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RM-4848-PR
FEBRUARY 1966

ANNOTATED BIBLIOGRAPHY O
SYSTEMS COST ANALYSI

P. A. DonVi

PREPARED FOR:
UNITED STATES AIR FORCE PROJECT RAND

The RAND Corporation
SANTA MONICA • CALIFORNIA

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P. A. DonVito

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PREFACE

This Memorandum consists of a bibliography of literature in systems cost analysis. The bibliography includes books, pamphlets, articles, papers, and technical and research memoranda. Written materials carrying security classification have not been included. A brief description is presented of the nature and content of each work. The materials were selected and included solely on the basis of their relevance to the subject matter of systems cost analysis. No interpretation or evaluation of the work was intended.

Titles have been grouped into categories reflecting broad areas of cost analysis and its application in the Department of Defense. This bibliography was prepared for use by the growing number of cost analysts, particularly those being organized at various levels of the Air Force. The titles and their annotation are intended for use as reference material. They are intended to permit cost analysts to learn of earlier work that may be relevant to a study at hand. Revisions are planned for the future in order to include material that becomes available after the date of publication of this Memorandum.

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I. COST ANALYSIS FOR PURPOSES OF SYSTEMS ANALYSIS

Clark, John J., "The Economics of Systems Analysis," Military Review, Vol. 44, No. 4, April 1964, pp. 25-31.

This article describes the more recent efforts of economists in regard to the central issues of defense policy and programming, which are defined as the allocation of funds, deployment of forces, logistical problems, research and development decisions and the size and mix of weapons to achieve tactical and strategic objectives. The problem of measuring the military worth of alternatives is discussed, together with the difficulty of allocating direct and indirect costs and deriving incremental costs. The effects of non-numerical elements, the elapsed time between decision and implementation and complex patterns of behavior are described as constituting weaknesses in systems analysis. The value of systems analysis is that it provides decisionmakers with a set of carefully described alternatives, and it also presents a challenge to staff preconceptions.

Ellis, J. W., Jr., and T. E. Greene, The Contextual Study: A Structured Approach to the Study of Political and Military Aspects of Limited War, The RAND Corporation, P-1840, February 1960, 15 pp. Also published in Operations Research, Vol. 8, No. 5, September-October 1960, pp. 639-651.

Describes the use of contextual studies for the simultaneous analysis of both political and military problems. The study of some military problems is hampered by the dominating effect of nonquantifiable variables, such as political factors. Static assumptions regarding political constraints are described as forming unreliable boundary conditions for the study of weapons and tactics. The contextual study is a structured analytical method whereby the military and political factors of the environment are considered simultaneously throughout a campaign or a series of campaigns. Advantages and limitations of the method are discussed, together with distinctions between the contextual study and operational war gaming.

Fisher, G. H., Analytical Support for Defense Planning, The RAND Corporation, P-2650, (DDC No. AD 607649) October 1962, 6 pp.

In this description of the development of systems analysis in the defense planning process, distinction is drawn between operations research and systems analysis. Operations research is conducted for current operational problems, while systems analysis is concerned with the future and is used as an aid for development and procurement decision-making. With the emphasis placed on future time periods of 5, 10, and 15 years, the problem of uncertainty takes on major proportions, making analysis and measures of variance important. The five major elements in systems analysis are described as (1) statement of objectives, (2) specification of alternatives, (3) cost estimating, (4) a model describing relationships and (5) criteria for choice among alternatives. The use of gaming as an alternative to systems analysis is also described. Techniques derived from systems analysis are (1) systems cost analysis, (2) force structure cost analysis and program budgeting, (3) Monte Carlo methods, (4) dynamic programming and (5) measures of systems effectiveness.

Fisher, G. H., The Role of Cost-Utility Analysis in Program Budgeting, The RAND Corporation, RM-4279-RC (DDC No. AD 608055), September 1964, 39 pp.

Cost-utility analysis pertains to the systematic examination and comparison of alternative courses of action which might be taken to achieve specified objectives for some future time period. The primary purpose of cost-utility analysis is usually not to "make" the decision, but rather to sharpen the intuition and judgment of the decisionmaker. This Memorandum outlines the main characteristics of cost-utility analysis and some of the major considerations involved in carrying out such analyses. In addition, two illustrative examples are presented to help add content to discussion of principles contained in the initial sections of the paper.

Hitch, C. J., An Appreciation of Systems Analysis, The RAND Corporation, P-699 (DDC No. AD 422837), August 1955, 25 pp. Also published in Journal of the Operations Research Society of America, Vol. 3, No. 4, November 1955, pp. 466-481.

Military systems analysis, an outgrowth of operations research of World War II, is described as a technique for examining military problems of broader context and longer range. The development of systems analysis has taken the following form: (1) the use of analysis to aid in force composition and development, as well as in operations decisions; (2) a great increase in the number of interdependent factors considered; (3) the explicit treatment of problems of uncertainty; (4) the explicit treatment of enemy reaction; (5) time phasing; and (6) a broader concept of objectives and criteria.

Hoag, M. W., An Introduction to Systems Analysis, The RAND Corporation, RM-1678-PR (DDC No. AD 101071), April 1956, 21 pp.

Describes the nature of systems analysis and its application in problems of military planning. Systems analysis is defined as the systematic examination of problems of choice in which each step of the analysis is made as explicit as possible. Its opposite is intuition. The problem of choice is addressed most importantly to future time periods. A number of constraints which exist in the analysis of current operations do not apply to systems analysis. Systems analysis is concerned with (1) the relevant alternatives, (2) the criteria for choice, (3) the balance of costs and benefits, (4) the structure of the model, (5) the application of the model and (6) the interpretation of the results.

McKean, R. N., Efficiency in Government Through Systems Analysis, John Wiley & Sons, Inc., New York, 1958, 336 pp.

General methodological problems of analyzing alternative actions are discussed, with illustrations taken from various activities, such as business, military planning and water resource development. Attention is given to the devising of criteria, the selection of alternatives, the treatment of intangibles, uncertainty and the methods of taking time streams into account. Special problems in the analysis of water

resource projects are discussed. Major topics include the criterion questions arising from this particular application of analysis and the difficulties of measurement or evaluation. An examination is also made of the potential use of analysis to increase efficiency in other government activities.

Novick, D., and G. H. Fisher, The Role of Management Tools in Making Military Decisions, The RAND Corporation, P-694 (DDC No. AD 422835), June 1955, 27 pp. Also published in Armed Forces Management, Vol. 2, September 1956, pp. 42-44; Vol. 3, October 1956, pp. 12-14; Vol. 3, November 1956, 25 pp.

Discusses decisionmaking processes in the military establishment, particularly as they apply to planning decisions and the problem of choice among future courses of action. The problem of the selection of proper management tools from among those available is described. A comparison is made between military and industrial applications of management tools. Because their purposes are different, tools for industry are only partly applicable to the military. Budgeting and accounting procedures are examined in the light of the needs of decisionmaking, particularly for military decisions concerned with the development, procurement and operation of weapon and support systems. Systems analysis is described as a tool to aid in R&D and procurement decisions; its features are outlined and discussed.

Quade, E. S., (ed.), Analysis for Military Decisions, The RAND Corporation, R-387 (DDC No. AD 453887), November 1964. Also published by Rand McNally, Chicago, 1964, 382 pp.

Consists of a presentation of the lectures from a RAND Corporation course of instruction entitled "An Appreciation of Analysis for Military Decisions." This material was prepared primarily for decisionmakers and not for analysts. Its purpose is to point out the weaknesses and possible abuses, as well as the effectiveness, of an analytical approach to long-range military planning. Included are descriptions of (1) the origins and development of systems analysis, (2) the elements and methods common to all analyses and (3) special problems. Illustrative examples are also included.

Quade, E. S., Cost Effectiveness: An Introduction and Overview, The RAND Corporation, P-3134 (DDC No. AD 616339), May 1965, 19 pp.

Cost-effectiveness analysis is defined as any analytical study designed to assist a decisionmaker in identifying a preferred choice from among possible alternatives. Examples of aspects of such analysis that may be of even greater significance are: the specification of the right objectives, devising satisfactory measures of performance, non-dollar costs, and the discovery of better alternatives. The elements of analysis are described as (1) the objective, (2) the alternatives, (3) the costs, (4) a model and (5) the criterion for choice. The limitations of analysis are discussed and include the "attention" bias, incompleteness, and the difficulty in measuring effectiveness.

Quade, E. S., Cost-Effectiveness Analysis: An Appreciation, The RAND Corporation, P-3248 (DDC No. AD 623105), October 1965, 6 pp.

This paper contains a discussion of the nature and scope of cost-effectiveness analysis. The purpose of the paper is to point out its proper role as an aid to decisionmaking. Cost-effectiveness analysis is described as characterized by a systematic and rational approach, with assumptions made explicit, objectives and criteria clearly defined, and alternative courses of action compared in the light of their possible consequences. The reliability and limitations of cost-effectiveness analysis and ways to improve its quality are considered within the context of national security problems.

Quade, E. S., Military Systems Analysis, The RAND Corporation, RM-3452-PR (DDC No. AD 292026), January 1963, 35 pp.

Systems analysis is described as an approach to complex problems of choice under uncertainty by systematically examining the costs, effectiveness, and risks of the various alternatives. The problems and procedures of such analysis when applied in the military context are surveyed. Total systems analysis requires numerous sub-studies--for example, operations research, cost analysis, war gaming, etc. The stages of systems analysis are outlined and discussed as (1) the formulation, (2) the search for data, (3) explanation through model development, (4) interpretation and (5) verification.

Wolf, R., Weapon System Analysis, Cornell Aeronautical Lab, June 1957, 32 pp.

Weapon system analysis is described as the application of scientific methods to military decisions in weapon systems. The historical background of weapon system analysis and its origin in World War II operations research are described. The objectives of weapon system analysis are (1) to assist in development decisions, (2) to improve present weapon systems and (3) to help create future weapon systems. The types of system studies are described as (1) development of system requirement (2) comparative evaluation of systems, and (3) defining system specifications and the conceptual design. The organization of an analysis is outlined and the techniques described.

II. COST ESTIMATING IN MILITARY PLANNING

Baumol, W. J., Economic Theory and Operations Analysis, Prentice-Hall, Englewood Cliffs, New Jersey, 1961, 438 pp.

Chapter 3, "Marginal Analysis," presents the economic basis for cost and resource analysis. The best interests of a firm, a consumer or any other economic unit require that decisions take into account the magnitude of the marginal yield. The distinction between average and marginal values is explained, and the effect of fixed costs on marginal costs is examined. Accounting data essentially ignore marginal data, which, although difficult to develop, are essential to decisionmaking. Marginal data are often hypothetical and beyond the range of actual experience. Economies of large scale and diminishing returns are described as the key determinants of the difference between average costs and marginal costs.

Berman, E., The Choice among Systems in a Hostile Environment, The MITRE Corporation, W-4443, November 1961, 10 pages.

The problem of choosing among systems for the development or procurement of weapons is considered with the recognition that the enemy may respond with development or procurement decisions which are optimal from his point of view. A general solution and a partial solution for resource allocation in a single mission area and between two mission areas are presented.

Colm, G., and M. Helzner, General Economic Feasibility of National Security Programs, Johns Hopkins University, Operations Research Office, ORO-SP-21, May 1957, 18 pp.

In this study of the effects upon the national economy of expenditures for military programs, four levels of defense spending are considered. The lowest level is the 1957 level, and three step increases are postulated. The question examined is whether such levels of defense expenditures could be sustained by the economy without causing inflation. The effects of tax cuts are also discussed for the various levels.

Curry, D. A., Costing Concepts for the Defense Programs Management System, Stanford Research Institute Memo Report No. SD-84, March 1962, 58 pp.

Describes the military budget, defense fiscal processes and their application to forecasting program costs. The concept and use of incremental costs are also discussed. The cost most appropriate to decisionmaking is the incremental cost with indication as to time phasing. Examples for the use of obligational authority, obligations and applied costs are given, along with a description of the program budgeting system in the defense establishment. The problem of supporting data through properly structured accounting records is considered, as well as that of devising cost categories.

