curve (Figure 4.8), the normal characteristic of specific maturing technologies. (See Paragraphs 4.2.2.4.2 and 4.2.2.4.3 for discussion of the Pearl and Gompertz equations, respectively.)

d. Double-exponential or even steeper increase, with subsequent flattening (Figure 4.9). These characteristics hold for some functional capabilities in areas of concentrated research and development; examples are maximum speed attained by man and operating energy in particle accelerators. It is interesting to note that, according to Ref 87, operating speed of commercial computers would belong to this class, whereas, according to Ref 32, the ratio of computer capacity to add time would, up to the present, be characterized by an exponential growth of class (b), above. (This ratio may be regarded as a "figure of merit" of overall computer development progress, whereas operating speed singles out one of the important parameters only.)

e. Slow exponential increase followed by sudden much more rapid increase, with eventual flattening (Figure 4.10). This type of curve applies, according to Ref 32, to the maximum explosive power available for delivery at a distance. The very steep rise is, of course, mainly due to the advent of nuclear fission and fusion weapons, but it already began in World War II with the conventional 10-ton "blockbuster."

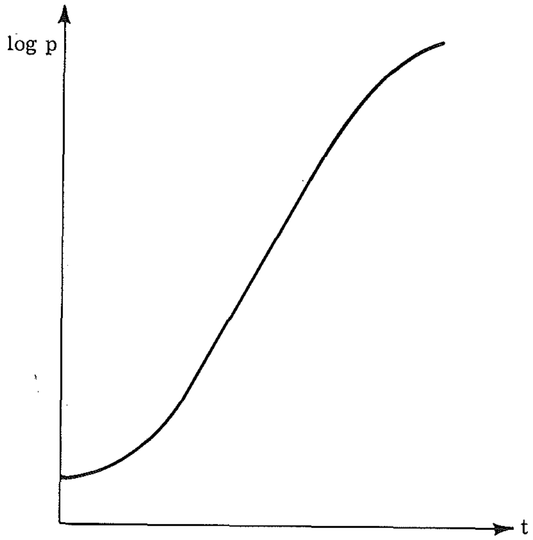


Figure 4. 9. Double-Exponential Curve

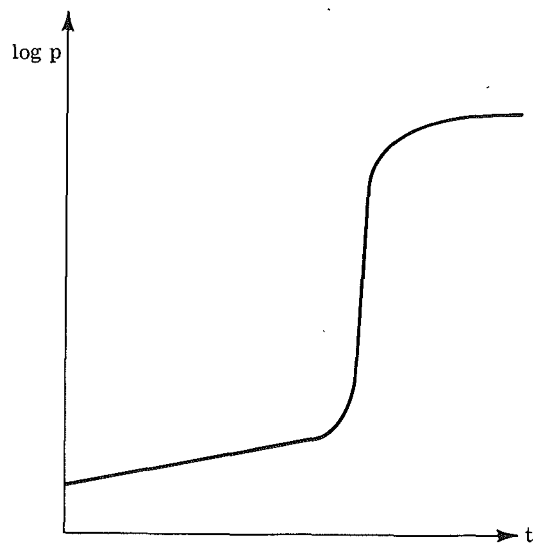


Figure 4. 10. Slow Exponential Curve

The flattening of the curve is caused by the effective limit of utility at approximately 100 megatons rather than by technical limitations.

4.2.2.4.1. Pearl's Formula.

Pearl's work on the analogy of population increase to the growth of biological organisms has been cited by writers in the field of population forecasting, economic forecasting, and technical forecasting (Ref 95). Pearl's thesis is that the increase of population in a given area follows a pattern similar to the increase of biological cells confined within limits and cites several examples.

Each of Pearl's examples follows the same simple mathematical law, which, applied to the generation of new information, would read:

$$I = \frac{L}{1 + ae^{-bt}} \qquad (4.16)$$

where I = Accumulated information (state of knowledge) at time

L = Upper limit of information (due to constraints)

t = Time

a = Constant, dimensionless

b = Constant, per time unit

e = Basis of the natural logarithmic system*

* e = 2.71828 . . . In a logarithmic plot the difference between the generally used decadic system (log) and the natural system (ln) is only one of scaling, i.e., ln x = 2.30. . . log x, but differentiation and integration processes involve the natural logarithmic system and its base e.

As Jantsch indicates (Ref 90), this simple mathematical formulation would be an ideal tool for quantitative trend forecasts if it can be proven that it holds for practical cases. The resulting curve is symmetrical in relation to an inflection point, and between the limits $I = 0$ (at $t = -\infty$) and $I = L$ (at $t = +\infty$). By setting the second derivative $d^2I/dt^2 = 0$ it can readily be shown that the inflection point occurs at $t = (\ln a)/b$ and that the accumulated information at that point is always half the ultimate limit: $I = L/2$.

The constant a fixes the position of the curve in the time dimension (a difference in a means shifting the curve to the right or to the left). The constant b fixes the slope of the curve.

The value of I at a given time in the past or at present is known empirically. If the upper limit L can be determined through basic considerations, the constant a can be fixed: $A = L/I_0 - 1$, with I_0 denoting I at time $t = 0$. The constant b can be determined either from the known or estimated tangent dI/dt at the time $t = 0$:

$$b = \frac{(1 - a)^2}{a} \quad \frac{dI}{dt} \qquad (4.17)$$

where $t = 0$,

or from the known or estimated doubling time $t_{1/2}$:

$$b = \frac{1}{t_{1/2}} \ln \frac{2a}{a - 1} \qquad (4.18)$$

Equation (4.18) holds only as long as the inflection point has not yet been reached (at that point the value of I is already L/2; it cannot double after the inflection point). If the inflection point is already covered by the empirical or estimated portion of the curve, b can be simply determined from the time t_i at which inflection occurs:

$$b = \frac{\ln a}{t_i} \qquad (4.19)$$

Thus, with the knowledge of an ultimate limit, the complete curve can be extrapolated on the basis of a very short time-series. The critical point is, of course, to know which scientific, technical, and functional parameters, if any, can be expected to follow that simple law precisely.

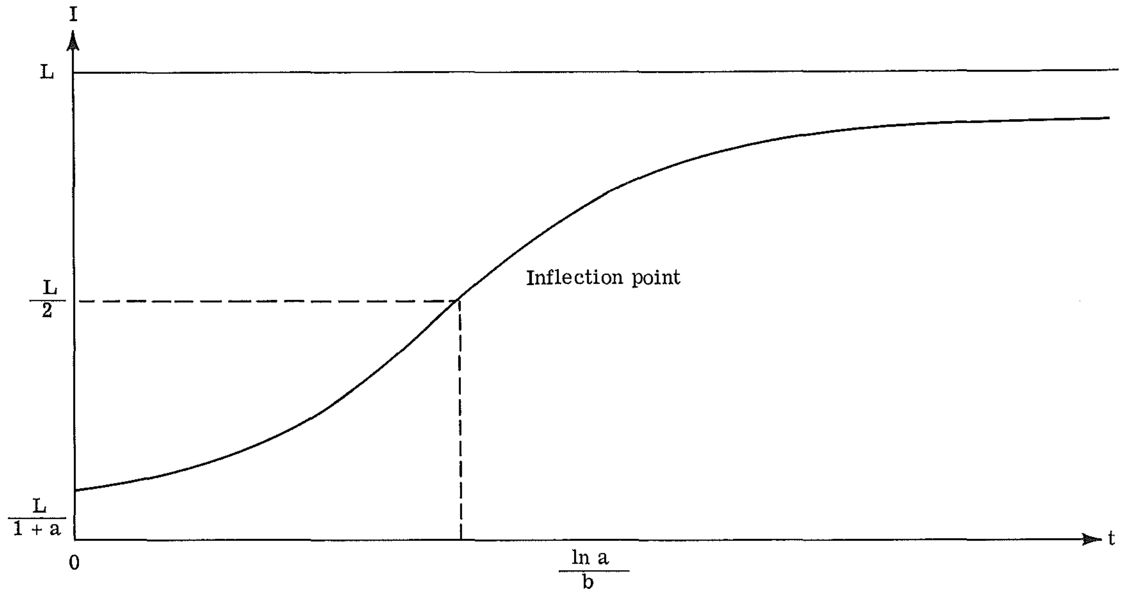


Figure 4.11. Pearl's Formula (Source: Jantsch)

4.2.2.4.2. Gompertz' Law.

It may be noted that, in addition to the logistic growth according to equation (4.16), one may also find S-shaped growth curves which can be better fitted to Gompertz' law, which describes growth phenomena in some areas of economics, income growth, for example. Its mathematical expression is:

$$P = L^{e^{be^{kt}}} \qquad (4.20)$$

where P = Growth phenomena
L = Limit (in the same units as the parameter P)
b, k = Constants
t = Time

In contrast to equation (4.16), Gompertz' equation (4.20) represents a nonsymmetrical S curve, with a value of $P = L/e$ at the inflection point at $t = (\ln b)/k$. However, like equation (4.16), this S curve also approaches the extreme values zero and L at t minus and plus infinity; at t - 0 the curve has the value $P - L/e^b$.

4.2.3. Trend Correlation Analysis.

As Lenz has pointed out (Ref 95), the trend of a technical parameter which is complex and difficult to predict by itself may be more easily expressed as a result of a relationship between two or more related trends. Whereas time-dependent trend extrapolation attempts explicit forecasting, interrelationships between parameters can be explored on a much more general level if they do not have to fit into an explicit time frame. Nevertheless, they may represent extrapolations of reality beyond present capability or estimates, in the instance of future technologies.

In order to use two or more trends to determine a third, the predictor must have available a number of primary trends which are related to the technical field of interest. To these he must add a knowledge of probable relationships that might arise from combinations of such variables. The predictor can then select the relationship and the primary variables which influence the desired technical improvement. The trends of the primary variables may be projected on the basis of any techniques which appear appropriate. The prediction is then completed by projection of the unknown variable on the basis of the relationship between the primary variables.

Trend correlation analysis bases a forecast on the relationship of demand to one or more independent variables, expressed in terms of a regression equation. If consistent correlations can be found, the method offers an objective approach to forecasting. It requires the forecaster to consider the major factors influencing the pacing parameters and to express his assumptions in measurable terms.

On the other hand, truly independent variables may be difficult to identify. The relationships between the dependent and independent variables are assumed to be constant in the future; a significant amount of past data is required in formulating even a simple regression equation. If more than one or two independent variables are used, the mathematics become complex and may require the use of a computer. While it is true that increasing the independent variables in the regression equation may increase the closeness of correlation, many forecasters argue that the resulting extra refinement usually is not needed to get adequate results. Often simple graphical correlations are adequate.

4.2.3.1. Precursor Events.

Forecasting by analysis of precursor events uses the correlation of progress trends between two developments, one of which is leading the other. Lenz (Ref 95) has stated that if the time lag is sufficiently long, a useful long-range forecast is possible. He provided an example of a sequential relationship in the correlation of the maximum speed of military aircraft to the maximum speed of commercial aircraft. As shown in Figure 4.12, the speed of commercial aircraft has consistently followed the speed of military aircraft, with the time lag increasing from six years in the 1920's to eleven years in the 1950's.

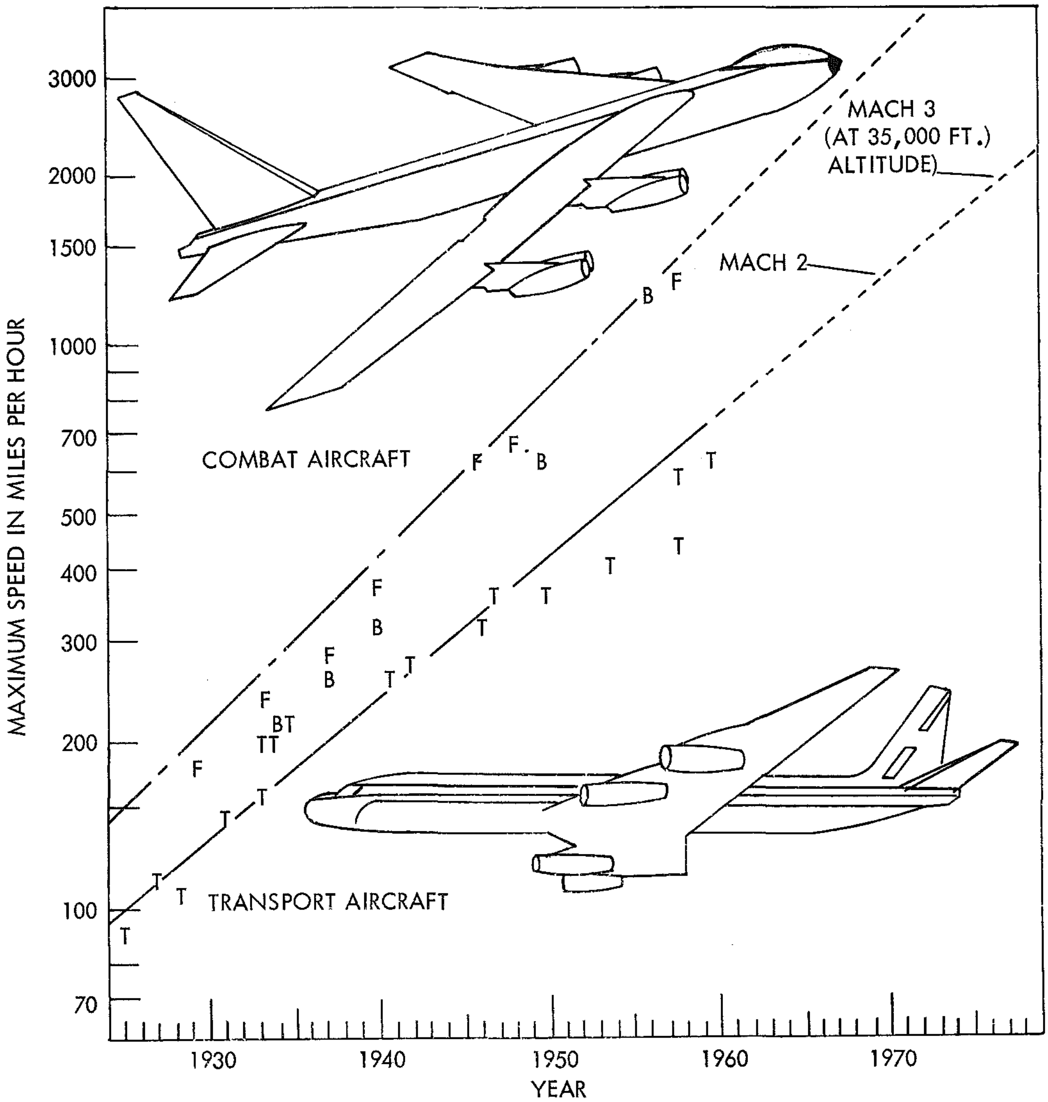


Figure 4. 12. Comparative Speed Trends of Combat and Transport Aircraft (Source: Lenz)

This approach is useful, of course, only insofar as the leader-follower relationship is maintained. Jantsch (Ref 90) notes that the relationship cited in Figure 4. 12 is being overtaken by events in that civilian transport aircraft is now, for the first time, receiving massive support from governments (i. e., SST developments).

4.2.3.2. Correlation Analysis.

Correlation covers problems dealing with the relationships between two or more variables, specifically, the degree of a certain special type of relationship among them. In practical problems, though, it is often more important to find out what the relationship actually is, in order to estimate or predict one variable (the dependent variable) from knowledge of another variable (the independent variable). The statistical technique appropriate to such a case is called regression analysis. When consistent correlations can be found, this method offers an objective approach to forecasting.

When more than two variables are involved, we have multiple correlation. Any number of "causal" factors can be handled by multiple correlation, as long as there are more observations than factors. While the procedure cannot be described graphically for more than two causal factors, or independent variables, the formulas and ideas are essentially the same. It is desirable that all factors be employed which have a bearing on the outcome and that any relationships among two or more which are known a priori be defined in advance.

Again, it is possible that the relations are not linear; the data may scatter appreciably about a best-fit straight line. A guiding principle in forecasting studies is to use the simplest shape that is consistent with the available information. When it is appropriate, curvilinear relations can be fitted by the method of least squares.

4.2.3.2.1. Correlation Coefficient.

The correlation coefficient, denoted by r, may be regarded as the ratio of two standard deviations. The numerator s_{y_c}, is the standard deviation of the calculated values, y_c, corresponding with the values of x in the sample. The numerator, therefore is what the standard deviation of y would be if all the observations were exactly on the line. The denominator is s_y, the standard deviation of the observed values of y in the sample. The correlation coefficient is considered positive or negative according to whether b, the slope of the regression line, is positive or negative. Ordinarily, r is computed from the formula

$$r = \frac{\Sigma (x - \bar{x})\ (y - \bar{y})}{\sqrt{\Sigma (x-\bar{x})^2 \ \ \Sigma (y-\bar{y})^2}} = \frac{\Sigma\, xy}{\sqrt{\Sigma\, x^2 \ \ \Sigma\, y^2}} \qquad (4.21)$$

The correlation coefficient ranges in value from +1.0, which indicates perfect correlation between the two variables, to -1.0, which indicates a perfect inverse relationship. An r of 0.0 indicates no relationship between the variables, that is, neither variable explains much of the variation in the other.

4.2.4. Analogy.

According to Lenz (Ref 95), attempts to develop a theory explaining why technical progress should proceed in an exponential manner date back at least as far as 1907, when a theory was advanced by Henry Adams comparing the acceleration of progress with the effect of a new mass, introduced into a system of forces previously in equilibrium, which is induced to accelerate its motion until a new equilibrium is established. The accumulated information would be seen as analogous to the distance traveled by the new mass, the rate of information gain as analogous to the speed, and the second derivative of information over time as analogous to an acceleration (assumed constant).

4.2.4.1. Growth Analogy.

Pearl's work on the analogy of population increase to the growth of biological organisms has been cited in Paragraph 4.2.2.4.1, above. To support his thesis, Pearl examined the rate of increase of fruit flies within a bottle, the rate of increase of yeast cells in a given environment, and the rate of cell increase within white rats.

De Solla Price (Ref 58) includes technological forecasting within the larger framework of all growth phenomena in science, including the number of scientists, scientific papers, etc. This analogy has some merit in that it normally gives a symmetrical curve without further assumptions. He also examines the growth of length of a beanstalk over time. Ayres (Ref 32) proposes autocatalytic chemical processes as a model.

Hartman derives his model (discussed by Jantsch in Ref 90) from a simple analogy with reaction processes in a gas. From Hartman's "gas," the molecules are scientists and pieces of information, both occurring at a given volume density. The scientist "molecules" do not move significantly, whereas the information "molecules" move with assumed constant velocity in random directions. A useful reaction (i.e., the generation of new information) is supposed to occur when the scientist "molecules" have a "reaction cross section" on being hit by the information "molecules." Hartman's formula for information gain is identical to that of equation (4.16). In criticizing Hartman's model, it is to be noted that his basic assumption that information gain is proportional to the amount of existing information ($dI/dt=kI$) holds only where (a) ideal communication between all investigators and all sources of information can be assumed and (b) every opportunity presented by this communication can in fact be exploited. The model may be a useful approach to research and development in a specific field or within a small or medium-sized research group.

For many technologies, a useful analogy can be drawn with biological growth. Growth equations can be used to estimate the degree of maturity of a technology in order to approximate the probable rate of growth and time to leveling off. Lenz[2] has given the following example of such an application:

1. Paper presented at First Annual Technology and Management Conference at Lake Placid, N. Y., 22-25 May 1967.

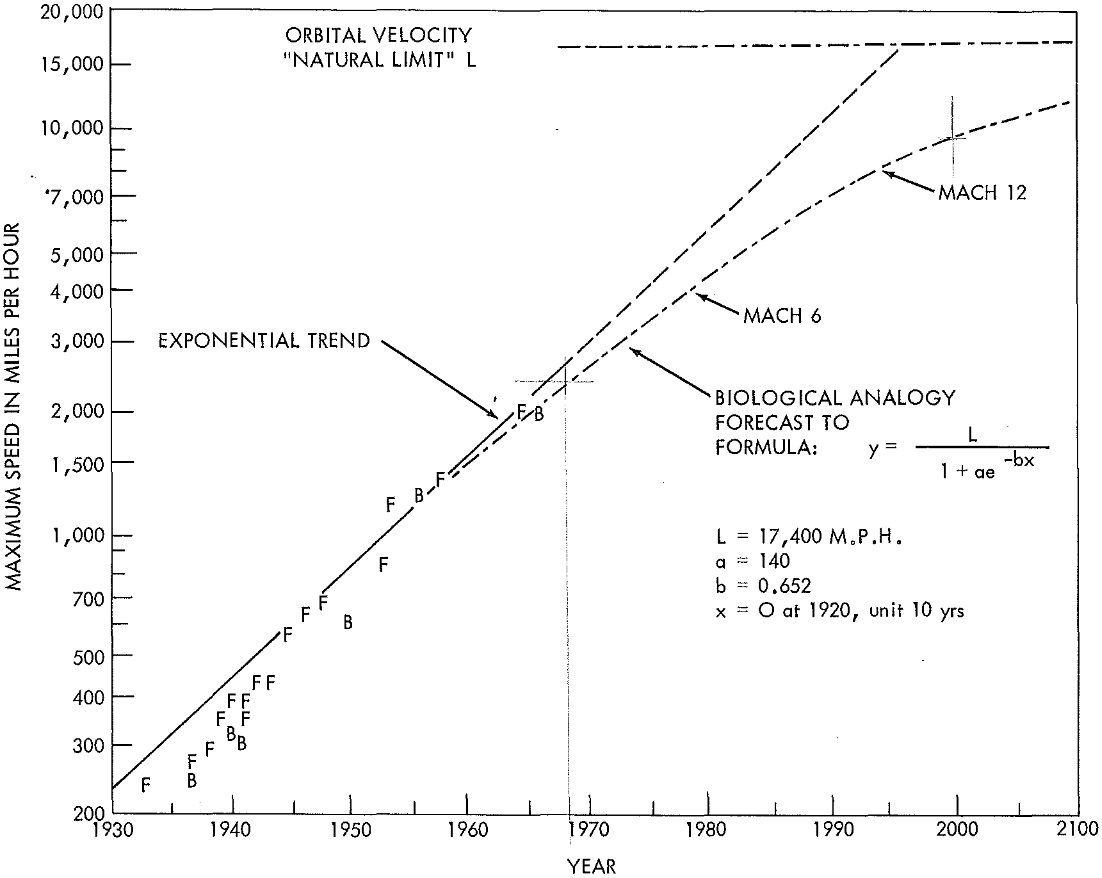


Figure 4.13. Speed Trends of U. S. Aircraft

". . . we may look at aircraft speed trends for an application of the biological analogy. To provide a comparison of the exponential trend method with the biological analogy, both are shown in Figure 4.13. The fixed growth limit is chosen as the speed representing orbital velocity at 100 miles altitude. This may be assumed to be the point at which spacecraft become fully çompetitive with aircraft, or alternatively, the point beyond which the vehicles cease to be aircraft. As shown, application of Pearl's formula results in an extrapolation asymptotic to this limit. According to this forecast, Mach 6 performance would not be expected until 1979. Mach 12 performance would not be achieved until 1995, ten years later than predicted by the exponential trend."

4.2.4.2. Historical Analogy.

To study the impact of a new technology on functional capability it may be desirable to consider what lessons history may have for us. For example, the General Electric Company (TEMPO)[2] could make a forecast of the relative contributions to the energy input to the United States to be made by various sources in the decades out to 2060, in which it estimates the contributions to electricity to be made by nuclear fuels, using the same type of growth curves which it observed for fossil fuels and hydroelectric power in the period 1800-1960.

4.2.5. Predictive Models.

Models are the mechanisms by which predictions of the performance of a process or system can be made. Generally, the scientist attempts to duplicate in some kind of model the behavior of the parameters, subsystem, or system with which he is working. Once he has achieved this parallelism between the real world situation and his model, he can manipulate the model to study the characteristics in which he is interested.