Davis, H., The Use of Cost-Effectiveness Studies in Military Decision-Making, Hq USAF, Operations Analysis Paper No. 1, November 1961, 18 pp.

The strengths and weaknesses of analytical studies in the military decisionmaking process are evaluated. Limitations outlined include (1) the difficulty of choosing a proper measure of effectiveness, (2) the lack of operational experience which hampers the evaluation of advanced systems, (3) the limited scope of studies because of the difficulty of fitting them into the total military-political picture and (4) the difficulty of treating the immeasurable aspects of the study. Cost-effectiveness studies are, in sum, described as useful inputs for decisionmaking but are not in themselves satisfactory for decisions in the broader aspects of the total military problems.

Enke, Stephen, "Using Costs to Select Weapons," American Economic Review, Vol. LV, No. 2, May 1965, pp. 416-426.

Describes the evolution, accomplishments and limitations in the application of economics to defense planning. This application has come to be known in the military establishment as cost-effectiveness analysis. The origins of economic analysis for defense planning are traced back to the early RAND Corporation strategic studies of the late 1940's. Cost-effectiveness analysis was introduced in the Pentagon in 1961 with the new programming system. Problems in the use of the

cost-effectiveness approach are discussed, such as the lack of system comparability and the lack of measurable output. Further refinements are indicated in the areas of discounting, salvage values and enemy reaction to system decisions.

Fisher, G. H., "Costing Methods" in E. S. Quade, (ed.), Analysis for Military Decisions, The RAND Corporation, R-387 (DDC No. AD 453887), November 1964. Also published by Rand McNally, Chicago, 1964, Chap. 15, pp. 264-299.

This chapter is concerned with how cost is estimated and taken into account in a system analysis. The principles and concepts of cost analysis are discussed together with their application in individual systems and force structure costing. An illustration is included of a system description used as the basis for costing. A discussion is also included regarding the nature and composition of the major cost categories. Cost sensitivity analysis is described with examples for its use.

Fisher, G. H., What is Resource Analysis?, The RAND Corporation, P-2688 (DDC No. AD 294994), January 1963, 14 pp.

This paper discusses the nature and need for resource analysis. The meaning and application of resource analysis can vary, depending on the problem at hand. Problems can vary according to the time horizon, the decision context (for R&D, investment or operations), or the involvement of the total force or individual systems. The major characteristics of a resource analysis capability designed to serve a long-range planning activity are (1) end-product orientation, (2) life-cycle identification, (3) resource and functional categories, (4) appropriate level of detail, (5) explicit treatment of uncertainty, (6) incremental resource impact, (7) identification of support with end-products, (8) levels of accuracy, (9) time-phasing and (10) data and estimating relationships.

Grosse, Robert N., and Arnold Proschan, "Military Cost Analysis," American Economic Review, Vol. LV, No. 2, May 1965, pp. 427-433.

Describes how costs are related to military worth for purposes of defense planning. The features of military cost analysis are outlined

and described. Such features include (1) total program costing, (2) cost categories, (3) timing of costs, (4) net costing, (5) developing relative costs, (6) recognition of uncertainties and (7) the use of estimating relationships. The introduction of cost analysis in the Department of Defense is discussed within the context of the new programming system. Current developments and the future needs of cost analysis are described.

Hatry, H. P., and F. S. Jackson, Cost of Alternative Programs Philosophy and Characteristics, General Electric Company, Technical Military Planning Operation (TEMPO), SP-96, July 1960, 9 pp.

Describes the development of a computational planning method for estimating costs of alternative military programs. The methodology is a computational device built on a series of mathematical and statistical techniques. Its purpose is to determine rapidly the impact of alternative decisions on requirements for resources in current and future time periods. Mathematical and statistical methods are examined for their application in estimating the economic impact of alternative program projections.

Hatry, H. P., Economic Analysis in the Selection of Space Systems, General Electric Company, Technical Military Planning Operation (TEMPO), SP-130, April 1961, 15 pp.

The need for economic analysis in system selection is described as being based on the objective of making the best use of available resources. Economic analysis should be continuing and sequential, paralleling the development of a system from its conception, through the design and production of specific hardware, to its maintenance and operation. The performance evaluation and the cost analysis should be undertaken jointly. The use of cost analysis to weigh the alternative characteristics or specifications of a system is described. Uncertainty in the analysis of future systems is discussed.

Heuston, M. C., Concepts of Cost Analysis for the Defense Industry, Douglas Aircraft Company, Missile and Space System Division, TM-3, April 22, 1963, 28 pp.

A number of the basic principles of systems cost analysis are discussed as well as its background and development. A description is given of both the DOD program budgeting system and the USAF program format. System costs are described as total force structure costs or total system costs. Cost elements and categories are defined and outlined. The need to define the scope of the military system as the basis of the system's cost and the problem of obtaining adequate data are discussed.

Hitch, C. J., and R. N. McKean, The Economics of Defense in the Nuclear Age, The RAND Corporation, R-346 (DDC No. AD 243098), March 1960, 442 pp. Also published by Harvard University Press, Cambridge, Mass., 1960.

In Part II the need for resource analysis in military planning for the nuclear age is described as stemming from our need to plan forces for deterrence and limited conflicts, and not, as in the past, from how to mobilize our reserve strength. The problem in planning is the monetary restraint, not that of specific resources. The GNP and its relationship to the military budget are considered. The efficient use of military (and other government) resources is a special problem because of the absence of built-in mechanisms, such as those in the private sector of the economy, which lead to greater efficiency. In the absence of a price mechanism or competitive force to insure that governments carry out each function at a minimum cost, resource allocation becomes a major problem. A discussion is included of optimal, efficient and feasible solutions to allocation problems through the use of economic concepts such as indifference curves.

Hoag, M. W., The Relevance of Costs in Operations Research, The RAND Corporation, P-820 (DDC No. AD 422838), April 1956, 18 pp. Also published in Operations Research, Vol. 4, No. 4, August 1956, pp. 448-459.

This paper describes the types of problems in which cost considerations become important. The real cost of a course of action is defined

as the value of the alternative objectives that are sacrificed for its attainment. If resources or inputs are specific to one use, cost considerations are not important; but they become important when two or more objectives compete for limited resources. Such problems are illustrated with graphics showing the substitutability of inputs for a given objective. The difficulty of establishing real cost is described together with the consequent resort to estimated money costs.

Johnston, J., Statistical Cost Analysis, McGraw-Hill Book Company, Inc., New York, 1960, 197 pp.

The purpose of this study is to subject certain economic hypotheses about cost/output relationships to empirical testing. These hypotheses are concerned with the variation of production costs within a firm as the level of output changes. Examined are both the short period variation, where certain factors of production are held fixed, and the long period variation, where no factor restraints apply. Six industries were selected for investigation: coal mining, road passenger transportation, food processing, electricity, insurance, and building societies.

Kazonowski, A. D., Cost Effectiveness Methodology and Limitations, North American Aviation, Inc., Space and Information Systems Division, October 1964, 42 pp.

This report in discussing cost-effectiveness analysis is not intended to be a textbook for its practice. It is meant as an examination, with illustrations, of the more common fallacies and misconceptions that tend to invalidate the application of cost-effectiveness analysis. Valid approaches and methodologies are also described, together with areas that appear profitable for additional investigation.

Kissel, J., Advanced Systems Cost and Cost-Effectiveness, USAF, Air Force Systems Command, Aeronautical Systems Division, June 7, 1962, 10 pp

This paper is concerned with the importance of force structure analysis and cost-effectiveness analysis to potential weapon systems. The capabilities of the Directorate of Advanced Systems Planning, ASD, for the performance of this function are described. Basic definitions of the terms and concepts of systems analysis are included.

Large, J. P. (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), 405 pp.

This collection of previously published studies discusses the basic concepts of cost analysis, as well as certain specialized prccedures for estimating the cost of particular types of equipment. The areas covered are (1) total force structure cost analysis, (2) cost analysis of individual systems, (3) estimating relationships, (4) derivation of estimating relationships, (5) uncertainty, (6) estimation of R&D costs of large launch vehicles, (7) equipment requirements, (8) aircraft costing, (9) missile costing, (10) estimation of installations requirements, and (11) estimation of total system personnel.

Margolis, M. A., Economic Aspects of Developing and Orbiting a Space Station, The RAND Corporation, P-1975 (DDC No. AD 224321), April 1960, 9 pp. Also published in Aerospace Engineering, Vol. 19, No. 5, May 1960, pp. 84-85.

Economic aspects become important when several means of carrying out a proposed space mission are under consideration. The possibility of funding the program in the light of existing military space commitments and the ability of the economy to support higher budgets are also economic problems. This paper is concerned, primarily, with the economic considerations of a space transfer station. The space transfer station is compared with the employment of large boosters for space missions. The costs of alternative methods of conducting space missions are discussed, as well as the economic impact of space expenditures on the national economy.

Margolis, M. A., and F. S. Pardee, Economic Considerations of Space Flight Ground Support Requirements, The RAND Corporation, P-1589 (DDC No. AD 224138), January 1959, 17 pp.

This paper describes the need to develop a complete systems cost for advanced systems, including all costs for research and development, initial investment, and the operation of the system. A format, with a list of cost elements, illustrates a method for ensuring complete compilation of program costs. Also considered is the cost implication of

the use of inherited resources. The growing importance of ground support is described. An outline of space flight facilities is provided to assist in the economic evaluation of procurement and construction of such facilities. The problem of determining the need for increasing the number of operating space facilities is discussed, along with the relevant considerations for such decisions.

McCullough, J. D., Cost-Effectiveness: Estimating Systems Costs, The RAND Corporation, P-3229 (DDC No. AD 622023), September 1965, 26 pp.

This paper presents a discussion of the significant features and general procedures applied to systems cost analysis. The discussion is directed primarily to users of cost estimates rather than cost analysts. The types of systems cost analysis are described. Cost sensitivity analysis is discussed as a means of examining more efficient arrangements within a given system. Individual systems cost analysis is described as an aid to system selection. The features of cost analysis are identified as (1) end-product orientation, (2) an extended time horizon, (3) incremental costing, (4) life cycle costs, (5) costs in constant dollars and (6) the use of statistical techniques. Examples are included of system descriptions, cost element lists and cost estimating relationships.

Naiman, J., Analytical Cost Predictions for Advanced Weapon Systems, USAF, Air Force Systems Command, Aeronautical Systems Division, Cost Analysis Information Report 62-5, May 1962, 18 pp.

Describes the functions and operations of ASD's Cost Analysis Branch. The paper also discusses tools and techniques for advanced system cost prediction. The functions of the branch are described as (1) the cost data research program, (2) cost prediction analysis, and (3) cost-effectiveness analysis. The tasks involved in carrying out these functions are defined.

Noah, Joseph W., Defense Systems Cost Analysis, Center for Naval Analysis, Cost Analysis Group, April 1965, 28 pp.

Contains a general discussion of the place of cost analysis in military planning. Uncertainties and biases in estimating costs are discussed, together with their resulting effects on the accuracy of the cost estimates. The causes of uncertainty and bias are examined. A number of the more fundamental methods of estimating costs are discussed. The DOD programming system is considered in its relationship to cost analysis, and the history of the development of systems cost analysis is related.

Novick, D., Concepts of Cost for Use in Studies of Effectiveness, The RAND Corporation, P-1182 (DDC No. AD 224030), October 1957, 14 pp.

The two major considerations in a systems analysis are described as (1) weapon system effectiveness, and (2) the weapon system costs; the two approaches to the selection of preferred systems are the fixed effectiveness approach and the fixed budget approach. For the fixed effectiveness case, minimum cost is the criterion for choice; in the fixed budget approach, maximum effectiveness is the criterion for selecting the system. This paper is concerned primarily with weapon system choice. The role of cost analysis and cost estimating is described in the context of campaign analysis and weapon studies.

Novick, D., Costing Tomorrow's Weapon Systems, The RAND Corporation, RM-3170-PR (DDC No. AD 287997), June 1962, 15 pp. Also published in The Quarterly Review of Economics and Business, University of Illinois, Spring 1963.

The role of cost analysis, the usefulness of cost studies, reliability of estimates, and the direction of effort for improving costing techniques are discussed in this memorandum. Costing future weapon systems is a difficult and uncertain but essential process in budgeting and decisionmaking. The major cause of unreliability in estimates is the uncertainty in the specifications of future systems. Techniques, such as cost sensitivity analysis, should be improved in order to examine the effects of changes in program and system characteristics.

Novick, D., and J. Y. Springer, "Economics of Defense Procurement and Small Business," Law and Contemporary Problems, Duke University School of Law, Vol. 24, No. 1, Winter 1959, pp. 118-131.

Examines the magnitude and nature of military procurement and the special commercial considerations involved. The analysis concentrates on equipment, including military materials, components, special products and services required for weapons and their directly related equipment. The weapon-system concept of procurement management is described. Also discussed are the national security considerations which make a distinction between the market for military goods and that for normal commercial contracts.

Novick, D., New Tools for Planners and Programmers, The RAND Corporation, P-2222, February 1961, 21 pp. Also published in The Executive, Vol. 5, No. 4, September 1961, 4 pp.

The information needs of military planners and decisionmakers are described as (1) a comprehensive and correlated flow of information, with an evaluation of both current and projected programs; (2) data on new technological developments and breakthroughs supported by an evaluation of their impact in terms of equipment, military concepts, and international commitments; (3) coordination of planning on an across-the-board basis; and (4) a framework for considering the alternative uses of resources to achieve national goals. A distinction is drawn between information needed to make decisions and that needed to carry out decisions or manage activities. For the decisionmaker, a format is required, oriented toward end-objectives and suited to the examination of alternatives. Administrators and managers require a presentation in terms of administrative categories suited to the execution of tasks.

Novick, D., Resource Analysis and Long-Range Planning, The RAND Corporation, RM-3658-PR (DDC No. AD 406844), June 1963, 27 pp.

Program budgeting, cost-effectiveness, and cost analysis are terms used frequently in military research programs. This RAND Memorandum contains a discussion of these terms. The purpose and features of program budgeting are discussed within the context of decisionmaking

for the military. Cost-effectiveness analysis is described as a method of analysis for the purpose of minimizing cost at specified levels of effectiveness or to maximize effectiveness with resource levels fixed. The role of cost analysis in the problem of choice among alternatives is discussed. The categories of cost--R&D, investment, and operating--are described and their significance is discussed. Sample formats for these categories and their elements are included.

Pardee, F. S., Economic Planning and the Military Electronics Industry, The RAND Corporation, P-2006 (DDC No. AD 419745), June 1960, 22 pp.

Economic analysis in defense activities is described as an application of both macro-economics and micro-economics. Macro-economics applies to aggregates such as GNP, R&D expenditures, the military budget, etc., while micro-economics examines, by cost sensitivity analysis, the economic aspects of military systems, such as alternative hardware designs, operating methods, and other features of individual systems. The elements of an electronic system and their sensitivity to costs are examined through cost-sensitivity analysis. Economic trade-off conditions, such as the cost of increased miniaturization versus increased payload capacity, are considered. Cost-sensitivity analysis is described as a method of estimating the economic pact of alternative engineering designs, concepts of maintenance, logistics, training, and other operational deployment considerations.

Pardee, F. S., Weapon System Cost Sensitivity Analysis as an Aid in Determining Economic Resource Impact, The RAND Corporation, P-2021, (DDC No. AD 224289), June 1960, 27 pp.

This paper describes cost-sensitivity analysis and its usefulness in military planning and operations. Cost-sensitivity analysis is defined as an examination of the financial implications of numerous alternatives to provide a range of values for the weapon system evaluation process. Illustrations show the range of costs associated with variations in certain system characteristics such as payload weight at missile salvo capability. Cost-sensitivity analysis is used to estimate the financial magnitude of total force structures, designs, test and operational concepts, and the time-phasing of such alternatives.

Sobin, B., Cost-Effectiveness Analysis, Institute for Defense Analyses, Weapons System Evaluation Group (WSEG), November 1962, 13 pp.

This paper describes the role, nature, and difficulties of cost-effectiveness analysis. The criterion is the satisfaction of military capability requirements at least cost. Under consideration for the analysis are (1) the technological relationships among weapon systems development and deployment, costs, and time; (2) effectiveness through time of possible systems; and (3) uncertainties. The obstacles to objective optimization are described as (1) contradictory objectives, (2) indefinite time horizons, and (3) inaccurate or missing data.

Yates, Edward H., The Role of Cost Analysis, AIAA Paper No. 64-408, June 1964, 11 pp.

Describes the general procedures of cost analysis and the derivation of cost estimates. Applications of cost analysis are considered, together with a discussion of future developments. An outline is included showing system characteristics used in estimating various cost categories. A list of cost elements is also included as typical of missile and space systems. Forms of estimating equations are described together with examples. A series of graphs is included on (1) the development of cost estimating relationships, (2) progress curves, (3) the selection of alternative systems, (4) effectiveness and the budget, and (5) sensitivity analysis.

III. PROGRAM BUDGETING IN THE DEPARTMENT OF DEFENSE

Department of the Air Force, Program Budget Control, June 1962, 28 pp.

Describes the Department of Defense program budget control system. The system is designed for continuous decisionmaking on major programs. Its objective is described as the integration of planning, programming, and financial management into a current "Five-Year Force and Financial Program." The major features of the system are (1) a program financial base structured on the DOD-wide mission, (3) a formal system of changes to the financial base, and (3) progress reporting of both financial and nonfinancial data against approved milestones.

Department of Defense, Programming System for the Office of the Secretary of Defense, Study Report, May 1962, var. pages.

This study was prepared in the Office of the Secretary of Defense at the completion of the first cycle under the new DOD program budgeting system. The report is presented in four sections with appendices. The new programming system is described, and definitions given for the program elements and resource categories. The cost estimates for elements and their analysis are discussed, together with the development of the system for the future. Information needed to support program budgeting and a system for providing it are examined.

"DOD Program Budget Structure and the Budget Process," Special Annex to USAF Industrial Newsletter No. 85, January 1964, 6 pp.

The Air Force portion of the Department of Defense programming, budget, and financial structure is described in this article. The program budgeting system is discussed and compared with the conventional budget process. The purposes and operation of the system, in terms of its contribution to the decisionmaking process, are examined. A distinction in decisionmaking is drawn between decisions to develop systems and decisions on force composition and force levels.

Fisher, G. H., The New OASD (Comptroller) Programming/Budgeting Process (A Lecture for the AFSC Cost Analysis Course), The RAND Corporation, RM-3048-PR (DDC No. AD 279597), March 1962, 23 pp.

Describes the OASD (Comptroller) program budgeting system introduced in DOD in 1961. The fundamental purpose of the system is to provide the Secretary of Defense and his military advisors with a better basis for making major program decisions. Such decisions include (1) the choice among future weapon systems, (2) their force size, and (3) the selection of operational concepts. The organization established to operate the system is described, together with the experience of the first program budgeting cycle for fiscal year 1963.

Fisher, G. H., Some Comments on Program Budgeting in the Department of Defense, The RAND Corporation, P-2721 (DDC No. AD 402137), March 1963, 10 pp.

Contains a discussion of the basic objectives of program budgeting. The fundamental purpose of the programming system is to provide the Secretary of Defense with a better basis for making major program decisions by providing financial and nonfinancial information in a more meaningful way. Another objective of the system is to integrate the planning/programming and the financial management functions. Future developments of the system are also discussed. Developments considered for the future include (1) supporting information systems, (2) a meaningful program element structure, (3) an effective program change system, and (4) an analytical capability for cost-effectiveness studies.

Hitch, C. J., Statement of Assistant Secretary of Defense Charles J. Hitch Before the Military Operations Subcommittee of the House Committee on Government Operations: Description of the Department of Defense Program Budgeting System, July 25, 1962, House of Representatives, 87th Congress, 2nd Session, U.S. Government Printing Office, Washington, D.C., 1962, 27 pp.

This statement presented before the Congress describes the Department of Defense program budgeting system. The discussion concerns (1) the five-year program package concept, (2) fiscal controls and cost-effectiveness analysis, and (3) the presentation of information to the Secretary of Defense for decisions. The bringing together of previously separate functions of budgeting and programming is described. The

functional arrangement of the DOD budget does not focus on forces and military programs in relation to missions. This need to relate costs to effectiveness is discussed. The program budgeting system is designed as an aid to the planning, execution, and control of defense programs. It is not a substitute for budgeting or for military planning but is a link between the two. The planning-programming-budgeting procedure facilitates the performance of cost-effectiveness analysis, since it brings together both programs and costs in the context of military missions.

Kaufmann, W. W., The McNamara Strategy, Chapter 5, "Cost and Effectiveness," Harper & Row Publishers, New York, 1964, 340 pp.

This chapter consists of a description of the Department of Defense planning-programming-budgeting system. The purposes and concepts of the system introduced by Secretary McNamara are discussed. The research and development, investment, and operating cost categories are described. The Five-Year Force and Financial Plan is described as the product of the system. A discussion is included of the application of the DOD system to the planning of forces.

Novick, D., Efficiency and Economy in Government Through New Budgeting and Accounting Procedures. The RAND Corporation, R-254 (DDC No. AD 116589), February 1954, 122 pp.

Proposes a new method of budgeting and accounting for the Federal Government, with special reference to the military departments and to the Air Force in particular. In the use of systems analysis for Air Force problems it has been necessary to consider not only weapon effectiveness -- the usual end objective -- but also the resource cost of alternative weapon systems. Existing Air Force financial accounting and cost accounting systems, however, did not provide the required information. Cost analysis studies indicated that a relatively simple but fundamental change in expenditure classifications used for budget proposals, appropriation acts, and federal financial accounting would provide the desired information and could be accomplished within the provisions of the Budget and Accounting Procedures Act of 1950 and

Title IV of the Amendments to the National Security Act of 1947. The introduction of the proposed uniform classification of accounts would provide accurate and consistent information for planning, programming, budgeting, operating and review purposes.

Novick, D., and G. H. Fisher, "The Federal Budget as a Business Indicator," Harvard Business Review, Vol, 38, No. 3, May-June 1960, pp. 64-72.

Presents a description of the form of the federal budget and its usefulness as an indicator of the Government's plans and objectives. The need for improvement is considered. Recommendations include (1) a format that provides identification of end-product activities and their associated resources, (2) an extended time horizon, (3) a more clear-cut distinction among outlays for investment, operations, and research, and (4) that the budget not be burdened with administrative considerations, funding concepts, and jargon. A proposed format is presented, patterned after the Department of Defense program budgeting structure.

Novick, D., The Federal Budget as an Economic Document, Hearings Before the Subcommittee on Economic Statistics of the Joint Economic Committee, Congress of the United States, April 23-30, 1963, pp. 52-62.

This statement contains a discussion of the improvements on the form of the federal budget that would be needed to evaluate its economic impact. The existing budget arrangement is not considered to be useful as an economic document. The principle reasons for the deficiency are described as (1) the lack of an "end-product" or "activity" oriented format, (2) too much of an administrative or organizational orientation, (3) the time span covered is too short, (4) insufficient distinction between one-time investments and recurring operating outlays, and (5) budget concepts and language that are too complicated. The changes recommended are based primarily upon the features of the DOD program budget system.

Novick, D., A New Approach to the Military Budget, The RAND Corporation, RM-1759-PR (DDC No. AD 112135), June 1956, 30 pp.

Describes the existing federal budget structure as it applies to military programs. The structure is described as not having kept up with military decisionmaking needs. For effective use by management, the budget should be presented in terms of specific and understandable objectives appropriate to the level of decision concerned. It should also provide for translating objectives into comprehensive and comparable units of financial measurement, and should permit expenditure implications to be projected over an extended period of time.