Models provide some of the most effective means yet developed for predicting performance. Indeed, it is hard to conceive of a prediction system which is not finally a model. To construct a model of a real process or system, careful consideration of just which elements of the system need to be abstracted is required. This in itself is usually a profitable activity, for it develops insights into the problem.

The following definitions were developed by Abt Associates (Ref 30):

a. Models are representations of processes describing in simplified form some aspects of the real world; in the case of technological forecasting, they attempt to include as many nontechnological factors as appears feasible.

b. Simulation is the operation of a model by manipulations of its elements with a computer, a human player, or both.

c. Gaming (game technique for simulation purposes) is a special type of model building, structured so as to permit multiple simultaneous interactions among competing and cooperating players. If a computer is used, the system can be manipulated and the effects analyzed by an observer.

In forecasting developments involving a complex system, it is often convenient to construct a model of it. If the model involves a representation by

2. "Energy Input to the United States, 1800-2060: History and Forecast," J. C. Fisher, Report 66 TMP-26, General Electric Company, Santa Barbara, California, 1966.

mathematical equations, it is called a mathematical model, but it is not essential that the model be a mathematical one.

Helmer (Ref 82) suggests the use of models in the development of methodology for use in the social sciences. His comments on models are appropriate to technological forecasting:

> "The purpose in constructing a model of a given situation is to single out certain elements as being relevant to the problem under consideration, to make explicit certain functional relationships among these elements, and to formulate hypotheses regarding the nature of these relationships. (It is these functional relations which are often most conveniently expressed in mathematical form.)
>
> "A characteristic feature in the construction of a model is abstraction: certain elements of the situation may be deliberately omitted because they are judged irrelevent, and the resulting simplification in the description of the situation may be helpful in analyzing and understanding it. In addition to abstraction, model building sometimes involves a conceptual transference. Instead of describing the situation directly, it may be the case that each element making up the real situation is simulated by a mathematical or physical object, and its relevant properties and relations to other elements are mirrored by corresponding simulative properties and relations. A model involving such transference, in addition to abstraction, is called a simulation model.
>
> "When an operations analyst constructs a model, simulative or not, he usually does so because his purpose is to determine the most appropriate action to take in the face of a given situation. (His function is to give operational advice.) Often he may find himself at the frontier of the state of the art, and he may have to rely heavily on whatever expert judgment may be available, rather than on a solid (nonexistent) theory. His model, therefore, is apt to be ad hoc, tentative (i. e., subject to modification and improvement), future directed and policy oriented. Frequently the reliability of such a model may leave much to be desired; yet its justification should derive from the fact that recommended actions based on it have a good chance of being more appropriate than actions selected without use of the model.
>
> "In recommending, as we do, that the social scientists divert some of their effort from the pursuit of pure science to problems of craftsmanship in social technology, we are implying among other things the deliberate and systematic use of models of the operations-analytical type, including in particular both mathematical models and simulation models . . .
>
> "The advantage of employing a model lies in forcing the analyst to make explicit what elements of a situation he is taking into consideration and in imposing upon him the discipline of clarifying the concepts he is

using. The model thus serves the important purpose of establishing unambiguous intersubjective communication about the subject matter at hand. Whatever intrinsic uncertainties may becloud the area of investigation, they are thus less likely to be further compounded by uncertainties due to disparate subjective interpretations.

"It should be pointed out in this connection that frequently the use of numerical parameters, and thus of a mathematical model, is an expedient device for conceptual clarification. Precise numbers, it may be objected, are an inappropriately rigid means of rendering concepts which are of necessity vague and possibly full of implied but unarticulated meaning. Yet consider, for example, the case where a political forecaster is questioned as to whether President Johnson will be reelected in 1968. He may feel more comfortable replying 'very probably' rather than with '80 percent probability'; but the questioner might well prefer having him express the degree of his uncertainty by adding 'plus or minus 10 percent' to the numerical probability statement rather than to have the onus of having to interpret 'very probably' according to his own subjective assessment of what that phrase may mean.

"A type of model, referred to before, which should prove of special importance in the area of social technology is the simulation model. Here, instead of formulating hypotheses and predictions directly about the real world, it is possible to make such statements about the simulative entities of the model. Any results obtained from an analysis of the model, to the extent that it truly simulates the real world, can then later be translated back into the corresponding statements about the latter. This injection of a (simulation) model has the advantage that it admits of what may be called 'pseudo-experimentation' ('pseudo' because the experiments are carried out in the model, not in reality). . . Pseudo-experimentation is nothing but the systematic use of the classical idea of a hypothetical experiment; it is applied when true experimentation is too costly or physically or morally impossible or . . . when the real-world situation is too complex to be analyzed directly. Since actual social experimentation is almost always a virtual impossibility, pseudo-experimentation in a simulative model world is evidently a substitute worth examining.

"Among the simulation models, incidentally, are a number of different varieties. There are paper-and-pencil models, usually involving sets of mathematical equations. These can be analyzed by standard mathematical techniques, or, if their complexity precludes this, their implications can be explored with electronic computers for any number of input parameter values. Then there are physical simulation models such as might be used, say, in the study of urban redevelopment, where the projected stages of transformation of a city may be displayed with the aid of a miniature mock-up.

"A particularly useful kind of physical simulation is that of operational gaming . . . It involves role-playing by human subjects in a laboratory situation in which the participants simulate real-world decision-makers in a conflict-of-interest context."

Gaming has been used in forecasting the possible impact of new or future technologies, mainly for studying the implications for the future of combinations of specific technological and strategic concepts, from the viewpoint of both one's own forces and those of the enemy. With forecasting assuming ever-increasing importance, gaming, using appropriate constraints on the moves of both players, may become a valuable technique for the evaluation of alternative technological developments.

Dynamic forecasting makes use of a rigid computer model to predict technological progress. Based on the technique of "Industrial Dynamics," developed by J. W. Forrester, it was utilized by Lenz (Ref 95) to denote the modeling of all significant cause-effect relationships which influence the growth of a functional capability or of technology in general, but it may be extended to include technology transfer in general.

Technological progress is defined in terms of a mathematical expression of the influence of those factors over which control may be exercised. These factors could include the number of people trained for a given research and development function, the number of people employed to perform that function, and the facilities provided for experiment. The effects of each factor, and the feedback relationships, are combined in equations which provide a prediction of the technological progress to be obtained from a given input of the factors involved. The greatest difficulty in this method is the determination of the transfer coefficients which relate quantities of the input factors to the quantities in which technological progress is measured. In most cases, the transfer coefficients will necessarily be based on the empirical relationship that has existed in the past between the input and output factors.

4.3. Discussion of Forecasting Aids.

The previous discussion in Paragraph 4.2 has concerned itself predominantly with forecasting of preselected overall performance parameters, which have been chosen as representative of the advance in a particular area. In more complex cases, where many technologies are interacting with each other and with the forces of economics, politics, and society, this approach may be an oversimplification. In these cases, attention must first be directed toward a search strategy which asks the questions: "What should be forecast?" and "Where is there going to be exploitable change?" Swager (Ref 137) has stated that these demanding questions imply there must be a search. There must be identification before there can be assessment. He further states:

"Decision theorists such as Simon, investigating heuristic problem solving, are pressing into service such terms as 'perception relationships, order and notation, redefinition, and perspective.' For them 'perception' means the 'identification of alternatives,' and 'relationships' means 'the placement of alternatives in a structure formed by the logical ties among them.' "

The following subparagraphs describe several methods which can be used to structure available information and thereby find a more systematic search pattern and appraisal routine.

4.3.1. Matrices.

The matrix approach has been widely used as a simple means of indicating the relevance of areas of research and/or technology to possible applications. The Materials Advisory Board of the U. S. National Academy of Sciences—National Research Council has used a two-dimensional one-step matrix which assesses the relationship between areas of materials research and missions. Cetron (Ref 50) has proposed the use of a two-step matrix approach for optimizing military research funding allocation. The matrices assess research vs technology and technology vs missions.

4.3.2. Contextual Mapping.

Many technical parameters can be related to one another beyond the current state of the art, either through extrapolation or through logical analysis of causal relationships. Combining parameters in such a way that dimensionless groups are compared may have a considerable potential use in forecasting. Contextual mapping in this sense was employed by the RAND Corporation in the late 1940's.

Technical and operational parameters can be related to each other in many ways. Value analysis can be applied to the development of new systems and, even more effectively, to the improvement of known technologies. The easily derived break-even point for the costs of an improvement in a system — for example, the higher price that can be paid per kilowatt for an improvement of one percent in the efficiency of a power plant — can guide the direction and level of effort in development projects.

Parameter-dependent trends as well as trends depicted as processes or evolutions can, of course, be put into a broad time frame. Their important feature, however, is the explicit recognition of causal relationships apart from the effect of time, and the simple possibility of conditional forecasting. Future developments which depend on the simultaneous progress of a number of parameters or capabilities, or on certain environmental (economic or other) conditions, can be forecast explicitly — for a given set of conditions — where it would be difficult to forecast with any reasonable probability time-dependent progress for all parameters involved.

It becomes clear that time-independent contextual mapping is of greatest importance where exploratory forecasting is employed to prepare a basis of potential system concepts which will be matched against operational objectives. If emphasis in operational planning includes the power of supporting the development of chosen system concepts, the task of exploratory forecasting can shift from the prediction of the future to the mapping of possibilities, relationships, and conditions.

Technological forecasting for the U. S. Air Force, from the Von Karman report "Toward New Horizons" (1946) through the different major efforts up to "Project Forecast" (1963), have systematically used contextual mapping by observing combinations of current and possible future technologies in expected future environments. This approach became a most valuable tool in defining new missions and in conceiving future complex weapon systems.

A way to communicate the relationship of events without risking a precise time prediction is to describe and depict the process involved in the quest for technological results. Figure 4. 14 is an example of expressing trend as process in the acquisition and application of knowledge. High-vacuum technology is shown as progressing over the decades by innovations and adaptations arising from various other technologies. This figure could be elaborated in great detail without loss of its communications value, especially if groups of blocks are color coded (e. g., inputs, devices, outputs, applications) and if the process arrows are coded for various meanings (e. g., A begat B, A merged into B, etc.). The logic implied by blocks related by arrows so coded could be conjectured inputs and impacts of potential future technologies. For the system planner, blocks could be tapped off at different points in the process; showing the effects on such things as feasibility of small fusion reactors, weight reduction in space vehicle structures, and high-performance cold electron tubes.

Large technology-based military systems evolve over years. The trend in their configuration is rooted in the past and it helps the producer of the forecast as well as the user of the forecast to visualize the evolution. The forecaster is forced to see the big picture when adding novel detail, and the user gains a sober impression of the inertia inherent in growth and change. Figure 4. 15 shows such a trend as evolution in the configuration of a system. The subject is the ground environment of air defense nets and the pictorial is quite schematic — almost like the budding pattern of organic growth. Directions of systems growth which were abandoned or are expected to flourish temporarily are depicted as buds that stop reproducing. The size and interfaces of buds can be used to imply the strength and sources of growth increments.

Sometimes the operational objectives of technology can be identified and expressed fairly easily. When this is the case, the progress expected of technology can be illustrated as partial fulfillment of these objectives.

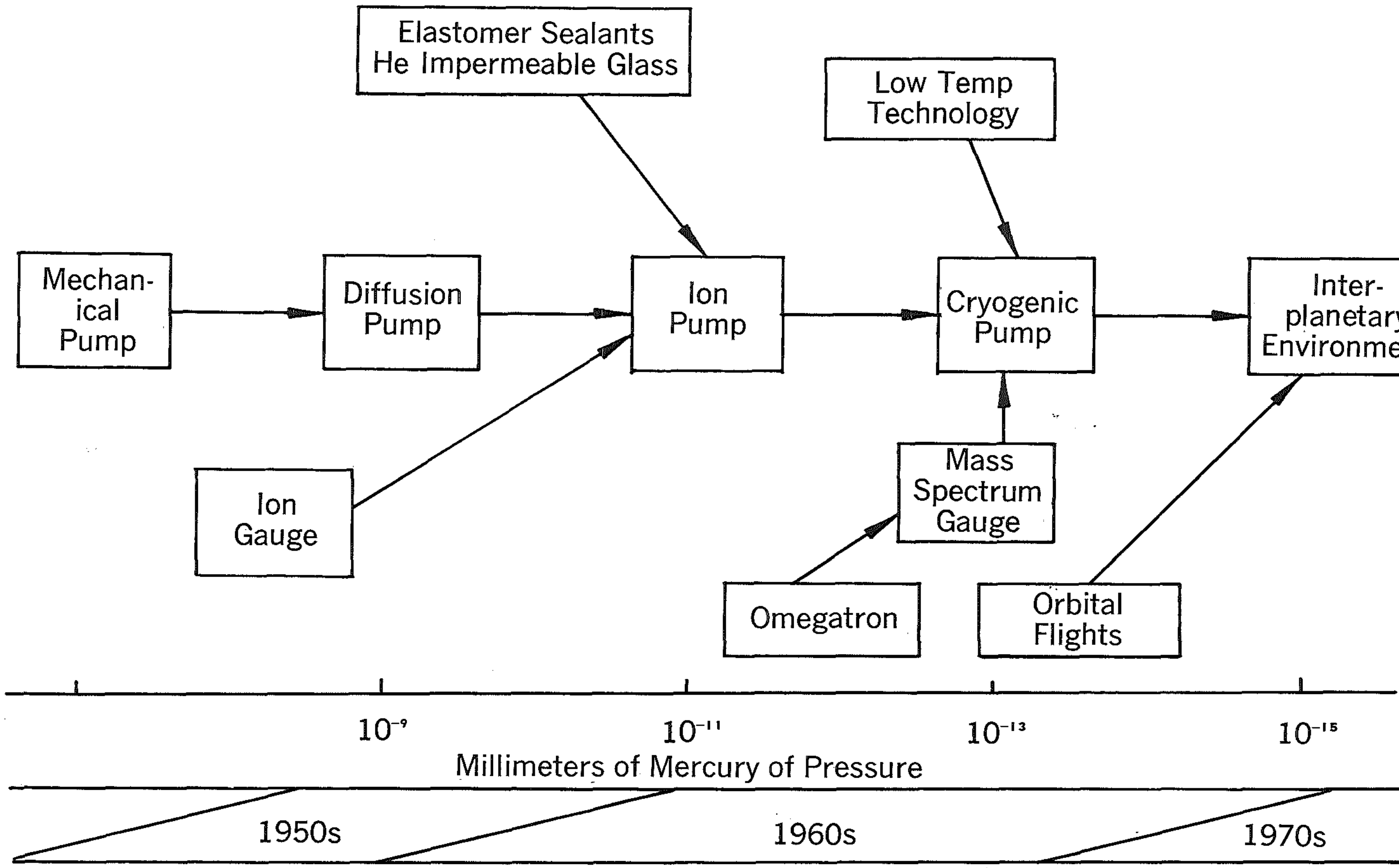


Figure 4.14. Trend Expressed as Process
(Example: High-Vacuum Technology)

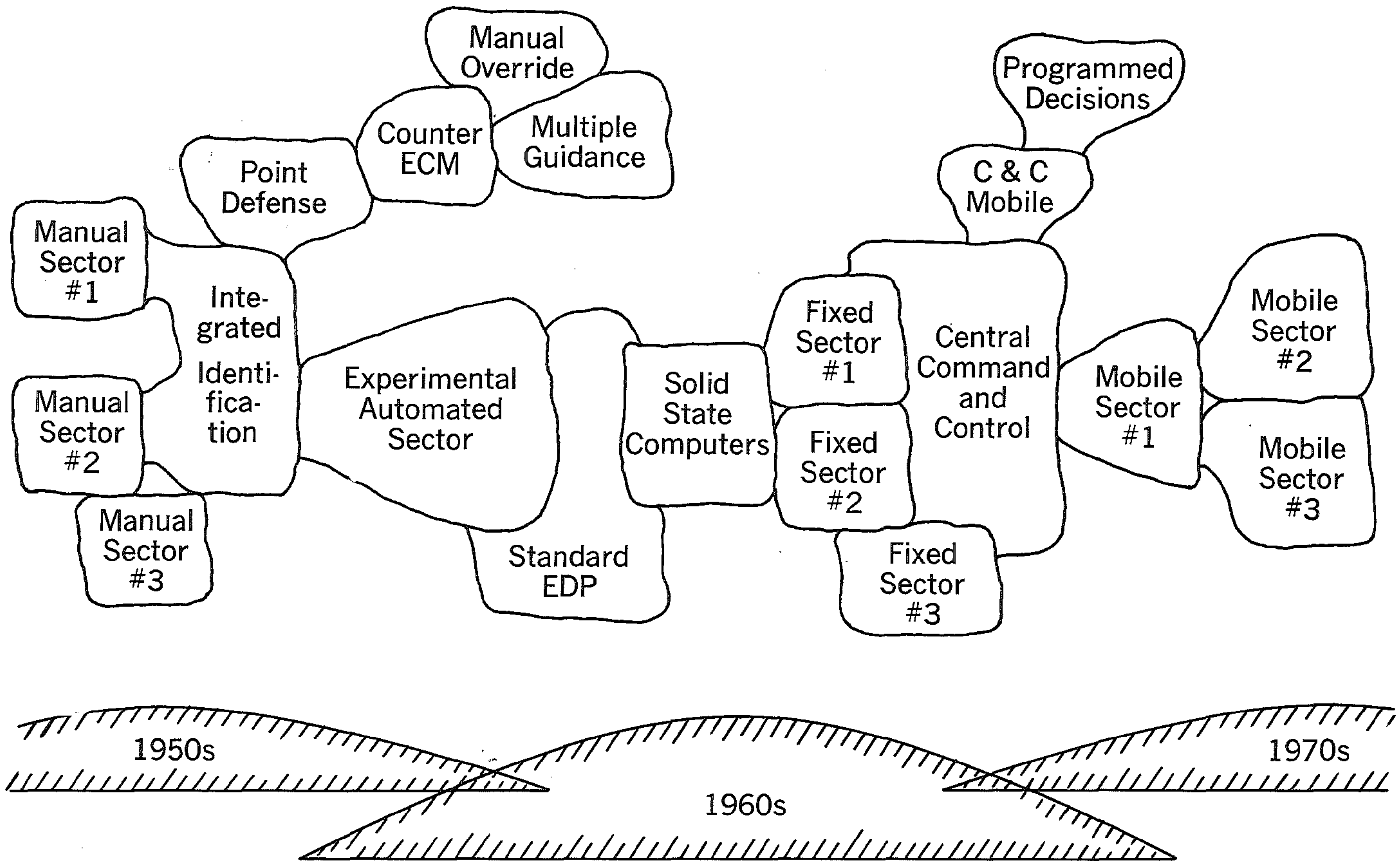


Figure 4.15. Trend Expressed as Evolution
(Example: Air Defense Ground Environment)

When trend is expressed as partial progress, the end point should make technical and operational sense. If the goal is merely the completion of a project or program, the time-wise progress graph may make good reporting data for programmers and budgeteers but not for forecasters and planners. The completion of a project may be essential to the success of a larger program, but the planner could hardly care less if such a project is twenty or ninety percent complete. Expected results are what he needs to know. (Of course, it would be a matter of concern if the cost of the program is not commensurate with results in terms of the technical/operational goal.) Not all technical programs are easily defined in terms of objectives. However, with some thoughtful and analytical attention, it is likely that many technical programs can be converted from "percent progress" or "percent budget spent" to presentations of substantive goal fulfillment. To do this, of course, requires the identification of the goal and its description in parameters directly relatable to the performance parameters of the end products of the technical program, which can be a painful exercise.

4.3.3. Morphological Analysis.

The following discussion is based on Jantsch's (Ref 90) excellent summary of the promising morphological research method developed by Zwicky.

The morphological approach provides a method of systematically exploring all opportunities at the technological levels, primarily at the level of functional technological systems, but also at the lower levels of technologies, technological resources, and even scientific resources. A systems planner normally selects from items generated in exploratory forecasting. It should be noted, moreover, that these techniques represent merely structuring devices and depend upon the input from the information-generating techniques.

According to Zwicky (Ref 161), there are three types of generic problems which morphological analysis attempts to solve. For our purposes in forecasting methodology, they may be described as:

"a. Which mission objective can be met if a given class of systems concepts is realized? Or, what system concepts are necessary to realize certain mission objectives?

"b. What potential can be realized from a given development?

"c. Outline all the solutions to a given problem."

Jantsch summarizes the step-wise solutions to a generic problem of the latter type as follows:

"a. An exact statement is made of the problem that is to be solved. For instance, we may wish to study the morphological character of all modes of motion, or of all possible propulsive power plants, telescopes, pumps, communication or detection devices, and so on. If one specific device, method, or system is asked for, the method immediately generalizes the inquiry to all possible devices, methods, or systems which provide the answer to a more generalized request. The task of formulating the initial statement or definition of the problem on hand is exacting. Zwicky affirms that "one is hard put to find in the existing literature satisfactory definitions even of well-known devices like pumps, stationary power plants, telescopes, and so on.

"b. The exact statement of the problem to be solved, or the precise definition of the class of subsystems or components to be studied, will reveal automatically the important characteristic parameters on which the solution of the problem depends. For instance, in the case of telescopes, some of these parameters are the location of the telescope (medium in which it is embedded), the nature of the aperture A and the recording device R, the nature of the changes to which the light is subjected from A to R, the motion of the telescope, the sequence of operations, etc. The second step thus involves the study of all of these significant parameters.

"c. Each parameter p_i will be found to possess a number of k_i different independent irreducible values p_i1, p_i2. . . . . . . It is essential that up to this point no questions be asked as to what value one or the other solution may have; such premature curiosity almost always defeats the unbiased application of the morphological method. Once all the solutions are found, however, one must know their relation to any given set of adopted performance values.

"d. The performance values of all the derived solutions are determined.

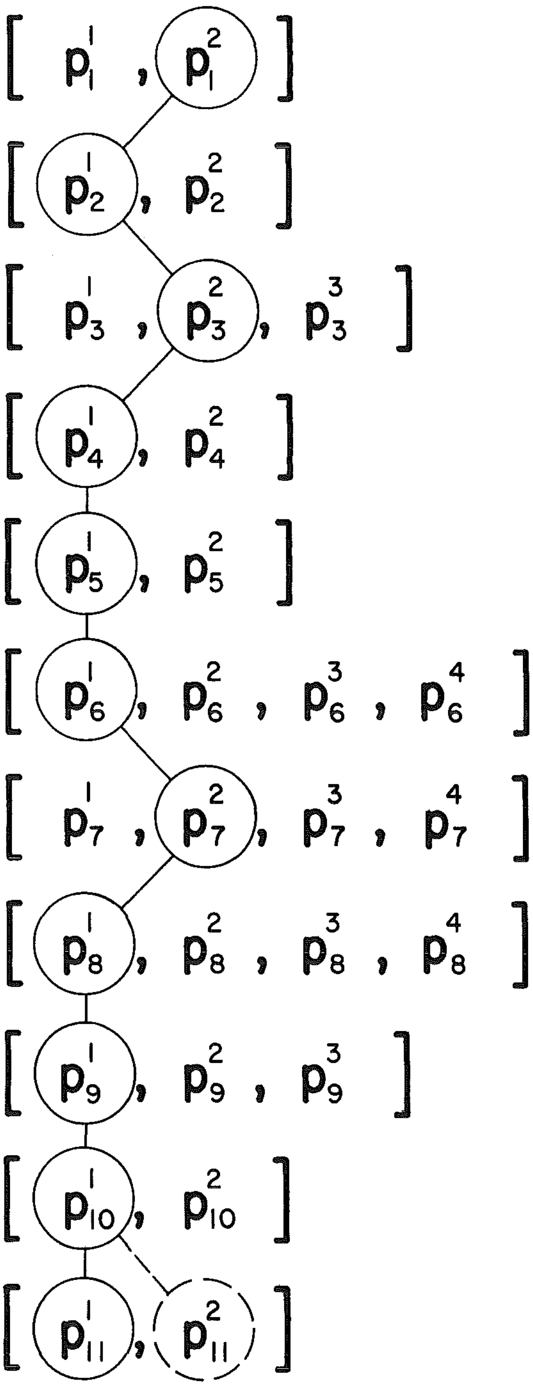
"e. Special solutions are identified and realized. While the conviction that all solutions can be realized is inherent in morphological analysis, some among the many solutions would ordinarily be of a relatively trivial nature."

An example from Ref 161 may illustrate the practical application of the matrix discussed above. It is shown in Figure 4.16 and concerns the totality of all jet engines which are composed of simple elements and activated by chemical energy, reflecting knowledge in 1951. (The chain of circles represents one possible solution of the original problem.) As Zwicky remarks, if no internal contradictions were present, this would make possible

$$2 \times 2 \times 3 \times 2 \times 2 \times 4 \times 4 \times 4 \times 3 \times 2 \times 2 = 36,864$$

pure-medium jet engines containing single, simple elements only and being activated by chemical energy. However, there are some internal restrictions, which reduce the above number to 25,344 possible simple engines. A first evaluation, in 1943, on the basis of fewer parameters, arrived at only 576 possibilities, which, however, correctly included the then secret German pulse-jet-powered aerial bomb, V-1, and the V-2 rocket.

The example marked in Figure 4.16 by circling specific parameters is the interplanetary aeroduct or ramjet. Zwicky remarks that "the principal point of interest is the presence of the element p_1^2 in the above matrix.



$[p_1^1, p_1^2]$ = intrinsic or extrinsic chemically active mass.

$[p_2^1, p_2^2]$ = internal or external thrust generation.

$[p_3^1, p_3^2, p_3^3]$ = intrinsic, extrinsic, and zero thrust augmentation.

$[p_4^1, p_4^2]$ = internal, external thrust augmentation.

$[p_5^1, p_5^2]$ = positive and negative jets.

$[p_6^1, p_6^2, p_6^3, p_6^4]$ = nature of the conversion of the chemical energy into mechanical energy.

$[p_7^1, p_7^2, p_7^3, p_7^4]$ = vacuum, air, water, earth.

$[p_8^1, p_8^2, p_8^3, p_8^4]$ = translatory, rotatory, oscillatory, and no motion.

$[p_9^1, p_9^2, p_9^3]$ = gaseous, liquid, solid state of propellant.

$[p_{10}^1, p_{10}^2]$ = continuous and intermittent operation.

$[p_{11}^1, p_{11}^2]$ = self-igniting and not self-igniting propellants.

Figure 4. 16. Morphological Matrix

This means that we derive our chemical energy entirely from the surrounding medium and that our jet engine is one which operates although it does not carry any propellants with it at all." One way to achieve this characteristic is to make use of the sun's energy, which is stored in the upper atmosphere in the form of excited and ionized atoms and molecules and newly formed molecules. The inclusion of a jet which conceivably might use this stored energy would stimulate research in two directions: high-atmosphere research, to find out about the nature and number of the excited particles (this is already well underway); and research in the possibilities of de-exciting the particles and using the energy gained in aeroducts, aeropulses, and other devices for the generation of propulsive power. Zwicky believes that such gradual and continuous acceleration might ultimately prove to be superior to the use of nuclear propulsion for spaceships leaving the earth.

It will be noted that the matrix includes possibilities that may appear to lie far in the future. For example, the elements p_7^3 and p_7^4 would be characteristic of varieties of hydrojets and terrajets (with propellants reacting with water or earth, for instance). One may discard these possibilities for a forecast restricted to a given time frame, or in general, after a thorough evaluation, but one should not do so a priori.

4.3.4. Network Construction.

4.3.4.1. Relevance Trees.

The concept of relevance trees was described by Churchman et al[3] in 1957. The application of quantitative techniques within the relevance tree framework was refined by Wells (Ref 9). The most prominent application of qualitative relevance trees is that of the Planning-Programming-Budgeting System (PPBS) of the U. S. Department of Defense, which is now being extended to all government agencies and departments.

The first large-scale application of relevance trees to numerical analysis for decision making has been made by Minneapolis-Honeywell's Military and Space Sciences Department and is identified as PATTERN (Planning Assistance Through Technical Evaluation of Relevance Numbers) (Ref 91 and 130). A qualitative scenario attempts to assess national objectives, activities, missions, etc, in the period 1970 to 1980, and beyond. These findings are used for the construction of the relevance tree and the assignment of significance numbers (how significant is the contribution of issue x to criterion y?). At the same time, a technology forecast is made at the primary systems level and at lower levels, aided by trend extrapolation and envelope-curve techniques, as well as other forms of qualitative and quantitative exploratory forecasting. Apart from an identification of primary systems, secondary systems, and functional subsystems and

3. C. W. Churchman, R. L. Achoff, and E. L. Arnoff, Introduction to Operations Research, John Wiley and Sons, New York, 1957.

their relationships, used for the relevance tree, two sets of characteristics are assessed explicitly: cross support, which means spin-off to other areas or general technological growth to be expected from tackling a specific technical system; and status (research, exploratory development, advanced development, product design, availability) and timing for systems and subsystems. These input data can be used in the computer program if such refinements are desired; at present, Honeywell does not use cross-support estimates (other than identical systems for different missions, etc) and uses status and timing only to sort out all projects that are already well underway. Honeywell's military and space relevance tree looks like this (1966):

Level	Number and Nature of Items
-	National objectives
A	3 national activities
B	13 forms of activities
C	64 missions
D	204 tasks
E	697 primary systems
F	2,368 secondary systems
G	Several thousand functional subsystems

W. L. Swager (Ref 138) has set up an "Objectives Network" for the petroleum industry based on the same relevance tree approach used in PATTERN. The objectives network aids in translating specific postulated business objectives into specific technical objectives.

The network shown in Figure 4.17 was constructed by starting with a statement of a postulated strategic objective, such as exploitation of changes demanded by growing economic and social pressures for abatement of air pollution. A number of subobjectives were then identified which might be pursued by the company or others. Each subobjective was examined to identify sub-subobjectives. Empty boxes were included at each level for the "yet to be discovered technical alternative." This apparently simple network is deceptively difficult to complete.

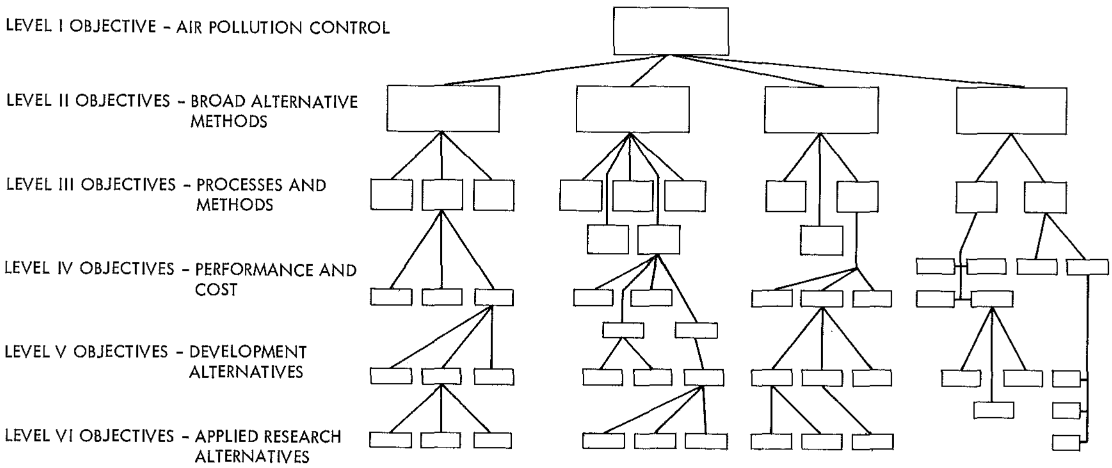


Figure 4.17. Pattern of a Graphic Model: an Objectives Network

At the top of Figure 4.17, Level I, is the market-oriented statement: to exploit changes demanded by growing economic and social pressures for abatement of air pollution. The broad alternatives at Level II by which this major objective might be achieved include:

a. To modify or develop new power plants.

b. To develop exhaust control for present automotive engines and fuels.

c. To develop needed petroleum technology to eliminate pollution-causing constituents.

d. To develop mass transit systems for urban areas, which need no exhaust control.

Furthermore at Level III, alternative objectives that might be pursued by a petroleum company (under c, above) might include:

a. To acquire and develop a higher percentage of low sulfur crudes.

b. To develop processes that remove sulfur from high-sulfur crudes prior to major refining steps.

c. To improve or develop new refining processes that reduce sulfur in automotive and other vehicle fuels.

d. To develop new additives that produce less toxic and objectionable combustion products.

e. To develop modifiers for present additives that stabilize or reduce combustion products or make them easier to remove.

The continued detailing of conceivable alternatives at subsequent levels forces consideration of alternatives at the very frontier of science. Swager stated: when a network of this type is attempted, it is surprising how the very preparation of it triggers ideas for new alternatives at nearly every level. The relationships are not obvious before the network is structured. Furthermore, the structuring makes explicit the paths of technological development that are competitive with one another.

4.3.4.2. Mission Networks and Functional Analysis.

In 1962 H. A. Linstone published a paper[4] addressed primarily to the problem of identifying and enumerating alternatives for performing missions pertinent to the U. S. national interests, and including activities of both a military and a nonmilitary nature. By displaying the relevant alternatives, it was suggested that the decision-making task of planning for general-purpose forces could be clarified. The display mechanism used was the "mission flow diagram," a graphic functional display of the various means that are available, planned, or presently conceivable for U. S. forces to fulfill each mission.

These ideas were extended in the MIRAGE 75 (Ref 99) and MIRAGE 80 reports. A set of mission charts (illustrated in Figure 4.18) of interest to general-purpose forces was constructed, and scenarios were provided as a guide to selection of concepts of operation and mission requirements. The scenarios were weighted in several alternative ways for importance, and these weightings were subsequently translated into mission priorities, and finally into technological weakness priorities. A set of research and development items of vital military importance was derived; it included such subjects as "target acquisition," "land barrier technology," and "information processing."

4.3.4.3. Graphic Model.

Swager (Ref 138) has structured graphic models for identifying and evaluating the forces affecting the future of the petroleum industry. Some of these forces are economic, social, and political; others stem from the possibilities uncovered by scientific investigations. The entangled interrelations among these forces are obviously complex, involving consideration of such diverse factors as competing sources of energy, changing conditions in the domestic market, changing

4. H. A. Linstone, The Weapon Planning Problem for General Purpose Forces: A Functional Approach, RAND report RM-3202-ISA, July 1962.

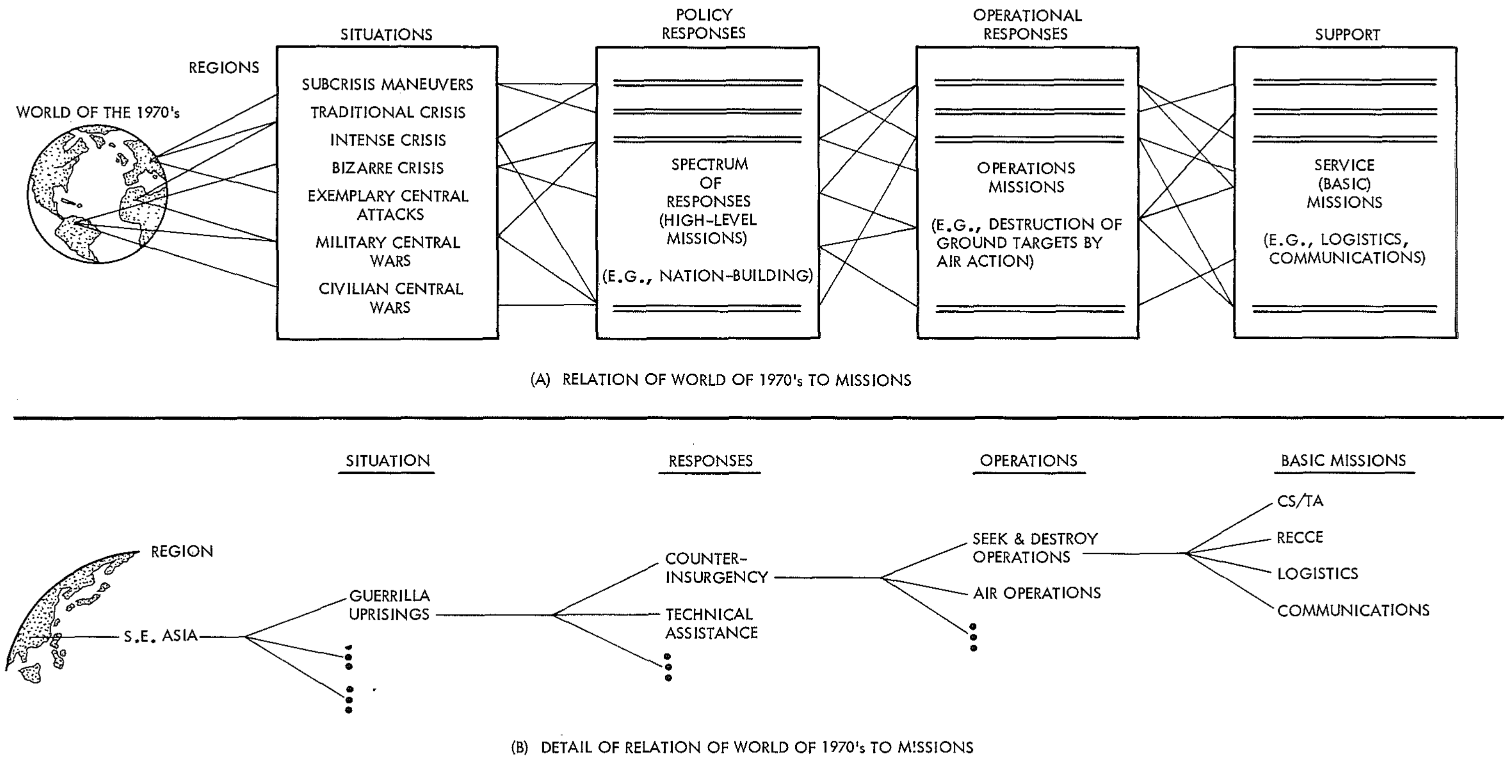


Figure 4. 18. Mission Network

conditions in overseas supplies, shifting markets for energy abroad, changing patterns of requirements and prices for petrochemicals, and the increasing political unrest among the developing countries of the world. An unstructured search through this labyrinth of detailed factors can be more confusing than revealing.

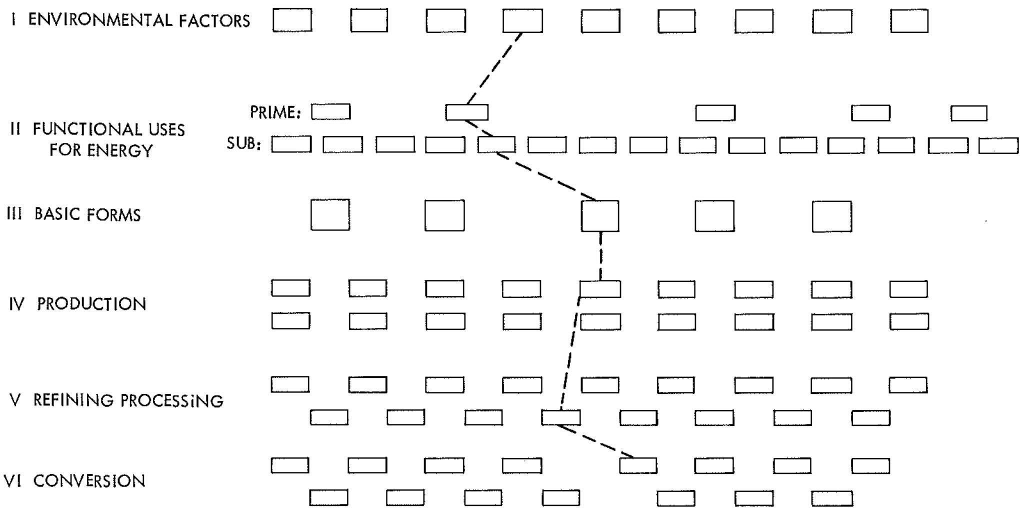


Figure 4.19. Pattern of a Graphic Model Relating Possible Changes in Petroleum Technology and Changes in the Environment of Energy Utilization

Based on experience in a number of previous programs of narrower scope, Swager attempted to structure a graphic model — an environmental network — to help him reason through the complexities and to guide much more detailed analyses. An overview of the large graphic model for petroleum in energy utilization is shown in Figure 4.19. There are obviously a number of categories of forces that could affect the future role of petroleum in energy utilization. These categories of forces are noted by the headings on the left-hand side of Figure 4.19. Indicative of the environmental factors are: rate of urbanization, population growth and demographic change, shifts in transportation requirements and physical distribution methods, increasing labor costs, shifting consumer expenditure patterns, and government research policies and programs. One of the prime functions of energy is for transportation with subfunctions including highway, rail, air, and conveyor, among others. Of course, the basic forms of energy include atomic energy, petroleum, natural gas, coal, water power, and solar energy. The factors under production include oil shale developments, the trend to high-sulfur crudes, advances in geophysical exploration, improved recovery methods, and off-shore exploration. Processing includes the many generic refining processes used in the petroleum industry, and conversion covers the many processes for converting energy from one form to another, such as fuel cells, turbines, gasoline engines, and thermoelectric devices. An empty box at every level is included for the factor of importance yet to be identified.

This graphic model is a working tool. With the rapidly increasing complexity of both technology and the economy, no person can have knowledge in the depth and breadth needed. Depth of knowledge in many disciplines is required. A high degree of perception of the relevant, however, requires a difficult-to-achieve level of communication among the disciplines. The model helps marketing men and economists communicate with technologists in identifying areas of possibly significant change and in allocating the additional effort needed to separate the relevant from the irrelevant.

Swager stated that prior to Battelle's attempt to use the model, marketing men and economists, when asked to identify changes in the environment, reported a myriad of detailed changes, only a small fraction of which were relevant to the future of energy utilization. Similarly, scientists and engineers, when asked to identify possible changes in technology, would report a seemingly endless list of detailed possibilities, only a small fraction of which were germane to the major relationships and patterns of energy utilization.

When the graphic model is used to relate specific changes in technology that might stimulate changes in the environment, the model serves to reduce noise in the system when we are listening for the reply to the question "What should be forecast?" This graphic model merely structures thoughts so that subtle, and perhaps important, factors are not overlooked and establishes relationships among them that may otherwise be obscured. It is a means of focusing men's minds on the relevant and a disciplined way to stimulate an efficient search for significant change — the basis for sound strategy formulation.

Subsequent efforts, of course, may then be directed to much more detailed study only on those relatively few paths through the network where a significant change in the environment is coupled with a significant change in technology.

A relatively well-known path through the network is indicated by the dotted line in Figure 4.19 made by linking the following factors:

I. Environmental factors: rate of urbanization, and population growth, and demographic shifts.

II. Prime functions: transportation. Subfunctions: automotive.

III. Basic forms: petroleum.

IV. Production: high-sulfur crudes.

V. Processing: all refining processes or concepts that may reduce sulfur in refined products and new concepts for automotive fuel additives.

VI. Conversion: gasoline engines and exhaust control, diesel engines and exhaust control.

This path leads to a possible business strategy — to take advantage of the shifts in product composition for automotive fuels demanded by air pollution restrictions caused by rapid population growth and urbanization. It points to a possible opportunity for the technical development of refining and other processes that reduce substantially the toxic and objectionable products of combustion from automotive engines.

4.3.4.4. Decision Trees.

Another network approach to the structuring of complex problems is the decision tree method which has been described by Magee (Ref 101). In this approach, the decision is not viewed as an isolated decision (because today's decision depends upon the one we shall make tomorrow) nor in terms of a set sequence of decisions (because under uncertainty, future decisions will depend on what has been learned in the meantime). The decision problem is examined in terms of a tree of decisions. The decision tree uses a series of nodes and branches to indicate the interrelationship of action choices with different possible events or results of action which are partially affected by chance or other uncontrollable circumstances. The decision tree method can vary from a simple qualitative branching network to a stochastic network in which formal probabilistic methods are used. A generalized example is given in Figure 4.20.

4.3.5. Systems Analysis; Operations Research.

Quinn (Ref 118) has observed the following useful approaches for analyzing technological futures which are offered by systems analyses. For one thing, they can help to identify weaknesses in present operating systems which are amenable to technological solutions.

A second systems analysis approach poses hypothetical or probable future problems and defines the characteristics of technologies needed to solve them. This technique is widely used for analyzing potential military or space problems, where the analyst must anticipate events in environments in which no specific prior experience can exist.

A third form of systems analysis, impact studies, can help in analyzing what effect new technological solutions, if found, would have on existing or anticipated operating systems. Such studies may simply start with the question, "If a technology could achieve the following capacities, what would be the results?"

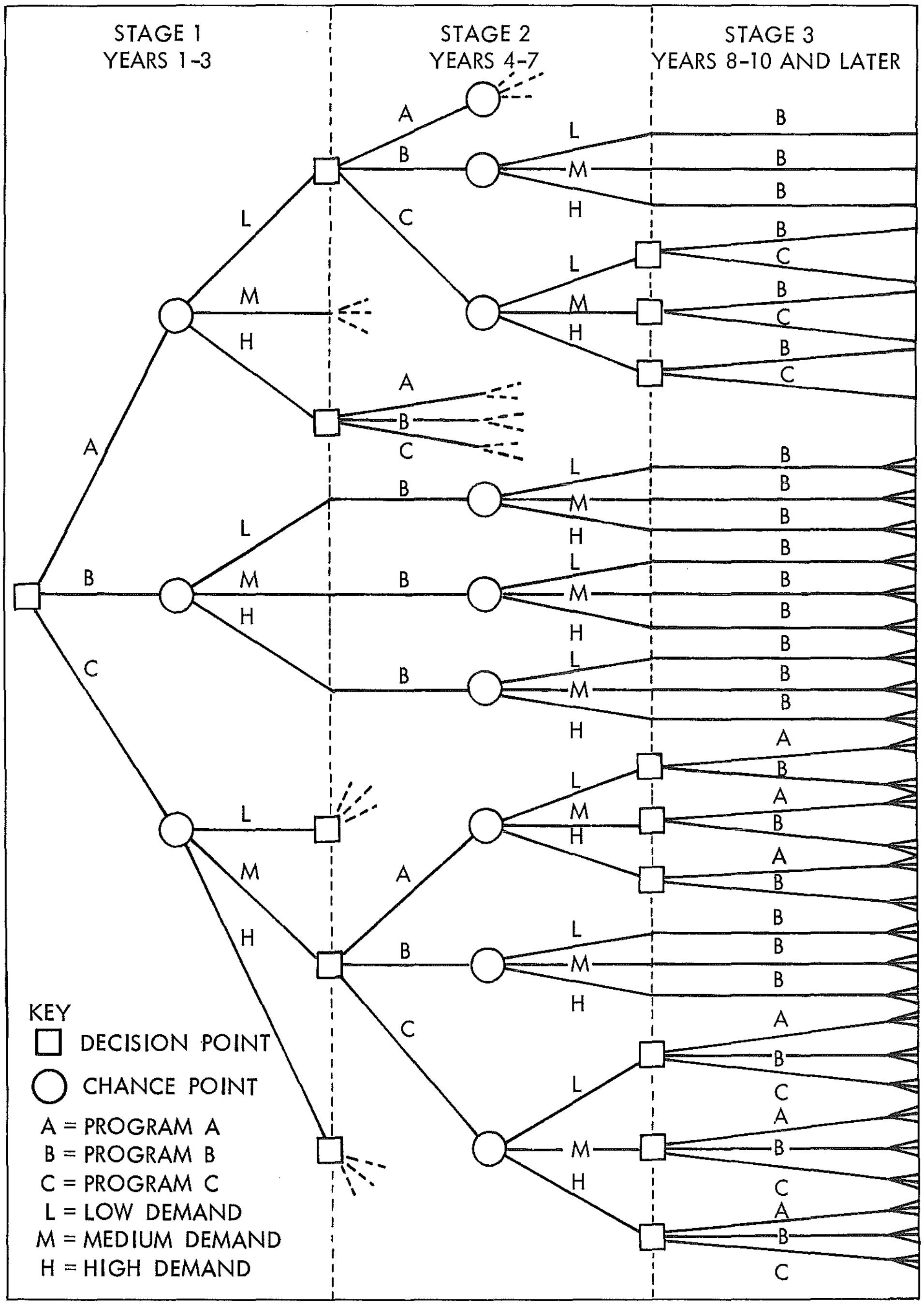


Figure 4.20. Decision Tree

Usually impact studies first anticipate some new technological capacity and then try to foresee the technical, social, or economic implications of that new state of the art. In this context, systems studies will normally

a. Define the performance characteristics that will be necessary for the operating system to achieve each of several different service levels.

b. Evaluate the economic or social implications of each service level.