Novick, D., Program Budgeting in the Department of Defense, The RAND Corporation, RM-4210-RC (DDC No. AD 604388), September 1964, 29 pp.

Discusses the introduction and development of the program budgeting concept in the Department of Defense. The significant feature of the new system is described as its approach to decisionmaking and control of defense expenditures. Planning is considered in long-range terms of missions, forces, and military systems. The annual budget is a part of a long-range plan. Since the system requires a continuous type of budget review, a program change proposal system has been developed. Thresholds have been established to concentrate attention on major programs, and the actual accomplishment of approved programs against milestones. Although the new process is having a large impact on financial management, it is leaving the traditional fiscal process relatively unchanged.

Novick, D., Program Budgeting: Long-Range Planning in the Department of Defense, The RAND Corporation, RM-3359-ASDC (DDC No. AD 289851), November 1962, 16 pp. Also published as "Planning Ahead in the Department of Defense," California Management Review, Vol. 5, No. 4, Summer 1963, pp. 35-42.

The planning and programming process that was introduced in the Department of Defense in early 1961 is described in this memorandum. In the system, planning is considered in long-range terms of missions, forces, and weapon systems, i.e., resource outputs, rather than in the standard input categories such as procurement, construction, and

personnel. The annual budget becomes an increment of a longer range plan. The procedure requires a continuous review which is provided by the program change control system. Milestones are established to mark the events and activities on which the financial plan is based, and actual accomplishment is reviewed against such milestones.

Novick, D., et al., Program Budgeting: Program Analysis and the Federal Budget, The RAND Corporation, 1965. Published by the Government Printing Office, Washington, D.C., 1965; and by the Harvard University Press, Cambridge, 1965.

This book is concerned with the decisionmaking process in the Federal Government and how program budgeting concepts and analytical techniques can assist in making major allocation decisions. The concentration is on the program aspects of the budget and not on the problems of fiscal policy, revenue and related issues. Included are a number of illustrative examples of how the concept of program budgeting, now applied in the Department of Defense, might be adopted to other areas of the Federal Government. The objectives of the book are (1) to make the budget a more useful and precise instrument for planning, appropriation, administration, and control within the federal establishment; (2) to contribute to broader public understanding of the allocation and use of federal funds; and (3) to facilitate economic analysis, forecasting and planning in the private sector.

Novick, D., The Role of the Military Comptroller in Defense Management, The RAND Corporation, P-2336, June 1961, 9 pp. Also published in The Armed Forces Comptroller, Vol. 6, No. 4, December 1961, pp. 29-32.

Describes the functions of management in the defense establishment. A comparison is made between military management and that of a large private business organization. Top management is responsible for allocating available resources to meet objectives. This carries with it a responsibility for implementing decisions and evaluating operating results. It is the Comptroller's responsibility to ensure (1) the availability of necessary data to make allocation decisions, and (2) to design and operate a reporting system within which the decisions can be evaluated and implemented. The DOD program budgeting concept is

described as a first step toward providing an effective system for top management decisionmaking.

Novick, D., Which Program Do We Mean in "Program Budgeting?", The RAND Corporation, P-530 (DDC No. AD 422827), May 1954, 22 pp. Also published in Armed Forces Management Association NEWSLETTER, Vol. 1, No. 6, August-September 1954, pp. 7-18.

The need for program budgeting and its advantages in the administration of the federal budget are discussed in this paper. The development of the concept of programs is described as originating from the needs of the War Production Board during World War II. A program is defined as a set of related tasks or resources necessary to carry out an end-object. The federal budget in most cases does not reflect programs; managers cannot use the budget as an administrative and control instrument; and Congress cannot review the budget in the light of the objectives of most agencies. A program is the sum of the steps or interdependent activities that contribute to the attainment of a specified objective and is budgeted in terms of all elements necessary to its execution.

Peck, M. J., and F. M. Scherer, The Weapons Acquisition Process: An Economic Analysis, Harvard University Press, Cambridge, Massachusetts, 1962, 736 pp.

This volume is primarily concerned with government-business relationships in the development and production of weapons. The weapons acquisition process, using private firms for most of the effort, includes the conception, development, and production of technically advanced weapons for use by the armed forces. The process consists of the flow of decisions and activities of government agencies and defense contractors. Economic analysis is used to examine the effects of the acquisition process on the quality, time, and cost of the weapons programs. The book includes a detailed compilation of the histories of 12 weapon system developments covering the three services. Also discussed are the constant presence of uncertainty in the weapon acquisition process and the absence of a market to integrate the needs of the government with the objectives of contractors. A definition of the

efficiency of the process is presented together with a method for its measurement.

Proschan, A., "Programming System of the Department of Defense," Armed Forces Comptroller, Vol. 8, No. 3, September 1963, pp. 14-21.

Describes the Department of Defense programming system. Its origins are traced from recommendations dating back to 1951. The purposes of the system are explained, together with its program element and package arrangement. The initial submission of departmental programs and subsequent modifications to the system are described. The Program Control System to keep programs current is explained.

IV. SYSTEM DEFINITION

Jones, M. V., A Generalized Cost Structure for Electronic Systems, The MITRE Corporation, TM-3299, May 1962, 17 pp.

Describes the elements of a generalized cost structure for electronic systems. The specifications of the structure reflect the definition of the military system. The cost structure is described by a set of system elements classified by cost categories. The particular structure selected from those possible depends essentially on the needs of the decisionmaking process. A generalized structure is presented, together with definitions for each category, element, and sub-element.

Novick, D., and R. L. Petruschell, "Cost Analysis of Individual Systems," in J. P. Large (ed.) Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. III-1 - III-34.

This chapter is concerned, in part, with system descriptions. An outline of descriptive data requirements is included. Examples of such data are given, using a ballistic missile system for illustration. System description data are categorized by (1) aerospace ground equipment, (2) installations, (3) operations and organization, (4) communications, (5) manning policies, (6) maintenance, and (7) training.

Pardee, F. S., The Financial Portion of a Management Information System, The RAND Corporation, RM-2836-PR (DDC No. AD 413607), December 1961, 52 pp.

'nnex C of this memorandum contains three checklists for assembling descriptive data on weapon systems. Checklist (1) outlines descriptive information for hardware design. Checklist (2) gives the system's development and operational concepts, and Checklist (3) contains information on the program's time phasing. For a more complete description of the study, see its entry under Section IX.

Pardee, F. S., Guidelines in Accumulating Financial Data on Future Weapons, The RAND Corporation, RM-2583-ARPA (DDC No. AD 418652), May 1960, pp. 19-27.

Part II of this memorandum is a discussion of the importance and nature of the system description. It is necessary that the system be described as specifically as possible, with particular attention paid to any factors sensitive in terms of system cost. Major checklists are furnished covering such characteristics as (1) the prime weapon hardware, (2) the development and operational concept, and (3) the phasing of the development, procurement, and operational program.

Petruschell, R. L., and J. M. Chester, Total System Cost Analysis--Part I, The RAND Corporation, RM-3069-PR (DDC No. AD 295149), January 1963 (For Official Use Only), 87 pp.

Contains a discussion of the fundamentals of Air Force systems cost analysis. Descriptions are included of weapon systems, support systems and the administrative structure. The cost categories of R&D, investments, and operation are discussed, along with their expenditure patterns over time. The cost elements of Air Force systems are outlined and detailed descriptions are given for estimating personnel and primary equipment requirements. The use of cost-quantity curves is explained and examples are included for the calculation of equipment requirements.

V. COST CATEGORIES

Curry, E. E., An Approach to Estimating Advanced Systems Operating Costs, USAF, Air Force Systems Command, Aeronautical Systems Division, October 1962, 21 pp.

This paper describes a method for deriving annual operating costs for manned aircraft systems and associated airborne missiles. These costs are defined as primary and support operating costs. Primary operating costs include the items necessary to support the major equipment regardless of the operational concept, and support costs include all other items. The cost elements within these groupings are outlined and described. Primary operating costs include flight crew pay and allowances, aircraft POL, and aircraft maintenance costs. Support operating costs include facilities maintenance, special services, annual training, and miscellaneous expenses. A sample format is included.

Jones, M. V., A Generalized Cost Structure for Electronic Systems, The MITRE Corporation, TM-3299, May 1962, 17 pp.

Chapter 3, "Conceptual Problems," is concerned with cost categories. Definitions are presented, together with a discussion of the usefulness of cost categories for decisionmaking purposes. For a more complete description of this report, see its entry under Section VII.

Noah, J. W., Identifying and Estimating R&D Costs, The RAND Corporation, RM-3067-PR (DDC No. AD 283794), May 1962, 74 pp. Also published as Chapter VII, "Estimating Research and Development Costs of Large Launch Vehicles," in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. VII-1--VII-54.

Consists of instructional material for estimating research and development costs, particularly for ballistic missile or launch vehicle systems. With some modification, the techniques presented can also be applied to aircraft and spacecraft. A detailed list of R&D cost elements is provided as a basis for data compilation and the development of estimating relationships. Methods for developing estimating relationships for R&D cost elements, and estimating equations for cost

elements are presented. The problems and methods of organizing R&D cost estimating tasks are discussed. Sample formats are shown for the system specifications needed for estimating purposes.

Noah, J. W., Identifying and Estimating R&D Costs: Quiz, Problems, and Possible Solutions, The RAND Corporation, RM-3067-PR (Supplement), (DDC No. AD 283795), May 1962, 29 pp.

Presents problems for testing the reader's or student's ability to analyze and apply the cost estimating techniques presented in the basic memorandum. Possible solutions to the quiz and problems with attendant explanations, graphs, and tabulations are included.

Novick, D., The Cost of Advanced Weapons, The RAND Corporation, P-2556, (DDC No. AD 291605), February 1962, 22 pages.

Discusses the increasing cost of advanced weapon systems. The increased cost of new weapons is balanced by the need for smaller quantities, thus keeping defense expenditures relatively stable. The factors responsible for higher costs are described as greater needs for research and development and higher labor and material costs. Increased reliability requirements and the difficulty of achieving them are also discussed. Program budgeting and an improved costing capability are suggested to offset cost increases by providing better information for better decisions in the selection of weapons.

Novick, D., Identifying R&D--A Management Problem, The RAND Corporation, P-2135 (DDC No. AD 224301), December 1960, 21 pp.

The nature and interrelationships of decisions in research and development, investment and operations are described in this paper. The historical growth of R&D is shown and with it the increase in the proportion of R&D costs to the total cost of systems. As research increases, the term itself is used so widely that measurement of R&D activity becomes difficult. The four R&D phases are offered as a basis for classifying research efforts.

Novick, D., Lead Time in Modern Weapons, The RAND Corporation, P-1240, December 1957, 15 pp. Also published as "Federal Spending for National Security," in Federal Expenditure Policy for Economic Growth and Stability, Joint Economic Committee Print, 85th Cong., 1st Sess., U.S. Government Printing Office, Washington, D.C., 1957.

This reprint of testimony given before the Joint Economic Committee, Eighty-fifth Congress, presents a discussion of elapsed time or the lead time needed to acquire advanced weapon systems. Continuity of research is required if the time is to be kept reasonably short. Steps in the acquisition process are outlined with the usual time demands for each step. From product research to manufacturing, the likely lead time is 8-13 years; a possible lead time is 5-9 years; and an optimistic lead time is from 3-6 years. The government procedure for approving expenditures for weapon acquisition is discussed together with a description of its time requirement. The time lag between the authority to obligate funds and actual expenditures is also considered.

Novick, D., System and Total Force Cost Analysis, The RAND Corporation, RM-2695-PR (DDC No. AD 257269), April 1961, pp. 13-58.

Chapter II, "Cost Analysis of Individual Systems," discusses cost categories. Categories are defined, and the cost category structure is outlined showing the cost element distribution among categories. Time phasing of the military system's financial requirements is shown by cost category.

Novick, D., What Do We Mean by "Research and Development"?, The RAND Corporation, P-1779, October 1960, 50 pp. Also published in California Management Review, Vol. 2, No. 3, Spring 1960, pp. 9-24.