The probability and cost of achieving each performance level can be compared with its potential economic or social benefit, and the net incentive to reach each level can be calculated. These calculations can then be combined with parameter analyses to serve as a basis for projecting the probable future state of the art and determining whether to support or monitor technological advances that might lead to solutions.

Systems analysis proves to be particularly successful under the following conditions, which are generally important to technological forecasting:

a. When the problem is considered in its entirety.

b. When great importance is attached to problem definition.

c. When uncertainty is properly acknowledged.

d. When scientific methods have been used to obtain objective results that can be checked and duplicated by others.

e. When the models constructed are flexible enough to integrate quantitative methods with judgment.

It is recognized that systems analysis is more of a frame of mind than a well-defined technique. However, if the systems approach is viewed as an orderly discipline for dealing with complex problems as a whole and under uncertainty, then the utility of this approach to broad technological forecasting problems can be seen. The RAND report edited by Quade (Ref 117) is recommended as an excellent survey of systems analysis.

4.3.6. Demand Assessment.*

"Several recent studies [e.g., Ref 92] have suggested that clearly perceived demand . . . technological capacity, tends to be the primary force stimulating technological change. In fact a technology is often utilized only if it responds to a need. Otherwise it remains a capacity and never becomes a functioning reality. Consequently, if one can identify important future needs which would be inadequately met by current technologies, he has an excellent starting point for analyzing prospective technological advances. If an anticipated demand is strong enough, it will generally call forth the . . . resources necessary to attack its technological problems. Once stimulated and adequately supported, human imagination is likely to solve these problems unless prevented by physical laws or by institutional barriers. And even institutions may change if demand is strong enough . . . .

"But the mere identification of such problems and opportunities is of little significance. To be useful, the analyses must indicate the rate at which these underlying demand factors will become strong enough to overcome the . . . rigidities, . . . inertias, and ingrained . . . [traditional ways of doing things] which always inhibit change. . . . Accordingly, the forecaster must weigh the force of these pressures and the feasibility and rate of potential technical progress, . . . [before he can arrive at realistic estimates as to when] new technologies will actually fulfill identified needs."

Editorial Note. For the purposes of this report, a distinction should be made between demand as an exogenous variable or as an endogenous variable. As explained in Paragraph 1.3, exploratory forecasting by the U. S. Army and Navy covers technological opportunities that can be available if selected and supported. In this framework, demand assessment would not be applied to technologies primarily controlled by the planners to whom the forecast is addressed (i.e., when demand is an endogenous variable). However, in broader technologies where demand is external to the military planners' sphere of influence, it would seem inappropriate to ignore the powerful influence of demand.

4.3.7. Analysis of Theoretical Limits and Barriers.

". . . [An interesting technique for] analyzing both the opportunities and the threats presented by new technologies . . . is to push a known apparatus or phenomenon to its theoretical limits and then try to visualize its potential implications.

* Paragraphs 4.3.6 (Demand Assessment), 4.3.7 (Analysis of Theoretical Limits and Barriers), and 4.3.8 (Predicting Technological Changeover Points) are based on the article by Quinn (Ref 118). Although these approaches are of lesser interest to exploratory forecasting, they were judged sufficiently unique and relevant to warrant discussion here.

"At the time new phenomena are discovered, it is often useful to ask how they might affect [operational capabilities] . . . if they were developed to their theoretical limits.

"Unfortunately, the kinds of imaginative projections implicit in this forecasting technique can lead one quickly into 'science fiction' possibilities which are too far into the future to have near-term significance. One must constantly be on guard against this tendency and check the timing and the reality of his [predictions] through the demand assessment . . . [and other forecasting techniques] ."

4.3.8. <u>Predicting Technological Changeover Points.</u>

"One technique helps define the critical performance characteristics [expressed quantitatively] which will enable one technology to substitute for another in a given class of applications. Because the existing technology and its potential substitute are advancing, the performance requirements to achieve changeover will normally become more severe as time progresses. When using changeover points to set targets for technical programs, one must be careful to consider the dynamics of this relationship. Too many R&D programs are designed to achieve substitution in terms of the technical requirements at the time of the program's inauguration, rather than to consider those characteristics that will be needed at the time it will be completed.

"Equally as vital in applying this approach is selection of the right performance factors for analysis. But unfortunately, traditional thinking often causes analysts to focus on the wrong characteristics. Histories of technology are filled with such errors . . ."

CHAPTER 5

SELECTION OF METHODS

5.1. Overview of Methodology.

The forecasting approaches discussed in Chapter 4 ranged from intuitive to statistical to cause and effect analysis to means of structuring the information in order to examine interrelationships and consider alternatives. The techniques have varying degrees of complexity and quantitativeness. None is a magic formula or an all-purpose tool. Each has its critics and its advocates. All can be useful. Which is best depends upon the circumstances under which the forecaster is working: the reliability, completeness, and quantitative precision of the data base; the time at his disposal; the purpose of the forecast (i.e., the kind of question being asked); and the length of the forecast period. In general, the level of treatment should correspond to the importance and level of complexity of the problem area. The approach selected should not be too sophisticated for the nature of the information available, i.e., "a micrometer should not be used to measure a sewer pipe."

Conversely, there is a very real need for improvement in the level or degree of sophistication with which many technologies are treated by forecasters. For example, the most unsophisticated forecasting technique is obviously the genius or intuitive type. It has been variously estimated that 80%, 90%, or perhaps even 95% of the forecasting done by the military services is of the genius type. Insufficiency of historical data often precludes the use of more sophisticated techniques; in many instances, however, substantial quantities of reliable data are available for analysis but are not used. As a result, the level of confidence that can be ascribed to the forecast is frequently much less than is desired.

When good data are not utilized to the maximum extent because of the application of unsophisticated forecasting techniques, we say that a Type I forecasting error has been made. If, on the other hand, sophisticated techniques are used for forecasting from imprecise and incomplete data, we say that a Type II forecasting error has been made. In either case, a wrong decision or error in judgment has occurred and the resulting forecast is of diminished value. Of the two types of forecasting error, Type I is more common when subject-matter specialists are called upon to prepare inputs to forecasts.

The major requisites of good forecasting must include:

a. A reliable data base (which normally consists of the scientific and technical specialists' knowledge in the subject-matter area as well as any supporting data).

b. Astute judgment and common sense on the part of the forecaster.

c. Understanding of available forecasting techniques and how and when to apply them.

The primary gain from the use of the more advanced techniques is the greatly improved insight one gains into the nature and interrelationships of influencing factors and into the sensitivity of solutions when these factors are varied. They also provide a possibility of evaluating, within a consistent frame of reference, distinct alternative technical solutions to a given operational problem. In effect, the techniques provide the tools whereby the technical knowledge and judgment of the forecaster can be applied to logical, systematic thinking about the pattern of development of the particular technology.

Various historians of science have commented on the importance to scientific investigation of structuring information and developing conceptual schemes. Asimov,[1] in commenting on scientific discoveries which were made separately but simultaneously by two investigators, developed the following criteria for scientific creativity:

a. The possession of a large number of "bits" of information (i.e., education, technical knowledge).

b. The ability to combine "bits" with facility and recognize the combinations formed (generation of "new ideas" and "novel outlooks").

c. The ability to intuitively recognize the consequences of the new combinations of "bits."

These criteria would also seem appropriate for technological forecasting. When viewed in this framework, the more successful forecasting methods are those which supplement technical knowledge and intuition (not substitute for them) by providing the means whereby the available data can be structured to improve pattern recognition or expose the dominant traits of a particular technology and thereby separate the most likely events from the least likely.

The previous point is emphasized because most of us have a way of becoming enamored of techniques which rightfully should be regarded as tools. An information gap which must be bridged by an intuitive leap will usually remain, but every bit of the problem that can be confidently analyzed removes one more bit of uncertainty from the forecast decision and thereby shortens the intuitive leap.

5.2. Combination of Forecasting Methods.

Lenz (Ref 95) has cited the benefits obtained by the use of more than one method as follows:

1. Isaac Asimov, Fact and Fancy, Doubleday, Garden City, N. Y., 1962, 264 pp.

". . . the best prediction for a given purpose may require several forecasts using alternate methods. The several forecasts may provide a range of probable developments; they may be combined to give us a single estimate of the future; or they may provide a choice of predictions according to the purpose for which it is to be used. Variation among the several forecasts may signal a change in the trend of events, or may emphasize the need for additional predictive effort.

"The combination of forecasts should start with the extrapolation of existing exponential trends. If these trends are well established and if artificial restrictions have not limited progress, then continued exponential progress is the maximum rate of progress likely to be achieved. To obtain a more rapid rate of progress, drastic changes are necessary; either in the procedures which have produced past progress, in the technology involved, or in the objectives toward which progress is directed. For example, the maximum speed of aircraft increased exponentially, doubling every ten years, so long as the technology was limited to manned aerodynamic vehicles and air-breathing propulsion systems. Speed increases greater than this rate were achieved only by the changes in technology and objectives represented by the unmanned ballistic missile with rocket propulsion.

"After the exponential rate of progress has been established, then other rates may be forecast by biological analogies, by use of correlative techniques or by use of dynamic forecasting methods. The smallest rate of progress predicted by these methods represents the minimum probable rate of progress.

"The maximum and minimum rates of progress enclose the area of probable progress. If this area is too broad, the forecasts may be examined to determine a single, most probable rate of progress. Although no logic supports the averaging of predictions, an average may be used if there is no evidence that any one of the predictions is more accurate than the others. Any technique of averaging may be used to obtain a forecast, but the forecaster should not assume that a major improvement in forecasting has thereby been obtained.

"The 'average' forecast may be used simply for the convenience of dealing with a single set of values representing future progress. A further advantage of a single forecast lying between the extremes occurs when the forecast is used by a large number of individuals to guide a variety of decisions. If it cannot be predetermined that such individuals would use the most appropriate forecast for their decisions, the least damage will be done by providing only a single, average forecast.

"If several different forecasts of the rate of progress of some parameter of technical performance have been developed, each of these forecasts may be used as a basis for separate actions or decisions. Such use of different forecasts does not imply inconsistency, but rather reflects the relative consequences of actions based on the different forecasts. As an example, if the decision concerns the rate of investment in research in a competitive situation, then a prediction that competitors will continue an existing exponential rate of progress is more conservative than one which assumes a lessened rate of progress. On the other hand, if the decision concerns investment in an old technology competing against a newer technology, a forecast of 'maturity,' or a declining rate of increase, in the old technology will be more conservative.

"A wide variation in forecasts may indicate that significant changes in the technology are about to take place. For example, a prediction by dynamic forecasting may indicate that the rate of progress in technology 'A' will rapidly diminish in the near future. At the same time exponential extrapolation may indicate a far more rapid rate of progress. Under these conditions the forecaster may well look for a new technology which will take over the burden of progress formerly borne by technology 'A'.

"Systematic forecasting offers a high probability of disclosure of changes, and frequently points to causal factors. Thus an entire body of evidence supporting such changes is highlighted for detailed examination.

"The variation in two forecasts of technological progress may indicate that the lower rate of progress will prevail, unless substantial changes are made in the supply of resources. In such a case, the variation signals for a managerial decision, either to increase the resources, and thereby the rate of progress, or to accept the lower rate of improvements. Thus the possibility of 'decision-by-default' is reduced when the facts are made clear by difference between two predictions.

"Most forecasters may be well pleased with the results of a single forecasting attempt, since it is an 'obvious' and 'unambiguous' prophecy. If, however, a second or a third method is used, which produces a different forecast of equal credibility, then the 'obvious' becomes subject to closer scrutiny. Additional investigation will usually disclose significant information leading to a better forecast; and will lead to greater knowledge of the factors involved in achieving further progress."

In addition to the above, multiple approach, combinations of techniques can be used sequentially in the preparation of a single forecast. For example, the forecast of a specific technique might begin with the construction of a qualitative relevance tree which would indicate such things as the pertinent functional capability, some key applications of the technique, and the research areas which are contributing to the advance of the technique. Contextual mapping might then be useful by providing insights into the evolutionary process of the improvement in the technique. This could be followed by envelope-curve extrapolation, which would indicate the overall progress of the functional capability achieved through this and other competitive techniques. Morphological research might then be useful in systematically examining the possible variations for achieving either the functional capability or the specific technique. Growth analogy could be used subsequently to examine the relative degree of maturity of the competing techniques. Analysis of causal factors stimulating or inhibiting the growth of the technique might be conducted by correlation analyses or the construction of a simple "learning" model. The final forecast could take the form of a trend extrapolation modified by judgment based on the insights gained from the earlier analysis.

The above example is given for illustrative purposes only. The actual choice of methods and the appropriate sequence for their application would be dependent upon the circumstances of each forecast situation.

CHAPTER 6

METHODS OF PRESENTATION

6.1. Introduction.

Uniformity and lucidity are needed in the written presentation and justification of estimates of the probable technical performance by proposed materiel. This is particularly important for those persons responsible for military applications and systems engineering who must combine potential advances from a number of technologies into concepts for future military systems. Considerable improvement can be made by the use of uniform time frames and common research status points as well as by the explicit treatment of the uncertainties and major assumptions. In addition, the informational value of forecasts can be increased by use of concisely worded narrative statements and appropriate graphical methods.

6.2. Timing Factors.

In forecasting developments in various technical areas, and performance characteristics within these technical areas, it is important that uniformity be obtained in both the time period and the phase of development which is covered. The following material drawn from Pardee (Ref 114) is appropriate to these discussions of forecasting.

"In preparing a series of projections to be used in a given major planning exercise, one should settle on a standard time period [as depicted by Pardee and shown in Figure 6.1]. This should be maintained throughout the study when projecting anticipated capability for the characteristics used to measure each technical area.

"In addition, although it may be suggesting a spuriousness in accuracy, it also would help avoid any unnecessary confusion in exactly what is to be plotted to specify whether calendar or fiscal year data are desired, as well as whether the point [represents the] beginning, middle, or end of the year... Likewise, for shorter term projections it may be desirable to plot anticipated progress for shorter increments of time although, once again, to do so may imply greater accuracy than really is possible. Care should be taken to point out that the objective is to be clear concerning the meaning of the projection rather than to imply precision about uncertain technological advances.

"A second source of unnecessary imprecision is misunderstanding concerning the state to which the level of performance identified actually will have been developed and tested by a given point in time. In the absence of explicit assumptions, the plot point could represent an analytic effort

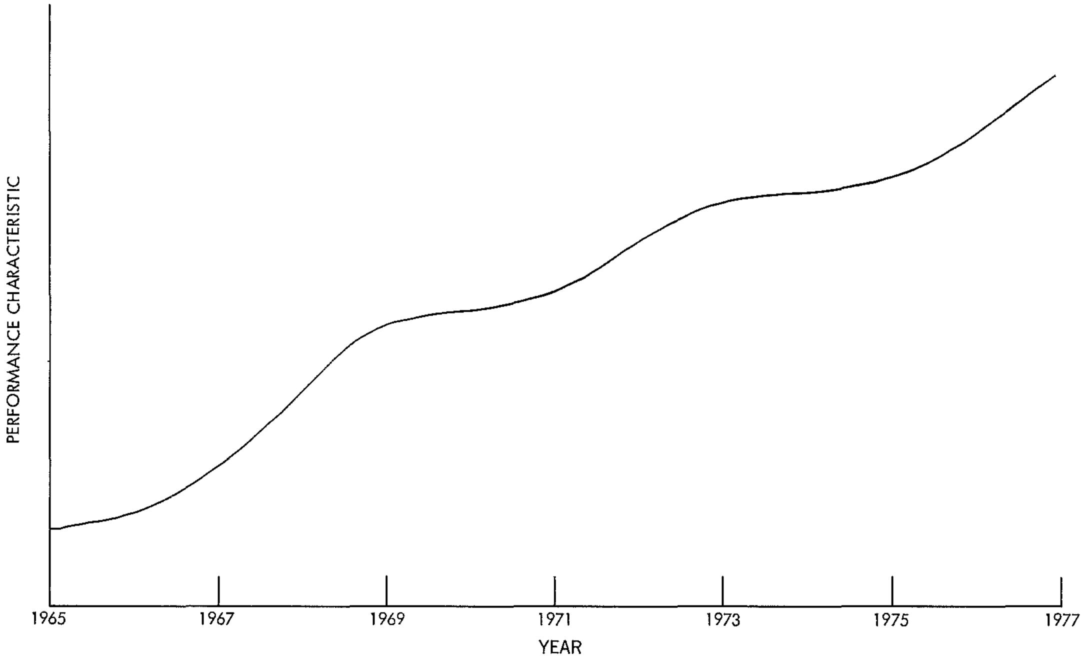


Figure 6. 1. Illustrative Standard Time Period
to Be Used in Projections

indicating that no physical law would be violated, that first full-scale production has been completed, or any of several intermediary points. In many instances, the duration represented by such a series of phases can extend over a period of several years. An illustrative list of major events, from which to select the one or more to be plotted, is as follows:

a. Analysis indicated that no known physical law was violated.

b. Technical feasibility of new approach proven.

(1) By paper studies (mathematical analyses, optimization studies, etc.).

(2) By small scale and/or short duration test.

(3) By full scale full duration test.

(4) By enough full scale, full duration tests to insure an adequate size sample.

c. Engineering design of full major subsystem complete.

d. Prototype of complete major subsystem thoroughly tested.

e. Improvement integrated into total weapon system.

(1) On paper.

(2) First test completed successfully.

(3) Total test series completed successfully.

f. Production redesign completed.

g. Production facility completed.

h. First production units produced at quantity rates ready for delivery.

and possibly:

i. Conversion from technical feasibility to commercial profitability, as either goods/or a service.

"This list may be more lengthy than will be required in a set of guidelines for preparation of technical projections. It is included in full here to emphasize the extent of the phases in the development process. In many instances it probably would be most logical to plot event number b(4) in the list; that is, the technical feasibility of the approach has been proved through a statistically adequate program of full-scale tests. At this point the technology is available to the systems engineer for inclusion in new overall weapon system developments. If event b(4) is selected as the standard to be used in a forecasting exercise, obviously any exceptions to this practice must be clearly identified — on the appropriate curve or at the plot point itself — for the various projections in an overall package to be meaningful."

6.3. Funding Assumptions.

In some instances programs in a scientific or technological area will not depend upon support by the several DOD agencies but will be spurred by civilian demand. Where, however, internal funding support is critical to what may be accomplished, the dependence of progress on funding level should be indicated explicitly.

For example, some indication could be given as to what the probable results would be, if

a. The funding were doubled each year over the total project life.

b. The funding were cut in half over the project life.

A statement may be appropriate covering any special benefits which might be obtained either by revising the timing of funding support or by applying additional resources selectively at certain key points during development.

6.4. Treatment of Uncertainty.

The user of the forecast is interested in the application of tomorrow's advances in technology to his long-range plans, but today's estimates of these accomplishments must point out the contingencies, conditions, limitations, and complexities, which impinge on the foreseeable trends. One situation to avoid is an implication of certainty by a forecast in an environment that actually is highly uncertain. This misunderstanding, usually caused by a casual observer's misinterpretation of a single-valued estimate, can be obviated by the explicit recognition of such uncertainties.

Uncertainty usually must be expressed as a subjective judgment on the part of the forecaster. His view of the future may take one of four basic forms:

a. Ignorance. He may see the future as a complete blank, finding himself unwilling or unable to make any useful statements about it. Decisions made under such conditions have been described as "heroic" rather than "rational."

b. Assumed certainty. He pretends, for all practical purposes, that the future is exactly known. When he assumes certainty about the future, single-valued estimates which are called deterministic are used.

c. Probabilistic. He may admit that he is not able to say exactly what is going to happen in the future but he is able to say that one of several possible futures will occur with stated probabilities. The classic example is that of flipping a coin.

d. Uncertainty. His view of the future may suggest simply that a variety of events is possible but he is unable to make any statements about their probability.

These possible views of the future lead directly to the classification of forecasts as being made under conditions of assumed certainty, risk, or uncertainty. Of course, any single forecast may have elements of all three classes. For example, the trend in the progress of a technology may be projected along either of two distinct curves, depending on the success or failure of a single technical

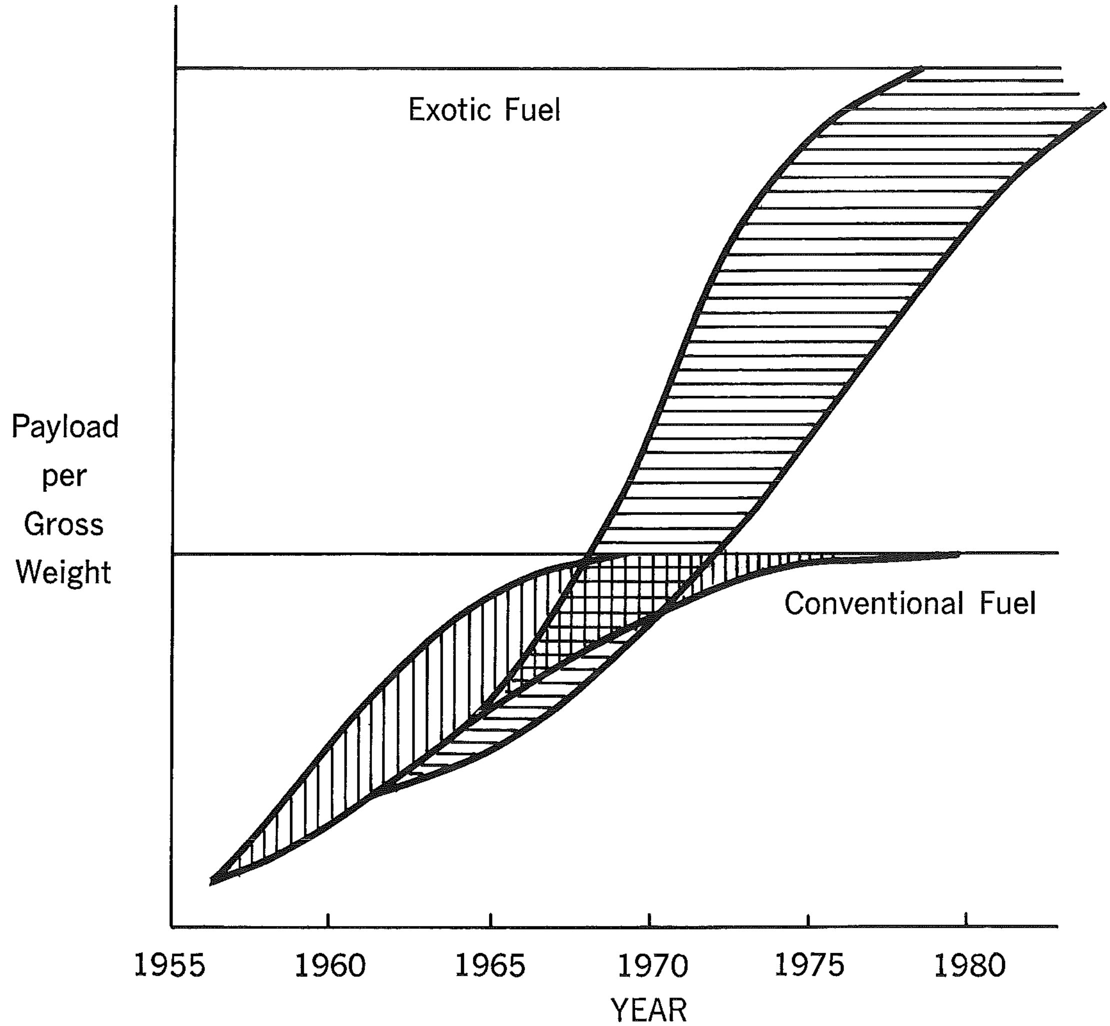


Figure 6. 2. Time-Dependent Trends
(Example: Personal Flying Belts)

approach. The success of the approach may be estimated by assigning probabilities to each of the two possible outcomes. At the same time, some upper limit of progress (such as the speed of light) may be known with certainty and can be so plotted. Unpredictable external circumstances may also bear upon the problem and can be noted as contingencies in the forecast.

Several simple graphical methods are available for recognizing uncertainty. Bands or ranges of varying thickness may be used to indicate upper and lower limits of the estimate (as illustrated in Figure 6. 2). Confidence levels can be indicated graphically by showing a single "most likely" trend accompanied by dotted trends or shaded areas depicting the ranges of uncertainty in the forecast. Contingency information can be included in the graphical trend curve, as shown in Figure 6. 3.

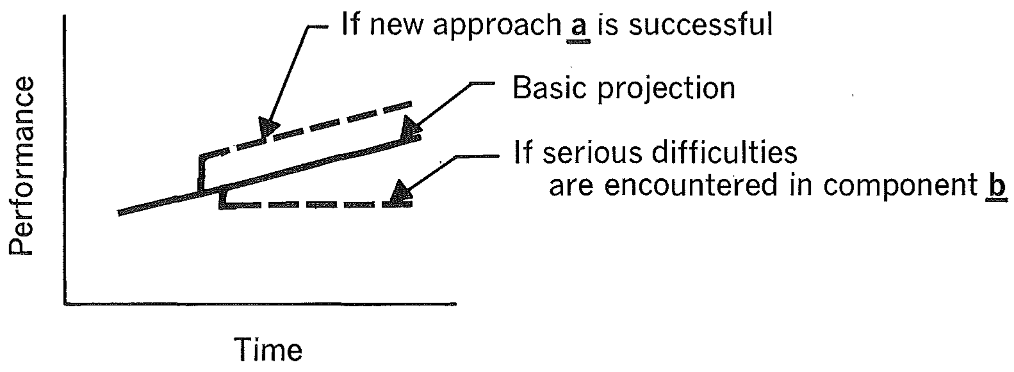


Figure 6. 3. Identification of Anticipated Results if Selected Special Circumstances Occur

The above techniques do not reveal the variation of probability within the indicated range. Jantsch (Ref 90) has stated that a better approximation is obtained if the probabilities are expressed by probability distributions about the mean value. For practical purposes, especially in the absence of empirical or theoretical analysis, a Gaussian, or normal, distribution is usually assumed. A single parameter, the standard deviation, then determines the shape of the symmetrical bell-like curve. Probabilities can be estimated from the area under the curve inclosed by a given number of standard deviations on each side of the mean as in the following example:

Probability	Limit
0. 50	mean ± 0. 675 standard deviation
0. 68	mean ± 1. 0 standard deviation
0. 90	mean ± 1. 645 standard deviations
0. 95	mean ± 1. 960 standard deviations
0. 99	mean ± 2. 58 standard deviations

The use of such a probability distribution also allows the precision of the range of an estimate to be expressed as a "confidence level", e. g. , a range representing ± 1. 645 standard deviations about the mean, would indicate a 90% confidence level.

The use of more formal probabilistic techniques has been described by Jantsch (Ref 90) and Cheaney (Ref 52). In these approaches, the technological transfer process is assumed to be governed by probabilistic laws, i.e., a stochastic process. The overall probability of success of achieveing a given capability through a number of sequential steps in a given time period can be approximated by such methods.

6.5. Techniques for Expressing Trends.

Words without pictures can be as uninformative as pictures without words. In the first instance, the reader must visualize from rhetoric alone what the writer intended to convey. In the second, the reader may acquire an inadequate, or erroneous, understanding of what the picture portrays. A technological forecast should use an effective combination of these two modes of expression.

Sometimes forecast can only be presented in narrative form, but they have limited value if broad generalities (e.g., higher, farther, faster) are stated about characteristics. Narratives can be fully informative, however, as in the following example taken from Quinn (Ref 118):

> "The chances are better than 8 in 10 that U. S. companies will be manufacturing a commercial supersonic transport (SST) by late 1972. A crash program might advance the manufacturing date to 1970, but major economic or military crises would probably delay its production indefinitely. Each craft will probably weigh about 700,000 pounds gross, be about 300 feet long, carry 300 to 350 passengers, cruise above 60,000 feet at speeds around 1,800 miles per hour, and cost between $30,000,000 and $35,000,000. The power plant for the SST will probably develop over 60,000 pounds of thrust and require new technological advances in high temperature materials, cooling systems, and control of engineer dynamics and noise. Although present knowledge makes a 1,800-mile-per-hour cruise speed appear quite feasible, the gas turbine cycle, heat transfer problems, and materials limitations will probably keep SST cruise speeds below 2,000 miles per hour until the late 1970's.
>
> "By 1975 the SST will probably force conventional jets out of first class travel on hops of over 1,500 miles where route structures are favorable. By the mid-1970's the SST will probably make intercontinental travel more commonplace for executives than New York-to-Chicago flights today."

6.5.1. Examples of Graphical Presentations.

The following examples are representative of the various ways in which forecasts can be presented. They are taken from forecasts which were made in the past and do not necessarily reflect present thinking. Consequently, they are to be considered qualitatively.

6.5.1.1. Time-Dependent Trends.

Figure 6.2 depicts a time-dependent trend. The ratio of payload to gross weight of flying belts is shown as it is expected to increase in the future. Conventional fuel is a barrier at one level of performance and exotic fuels at another level of performance. The improvements between these barriers are those expected in the usual history of applied science and engineering extending from the demonstration of feasibility to the application of incremental improvements. The figure implies that new fuel research could "break out" in 1963. It also implies that between 1965 and 1970, competition will exist between the undeveloped new configuration and the fully developed older configuration. The broad hatched areas indicate the levels of confidence ascribed to the projected trends.

Figure 6.3 typifies a set of time-dependent curves which identifies anticipated results if selected special circumstances occur.

A specific example of dependence on special circumstances is depicted in Figure 6.4, which shows the trend projection of thrust-to-weight ratio of engines. The uncertainty is shown by the broad lines. The impact of the availability of new materials of better characteristics is shown by the increased values for the parameter.

The case of a development involving the projection of two critical parameters (in this instance, power gain, bandwidth, and system noise of solid-state amplifiers) is shown in Figure 6.5.

The projection of a critical parameter in a technology, in which specific milestones in research and development are identified, is shown in Figure 6.6. The actual and anticipated gains in air-cushion vehicle performance, in terms of a factor of merit, are projected for a vehicle with a bare bottom and one with a skirt and trunk system. Significant improvements have resulted from the development of skirts and flexible jet extensions. Aerodynamic problems associated with these developments have been largely resolved, but finding suitable materials for the air-cushion devices is a continuing problem.

The projection of the critical parameters in each of several alternate techniques, portraying specific developments in perspective, is shown in Figure 6.7. Considerable improvements in specific impulse have been made in solid and liquid propellants, especially in recent years. The figure shows, however, that no one parameter can be used by itself as a basis for comparison of the various propulsion systems. Solid propellants have lagged liquid propellants in specific impulse for years. This trend will continue because performance must be compromised to attain certain physical and ballistic properties in the solid-propellant grain. Solid-propellant motors, however, are less complex and lighter in weight than liquid-propellant systems and an overall advantage can be gained by selecting the less energetic solid-propellants.

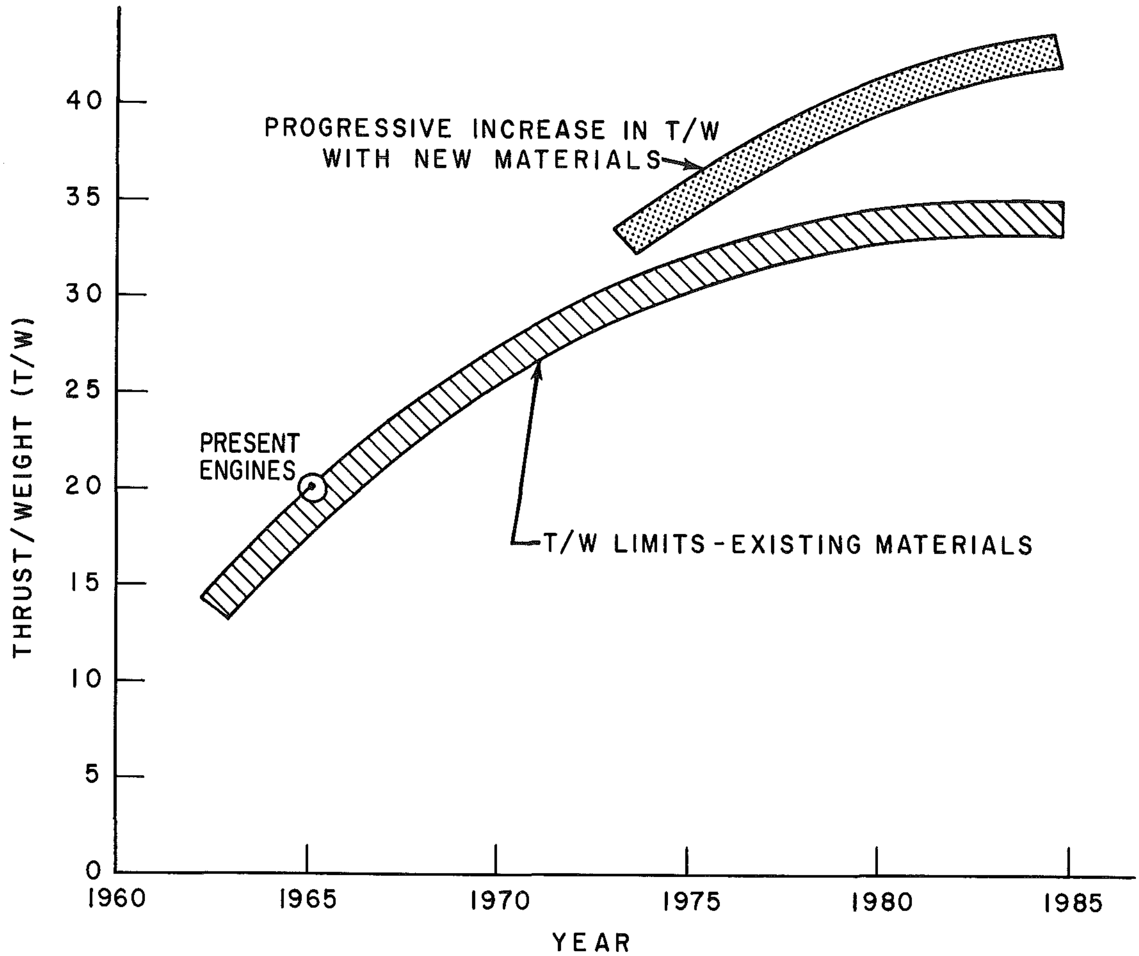


Figure 6.4. Trends in Thrust-to-Weight Ratio
of Dependent Lift Engines

6.5.1.2. Parameter-Dependent Trends.

Often the real times when steps in a developmental process will occur are dependent upon one or more variable factors (parameters) and real time cannot be precisely determined. Figure 6.8 depicts a parameter-dependent trend. It shows the anticipated trends in output (gal/day) of desalinized ocean water as the cost of power (watts/dollar) changes and as the membrane diffusion rate changes. The time at which the latter two parameters will change cannot be predicted with confidence. A quantitative indication of output in real time is dependent upon time-related predictions of cost, diffusion rate, and other factors. In the absence of such quantitative information, parameter-dependent trend figures are used.

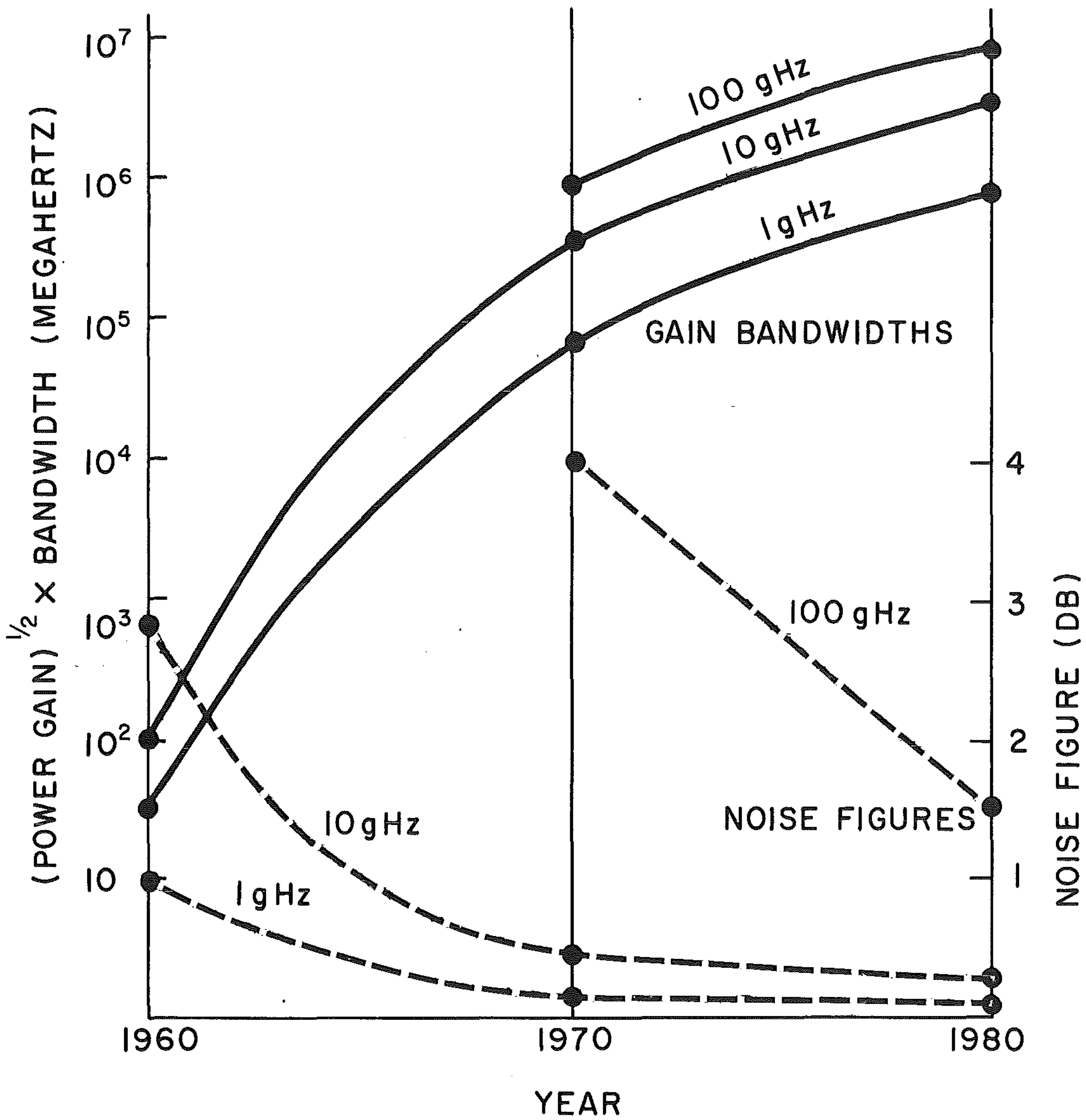


Figure 6.5. Projected Development of Solid-State Amplifiers

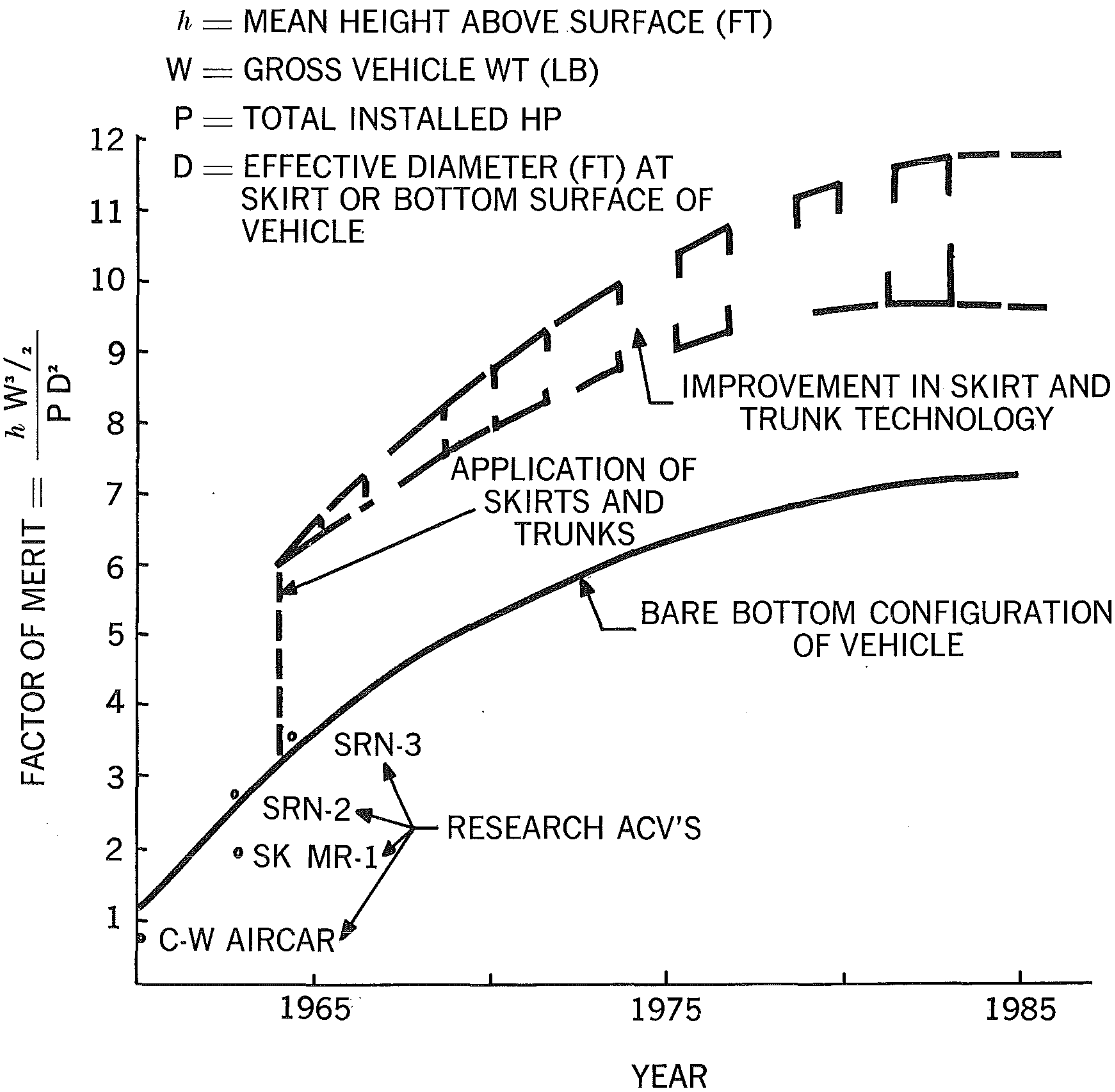


Figure 6.6. Air-Cushion Vehicle (ACV) Performance

The visual presentation of parameter-dependent trends is difficult. In the first place, partial and contingent dependency cannot be shown well graphically. For instance, in Figure 6.8 a combination by addition of the partial effects of y and z on x is not necessarily valid even though it may be implied by the chart. There may be complex relationships between diffusion rate and power in specific designs because of such things as induced potentials. On the other hand, if x, y, and z are graphed together in a three-dimensional picture to account for this specific design interaction, the general trend of effects for nonspecific

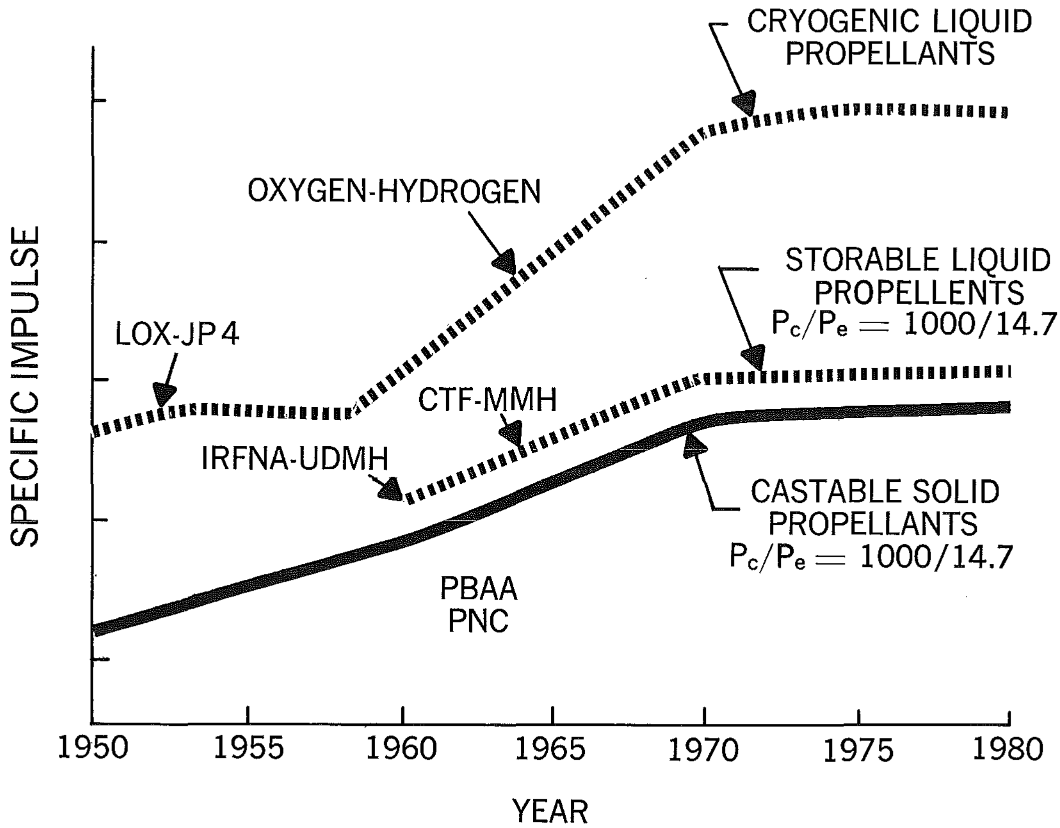


Figure 6.7. Predicted Improvements in Specific Impulse

designs may be obscured. Specific functionally related curves are basic to systems design, whereas the trend curves are the engineeringly imprecise but directionally correct information for planning. The first-named curves will be used by the engineer and not the planner, and only the planner will use the latter.

The portrayal of parameter-dependent trends in meaningful graphics is a major problem that affects the feasibility of forecasting in terms of time and probability. Almost all forecasting, if done in serious detail, involves parameter-dependent trends as elemental considerations. Time, as an independent variable, becomes more and more the modulus instead of real time.