The successive stages of research and development are outlined and described. Measuring R&D effort is difficult without a suitable classification system. A four-step system is suggested: step I includes Basic Research, Experimental Research, Basic Development and Advanced Research; step II includes Applied Research, Advanced Development, Basic Evaluation and Basic Testing; step III includes Product Development, Product Testing, Product Evaluation and Pilot Production; and step IV includes Product Application, Application Research, Applied

Testing and Application Evaluation. Research and Development expenditures are classified by the system and the relative shares in the steps are discussed.

Novick, D., "What Do We Mean by Research and Development"?, California Management Review, Vol. 2, No. 3, Spring 1960, pp. 9-23.

This article contains a discussion of the difficulty of devising a satisfactory classification system for research and development activities. The successive stages of research and development are discussed, and a system for categorizing activities is considered and presented.

Waks, N., Criteria for Cost Categorization, The MITRE Corporation, TM-3050, June 1961, 6 pp.

This paper sets out criteria for classifying cost data into categories and elements for cost analysis in USAF electronic systems. Cost categories are described as the initial classification of total system costs, and cost elements are the detailed constituents of a cost category. This classification of costs into categories and elements is made to provide the means of identifying and stratifying the different types of cost for purposes of developing total system costs.

VI. COST ELEMENTS

Campbell, H. G., Missile Airframe Cost Estimating Techniques, The RAND Corporation, RM-3068-PR (DDC No. AD 411570), April 1962, (For Official Use Only--Limited Distribution), 41 pp. Also published as Chapter X in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. X-1-X-35.

This memorandum contains a discussion of methods for estimating the cost of missile airframes by the major production inputs--labor, materials, tooling, etc. Ratios of cost to propellant weight are described as the basis for estimating labor hours per pound of airframe. The use of material price indexes for estimating material costs and some possible approaches to scaling existing data for airframes under study are discussed. A tabulation of costs per pound is included for subsystems and components and a cost estimating equation for tooling presented. Other production costs are discussed and the application of the complete airframe costing method is illustrated.

Carrier, J. M., and R. W. Smith, Aircraft Airframe Cost-estimating Techniques, The RAND Corporation, RM-3375-PR (DDC No. AD 293863), November 1962, 266 pp. Also published as Chapter IX in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. IX-1-IX-57.

Presents an introduction to estimating techniques applying primarily to aircraft airframes. The production inputs are discussed and a procedure is presented for estimating both recurring and nonrecurring airframe production costs. The procedure consists of a series of steps in developing cost estimates. The prediction of cost as a function of several variables in airframe characteristics is considered. The elements of airframe production, discussed individually, are: direct labor, materials, overhead, subcontracting, engineering, tooling, and general and administrative expenses. An example of the use of cost estimating relationships is also provided.

Cochran, D. W. and L. F. Eliel, The Costing of Weapon System Equipment Logistics, Aerospace Corporation, December 1961, 12 p.

Describes the role and costs of logistics for military systems. Maintenance costs are described as functions of (1) the maintenance echelon, (2) the waiting lines (queues), (3) failure rates, and (4) component costs. An approach to costing "equipment logistcs," defined as the set of subsystems of the weapon system, is outlined. The maintenance system and its characteristics are described. Functional relationships of spares allowances to the failure rate of missiles are derived.

Dienemann, P. F. and G. C. Sumner, Estimating Aircraft Base Maintenance Personnel, The RAND Corporation, RM-4748-PR, October 1965, 91 pp.

Contains a discussion of methods for estimating aircraft base maintenance personnel requirements. Maintenance personnel are divided into three functional categories: direct maintenace, maintenance overhead, and other maintenance. A series of relationships is developed for the first category for advanced aircraft to estimate personnel requirements on the basis of design and performance characteristics. Requirements for maintenance overhead are derived from these estimates. Techniques using current USAF manning procedures are described to estimate all other maintenance personnel.

Dole, S. H., and M. A. Margolis, Sources, Availability, and Estimated Costs of Propellants, The RAND Corporation, P-1639, (DDC No. AD 224279), March 1959, 23 pp. Also published in S. S. Penner and J. Ducarme (eds.), The Chemistry of Propellants, Pergamon Press, New York, 1960, pp. 1-24.

Cost and availability criteria for the selection of propulsion systems and propellants for particular applications, and a compilation of propellant availability and costs are presented in this paper. Propulsion system costs are examined in relation to costs of complete systems. The effect of the volume of production on cost is considered. The availability of rocket fuels and oxidants and expanding their production are discussed.

Fisher, G. H., Distribution of Indirect Costs: A Method of Allocating the Cost of Air Force Interpendent Support Activities to Mission Activities, The RAND Corporation, RM-1199-1 (DDC No. AD 85487) (revised February 1955), 22 pp.

Presents a method for allocating costs of support activities to basic mission activities. It takes into account the interdependency of such activities, i.e., support of each other as well as of mission activities. The method of cost allocation is based on the use of an interactivity flow model. The problem of cost allocation is treated in two stages: (1) A simplified cost allocation problem involving three support and two mission activities is solved algebraically. (2) A numerical example of the same problem is introduced with the computational steps for solving it. A general case involving non-support activities with an algebraic solution is also presented.

Harris, H. F., "Installations," in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. XI-1-XI-8.

This chapter describes procedures for estimating requirements and costs of installation facilities. Cost estimates for a missile base are presented as illustration, and a list of estimating relationships for the individual items of construction is included.

Heuston, M. C., Concepts for Estimating Air Force Manpower Requirements for Planning Purposes, The RAND Corporation, RM-2611-PR (DDC No. AD 250725), December 1960, 45 pp.

The basic concepts for preparing manpower estimates for current and, particularly, advanced Air Force systems are discussed in this memorandum. The procedures provide total system manpower requirements, including operations, unit administration, maintenance, support and prorations for logistic support, and higher headquarters administration. A series of steps is outlined for estimating personnel for advanced systems. Worksheets and sample formats, including cost elements,are included.

Jones, M. V., A Generalized Cost Structure for Electronic Systems, The MITRE Corporation, TM-3299, May 1962, 17 pp.

This paper presents a generalized structure for cost analysis in electronic systems. The structure serves as (1) a framework for organizing cost estimating data, (2) a display format to exhibit comparisons of costs of diverse electronic systems, and (3) a checklist from which to develop special cost structures for particular system cost studies. Each of the cost elements is defined and the conceptual problems of developing a cost structure are discussed.

Losee, J. E., et al., Methods for Computing Manpower Requirements for Weapon Systems Under Development, USAF, Air Force Systems Command, Aeronautical Systems Division, Technical Report 61-361, August 1961, 163 pp.

A method of forecasting the manpower requirements of new weapon systems is described in this report. The manning estimate is derived through a series of integrated steps leading to position descriptions and numbers of men required. The prediction of manpower for a new weapon system requires data on (1) operational, logistics, and maintenance concepts, (2) reliability of components and subsystems, and (3) statistical estimates of occurrence rates. A checklist of data requirements is included. The procedure consists of the development of a task equipment analysis, a task frequency analysis, a time requirement analysis, direct maintenance personnel requirements, and flow charting for inclusion in the completed Air Force Qualitative and Quantitative Personnel Requirements Information Program.

Novick, David, System and Total Force Cost Analysis, The RAND Corporation, RM-2695-PR (DDC No. AD 257269), April 1961, pp. 13-58.

A list of system cost elements is included in Chapter II of this Memorandum, where each element is defined and discussed. For a more general description of this Memorandum, see its entry in Section X.

Petruschell, R. L., "Total System Personnel Estimating," in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. XII-1-XII-25.

This chapter presents methods and data sources for developing personnel estimates for individual systems. The procedures apply to the number of personnel required but not to their cost. Manned aircraft and missile systems are discussed separately. The steps in the procedure apply to (1) operation personnel, (2) maintenance personnel, (3) administration personnel, and (4) support personnel. A detailed example is given for a manned aircraft system.

Planning Research Corporation, Methods of Estimating Fixed-Wing Airframe Costs, PRC-547, February 1965, 219 pp.

Describes the development of equations for estimating the production costs of airframes for new fixed-wing aircraft. Cost data on post World War II military aircraft were collected and analyzed. Costs were divided into four major elements (manufacturing labor, manufacturing materials, engineering, and tooling), and the costs for each element were developed at four production points (units 10, 30, 100, and 300). Sixteen cost-estimating equations were then derived, one for each of the four elements of cost at each of the four production points. Procedure for using the equations and methods for computing standard deviations and prediction intervals for the cost estimates are also presented.

Wright, T. P., "Factors Affecting the Cost of Airplanes," Journal of Aeronautical Sciences, Vol. 3, No. 4, February 1936, pp. 122-128.

Presents a discussion of the effect of quantity production on cost. The type of airplane construction is described as a factor governing the cost and shape of the progress curve. The factors that make cost reductions possible with increases in the quantity produced are discussed. Labor improvement is considered, together with increased efficiency in the use of materials. Overhead costs are also discussed in relation to quantity production.

Yates, E. H., A Method for Estimating the Procurement Cost of Aircraft, Vol. 1, General Electric Company, Technical Military Planning Operation (TEMPO), RM-60-TMP-39, June 1960, 57 pp.

This report contains equations for estimating aircraft costs. The statistical approach is employed with costs presented in functional form. Cost is described as the function of various aircraft physical and performance characteristics. This approach permits cost analysis in support of decisions on system design. The elements of aircraft costs are discussed individually, including: (1) airframe (direct labor, materials, overhead, evaluation of learning curve, engineering and tooling, G&A, ECP, and profit), (2) propulsion, and (3) other GFAE. A computational example of the use of the techniques and data is included.

VII. COST ESTIMATING RELATIONSHIPS AND METHODOLOGY

Alchian, A., Costs and Outputs, The RAND Corporation, P-1449 (DDC No. AD 607003), September 1958, 28 pp. Also published in P. Baran, T. Scitovsky, and E. S. Shaw (eds.), The Allocation of Resources, Stanford University Press, Stanford, California, 1959.

This paper examines the relationship between costs and outputs. Graphic and tabular examples are included. A distinction is made between the rate and quantity of output. Delivery dates are shown to be a major feature of the cost-output relationship. Long-run and short-run effects on such relationships are also discussed.

Arrow, K. J., and S. Arrow, Methodological Problems in Airframe Cost-Performance Studies, The RAND Corporation, RM-456-PR (DDC No. AD 116556), September 1950, 33 pp.

This study examines the problem of defining the relationship between cost and performance aircraft. In relating costs to performance, cost is considered a function of both the technical and performance characteristics of the aircraft. Material and labor costs are discussed, together with cost reduction through learning.

Arrow, K. J., S. Arrow, and H. Bradley, Cost-Quality Relations in Bomber Airframes, The RAND Corporation, RM-536-PR (DDC No. ATI 210678), February 1951, 43 pp.

Describes a method for predicting how changes in bomber performance affect production costs. Production cost is expressed in direct man-hours. The learning curve concept is employed in the formulas presented for cost prediction.

Asher, Harold, Cost-Quantity Relationships in the Airframe Industry, The RAND Corporation, R-291 (DDC No. AD 105540), July 1956, 199 pp.

In this study, a comprehensive examination is made of the relationship between costs and quantities in the production of airframes. The literature and prior studies are discussed, together with the development of the theory of progress curves. The elements of airframe costs are examined in detail. Empirical data are included, and graphs have

been developed to demonstrate cost-quantity relationships for past production. The conventional progress curve, which is linear on logarithmic grids, is described as an inaccurate description of the relationship between cost and cumulative output. For certain values of cumulative output, labor and production curves become convex.

Dolan, T. E., W. G. Long, and R. H. Lundberg, "Costing Methodology and Program Costs for a Manned Lunar Landing and Return Mission--Project Mallar," in Horace Jacobs (ed.), Proceedings of the Seventh Annual Meeting--January 16-18, 1961, Vol. 8 of Advances in Astronautical Sciences--Proceedings of the Meetings of the American Astronautical Society, Plenum Press, New York, 1963, pp. 332-352.