Figure 6.9 shows performance characteristics of microwave tubes over the past 25 years and as projected through the next 15 years. The trend of a critical parameter may also be presented in a bar graph, as shown in Figure 6.10.

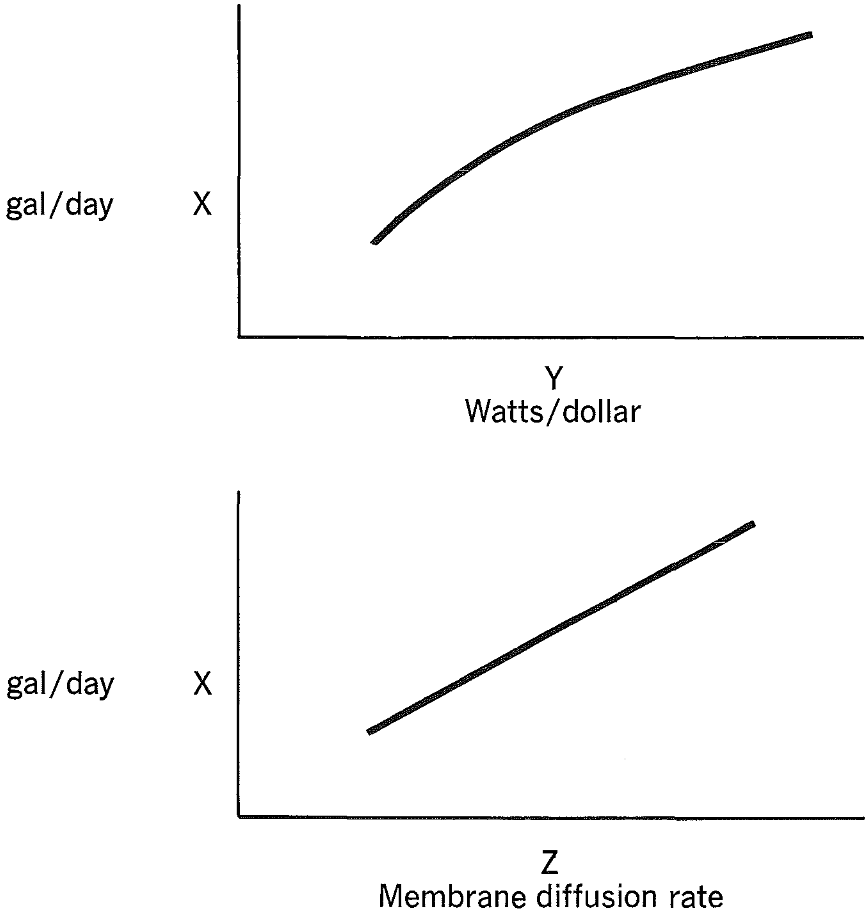
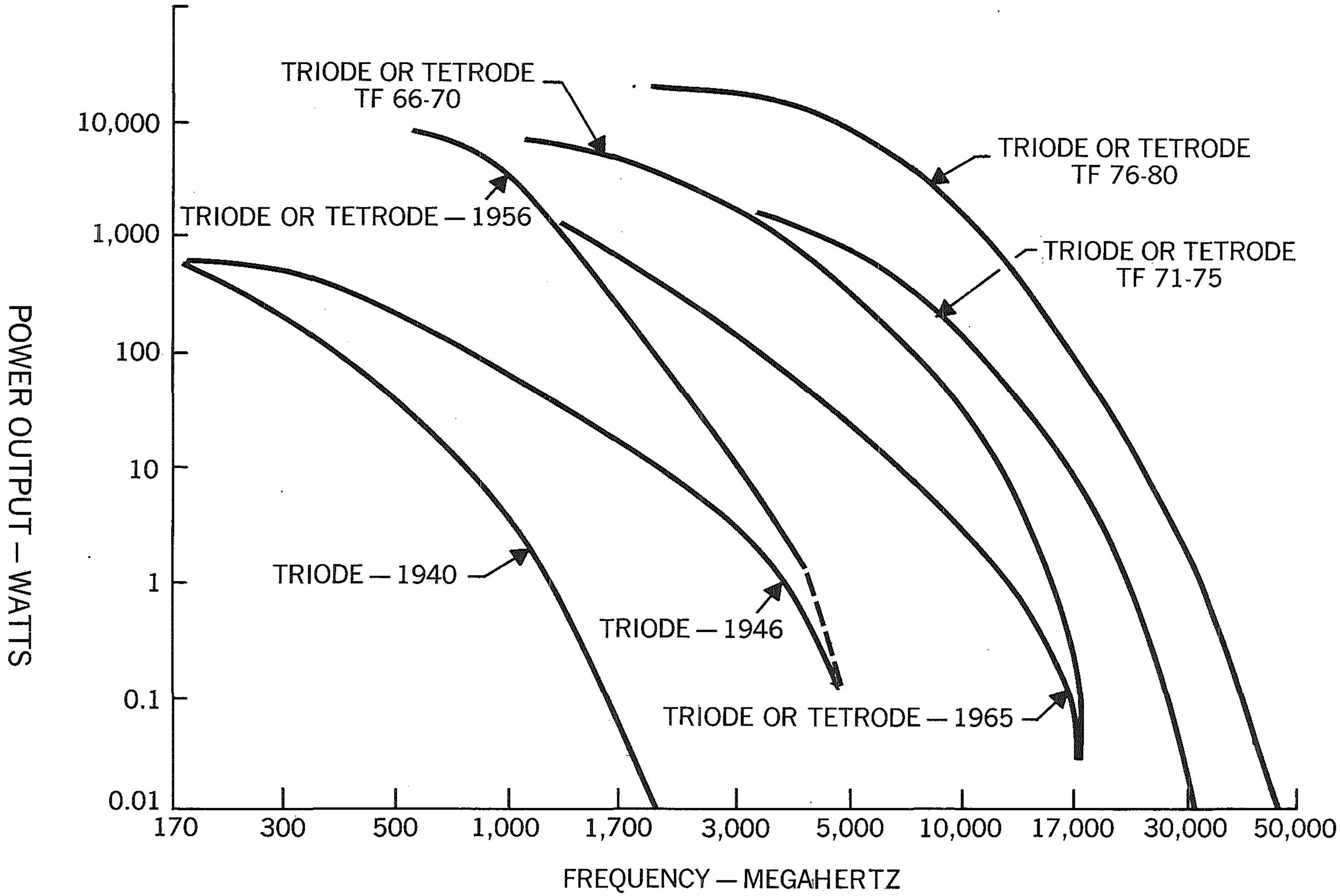


Figure 6.8. Parameter-Dependent Trend
(Example: Desalinization of Ocean Water)

The projection of a critical parameter in terms of other constraining parameters is shown in Figure 6.11. In order to resist the intense temperature, high pressure, shear force, corrosion, and erosion of exhaust gases, the uncooled nozzle on a solid-propellant rocket motor had, of necessity, been undesirably heavy. The flame temperatures of exhaust products in 1960 ranged between 5,400° F and 5,900° F (Figure 6.11) and were expected to approach 7,000° F soon. This increase would prevent the use of nozzles based upon the heat-sink method of operation and designs would have to be developed to use the highly refractory metals, hafnium, tantalum, and tantalum-zirconium alloys, which have melting points around 7,000° F.

Figure 6. 9. Progress in Capacities of Microwave Tubes



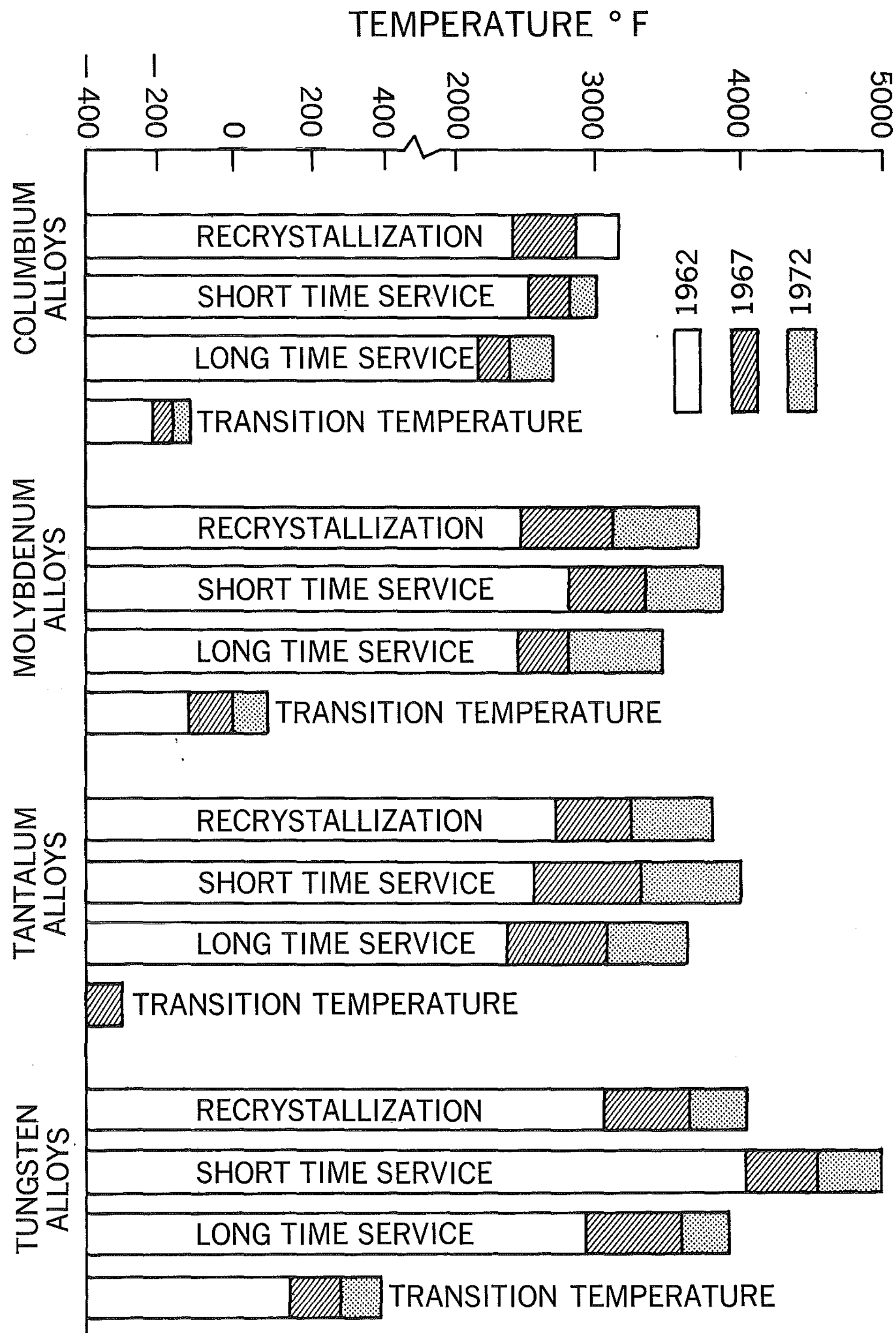


Figure 6. 10. Critical Parameter Trend — Refractory Metal Alloys

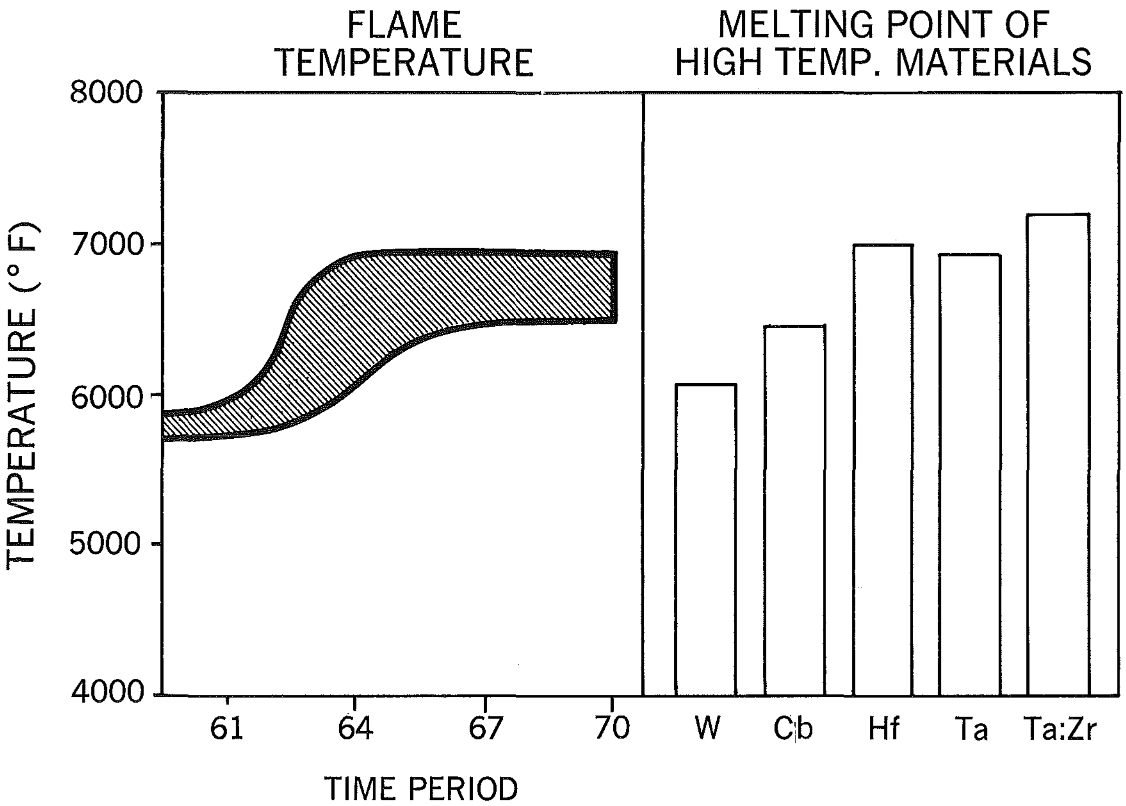


Figure 6. 11. Critical Parameter in Terms of Constraining Parameters

6.5.1.3. Forecast of Functional Capabilities.

A forecast of projected functional capabilities in terms of the state of the art is shown in Figure 6. 12. The advantages of a combination of sensing means for tracking a missile become obvious from examination of the figure because each is most effective in a given portion of the trajectory. For example, infrared (IR) is probably the most widely used and generally most efficient for use in tracking a missile through its powered phase and upon reentry. Ultraviolet (UV) is an extremely effective means for detection and tracking in the powered or mid-course portion of the trajectory, but only from a space platform when the target is above the ozone layer. Electrooptical (E/O) techniques are usable in any part of the trajectory if the target is self- or solar-illuminated. Active electrooptical techniques, i. e., using a laser transmitter to illuminate the target, will give greater tracking capabilities.

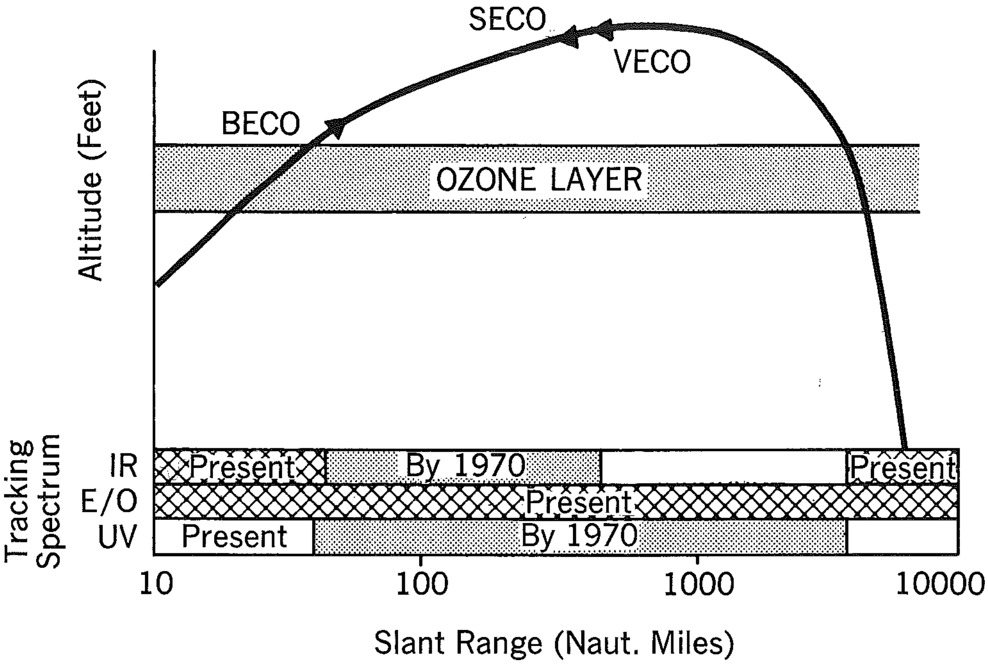


Figure 6. 12. Typical ICBM Trajectory, Showing Optical Tracking Capabilities in Various Spectral Regions

Graphics can also show the interrelationships between the characteristics and performance of devices and subsystems within a military system and between related systems. A "best" system may have to be modified to only a "better" system to gain maximum effectiveness when several systems are used in combination; trade-offs must be made. Figure 6. 13 shows the increasing military use of the frequency spectrum and emphasizes the need for precise control of the emissions from electronic devices to minimize interference between them. It also indicates that, in future, the techniques and devices for analysis, measurement, and control of interference from emissions of electrical energy must be effective over all frequencies from DC (0. 1 mHz) to infrared, visible, and ultraviolet.

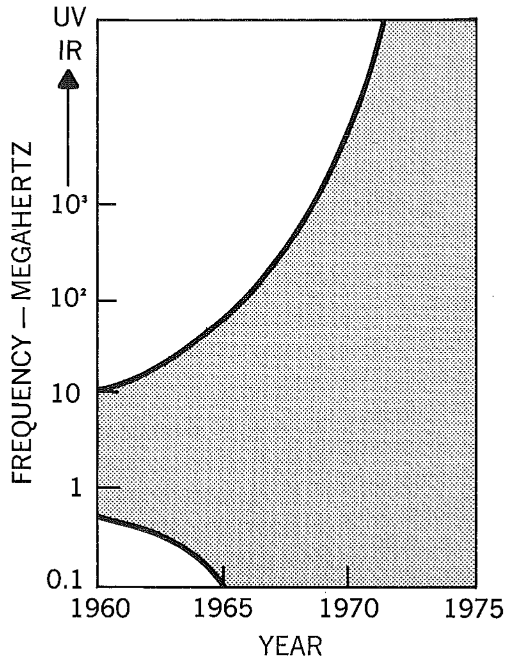
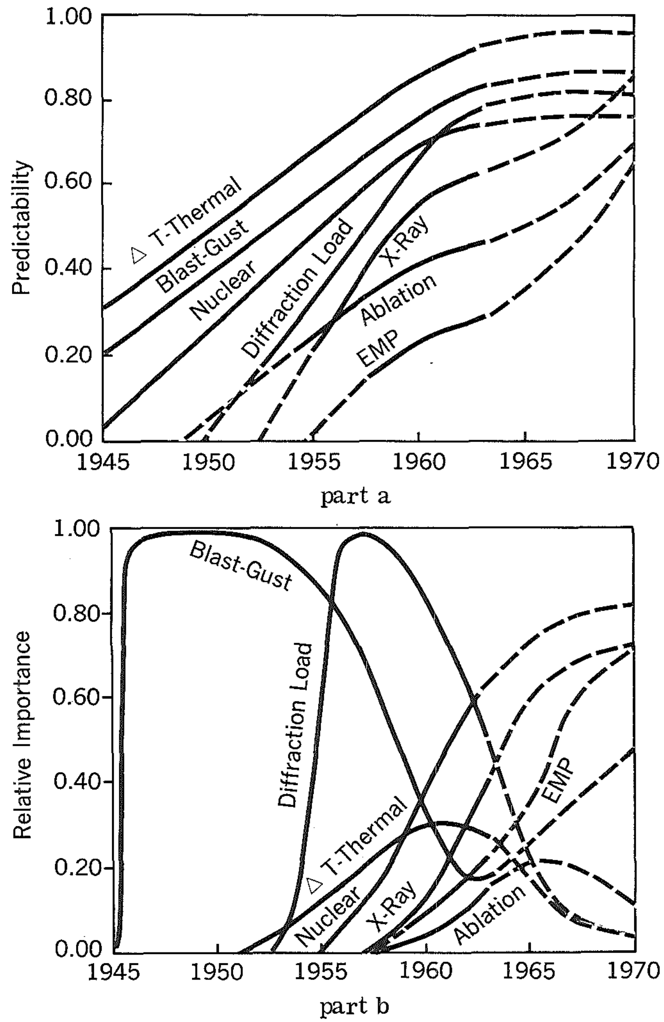


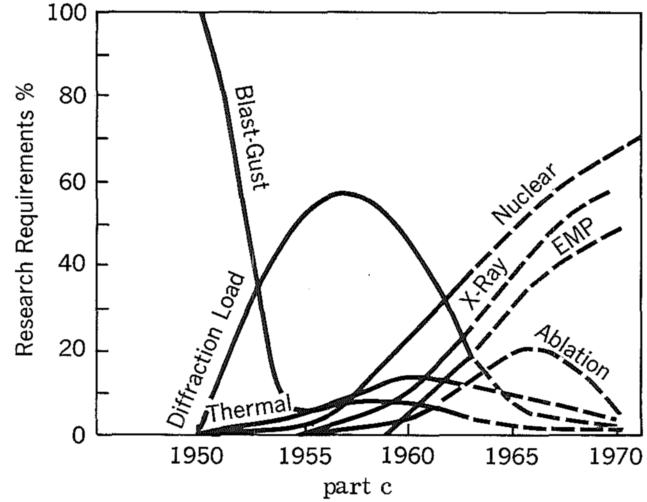
Figure 6.13. Expanding Frequency Spectrum Utilization and Increase in Need for Interference Control Procedures

In some areas of investigation, it is necessary to define the requirements for research and development in terms of more than one technological factor so that a more informative representation of these requirements can be depicted in one illustration. It is possible to forecast the state of the art in several disciplinary areas and to estimate the relative importance of each to an operational requirement during a forecast period. Once this is established, it should then be possible to determine research requirements and associated resource needs (personnel, funding) during the projected time frame. Figure 6.14 is an example of this graphical method. It was used in formulating the research requirements to reduce to a minimum the hazards to an aircraft and its crew from the effects of the detonation of a nuclear weapon. It was assumed that there would be an extended moratorium on testing nuclear weapons in the atmosphere. The predictions of effects (P) in part a of the figure when combined with the relative importance (RI) of the effects (part b), according to the formula

$$RR = \frac{RI \times (1-P)}{\Sigma[\,RI \times (1-P)\,]} \times 100$$

define the research requirements (RR) shown in part c of the figure.





Shown is the interrelationship between what is known and what can be predicted (P) from current research in nuclear weapons effects based on an extended moritorium of atmospheric nuclear testing (part a); relative importance (RI) of the effects, properly weighted for maximum protection of an aircraft and crew during operations (part b), and research requirements (RR) (part c) after correlating these factors (from parts a and b).

Figure 6. 14. Determining Research Requirements from Critical Factors

CHAPTER 7

LIMITATIONS AND PITFALLS OF FORECASTING

7.1. Introduction.

Previous chapters have been devoted to the positive aspects of forecasting, including techniques, methods of data structuring, cause and effect relationships, and the purposes of forecasting. While this is still the goal, it seems essential that some brief treatment be devoted to pointing out some of the major shortcomings and limitations of existing forecasts, since erroneous forecasts may lead to misdirected goals, loss of lead time, and wasted resources. It is possible to overcome many of these limitations if the users and producers of the forecast are made fully aware of them and the potentially adverse effects which can result.

7.2. Limitations of Forecasts.

Quinn, in a recent article (Ref 118), cites the following limiting factors of technological forecasts which require consideration.

7.2.1. Unpredictable Interactions.

"The interaction of several technological advances may create totally unexpected potentialities which can shatter all forecasts. For example, post-World War II decisions to emphasize manned bombers rather than missiles did not anticipate the potential interactions of more compact, higher powered atomic weapons, the increased reliability and decreased size of solid-state devices, the guidance and control capabilities of computers, and the impact of new heat-resistant materials. . . .

"In more applied fields, one can sometimes analyze how various advances in component technologies might affect a relatively simple system's overall operating characteristics. But the total scope of potentially supporting and competing technologies is often so great that no forecaster could hope to deal with all explicitly. Normally, he can only define the range within which the most likely resultants of the impinging forces will lie."

7.2.2. Unprecedented Demands.

"Completely unforeseeable future conditions and events may occasionally create whole new areas of primary and secondary demand. Thus:

"The development of atomic energy and missile systems created new computational demands on a scale never previously conceived. Virtually no one in the late 1930's could have foreseen that wholly new weapons systems would create such requirements by the mid-1940's. . . . Highly imaginative systems and parameter analyses may sometimes help to identify such potentials, but they will probably never be completely satisfactory.

"Moreover, occasionally a new technological capacity will itself create a whole new range of demands never recognized before. For example:

"In the early 1950's savants estimated that only some 30 electronic computers would be needed to handle all the calculations then being made by every bookkeeper, scientist, and technologist in the United States. This seeming lack of demand discouraged most potential manufacturers from entering the field. Only when actual use demonstrated that the computer made it possible to attack problems previously beyond imagination did the true nature of the market become apparent. In effect, the enormous new capacity to compute served to stimulate people to think of more complex problems requiring computation. . . .

"Dramatic new technologies will undoubtedly continue to have such self-amplifying effects on demand. Imaginative conception of product use and formal planning to supplement the product's initial demand cycle can help foresee some effects of this sort. But one can never hope to completely anticipate the ways an entire consuming population will ultimately use a new technology."

7.2.3. Major Unforeseen Discoveries.

"The discovery of wholly new phenomena may open significantly new technological potentials. Virtually no one anticipated such important discoveries as the transistor effect, superconductivity, lasers, or steroid activity. Each of these major breakthroughs has opened totally unexpected technological opportunities.

"The importance of such discoveries is so great that they are often cited as sufficient reasons for discounting all attempts at technological forecasting. What is overlooked is that relatively few of these breakthroughs occur during one generation. Also, to emphasize a point made earlier, these advances are not always as completely unprecedented as people assume. For instance, there is much evidence that some substance like penicillin was used during the Middle Ages. And the basic knowledge needed to construct lasers was essentially in hand in the 1930's, but the potential of such devices was unrecognized. In any event, such breakthroughs do not often simply burst forth on the world; rather, they frequently result from long streams of work, with small increments of knowledge accumulating until they suddenly "fit" into a new insight.

"Consequently, imaginative evaluations of current scientific activities may sometimes foresee the possibility and timing of significant breakthrough without being able to specify the precise form its results will take. However, both the shortcomings of imagination and the essential randomness of scientific discovery will undoubtedly keep forecasters' batting averages low in anticipating those major breakthroughs which disclose entirely new phenomena for the first time."

7.2.4. Inadequate Data.

"Perhaps the single factor most limiting the development of better technological forecasts is the inadequacy of source data. Only since the mid-1950's has the United States had reasonably reliable information on its scientific resource commitments. . . . Industry data are heavily limited by proprietary considerations. And economists have ignored technology — or assumed it as a constant — so long in their calculations that there are few past historical studies on which to base trend calculations. Consequently, not many organized data exist on which to hinge forecasts.

"All this means that forecasters often must develop their own primary data before proceeding to analyses. Cost considerations generally limit the relevant population the analyst can sample. And the accuracy of his studies can be correspondingly affected.

"Fortunately, in recent years the government, foundations, and large corporations have sponsored some major studies of specific problems and have introduced their results into the general literature. Reports by RAND Corporation, Stanford Research Institute, TEMPO, National Science Foundation, National Aeronautics and Space Administration, and Battelle Laboratories, among others, have dug out and presented important trends in technological progress. These reports can now serve as references and checks for other forecasters."

7.3 Complexity of the Problem.

Technological forecasting is an initial and basic part of the Defense Department planning cycle for research and development. The R&D program plan has been instituted to reduce risks inherent in the innovation of new military systems. Failure to reduce risks to a low or manageable level can result in large fiscal losses and disastrous effects on our defense posture. Forecasting plays an important part in the reduction of risks in the defense research and development program. Forecasting has to be responsive to the complex environment of the large number of decision-type problems experienced in research and development management.

Numerous choices for technical alternatives are now available from increasingly active R&D programs. Advanced systems will have a shorter life cycle, but will require long lead times for studying the larger number of technical alternatives. The demand for higher reliability and effectiveness of new systems accelerates the exploratory research and development work needed to test the feasibility of new components. Forecasting must precede this phase and make projections in an environment of considerable uncertainty.

Another condition which contributes to the complexity of the problem is lack of resources and demand in many areas of basic and applied research. Specifically, this refers to those for which there is no apparent end use, or which will require large expenditures for uncovering basic knowledge. Without the knowledge effort in these areas will provide, long-range effects or capabilities will remain unknown. Forecasting, then, has to attempt to visualize and present their potential on a basis of skimpy or seemingly unrelated data.

In addition to the problems evolving from the R&D management aspects, the forecaster has to deal with a formidable communication gap. Forecasting data, in general, are multicustomer products. The generated data are broad in scope and exhaustive in nature for many scientific disciplines. The body of data to support predictions is developed at the basic working research level and is highly technical in content. The key decisions for which the forecast is intended to provide justification and background data are made at the highest levels of management. The forecast has to transform highly scientific information which has a varying degree of reliability into a form for use by high-level planners and innovators. Just as one innovation or bit of new knowledge can have applicability in numerous areas, so also the development of a new device, capability, or system may require inputs from a multiplicity of disciplines and technologies. The resulting complex communications network must also provide a mechanism for identifying and communicating those incremental improvements in technology which individually have seemingly limited significance but, in combination, result in the bulk of technological advance. The input data for a technological forecast is not always amenable to a definite or dogmatic probability assessment and difficulties can arise from efforts of the forecaster to associate probabilities with his projections in order to effectively communicate with planners. This overall information transfer process has many probabilities of producing loss of meaning and significance.

7.4. Some Common Pitfalls.

To provide additional guidance to the forecaster, some typical pitfalls or hazards of forecasting from a paper by Robert U. Ayres (Ref 32) are summarized below.

7.4.1. Lack of Imagination.

Some technological forecasts presented in the past have been prepared as committee reports. Typical is the report "Technological Trends and National Policy" (Ref 151). Notwithstanding its virtues, certain forecasting shortcomings can be noted in this report. These shortcomings stemmed from overcautiousness that inhibited imagination. For example, the future possibilities for atomic energy, radar, antibiotics, and jet propulsion were not foreseen although all four were under intense development effort at that time. A bold prediction of large increases in not fully known functional capabilities requires considerable imagination on the part of an expert. Committees of experts, especially, are apt to make projections that are too cautious rather than imaginative.

This lack of imagination, however, can also be demonstrated by individuals. A classic example cited by Ayres (Ref 32) is that of Nevil Shute Norway, the English aeronautical engineer. In 1929, although very optimistic about civil aviation, he predicted that in 1980 commercial aircraft would be limited to a cruising speed of 110 to 130 mph and a range of 600 miles.

7.4.2. Overcompensation.

Many inventors and innovators have been ignored in their own time and country and later shown to be true pioneers in the causes and inventions they espoused. Typical cases are Goddard and his work on rockets, Whittle and the jet engine, and Henry Ford, with his early faith in the wide use of automobiles by the masses. Consequently, this causes some forecasters to become very bold and make predictions of enormous incremental increases bordering on the fantastic. There are people of scientific bent who hold that given the resources, time, and motivation, the human intellect can create virtually anything it can conceive. This type of pitfall can be overcome by the forecaster if he does not attempt to predict to the nth limit or too far in advance.

7.4.3. Failure to Anticipate Converging Developments and/or Changes in Competitive Systems.

Aspects of future scientific progress can be underestimated because of lack of consideration of nonrelated or nondisciplinary factors, such as resistance to change by vested interests, public inertia, costs, available resources, and lack of understanding of new technologies. Many research and development programs of a few years ago which induced great expectations failed to have a truly significant or very evident effect on our present environment. Borated high-energy fuels, nuclear-powered aircraft, and the relatively slow advancement of nuclear power for civilian use in the past are typical examples.

7.4.4. Concentration on Specific Configurations.

This pitfall can lead to large errors of underestimation, which can be minimized by extrapolating aggregated figures of merit or broad functional capabilities. These errors generally result from too much expertise, which concentrates on a small part of a scientific discipline or technology and does not view the whole picture.

7.4.5. Incorrect Calculation.

J. W. Campbell, in "Rocket Flight to the Moon," Philosophical Magazine, 1941, calculated that a moon rocket would weigh 10^6 tons in order to carry one pound of payload. Unrealistic assumptions led to an error of six orders of magnitude.

7.4.6. Intrinsic Uncertainties and Historical Accidents.

Many technological advancements depend on irrational, incalculable events, coincidence, individual insight, individual or personal drives, and personality quirks. In fact, the creative process in humans, which is probably the greatest force for the advancement of technology, is not yet understood and should be subject to more intensive study. Technological history has a large source of "what if" events such that technology could have progressed down a different path, had an opposite consequence taken place.

CHAPTER 8

CONCLUSION

The thesis advanced in this report is as follows: the current technology race places a high premium on the ability to assess developing technological trends correctly. The pace of this race and the increasing complexity of the problem have exceeded the ability of military forecasters to assess these trends by intuitive methods alone. In recent years a more systematic methodology of technological forecasting, which could lead to improved technological forecasts, has been evolving. The qualities sought in a forecast are explicitness, quantitative expression, reproducibility of results, and derivation on a logical basis. A number of forecasting techniques and conceptual schemes have been described which, hopefully, can increase the degree to which these qualities are found in future forecasts. It is emphasized that none of the methods is a universal one, nor should any be used as mechanistic "black box" approaches that substitute for, rather than supplement, the informed judgment of the forecaster. Their utility lies in enabling him to structure the available information so that the pattern of technological advance becomes more visible. If properly used, they can be expected to lead to a systematic, logical method of analysis conducted within a broader problem context.

BIBLIOGRAPHY

I. Air Force Documents.

1. Technology for Tomorrow, 5th Edition, 1962-63, Aeronautical Systems Division, AFSC, Wright-Patterson AFB, Ohio, 62ASOP-300, December 1962. (SECRET).

2. Project FORECAST. Organization and Mission Planning Group Report, 13 April 1963.

   Discusses organization and planned operation of the 1963 study, Project FORECAST, conducted by the Air Force. Explains duties of the individuals and panels and how it was expected the panels would interact.

3. Operation FORECAST, 14 Volumes, SCGF-46-7, Forecast Special Project Office, HQ, AFSC, Andrews AFB, Maryland: January 1964.

Flight Dynamics	(AD 354 051)	Secret
Propulsion	(AD 354 052)	Secret
Power Generation	(AD 354 053)	Secret
Materials	(AD 354 054)	Secret
Bioastronautics	(AD 354 055)	Secret
Weapons	(AD 354 057)	Secret
Communications, Vol. I	(AD 354 058)	Secret
Communications, Vol. II	(AD 354 059)	Secret
Navigation and Guidance, Vol. I	(AD 354 060)	Secret
Navigation and Guidance, Vol. II	(AD 354 061)	Secret
Electronic Countermeasures and Counter-Countermeasures	(AD 354 062)	Secret
Intelligence and Reconnaissance	(AD 354 063)	Secret
Data Processing and Display	(AD 449 391)	FOUO
Geophysics	(AD 449 392)	FOUO

4. A Systems Development Planning Structure, an interim report by Abt Associates, Inc., 14 Concord Lane, Cambridge, Mass., to HQ, Air Force Systems Command (SCLS), Andrews Air Force Base, Washington, D.C.: 18 November 1965.

   In the development of systems, this computerized technique is intended to provide the decision-maker with an estimate of the implications of his placing special emphasis on particular policies by describing possible situations related to each policy. It is designed to assist with the assignment of a consistent set of relative values to any number of objectives by eliciting "Yes" or "No" responses from the decision-maker to questions about preferences for various combinations of objectives.

5. An Approach to Research and Development Effectiveness, a paper presented by A. B. Nutt, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio, to 17th NAECON Conference Proceedings, 12 May 1965.

   This paper describes the rationale and use of RDE (Research and Development Effectiveness); a computerized planning program developed in-house and designed to utilize analytical techniques in the management of R&D resources in the Air Force Flight Dynamics Laboratory, RTD, AFSC.

6. AFSC Technological War Plan, formerly prepared by the Deputy Chief of Staff, Plans, AFSC, Washington, D. C. (SECRET).

   This report, which was discontinued in 1967, was the AFSC Command Plan for the conduct of R&D activity in support of their assigned responsibility. The TWP consisted of a basic plan and five supporting annexes. Purpose of each is stated briefly as follows:

   The "Basic Plan" integrated the content of the annexes and provided the transition of planning effort into programs and budgets.

   Annex A, "Environment," discussed the broad setting within which the technological threat and our military policy goals are evolved.

   Annex B, "Threat," described the expected evolution of aggressor systems and technology.

   Annex C, "Systems," projected and described concepts and capabilities which might evolve into the systems of the future AF force structures.

Annex D, "Technology," described technology for deriving system capabilities and projected efforts to strengthen the Command's technological base.

Annex E, "Resources," projected mission man-years, technical facilities and RDT&E funds necessary to develop, test and evaluate both technology and systems.

7. Technical Objectives Documents, Research and Technology Division, AFSC, 36 Technical Area Reports, November 1965. (Classified according to subject covered.)

These documents are prepared to provide means of communicating with science and industry, to describe the Air Force's objectives in each of 36 different technical areas. As is the case in any selective grouping of science and technology, it is difficult to draw sharp boundaries between areas and thus overlaps occur.

8. RTD Technological War Plan/Long Range Plan, Research and Technology Division, AFSC, Washington, D.C. Report No. RTL 64-25 April 1964 and changes. (SECRET).

This plan describes the future course of action that the Research and Technology Division will take in managing the Air Force Exploratory and Advanced Development Programs. It is prepared by the people most familiar with these programs — the working scientists and engineers in the Air Force laboratories. It is an attainable plan; it describes how RTD will allocate those resources which it may realistically expect to have available over the next decade.

The Plan is oriented toward achieving the level of technology required to attain the future Air Force capabilities identified by PROJECT FORECAST. It also recognizes that a major objective of this division is the building and maintaining in our laboratories a strong in-house technical capability.

Changes will undoubtedly alter various parts of this Plan. Breakthroughs will occur and unsuccessful efforts will be terminated. On the whole, however, the Plan represents a coordinated picture of where RTD is going over the next decade, as we now see it.

9. Wells, H. A., The Allocation of Research and Development Resources. WADC Technical Note 58-119, Air Research and Development Center, Wright-Patterson AFB, Ohio: 1959. (AD 155 784)

II. Army Documents.

10. Army Long Range Technological Forecast, 4th Edition. Prepared by the Army Materiel Command under the staff supervision of the Office of the Chief of Research and Development, Department of the Army, 3 Volumes. 1967. (SECRET RD NOFORN).

The Army Long Range Technological Forecast (ALRTF) is designed to be of value in both technical and operational planning. It covers a period of 20 years.

The Forecast describes knowledge, capabilities, and examples of materiel which science and technology can be expected to produce if supported by orderly programs of research and development and represents one element of a current and comprehensive plan for long-range technical planning.

Published in 3 volumes entitled: "Scientific Opportunities," "Technological Capabilities," and "Advanced Systems Concepts."

11. Forecast in Depth - Information Processing Systems for the Field Army, H. T. Darracott, Technical Forecasting and Objectives Branch, Research and Development Directorate, U. S. Army Materiel Command, Washington, D. C. (For Official Use Only) (AD 479 282L)

Comprehensive study of the peripheral equipments in an automatic information processing system. Part of its purpose was to provide a tool to aid in the design of such equipment for tactical data processing systems.

12. The Army Research Plan, Industry Edition, Office of the Chief of Research and Development, Department of the Army, No. ARP-65, dated 1 March 1965. (CONFIDENTIAL).

The Army Research Plan (ARP) is an extension of the Army Research and Development Long Range Plan. Its purpose is to afford guidance to those commanders and agencies responsible for the detailed formulation of the Army's research programs by assigning relative levels of recognition to scientific and technological areas of interest to the Army.

13. Combat Development Objectives Guide. Combat Development Command, Department of the Army, 15 August 1964. (SECRET RD-NOFORN).

The purpose of the Combat Development Objectives Guide is to provide guidance for the development of future operational concepts, organizations and materiel. States general combat development objectives and consolidates the studies, field experiments, and

approved qualitative materiel requirements which are pointed toward the attainment of those objectives.

14. The Army Study System, Director Special Studies, Department of the Army, Office of the Chief of Staff, Washington, D.C., 3 Volumes, 18 May 1964. (For Official Use Only).

Examines current (1964) Army major study activities and evaluates effectiveness of the studies as inputs to planning, programming, budgeting, and other needs. The three volumes are: Basic Study (Vol. I); Study Documentation and Information Retrieval (Vol. II); and Bibliography of Current Major Army Studies, 1962 to Date (1964) (Vol. III).

15. The Army Master Study Program 1967, Army Study Advisory Committee, Chief of Staff, Department of the Army, dated 27 December 1966. (CONFIDENTIAL).

The Army Master Study Program, 1965, is designed to provide:

a. A formal, approved list of those major studies being pursued under the sponsorship of the Army Staff Agencies, HQ, Department of the Army, which are considered to be of prime importance to overall Army planning, force development and programming.

b. A mechanism for the use of the Army Staff to determine gaps or unbalanced emphasis within the overall study effort and thus enable more effective support by studies to the orderly development of the well-balanced, multipurpose Army of the future.

c. An orientation of the Army's study processes toward the unifying concepts, missions and guidance for the Army of the future which are enunciated in the document "Assessment of the Army, 1964."

d. A useful compendium of major Army study efforts for the information of the Office of the Secretary of Defense and other interested government agencies.

III. Navy Documents.

16. Navy Long Range Strategic Study (NLRSS)-73, prepared by Strategic Plans Division (Op-60), Chief of Naval Operations, 9 May 1965. (SECRET).

17. Navy Mid-Range Objectives Through 1975 Under Limited Funding Assumptions (MRO-75), prepared by Long Range Objectives Group (Op-93), Chief of Naval Operations, 1 June 1964. (SECRET).

18. Bureau of Naval Weapons Research and Development Planning Guide, Plans Division, RDT&E, BuWeps, 1 July 1963. (SECRET).

19. Bureau of Ships Long Range Plan for Research and Development, (LRP-62), Volume IA (CONFIDENTIAL), Volume IB (SECRET), Volume IC (CONFIDENTIAL); Department of the Navy, Washington, D. C.: August 1962.

20. Cetron, M. J., R. J. Happel, W. C. Hodgson, W. A. McKenney, T. I. Monahan, A Proposal for a Navy Technological Forecast, 2 Volumes, HQ, Naval Material Command, Washington, D. C.: 1 May 1966.

21. Index of Navy Development Requirements, DCNO(D), Encl (1) to CNO 0201P70, January 1965. (CONFIDENTIAL).

Contains: (a) A list of Planning Objectives, General Operational Requirements, Tentative Specific Operational Requirements, Specific Operational Requirements and Advanced Development Objectives (Part I) for use in verifying that requirements files are current; (b) An index of Operational Requirements and Development Characteristics (Part II), which will be phased out as they are replaced by updated GOR's and SOR's.

22. Department of the Navy RDT&E Management Guide, Volumes I and II, NAVEXOS P-2457, July 1964.

Published in two volumes: "Volume I - Organization and Procedures" and "Volumes II - Appendices." Prepared to aid both newcomers and practicing "journeymen."

23. Rationales for Goals in Part I - The Undersea Target of Goals for Technology in Exploratory Development. Draft Report, Chief of Naval Development (MAG 311), 31 August 1965. (SECRET).

Gives rationales used in deriving the goals for technology in exploratory development.

24. Goals for Technology in Exploratory Development - The Undersea Target, Preliminary report published by the Chief of Naval Development (MAG 311), 31 August 1965. (SECRET).

Purpose is to assist in formulating the Exploratory Development Program of the Navy. The goals included herein are based on various formal long term statements of need expressed by the Chief of Naval Operations and the Commandant of the Marine Corps. This

document is intended for in-house use by personnel concerned with planning and programming the Exploratory Development Program at all levels of the technical community.

25. Goals for Technology in Exploratory Development - The Air Target. Preliminary report published by the Chief of Naval Development (MAG 311), 17 November 1965. (SECRET).

Purpose is to assist in formulating the Exploratory Development Program of the Navy. The goals included herein are based on various formal long term statements of need expressed by the Chief of Naval Operations and the Commandant of the Marine Corps. This document is intended for in-house use by personnel concerned with planning and programming the Exploratory Development Program at all levels of the technical community.

26. "Advanced Developments and Advanced Development Candidates for Tactical Missiles and Weapons," PROJECT SMEADO '67, Missile Development Office (RM), Bureau of Naval Weapons, RM-67-1A, June 1965. (SECRET).

Main body, Sections 1 through 9, consists of brief summaries of FY 67 plans for Advanced Developments and Advanced Development Candidates in the Tactical Missiles and Weapons Area. These summaries are abstracts of forty individual current planning documents, prepared under PROJECT SMEADO. Taken together, the forty summaries constitute a SMEADO '67 Catalog for Missile Development Office (RM) operations. Plans for the Missile Flight Evaluation Systems Area are not included.

27. Navy Program Factors, Office of Chief of Naval Operations, OPNAV 90P-02, Revised May 1965. (CONFIDENTIAL RD).

"Navy Program Factors" supplements the Navy Programming Manual (OPNAV 90P-1). It is comprised of Program Factor Description Sheets and Program Factor Data Sheets grouped by the major resource areas of ships and aircraft. The program factors will be used in the Navy planning and programming analytical procedure (Cost Model) for estimating the resource implications (material, personnel, dollars) of various force levels and varying levels of support of these forces.

28. "Project SEABED," Advanced Sea-Based Deterrence Summer Study 1964, Naval Ordnance Laboratory, Silver Spring, Maryland: July 1964. (SECRET RD).

Four-volume report giving the results of the summer study held in Monterey, California, by the Special Projects Office. The four

volumes are as follows:

Volume I - Summary
Volume II - Contemporary Analysis of Sea-Based Deterrence
Volume III - Weapons Systems for Sea-Based Deterrence
Volume IV - Advanced Undersea Technology

29. Pellini, W. S., Status and Projections of Developments in Hull Structural Materials for Deep Ocean Vehicles and Fixed Bottom Installations, Naval Research Laboratory, NRL Report 6167, Washington, D. C.: 4 November 1964.

Projects state-of-the-art in materials for deep ocean operation. Used at PROJECT SEABED in defining the potentials for deep-ocean vehicles and installations in the 1980's and the R&D necessary to make these potentials a reality.

IV. Non-Service Documents.

30. Abt Associates, Inc., "Survey of the State of the Art: Social, Political, and Economic Models and Simulations," report prepared for the National Commission on Technology, Automation, and Economic Progress. Published in Applying Technology to Unmet Needs, Appendix, Volume V, Technology and the American Economy, Washington, D. C.: U. S. Government Printing Office, February 1966.

31. Aerospace Industries Association, Aerospace Technical Forecast - 1962 - 1972, Aerospace Industries Association (A. I. A.), Washington, D. C.: 1962.