A cost analysis methodology is described as it applies to the conceptual and preproposal phases of advanced systems design. It is characterized by (1) basic cost data preparation, (2) application to system concepts, (3) refinement of system design and summary costs, (4) breakdown of summary cost information and refineme- with specific cost inputs, (5) introduction of contingency factors, and (6) final program cost analysis and summary. As an example, the method is applied to the lunar mission.

Eisemann, D. M., The Progress Curve Computer, The RAND Corporation, P-1492 (DDC No. AD 224123), September 1958, 5 pp. Also published in Operations Research, Vol. 7, No. 1, January-February 1959, pp. 128-130.

This paper describes the use of the progress curve computer, a device to obtain average, unit, and total costs for all quantities of output from 1 to 1,000. The progress curve consists of a logarithmic grid upon which a family of curves is presented. It shows the cost implications of varying the levels of output and indicates differences between average prices and unit prices.

Eliel, L. F., Compound Progress Curves--An Approximation to Multi-Element Learning Curves, Aerospace Corporation, 18 pp.

The construction and nature of the multi-element cost curve are described. This curve is described as a more realistic model of total cost per unit than the conventional linear learning curve. The compound curve, which is convex on log paper, is readily integrable. A normalized approach to cost simulation is presented, together with the

resulting parameter values of the compound progress curves. Data reduction procedures for minimum information are discussed, and possible uses of the compound progress curves. Data reduction procedures for minimum information are discussed, and possible uses of the compound progress curve theory are indicated.

Erickson, H. G., An Empirical Method for Estimating the Cost of an Aircraft, LING-TEMCO-VOUGHT, Inc., May 1962, 16 pp.

Describes methods for estimating aircraft costs without the prior preparation of detailed work statements. Mathematical relationships are presented for deriving total contractor program costs for aircraft ranging from a Mach .6 propellor configuration to Mach 2+ jet powered airplanes. Eight variables associated with the design and construction of the aircraft are used for estimating costs. Charts are included plotting costs for the aircraft structure and for related equipment.

Fehr, F. W., "Some Points to Watch in Studying the Fluctuation of Cost with Volume," NAA Bulletin, March 1960, 9 pp.

Contains a discussion of cost-quantity relationships. The nature of fixed and variable costs is examined. Costs are described as remaining fixed by (1) management decision, (2) their inherent nature, or (3) interpretation of accounting policy. The time element is important inasmuch as costs fixed in the short run may be variable in the longer run. Some costs such as material inputs vary automatically with the activity; others, such as direct labor, vary as a result of management decision. Degrees of variation and stepped costs are discussed.

Fisher, G. H., Derivation of Estimating Relationships: An Illustrative Example, The RAND Corporation, RM-3366-PR (DDC No. AD 290951), November 1962, 90 pp. Also published as Chapter V, "Use of Statistical Regression Analysis in Deriving Estimating Relationships," in J.P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. V-1-V-83.

This memorandum illustrates how statistical regression analysis can be used to derive estimating relationships from historical data.

The specific illustration pertains to estimating relationships for initial tooling cost as a function of aircraft performance and physical characteristics. Examples of the use of simple linear regression, logarithmic linear regression, second degree regression, and multiple linear regression analysis are discussed. Instructional problems are included in appendices.

Fisher, G. H., Generalized Depot Maintenance Cost Estimating Relationships for Bomber and Fighter Aircraft, The RAND Corporation, RM-3064-PR (DDC No. AD 276151), (For Official Use Only), May 1962, 28 pp.

Fighter and bomber depot maintenance costs are examined in relation to various features of the aircraft. Statistical regression analyses are used to determine the variable or set of variables that best explain variations in aircraft depot maintenance costs. The results indicate that simple relationships between maintenance costs and aircraft level-off costs can serve as well as the other aircraft features studied. The estimating relationships derived are presented together with accompanying standard errors of estimate, prediction intervals, and other statistical measures.

Fowlkes, T. F., Aircraft Cost Curves, General Dynamics, Fort Worth, August 1963, 64 pp.

Provides a general study of cost curves, covering their origins and development. The characteristics of cost curves are discussed together with their use in projecting and establishing costs. Examples are presented of calculations for unit costs and cumulative total manufacturing hours for a number of percentage cost curves. Tables and graphs are included for the projection and analysis of costs.

Friedland, E. I., On the Construction of Cost Estimating Relationships, The MITRE Corporation, W-5440, December 1962, 17 pp.

Examines several methodological questions in developing cost estimating relationships. The derivation of relationships is discussed separately for existing and future equipment. A distinction is also drawn between estimating costs of equipment within the current state

of the art and that beyond it. The uncertainty associated with estimating these costs is outlined. The selection of independent variables and the proper level of aggregation are examined. The value and limitations of statistical techniques are discussed as they apply to cost estimating relationships.

Hatry, H. P., Estimation of Military Support Activity Costs, General Electric Company, Technical Military Planning Operation (TEMPO), RM-60-TMP-49, August 1960, 29 pp.

This report outlines a general procedure for estimating support costs of military forces. The steps are (1) the identification and categorization of various activities of the military service, (2) the determination of each support activity, (3) the derivation of numerical relationships between support and supported activities, and (4) the application of such relationships to force alternatives under consideration. It is assumed in the outlined steps that the magnitudes of support vary in linear fashion with the selected variables and that the relationships indicated by the year examined will apply substantially to future years.

Hatry, H. P., Techniques for Estimating Future Force Compositions for Aircraft Weapon Systems, General Electric Company, Technical Military Planning Operation (TEMPO), RM-59-TMP-39, August 1959, 53 pp.

Mathematical techniques are considered for estimating future aircraft inventories from procurement schedules or for developing the aircraft procurement schedules necessary to meet future aircraft inventories. The problem of fixed and variable attrition rates is also discussed in developing methods for determining end-position inventories or in arriving at time-phased inventories.

Hirschmann, W. B., "Profit from the Learning Curve," Harvard Business Review, Vol. 42, No. 1, January-February 1964, pp. 125-139.

Contains a discussion of the nature and use of the learning curve. The effects of assembly and machine work on the slope of the curve are explained. It is pointed out that the learning curve has not been

generally adopted outside the aircraft industry. An application of the learning curve to petroleum refining is examined, and the shorter time required for start-up operations through repetition is described as an example of learning in a labor-intensive refinery operation. The maintenance learning curve is also considered, and improvement through learning in the construction of refineries is examined.

Jones, M. V., Cost Factors as a Tool in Military System Cost Analysis, The MITRE Corporation, TM-3172, November 1961, 10 pp.

This memorandum defines and describes cost factors, their advantages, and their limitations. A system is outlined for deriving, documenting, and using cost factors. Factors are statistically derived from average or general relationships in historical data, as modified by the judgment of the analyst. The cost factor can represent linear or nonlinear relationships and can be related to several variables. The basic advantage of using factors is their convenience. The proper use of factors as opposed to direct measurement is discussed. Documentation of the derivation of cost factors is important and examples of such documentation are included in appendices.

Marvin, K. E., "An Approach to Cost Estimating by Formulas," NAA Bulletin, July 1960, pp. 31-42.

This article contains a discussion of the derivation and use of mathematical formulas for cost estimating. Conversion of plotted points to numerical relationships makes it possible to develop reliable cost estimates rapidly, which is highly advantageous in business operations. Steps in the process are outlined, including the selection of relationships and the collecting and plotting of data.

Marvin, K. E., "Development and Potentials of a Formula Estimating Capability," NAA Bulletin, October 1963, pp. 19-21.

Describes the nature and usefulness of formula estimating, and includes examples of its application. The process requires the continuous integration of highly skilled manual analysis and the handling of

massive computations. Included are data collection, data reduction, the development of mathematical relationships, and cost estimation through the rapid selection and solution of such relationships.

McClenon, P. R., Cost Finding Through Multiple Correlation Analysis, The RAND Corporation, P-2619, August 1962, 18 pp.

The development of cost estimates through the use of multiple correlation analysis is described in this paper. The technique can be used as an alternative for cost finding when regular cost accounts are not available. The discussion includes an example of the computation and a description of data requirements for correlation analysis.

Mooz, W. E., The B-X: A Hypothetical Bomber Cost Study, The RAND Corporation, RM-4635-PR (DDC No. AD 466398), July 1965, 81 pp.

Illustrates some of the techniques used at RAND for costing weapon systems. It describes how the cost analyst, when supplied with information concerning the characteristics of a weapon and its operation, makes an estimate of the resources required to develop, purchase, and operate the weapon as a system. It details the use of estimating relationships for such elements as engineering and tooling under research and development, investments in equipment and spares, and personnel and maintenance costs for operations. Sensitivity analysis is also described for applications regarding possible error and for examining the effects on cost of varying the operation of the system.

Mosbaek, E. J., Expedient and Reliable Unit Cost Estimating, General Electric Company, Technical Military Planning Operation (TEMPO), RM-58-TMP-69, December 1958, 60 pp.

This report summarizes a study on unit cost estimating. A method is described for calculating the unit cost as a function of the quantity produced. The method is designed for costing complex electronic components that are characterized by high purchase parts costs relative to other costs of production. The report describes how the unit cost for any level of production can be approximated by a weighted sum of 3 or 4

group costs. The weights are provided in a table. The method can also be used to determine the difference in production cost for alternative production scheduling.

Mosbaek, E. J., Handbook for Applying Expedient Unit Cost Estimating, General Electric Company, Technical Military Planning Operation (TEMPO), RM-59-TMP-2, January 1959, 13 pp.

A method for estimating unit costs at varying production levels is illustrated in this report, which also outlines the techniques described in TEMPO RM-58-TMP-69, "Expedient and Reliable Unit Cost Estimating." The general approach is to derive the unit cost for a specified production level, referred to as the "first cost estimate," and then to use the information for the rapid calculation of other cost estimates. The procedure is outlined in five steps. The first three are used to develop adjusted costs for five groups of vendor products, the fourth to adjust labor and material costs, and the fifth to sum costs.

Noah, J. W., and R. W. Smith, Cost-Quantity Calculator, The RAND Corporation, RM-2786-PR (DDC No. AD 279346), January 1962, 30 pp.

This memorandum explains the use of the Cost-Quantity Calculator, a device included with the document. The calculator provides cost analysts with a tool for constructing and interpreting cost-quantity relationships, also referred to as learning, progress, or improvement curves. The two most common types--the log-linear cumulative average curve and the log-linear individual unit curve--are defined and their differences and interactions are explained. Tables of slope-quantity factors are provided for applying relationships.

Novick, D., Use of the Learning Curve, The RAND Corporation, P-267 (DDC No. AD 422816), November 1951, 6 pp.

Contains a discussion of the constituents of the learning curve--direct labor and materials. The learning curve is described as applicable only to the direct labor element of cost in the facility producing

the finished item. Although purchased items are subject to the improvement curve, it may be misleading to aggregate both direct labor and purchased parts and apply the uniform learning curve. A table is included showing the average percentage reduction for successive numbers of units for an 80 percent learning curve. It is also pointed out that learning carried over from related production must be placed at the proper position on the curve.

Petruschell, R. L., The Derivation and Use of Estimating Relationships, The RAND Corporation, RM-3215-PR (DDC No. AD 276673), June 1962, (For Official Use Only), 40 pp.

Describes various estimating techniques and procedures developed by the Cost Analysis Department in the course of its research on Air Force systems. The use of estimating relationships in costing is discussed and the approach to their development is described. Illustrations show their application in cost analysis. The skills needed by the cost analyst to develop estimating relationships are defined, and the application of statistical procedures, including scatter diagrams, correlation analysis, and regression analysis, is described.

Petruschell, R. L., "An Introduction to Estimating Relationships," in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. IV-1-IV-28.

This chapter describes cost estimating relationships, their derivation, and the data for dependent variables and generating activities. Various display forms depicting relationships are presented. The use of cost estimating relationships is explained and an example is provided to illustrate a method for deriving such relationships.

Raborg, W. A., Jr., "Mechanics of the Learning Curve," Aero Digest, November 1952, pp. 17-21.

This article consists of a description of the learning curve and its construction. The use of the learning curve expanded rapidly with the expansion of the aviation industry. The learning curve is described

as a graphed line showing (1) that the time required to do a job will decrease with repetition and (2) the amount of decrease will be less with each successive unit. The graphical construction of the curve is done in three parts: (1) the cumulative average line, (2) the cumulative total line, and (3) the unit time line.

Taylor, M. L., "The Learning Curve--A Basic Cost Projection Tool," NAA Bulletin, February 1961, pp. 21-61.

The principle of continuous learning is reviewed in this article as the basis for discussing the nature and usefulness of its application in the learning curve formula. Also discussed is the application of the formula in practice by those uninitiated in the underlying mathematics.

Tenzer, A. J., O. Hansen and E. M. Roque, Relationships for Estimating USAF Administrative and Support Manpower Requirements, The RAND Corporation, RM-4366-PR (DDC No. AD 611587), January 1965, 39 pp.

Presents the results of a study conducted to develop a generalized method for estimating future administrative and support personnel requirements. The study pertained to bases of the Strategic Air Command, Tactical Air Command, Air Defense Command, and the Military Air Transport Service which are located within the continental United States. From an examination of statistical data it was found possible to estimate the relationship between operations and maintenance personnel and the number of administrative and support personnel. The specific estimating relationships for the major commands and for major systems are presented.

Walters, A. A., "Production and Cost Functions: An Economic Survey," Econometrica, Vol. 31, Nos. 1-2, January-April 1963, pp. 1-66.

This article contains a discussion of short and long run production cost functions. Relationships between quantities of output and costs are examined. The problem of obtaining suitable cost data from engineering or accounting data is considered. The results of a number

of studies are examined to determine the shape of long and short run cost curves.

Watts, Frank A., Aircraft Turbine Engines - Development and Procurement Cost, The RAND Corporation, RM-4670-PR (Abridged) (DDC No. AD 363904), November 1965, 71 pp.

The results of this study are based on the history of 14 engines representing expenditures of approximately $8 billion. Satisfactory multiple regression equations were derived for turbojets and turboprops relating cost to engine size and quantity. A discussion is included of the institutional and environmental influences on cost. Such influences include the relative capability of the contractor, the urgency of the program, the number of changes, the amount of funds known to be available, and the contractor's level of current business. The study is intended primarily for use in long-range planning exercises on manned military aircraft.

Yaross, A. D., Cost Prediction Based on CER Utilization, USAF, Air Force Systems Command, Aeronautical Systems Division, Cost Analysis Information Report 62-6, May 1962, 29 pp.

Reviews statistical techniques for developing cost estimating relationships or cost factors. A cost estimating relationship or cost factor is defined as a functional expression which states that the cost of an item may be predicted on the basis of one or more independent variables. The difficulty of developing such factors and relationships is discussed. Illustrations show the application of data and techniques. Historical contractor cost information provides a base for system cost predictions. The selection of variables is assisted by the use of measures of dispersion to determine their reliability for estimating. Relationships can be measured by correlation and regression analysis. The use of the diagram, ratios, and index numbers is also discussed.

Yates, E. H., A Method for Estimating the Procurement Cost of Aircraft, Vol. I, General Electric Company, Technical Military Planning Operation (TEMPO), RM-60-TMP-39, June 1960, 57 pp.

This paper describes a statistical approach to aircraft cost estimating. Cost is presented in functional form, that is, it is related to the physical and performance characteristics of aircraft. The individual elements that contribute to aircraft cost are discussed in detail. A generalized estimating equation is derived and a computational example is given to illustrate the technique.

VIII. DATA REQUIREMENTS

Galin, M. P., and J. M. Cappelletti, The Central Technical Cost Library, The MITRE Corporation, TM-3136, July 1961, var. pages.

Describes the MITRE Central Technical Cost Library, which has been established to provide a comprehensive depository for cost, economic, and resource data and to accomplish the receipt, indexing, storage, and recovery of the information gathered. Three appendices describe (1) the library organization, (2) procedures, and (3) method for implementation. The abstracting of material and its preparation for indexing and classifying are explained. Exhibits are included showing the library forms.

Jones, M. V., Bidder Cost Estimates as a Data Base Source for Advanced Systems Costing, The MITRE Corporation, TM-3538, January 1963, 8 pp.

This paper proposes that bidder cost estimates received in the course of system source selection be included in the data base for costing advanced military systems. It describes the advantages of bidder cost estimates, suggests precautions in their use, and recommends standards for their effective utilization. The type of data that can be derived from bidder cost estimates is specified.

Pardee, F. S., Guidelines in Accumulating Financial Data on Future Weapons, The RAND Corporation, RM-2583-ARPA (DDC No. AD 418652), May 1960, 46 pp.

Provides guidance for the collection of the financial data necessary to evaluate weapon systems. Such data are needed for the analytical process of measuring operational capability and total financial requirements. A background discussion deals with cost concepts, uncertainty, and the form of the data. Weapon system descriptive data and their importance are discussed. Two basic formats present the major cost elements to be considered in predicting the economic impact of a future weapon system. A checklist of cost elements is provided.

Pardee, F. S., The Financial Portion of a Management Information System, The RAND Corporation, RM-2836-PR (DDC No. AD 413607), D December 1961, 52 pp.

This memorandum presents the objectives and features of an information system for military planners and decisionmakers. The system should permit an evaluation of the cost implications of alternative courses of action. It should contain the following features: (1) R&D, investment, and operating cost categories, (2) data on the sensitivity of cost to system design and operational concept, (3) data to make force composition analyses, (4) data aggregations consistent with varying management levels, (5) data to permit the derivation of estimating relationships, and (6) data for status reviews.

Schlosser, K. P., and B. Lyon, Cost Data Bank--Problem Areas, USAF AIR Force Systems Command, Aeronautical Systems Division, Cost Analysis Information Report 62-4, May 1962, 20 pp.

Describes a cost data research project to establish a centralized facility for the collection, storage, and retrieval of cost estimating relationships and related data. Problem areas in establishing such a data bank are described. The form, source, and amount of data required are discussed, together with updating, mechanization, and workloads.

Slivinski, S. C., The RAND Cost Analysis Department Data Bank, The RAND Corporation, P-2985, (DDC No. AD 606581), September 1964, 8 pp.

Contains a description of the cost data bank maintained at The RAND Corporation. The physical arrangement and operation of the facility are explained. Sources of data for cost analysis are discussed together with the manner in which useful data are extracted for inclusion in the data bank. The organization and classification of the cost data files are outlined and discussed along with considering automation for the facility.

IX. INDIVIDUAL SYSTEM ANALYSIS

Devlin, W. G., Tactical Fighter Weapon System Costing--Initial Investment and Annual Operation and Maintenance, The Boeing Airplane Co., D6-9909 as revised, March 1964, 24 pp.

Describes a methodology for developing program costs of tactical fighter systems. Program costs are developed as part of presentations to the military and also for the purposes of evaluating new aircraft designs. The F-105 system, with illustrative values, is used as an example of the development of program costs. Cost element lists and corresponding estimating equations are included. The cost elements within each cost category are outlined and defined. Methods for developing personnel requirements are also described.

Fisher, G. H., Military Systems Cost Analysis (A Summary Lecture for the AFSC Cost Analysis Course), The RAND Corporation, RM-2975-PR, January 1962, 29 pp.

Contains a discussion of the concepts and principles of weapon system cost analysis. Cost analysis is described as the determination of the probable economic resource impact of future military systems. Five major aspects of cost analysis are (1) understanding the problem of context in which cost estimates are to be used, (2) assembling the basic data, (3) deriving cost estimating relationships, (4) using these relationships to develop estimates, and (5) presenting the results. Hardware and non-hardware system cost components, and the sensitivity of total system cost to variation in the specifications of these components, are considered. A list of cost elements for a missile system is also included.

Jones, M. V., A Generalized Cost Structure for Electronic Systems, The MITRE Corporation, TM-3299, May 1962, 17 pp.

This report presents a chart of accounts for military electronic systems and the definitions of the elements. For a more detailed description of this report, see its entry under Section V.

Jones, M. V., System Cost Analysis: A Management Tool for Decision-Making, The MITRE Corporation, TM-04063, July 1964, 178 pp.

A generalized and integrated conceptual approach to the major steps in costing military systems is presented. Methodological problems and the necessary tasks are identified and described, as well as the process of system costing. The analyst's need for background information for costing is discussed. The types of resource and activity data required are explained, including their availability. How to present cost estimates to users is also discussed.

Novick, David, System and Total Force Cost Analysis, The RAND Corporation, RM-2695-PR (DDC No. AD 257269), April 1961, pp. 13-58.

Chapter II of this memorandum contains a discussion of individual system cost analysis. An outline of the specifications and assumptions needed for system costing is provided together with a chart of accounts. Each cost element is defined and described. For a more detailed description of this memorandum, see its entry under Section X.

Novick, David, and R. L. Petruschell, "Cost Analysis of Individual Systems," in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. III-1-III-34.

This chapter discusses the costing of individual USAF systems. Requirements for descriptive data for individual systems are outlined and illustrated by a ballistic missile system description. A chart of accounts is provided and the cost elements are defined. The R&D investment, and operating cost categories are discussed. Administrative and support costs are defined and related to the USAF organizational structure.

Petruschell, R. L., "Estimation of Requirements for Primary Mission Equipment," in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. VIII-1-VIII-22.

This chapter describes a method for computing military system requirements for aircraft and missiles. The time phasing of requirements

and the use of cost-quantity relationships for the procurement of equipment are outlined. A step-by-step procedure is presented for developing required quantities as derived from the mission needs.

Pardee, F. S., Guidelines for Accumulating Financial Data on Future Weapons, The RAND Corporation, RM-2583-ARPA (DDC No. AD 418652), May 1960, pp. 19-27.

Part II of this memorandum concerns the missile and space system descriptive data needed for costing purposes. An outline of development and operational concepts is provided as an illustration. Cross-identification is made among (1) the contractor development, production and support elements, (2) system cost elements, and (3) the USAF budget. A chart of accounts for missile systems is provided on a sample format with each element defined.

Sotelo, R., Weapon System Costing for Strategic Air Command--Initial Investment and Annual Operation and Maintenance, The Boeing Airplane Co., D6-9905 as revised, January 1964, 22 pp.

Describes a methodology developed for determining program costs of Strategic Air Command aircraft systems. Such costs are developed as part of presentations to the military and in the evaluation of new aircraft design. The B-52H system is used, with illustrative values, for an example of the development of program costs. Cost element lists and corresponding estimating equations are included. The cost elements within each cost category are outlined and described. Methods for developing personnel requirements are also described.

Steiner, R. G., Military Transport System Costing--Initial Investment and Annual Operations and Maintenance, The Boeing Airplane Co., D6-9600 as revised, September 1963, 22 pp.

Describes a methodology for developing program costs of air transport systems. Program costs are developed as part of presentations to the military and also in order to evaluate new aircraft design. The CX-4 system, with illustrative values, is used as an example in the development of a program cost. Cost element lists and applicable estimating relationships are outlined and defined. Methods for developing system personnel requirements are also presented.

X. TOTAL FORCE STRUCTURE ANALYSIS

Clegg, D., Procedures for Development of a Weapon System Cost Methodology for Navy Weapons, General Electric Company, Technical Military Planning Operation (TEMPO), R-59-TMP-19, May 1959, 49 pp.

This paper is an introduction to weapon systems cost analysis for naval systems, systems costing being considered as a technique for military planning. Procedures are presented for developing a methodology suited to Navy systems costing. Data requirements are described in terms of existing data and the need for additional data, such as cost factors. The development of cost factors and the choice of variables are discussed. Sources for cost data and automatic compilation methods are described. Appendices present (1) a description of accounts, (2) the Navy appropriation structure, and (3) the series of expenditure accounts.