32. Ayres, Robert U., On Technological Forecasting, Report HI-484-DP, January 17, 1966. Hudson Institute, Harmon-on-Hudson, New York. (RESTRICTED).

33. Ayres, Robert U., Technology and the Prospects for World Food Production, Report HI-640-DP (Rev. 2), Hudson Institute, Harmon-on-Hudson, New York: 19 April 1966. 71 pp.

34. Baade, Fritz, The Race to the Year 2000. Doubleday, New York: 1962. 246 pp.

35. Bagby, F. L., et al., A Feasibility Study of Techniques for Measuring and Predicting the State-of-the-Art, Batelle Memorial Institute, Columbus, Ohio: July 1959. DDC Report (AD 233 350).

Discusses the results of a feasibility study on techniques for measuring and predicting the state-of-the-art. The method used relied heavily on case histories in system development. The study was conducted for the Air Force.

36. Bell, Daniel, "Twelve Modes of Prediction." J. Gould, (Ed.), Penguin Survey of the Social Sciences, Penguin Books, 1965, 96 pp.

37. Bicker, Robert E., The Changing Relationship Between the Air Force and the Aerospace Industry, Memorandum RM-4101-PR, RAND Corporation, Santa Monica, California: July 1964. 79 pp.

38. Bisplinghoff, R. L., New Technology, its Selection and Development, Office of Advanced Research and Technology, National Aeronautics and Space Administration, Washington, D. C.: February 1965.

39. Blackett, P. M. S., "Tizard and the Science of War," Nature, March, 1960.

40. Bliven, Bruce, Preview For Tomorrow. The Unfinished Business of Science. Alfred A. Knopf, New York, N. Y.: 1953. 345 pp.

41. Bright, James R. (Ed.), Research, Development, and Technological Innovation, Richard D. Irwin, Homewood, Illinois: 1964. 783 pp.

42. Bright, James R. "Opportunity and Threat in Technological Change," Harvard Business Review, Nov/Dec. 1963.

43. Bright, James R. (Ed.), Technological Planning on the Corporate Level, Division of Research, Harvard Business School, Boston, Massachusetts: 1961.

44. Brown, Bernice and Olaf Helmer, Improving the Reliability of Estimates Obtained from a Consensus of Experts, Report P-2986, The RAND Corporation, Santa Monica, California: 1964.

45. Brown, Harrison, The Challenge of Man's Future: An Inquiry Concerning the Condition of Man during the Years that Lie Ahead. Viking Press, New York: 1954. 290 pp.

46. Brown, J. H., and E. S. Cheaney, Report on a Study of Future Research Activity and Pertinent Forecasting Techniques for Battelle's Trends in Research Study, Battelle Memorial Institute, Columbus, Ohio: 1965. 51 pp.

47. Brozen, Yale, "Determination of the Direction of Technological Change," American Economic Review, Volume 43, May 1953, pp. 288-302.

48. Bruce, Robert D., The Dimensions of Change, paper presented at the First National Joint Meeting, Operations Research Society of America and the Institute of Management Sciences, San Francisco, California: 9 November 1961.

49. Calder, Richie, After the Seventh Day. The World Man Created. Simon and Schuster, New York: 1961. 448 pp.

50. Cetron, M. J., "Quantitative Utility Estimates for Science and Technology (QUEST)," IEEE Transactions on Engineering Management, Volume EM-14, No. 1, March 1967. pp. 46-55.

51. Cetron, M. J., Joseph Martino, Lewis Roepcke, "The Selection of R and D Program Content, Survey of Quantitative Methods," IEEE Transactions on Engineering Management, Volume EM-14, No. 1, March 1967. pp. 4-12.

52. Cheaney, E. S., Technical Forecasting as a Basis for Planning, ASME paper 66-MD-67, presented at the Design Engineering Conference, Chicago, Illinois, 9-12 May 1966, ASME, New York.

53. Conant, James B., Science and Common Sense, Yale University Press, New Haven, 1952, Yale Paperbound (Tenth Printing): July 1964. 344 pp.

54. Dalkey, N., and Olaf Helmer, "An Experimental Application of the Delphi Method to the Use of Experts," Management Science 9, pp. 458-67. (April 1963).

55. Darwin, Charles Galton, The Next Million Years, Rupert Hart-Davis, London: 1952. 210 pp.

56. De Solla Price, D. J., "The Acceleration of Science - Crisis in our Technological Civilization," Product Eng. 32, 56-9 (March 6, 1961.)

57. De Solla Price, Derek J., "A Calculus of Science," International Science and Technology, No. 15, March 1963.

58. De Solla Price, Derek J., Little Science, Big Science, Columbia University Press, New York, 1963, Columbia Paperback Edition, 1965. 118 pp.

59. Long Range Scientific and Technical Intelligence Assessment (LRTIA) of the USSR, Defense Intelligence Agency, Washington, Report No. ST-CS-17-1-65-INT, dated 1 August 1965. (SECRET-NOFORN)

60. Dockx, S., and P. Bernays, Ed., Information and Prediction in Science. Academic Press, New York: 1965. 272 pp.

61. Domar, E. D., "On the Measurement of Technological Change," Economic Journal 71, pp. 709-29. (December 1961.)

62. Doyle, L. B., How to Plot a Breakthrough, System Development Corporation, Santa Monica, California: Dec. 1963. (AD 427 161).

63. Ellul, Jacques, The Technological Society. Alfred A. Knopf, New York: 1964. 449 pp.

64. Emme, Eugene M., A History of Space Flight, Holt, Rinehart, and Winston, Inc., New York: 1965.

65. Ewell, L. N., "Uncle Sam Gazes into his Crystal Ball," Armed Forces Chemical Journal, Volume VI, January 1953. pp. 9-15.

66. Fedor, Walter S., Senior Editor, "Commodity Forecasting by Computer Time Sharing," C&EN Feature, 12 September 1966.

67. Forrester, Jay, Industrial Dynamics, M.I.T. Press, Cambridge, Massachusetts: 1961.

68. Furnas, C. C., The Next Hundred Years - The Unfinished Business of Science, Williams & Wilkins, Baltimore, Md.: 1936.

69. Gabor, Dennis, Inventing the Future, Secker and Warburg, New York, 1963, Pelican Book A 663, Penguin Books, Harmondsworth, Middlesex: 1964. 199 pp.

70. Garrison, W. L., and D. F. Marble, A Prolegomenon to the Forecasting of Transportation Development, Northwestern University, Evanston, Illinois: August 1965 (AD 621 514).

71. Gilfillan, S. Colum, "The Prediction of Inventions," in: U. S. National Resources Committee, Technological Trends and National Policy, Part One, Section II, pp. 15-23. U. S. Government Printing Office, June 1937.

72. Gilfillan, S. Colum, The Sociology of Invention, Follett Publishing Co., Chicago, Illinois: 1935.

73. Gilfillan, S. Colum, "The Prediction of Technical Change," The Review of Economics and Statistics, Volume XXXIV, November 1952, pp. 368-385.

74. Gilman, William, Science: USA, The Viking Press, New York: 1965.

75. Gordon, R. J., O. Helmer, Report on a Long-Range Forecasting Study, Report P-2982 RAND Corporation, Santa Monica, California: September 1964.

Describes an experimental trend-predicting exercise covering a period extending as far as fifty years into the future. The experiment used a sequence of questionnaires to elicit prediction from individual experts in six broad areas: scientific breakthroughs; population growth; automation; space progress; probability and prevention of war; and future weapon systems.

76. Gordon, Theodore J., The Future, St. Martin's Press, New York: 1965. 185 pp.

77. Granger, Charles H., "The Hierarchy of Objectives," Harvard Business Review, May/June 1964, pp. 63-74.

78. Greenberger, Martin (Ed.), Computers and the World of the Future, MIT Press, Cambridge, Massachusetts: 1962.

79. Griliches, Zvi, "Hybrid Corn: An Exploration in the Economics of Technological Change," Econometrica (Journal of the Econometric Society), Volume 25, No. 4, October 1957, pp. 501-522.

80. Haase, R. H., and W. H. T. Holden, Performances of Land Transportation Vehicles, Memorandum RM-3966-RC, The RAND Corporation, Santa Monica, California: January 1964. p. 138.

81. Helmer, O., and N. Rescher, On the Epistemology of the Inexact Sciences, Report R-353, RAND Corporation, Santa Monica, California: February 1960. (AD 236 439)

82. Helmer, Olaf, Social Technology, Report P-3063, The RAND Corporation, Santa Monica, California: February 1965. (AD 460 520)

83. Hertz, D. B., "The Management of Innovation," Management Review, April 1965, pp. 49-52.

84. Hetrick, J. C., and G. E. Kimball, "A Model for the Discovery and Application of Knowledge," in: Basic Research in the Navy, Volume II, U. S. Department of Commerce, Washington, D. C.: 1959, pp. 5-29.

85. Hitch, Charles J., Decision-Making for Defense, University of California Press, Berkeley and Los Angeles: 1965.

86. Holton, Gerard (Ed.), "Science and Culture - A Study of Cohesive and Disjunctive Forces," The Daedalus Library, Volume 4, Houghton Mifflin Co., Boston, Massachusetts: 1965.

87. Isenson, Raymond S., "Technological Forecasting in Perspective," Management Science, October 1966.

88. Industrial Research, "Exploring the Sea, Etc.," Series of Articles in Industrial Research, March 1966, pp. 7-114.

89. Institute of Radio Engineers, "Communications and Electronics - 2012 A.D.," Proceedings of the IRE, Volume 50, No. 5, 1962, The Institute of Radio Engineers, Inc., (IEEE - The Institute of Electrical and Electronics Engineers), New York.

90. Jantsch, Erich, Technological Forecasting in Perspective, Working Paper DAS/SPR/66.2, Organization for Economic Cooperation and Development, Paris, France, October 1966. To be published in Spring 1967.

91. Jestice, A. L., Project PATTERN-Planning Assistance Through Technical Evaluation of Relevance Numbers, paper presented to Operations Research Society of America, October 7-8-9, 1964. Pamphlet Minn.-Honeywell, Inc., Washington, D.C. (n.d.)

Discusses a method of evaluating and determining how to structure a research and development program, utilizing Honeywell's relevance tree approach.

92. Jewkes, John, David Sawers, Richard Stillerman, The Sources of Invention, MacMillan & Co., LTG., London, England: 1958.

93. deJouvenel, B., Futuribles, Report P-3045, RAND Corporation, Santa Monica, California: January 1965. (AD 610 217)

94. deJouvenel, B., The Art of Conjecture, translated by Nikita Land, Basic Books, Inc., New York: 1967.

95. Lenz, R. C., Jr., Technological Forecasting, 2d Edition, Aeronautical Systems Division, AFSC, ASD-TDR-62-414, Wright-Patterson AFB, Ohio: June 1962. (AD 408 085)

Presents several methods of forecasting rates of technological advance. The methods include forecasting by extrapolation of existing rates; by analogies to biological growth processes; by precursive events; by derivation from primary trends; by interpretation of trend characteristics; and by dynamic simulation of the process of technological improvement. The investigation included a search of the literature for references to principles of technological progress and for methods which have been used for predictive purposes.

96. Lessing, Lawrence, "Where the Industries of the Seventies Will Come From," Fortune, January 1967. p. 96.

97. Arthur D. Little, Inc., Patterns and Problems of Technical Innovation in American Industry, Report to National Science Foundation, Boston, Massachusetts: September 1963. (Available OTS, Washington, D.C., PB-181573.)

98. Litton Systems, Inc., U. S. Defense Posture - Overview 1964-1974, Guidance and Control Systems Division, Publication No. 3373, OPR64-1, June 1964.

Provides an overview of the economic, political and military context of the defense market over the next ten years. The major environmental conditions that will shape the domestic and international economic and political climate which will prevail during this time period are evaluated in light of their impact on the defense market.

99. Linstone, H. A., Mirage 75 - Military Requirements Analysis Generation 1970-75, Report No. LAC/592371, Lockheed Aircraft Corporation, Burbank, California: January 1965. (SECRET RD).

This report is the Lockheed corporate planning study on military requirements. Projects the environment to 1970-75 and forecasts systems and technology to meet the projected environment. A similar study, "Mirage 80," is under way.

100. Lovewell, P. J., and R. D. Bruce, Stanford Research Institute, "How We Predict Technological Change," New Scientist, No. 274, 15 February 1962.

101. Magee, John F., "Decision Trees for Decision-Making," Harvard Business Review, Volume 42, July/August 1964, pp. 126-138.

102. Mansfield, Edwin, and Carlton Hensley, "The Logistic Process: Tables of the Stochastic Epidemic Curve and Applications," The Journal of the Royal Statistical Society, 1960, pp. 332-337; Reprint No. 60, Graduate School of Industrial Administration, Carnegie Institute of Technology, Pittsburgh, Pennsylvania: 1960.

103. McGraw-Hill, Research and Development in American Industry, Department of Economics, McGraw-Hill Publications, New York: 6 May 1966.

104. McLuhan, Marshall, Understanding Media: The Extensions of Man, McGraw-Hill Paperback, McGraw-Hill, Third Printing, New York: 1966. 364 pp.

105. Mesthene, Emmanuel G., "On Understanding Change: The Harvard University Program on Technology and Society," Technology and Culture, Spring 1965. pp. 222-235.

106. Mumford, L. S., "Loneliness of the Long Range Forecaster," Chemical Industry, 1788-96, (November 9, 1963).

107. Myers, Sumner, Industrial Innovations - Their Characteristics and Their Scientific and Technical Information Bases, a Special Report to the National Science Foundation; National Planning Association, Washington, D.C.: April 1966. 24 pp.

108. Nelson, Richard A., The Link Between Science and Invention: The Case of the Transistor, RAND Corporation, P-1854-RC, 15 December 1957. (AD 222-163)

109. Neumann, John von, "Can We Survive Technology," Fortune, June 1955.

110. New York Times Magazine, "The Future," New York Times, Section 6, Part 2, 19 April 1964, pp. 86-118.

111. Ozbekhan, Hasan, The Idea of a "Look-Out" Institution, System Development Corporation, Santa Monica, California: March 1965. 20 pp.

112. Ozbekhan, Hasan, Technology and Man's Future, Report SP-2494, System Development Corporation, Santa Monica, California: 27 May 1966. 41 pp.

113. Page, Robert Morris, "The Origin of Radar," Science Study Series, Anchor Books, Doubleday & Co., Garden City, N. Y.: 1962. 198 pp.

114. Pardee, F. S., State-of-the-Art Projection and Long Range Planning of Applied Research, The RAND Corporation, Santa Monica, California: July 1965. (AD 618 561)

115. Peterson, M. S., "The Trouble with Technological Forecasting," Science 144, 15 May 1964, pp. 796-6.

116. Prehoda, Robert W., The Future and Technological Forecasting. Prepublication manuscript, expected to be published in the U. S. in 1967.

117. Quade, E. S., (Ed.) Analysis for Military Decision, The RAND Corporation, R-387-PR, November 1964.

118. Quinn, James Brian, "Technological Forecasting," Harvard Business Review, Mar/April 1967.

119. Ridenour, Louis N., "Physical Science and the Future," in: Lyman Bryson (Ed.) Facing the Future's Risks - Studies Toward Predicting the Unforeseen, Harper & Brothers, New York: 1953. pp. 60-89.

120. Rogers, Everett, M., "Diffusion of Innovations," Free Press, New York: 1962. 367 pp.

121. Samson Science Corporation, Microelectronics - Revolutionary Impact of New Technology, Samson Report No. 2, available from Samson Science Corporation, 270 Park Avenue, New York, N. Y.: 1965. 34 pp.

122. Samson Science Corporation, Satellite Communications - Comsat and the Industry, Samson Report No. 1. Samson Science Corporation, 270 Park Avenue, New York, N. Y.: December 1964. 84 pp.

123. Sarnoff, David, "By the End of the Twentieth Century," Fortune Magazine, May 1964, pp. 116-119.

124. Schaeffer, K. H., J. B. Fink, M. Rappaport, L. Wainstein, and C. J. Erickson. The Knowledgeable Analyst: An Approach to Structuring Man-Machine Systems, Project IMU 3546, Stanford Research Institute, Menlo Park, California: 1963. (AD 297 432)

125. Schon, D., et al., The Role of the Federal Government in Technological Forecasting, Interagency Task Group on Technological Forecasting in Federal Government, January 1966.

A report to the President's Committee on Manpower and to the National Commission on Technology, Automation and Economic Progress. Specifically, the investigation focused on:

a. Action points in government at which technological forecasting might be useful and used, if available.

b. Criteria for information at these points.

c. Current technological forecasting activities and methodologies and their adequacy to Federal requirements.

126. Scientific American, "The Future as Suggested by the Development of the Past 75 Years," October 1920.

127. Scientific American, A symposium comprising the following articles: J. Bronowski, "The Creative Process"; Paul R. Halmos, "Innovation in Mathematics"; Freeman J. Dyson, "Innovation in

Physics"; George Wald, "Innovation in Biology"; John R. Pierce, "Innovation in Technology"; John C. Eccles, "The Physiology of Imagination"; Frank Barron, "The Psychology of Imagination"; Warren Weaver, "The Encouragement of Science"; Scientific American, September 1958.

128. Semkov, B. F., "Soviet Scientists Discuss Methodology and Planning of Scientific Research," translation from Voprosy (Problems of Philosophy) (Vopr. Filosofii), No. 7, TT-65-30027, Joint Publ. Research Service, OTS, U. S. Department of Commerce, Washington, D. C.: 1964.

129. Siegel, Irving H., "Technological Change and Long-Run Forecasting," The Journal of Business of the University of Chicago, Volume XXVI, No. 3, July 1953, pp. 141-156.

130. Sigford, J. V., and R. H. Parvin, "Project PATTERN: A Methodology for Determining Relevance in Complex Decision-Making," IEEE Transactions on Engineering Management, Volume EM-12, No. 1, March 1965, pp. 9-13.

131. Silberman, C. E., "Is Technology Taking Over?" Philosophies of J. Ellul and M. McLuhan, Fortune 73, February 1966, pp. 112-115.

132. Smith, Bruce L., The Concept of Scientific Choice: A Brief Review of Literature, Report P-3156, RAND Corporation, June 1965. 54 pp. (AD 616 977)

133. Stanford Research Institute. The World of 1975, (Composite of following SRI Reports: 232, 233, 234, 235, 236). (n. d.)

Composite of reports on forecasts by SRI Long Range Planning Service in predicting the world of 1975. Includes the following subjects:

a. The International Prospect.
b. Economic Trends.
c. Governmental and Political Trends.
d. Science and Technology.
e. Social and Cultural Framework.

134. Stockfish, J. A., (Editor). Planning and Forecasting in the Defense Industries, Wadsworth Publishing Co., (papers presented at a UCLA seminar on 4-5 May 1960), Belmont, California: 1962.

135. Stromer, P. R., Long-Range Planning and Technological Forecasting: An Annotated Bibliography, SRB-63-12, Lockheed Missiles and Space Co., Sunnyvale, California: November 1963. (AD 441 618).

136. Stromer, P. R., Long-Range Planning and Technological Forecasting: An Annotated Bibliography, Supplement I, SRB-65-1, Lockheed Missiles and Space Co., Sunnyvale, California: February 1965. (AD 457 949).

137. Swager, William L., Industrial Implications of Technological Forecasting, paper presented to the Fourth Symposium of the Engineer-Economy Division of the American Society for Engineering Education in Chicago, Illinois, 19 June 1965. Battelle Memorial Institute.

138. Swager, William L., "Technological Forecasting for Practical Planning," Petroleum Management, July 1966.

139. Sweezy, Eldon E., Technological Forecasting - Principles and Techniques, paper presented at the 4th Symposium of the Engineering Economy Division, the American Society for Engineering Education, Chicago, Illinois: 19 June 1965.

140. Syracuse University Research Corporation (Project 1985), The United States and the World in the 1985 Era, DDC Report AD 613 527 (Annex, AD 613 528), March 1964.

Prepared in response to request by the Marine Corps to predict what certain aspects of the world would be like in 1985. In the language of the Marine Corps, "This study will examine projected national objectives and policies, and international and domestic military, economic, and technological factors affecting the United States in the 1985 era."

141. Syracuse University Research Corporation, Science and Technology in the 1985 Era, (Project 1985), DDC Report AD 613 525 (Appendix AD 613 526), May 1964.

Covers the technological aspects of the projection. Forecasts technology as related to the Marine Corps of the next two decades.

142. Teilhard de Chardin, Pierre, (Translation), The Future of Man, Collins, London, England: 1964.

143. Thomson, Sir George, The Foreseeable Future, Cambridge University Press: 1955. 166 pp.

144. Thirring, Hans, Energy for Man: From Windmills to Nuclear Power, Harper and Row, New York: 1958. 409 pp.

145. U. S. Department of Labor, Measurement of Technological Change, by Solomon Fabricant, Seminar on Manpower Policy and Program, No. 4, October 1964. 32 pp.

146. U. S. National Academy of Sciences-National Research Council, Chemistry: Opportunities and Needs, Publication 1292, Academy of Sciences-National Research Council, Washington, D. C.: 1965.

147. U. S. National Academy of Sciences, Physics: Survey and Outlook: Reports on the Subfields of Physics, National Research Council, Washington, D. C.: 1966.

148. U. S. National Academy of Sciences, Theoretical Chemistry - A Current Review, Publication 1292-D, National Research Council, Washington, D. C.: 1966. 44 pp.

149. U. S. National Bureau of Economic Research, The Rate and Direction of Inventive Activity - Economic and Social Factors, A Conference of Universities - Princeton University Press, Princeton, N. J.: 1962.

150. U. S. National Commission on Technology, Automation, and Economic Progress, Report, Volume I, Technology and American Economy, Washington, D. C.: February 1966. 115 pp.

151. U. S. National Resources Committee, Technological Trends and National Policy - Including the Social Implications of New Inventions, a Report of the Subcommittee on Technology, U. S. Government Printing Office, Washington, D. C.: June 1937.

152. United Nations, A Select Bibliography on Industrial Research, from 1944 to June 1964, reference paper 1, prepared for the Inter-regional Seminar on Industrial Research and Development Institutes in Developing Countries, 30 Nov - 12 Dec 1964, Beirut, Lebanon, Centre for Industrial Development, Department of Economic and Social Affairs, United Nations, New York: 1964. 37 pp.

153. Ubbelohde, A. R., Man and Energy. George Braziller, New York: 1955. 247 pp.

154. Vassiliev, M., and S. Gouschev (editors), Life in the Twenty-First Century, translated from Russian, first published in Russia 1959, Penguin Special, Penguin Books, Harmondsworth, Middlesex: 1961. 222 pp.

155. Wagle, B., "Some Statistical Aids in Forecasting," Internal Report Esso Petroleum Co., LTD., London; introduction published under the title "A Review of Two Statistical Aids in Forecasting," The Statistician, Volume 15, No. 2, (1965).

156. Warner, Aaron W., Dean Morse, Alfred S. Eichner (Editors). The Impact of Science on Technology, Columbia University Press, New York: 1965.

157. Warner, Aaron W., and Dean Morse (Editors). Technological Innovation and Society, Columbia University Press, New York: 1966.

158. Ways, Max, "The Road to 1977," Fortune, January 1967, p. 93.

159. Wolstenholme, Gordon (Editor), Man and His Future, A Ciba Foundation Volume, Little Brown and Company, Boston, Massachusetts: 1963. 410 pp.

160. Wohlstetter, A., "Technology, Prediction and Disorder," Bulletin of the Atomic Scientists, October 1964, pp. 11-15.

161. Zwicky, Fritz. Morphology of Propulsive Power. Monographs on Morphological Research No. 1, Society for Morphological Research, Pasadena, California. Available from the Bookstore of the California Institute of Technology, Pasadena, California: 1962. 382 pp.

INDEX

AFSC-AAFB-WASH.,D.C. 1970