Fisher, G. H., Total Force Structure Cost Analysis, The RAND Corporation, RM-3070-PR (DDC No. AD 292751) (For Official Use Only), 26 pp. Also published as Chapter II in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. II-1-II-14.

Contains a summary description of total force structure cost analysis. Detailed costing procedures and techniques are not included. The purposes of the analysis are reviewed and the relationships between total force cost analysis and individual weapon or support systems are examined. An illustrative format shows the summary of total force structure cost estimates.

Novick, D., System and Total Force Cost Analysis, The RAND Corporation, RM-2695-PR (DDC No. AD 257269), April 1961, 154 pp.

Describes the aims, concepts, and methods of military cost analysis as developed by RAND's Cost Analysis Department. Included are descriptions of methods for estimating the costs of individual systems and total forces. The elements of cost for military systems are outlined and described for each of the cost categories: R&D, investment, and operating. The concepts and elements of total force structure cost

analysis are discussed. Examples of the use of cost sensitivity analysis are given, as well as EDP output formats. A bibliography is included.

XI. MODELS

Berman, E., T. Jannsen, and H. Glazer, WSPACS Integration Model, The MITRE Corporation, W-5645, December 1962, 20 pp.

Describes the Weapon System Planning and Control System, which has been designed to measure the cost impact of modifying Air Force programs. Models for reprogramming USAF subsystems are integrated in the force structure model. This report is concerned with the first portion of the integration model, the development and production model. Definitions and notation are given in Section 2, and data requirements in Section 3. Major contractor scheduling and costing subroutines are discussed in Section 4. Section 5 contains a narrative and flow chart of the integration scheduling procedure and a description of the integration cost allocation procedure.

Boren, H. E., Individual Weapon System Computer Cost Model, The RAND Corporation, RM-4165-PR (DDC No. AD 603005), July 1964, 177 pp.

This memorandum contains a description of the operation of a computerized cost model. The model is used to determine resource requirements for individual weapon systems, including aircraft, aircraft with ASM, and personnel requirements for strategic missile systems. A flow chart of the general operation of the model is included. The model is structured on aircraft cycle time, i.e., the time from the beginning of one mission to the beginning of the next. The cycle consists of flying, waiting, and maintenance time. In application, the model determines the resources needed to sustain a specified number of aircraft on station continuously.

Bradley, B. D., Building a New Force Structure Cost Analysis Model, The RAND Corporation, RM-4764-PR, October 1965, 21 pp.

This memorandum describes a cost model that is being developed by the RAND Cost Analysis Department. The new model is being designed to incorporate explicitly the analysis of non-weapon support activities. The concepts underlying the model and their application in the analytical process are also discussed. Among these are the concepts of

alternative planning end-products, fixed and variable costs, incremental costs, identification of investment and operating costs, and the application of generalized estimating relationships. The model is structured similarly to the format of the USAF Force and Financial Program. It employs cost elements related to the budget/appropriation structure, and end-product elements defined by organizations and their related equipment and activities.

Bradley, B. D., R. E. Clapp, and R. L. Petruschell, A New Cost Model to Support Air Force Long-Range Planning, The RAND Corporation, P-3133, (DDC No. AD 615401), May 1965, 21 pp.

Describes the concepts, structure and objectives of a planned Air Force cost analysis model. The model is intended for use in estimating the costs of total force structures and will assist in the analysis of resource implications of planning alternatives. This paper contains descriptions of the long-range planning process, the place of cost analysis in planning, and the general characteristics of cost modeling.

Cost Analysis Department, Interim Report on Phoenix System Costs Volume II: Generalized Cost Model, The RAND Corporation, RM-2770-SSD, April 1961 (For Official Use Only), 137 pp.

This memorandum describes a generalized mathematical model for estimating the cost of space and ballistic missile booster systems. The model considers "cradle-to-grave" costs. The model does not apply solely to the Phoenix system; with possible modification, it can be applied to costing systems employing different operating concepts. Cost elements are described within the category structure--R&D costs, nonrecurring operating costs, and operating costs. Included are the subroutines for computing costs of flight vehicles, ground support equipment, and military facilities.

Eliel, L. F., A Generalized Cost Model for Military Systems, Aerospace Corporation, January 1962, 9 pp.

This paper contains a description of the major features of cost models. Various types of cost models are included. Relationships

between system design, technology, and resource requirements are described. Marginal analysis as a resource allocation tool is discussed as an element of the model. The relationship between system costing and financial planning is described, as well as the use of models for resource allocation or economic planning activities.

Grosse, R. N., Army Cost Model, The RAND Corporation, RM-3446-ASDC (DDC No. AD 293801), December 1962 (For Official Use Only), 64 pp.

Describes an Army cost model developed by The RAND Corporation for the Programming Office, Assistant Secretary of Defense (Comptroller). The model is used for rapid cost estimating of alternative forces for use in cost-effectiveness studies and for projecting approximate budget sizes. The model is structured to simulate Army processes in a simplified manner. Data needs and sources for developing the model inputs are described. An outline of the time scheduling for its development is included.

Grosse, R. N., And A. Proschan, Uses of Automated Force Cost Models, The RAND Corporation, RM-3608-ASDC (DDC No. AD 403268), April 1963 (For Official Use Only), 21 pp.

An automated force cost model is described in this memorandum as a device for rapidly computing the resource requirements of a force having a specified composition, deployment, equipping and manning levels, and other characteristics affecting costs. The major uses of automated cost models are (1) for the planning of alternative force structures and employment and (2) for programming and budgeting. For planning purposes, cost models permit the rapid calculation of cost estimates for alternative force compositions under consideration for future time periods. Experience in the use of cost models for programming and budgeting is limited. The adaptation of cost models to the DOD program/budgeting system is described.

Hatry, H. P., Techniques for Estimating Future Force Compositions for Aircraft Weapon Systems, General Electric Company, Technical Military Planning Operation (TEMPO), RM-59-TMP-39, August 1959, 53 pp.

This paper describes mathematical techniques for estimating future aircraft inventories from procurement schedules, and for developing

aircraft procurement schedules to meet specified future inventory positions. The first section presents equations which assume a pre-established attrition rate for each year. Attrition rate as a function of flying hours is then introduced. Three approaches are presented for estimating future inventory positions from procurement schedules. Though computationally different, they yield similar results. Equations are included for estimating both numbers of aircraft and numbers of aircraft squadrons.

Jannsen, T. J., and H. Glazer, Electronic System Cost Model, The MITRE Corporation, TM-3364, August 8, 1962, var. pages.

A computer model for costing electronic systems is described which is designed to provide (1) single time-phased estimates of system costs for given configurations and (2) multiple estimates of system costs as selected parameters are varied. The first section of the paper presents a general discussion of the model and its use in system cost analysis. The next section contains a description of the model, including input elements, the cost estimating structure, cost estimating relationships, and output formats. Planned extensions of the model are discussed in the last section. Input data forms, the detailed cost estimating structure, and output format examples are presented in appendices.

Novick, D., System and Total Force Cost Analysis, The RAND Corporation, RM-2695-PR (DDC No. AD 257269), April 1961, pp. 76-91.

A part of this memorandum is devoted to a description of the RAND PROM force cost model. A method for including R&D elements is outlined and described. Data requirements and their formats are shown for constant data, for the derivation of program requirements from deliveries data, and for the derivation of expenditure estimates from program requirements. Input data and formats describing the force are included. The methods of calculation are presented, and the print-out formats are provided for illustration.

String, J., A Model for Projecting Costs of Space Exploration, The RAND Corporation, P-3119 (DDC No. AD 615517), April 1965, 23 pp.

Describes a model for estimating the costs of advanced space hardware and for assessing the budgetary implications of integrated space exploration plans. The model is described as a long-range planning model for evaluating alternative overall space plans and their funding requirements.

XII. UNCERTAINTY

Alchian, A., Reliability of Progress Curves in Airframe Production, The RAND Corporation, RM-260-1-PR (DDC No. ATI 210621), revised February 1950, 35 pp.

This memorandum contains an assessment of the reliability of cost predictions made on the basis of airframe cost/quantity curves. The functions are shown to differ in direct labor per pound of airframe among the various types and the different manufacturing facilities. The average error in prediction is described and measured. If curves for specific manufacturing facilities are used, the margin of error in prediction is reduced.

Carter, R. D., A Survey of Techniques for Improving Cost Estimates of Future Weapon Systems, Analytical Services, Inc., AM-65-2, March 1965, 85 pp.

This study examines the causes of error in costing weapon systems and evaluates techniques for improving estimates in the future. The causes of error are categorized as technological uncertainty, requirements uncertainty, and cost uncertainty. Various techniques that have been developed in the past for dealing with uncertainty are discussed and evaluated. These techniques include (1) cost estimating relationships, (2) adjustment factors, (3) subjective probability distributions, and (4) cost sensitivity analysis.

Fisher, G. H., A Discussion of Uncertainty in Cost Analysis, The RAND Corporation, RM-3071-PR (DDC No. AD 279936), April 1962, 28 pp. Also published as Chapter VI, "The Problems of Uncertainty," in J. P. Large (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation RM-3589-PR (DDC No. AD 411554), June 1963 (For Official Use Only), pp. VI-1-VI-26.

Contains an exploratory discussion of the problem of uncertainty in the cost analysis of future military systems and forces. A number of earlier studies of costing uncertainties are considered. The major sources of uncertainty--requirements uncertainty and cost estimating uncertainty--are outlined, and various proposals for their treatment are discussed. Sensitivity analysis, suggested as a possible solution, is also described.

Marshall, A. W., and W. H. Meckling, Predictability of the Costs, Time, and Success of Development, The RAND Corporation, P-1821 (DDC No. AD 224160), December 1959, 24 pp.

Presented in this paper are the results of research into the extent and nature of uncertainty in Air Force development projects. The general conclusions are that early estimates are usually low because of over-optimism and error. Changes in design and plans as development proceeds are largely responsible for the inaccuracy of the original estimates. Data are presented showing total factor increases in the costs of various types of military aircraft. The factors express differences between the earliest available estimates and the actual cost. The technological advancement necessary and basic uncertainty are the major determinants of the size of the error.

Sobel, S. A., A Computerized Technique to Express Uncertainty in Advanced Systems Cost Estimates, The MITRE Corporation, TM-3728, September 1962, var. pages.

Contains a description of a technique to express quantitatively the uncertainty in advanced systems cost estimates. The technique uses subjective probability distributions to describe the uncertainty in each system element, and these, in turn, serve to develop an approximate distribution for the total system cost. A 7070 computer program has been written for the computational operations. A glossary, illustration of calculations, card formats, and flow charts are also provided

Summers, R., Cost Estimates as Predictors of Actual Weapon Costs: A Study of Major Hardware Articles, The RAND Corporation, RM-3061-PR (DDC No. AD 329265), March 1965, 83 pp.

Consists of a statistical study of the accuracy of past cost estimates. The purpose of the study is to assess the probable accuracy of cost estimates of major hardware that are still in development. The study is based on a sample of 68 estimates for hardware used in 22 weapon systems. Techniques are derived and presented for the purpose of decreasing uncertainty about future hardware costs.

Tenzer, A. J., Cost Sensitivity Analysis, The RAND Corporation, P-3097 (DDC No. AD 620836), March 1965, 23 pp.

Contains a discussion of cost sensitivity analysis as a method for treating uncertainty. Cost sensitivity analysis is also discussed as an aid to comparing alternative weapon configurations and operational plans. Cost sensitivity analysis is described as a process for determining how variations or uncertainty in the configuration of a weapon system can affect its cost. The technique is described through the use of an illustration.

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10. ABSTRACT

A bibliography of unclassified literature on systems cost analysis, including books, pamphlets, articles, papers, and technical and research memoranda, giving the nature and content of each work. The titles are grouped into categories representing broad areas of cost analysis and its application in the Department of Defense.

11. KEY WORDS

Bibliography
Systems analysis
Cost analysis
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