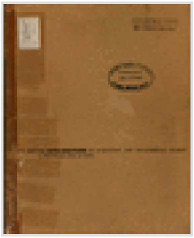

Toward Better Utilization of Scientific and Engineering Talent: a Program for Action; Report (1964)

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WASHINGTON D.C., 1964

TOWARD BETTER UTILIZATION OF SCIENTIFIC AND ENGINEERING TALENT
A PROGRAM FOR ACTION

REPORT
OF THE COMMITTEE ON UTILIZATION OF SCIENTIFIC AND ENGINEERING MANPOWER

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PREFACE

Suggestions that a study be undertaken to examine the utilization of scientists and engineers in the United States originated in the President's Science Advisory Committee and in the Federal Council for Science and Technology. As early as 1959, both bodies had expressed a need for such a review and had taken first steps toward initiating a study.

In 1961, in response to a recommendation to President Kennedy by Jerome Wiesner, his Special Assistant for Science and Technology, the President approved the undertaking of a study on utilization, together with a review of requirements for the development of scientists and engineers between now and 1970. This latter review, it was agreed, should be undertaken by the President's Science Advisory Committee.

The study of utilization, it was felt, could best be conducted through a non-governmental body and supported from private sources. The National Academy of Sciences was requested to appoint a committee to make such a study, and to secure the necessary funds. The Academy agreed and in 1962 appointed the Committee on Utilization of Scientific and Engineering Manpower; and, in response to a proposal from the Academy, the Ford Foundation made a grant to finance the Committee's work. This report reflects the views of the Committee, based on its two years of study.

The Committee expresses its gratitude for the subvention of the Ford Foundation and for the generous conditions governing its use.

The Committee has been supported by an able staff: Marvin Adelson, Executive Director, on leave from System Development Corporation; for various periods, Vincent P. Rock, on leave from the Institute for Defense Analyses; Arnold Nemore; Ernest Mosbaek; Allen

O. Gamble; and John Dixon. The Committee, together with its staff, acknowledges the extensive technical support of the National Science Foundation, especially through the services of Walter Koltun and Wilbert Annis. On pages 59-61 is recorded our indebtedness to many others who made important contributions to the study.

Three members of the Committee undertook executive responsibilities in the course of the study. Richard H. Bolt assembled the staff and gave it leadership. Walter H. Gale supported the chairman in the general direction of the study, in addition to performing his duties as a member of the Committee. For a period when the chairman was unavailable, Clark Kerr served as chairman of the Committee.

The Committee owes a special debt of gratitude to the President of the National Academy of Sciences, Frederick Seitz, for his direct assistance in furtherance of this study.

Several panels were convened to discuss problems under consideration by the Committee, including three groups from industry and a group from the universities. A large group from the government and universities met for two days, with the Industrial Relations Section of Princeton University serving as host. To all these wise counselors we express our deep appreciation.

While its report, by request, is concerned with "utilization," the Committee wishes to make clear that it views utilization in a broad context: it is concerned with humanistic goals as well as economic, with the freedom and worth of man as well as his utility. In the context established by the Committee, utilization denotes: the work scientists and engineers are doing, where they are doing it and for what purposes, and the effectiveness of their efforts. Within this broad meaning, the report touches upon: the distribution of personnel in relation to needs, productivity in various working environments, and the effects of education and training upon productivity. These elements are considered in two dimensions: the values of the work done, and the development of the people doing it.

This report is one of several studies dealing with important aspects of scientific and engineering manpower. In January 1963 the President's Science Advisory Committee published a report entitled *Science, Government, and Information: the Responsibilities of the Technical Community and the Government in the Transfer of Information.* Because this report is so comprehensive, we have not dealt with the growing problem of information dissemination, even though it has a direct bearing on the efficiency of research and other technical activities. More recently the same committee issued a report on *Graduate Training in Engineering, Mathematics and Physical Sciences*, a topic only touched on in this report. Similarly, we have not emphasized the importance of the technician to the utilization of scientists and engineers because of an impending report by the President's Science Advisory Committee on the education of technicians. And finally, it would have been necessary to say more about the ways in which the federal government supports basic research in the universities were it not for the recent appearance of the National Academy of Sciences' report, *Federal Support of Basic Research in Institutions of Higher Learning.* These excellent studies deal with important aspects of the utilization of scientists and engineers, and thus supplement this report.

Following the seven chapters that comprise the Committee's report, Part I, this volume presents a number of study papers, Part II, under independent authorship. These papers are significant additions to the all too meager literature on utilization and are an integral part of this report. The Committee wishes to make clear, however, that the study papers express the views of their authors and not necessarily those of the Committee. The authors, in turn, do not necessarily agree with all the views of the Committee.

The effective utilization of scientists and engineers is but a part of the broad requirement that our society must recognize for the better utilization of *all* its human resources. We cannot afford to squander any of our human capital, or to deny any individual an opportunity to realize his full potential.

James R. Killian, Jr., Chairman
Richard H. Bolt
Bernard R. Berelson
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Karl A. Folkers
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Haakon I. Romnes
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PART ONE REPORT OF THE COMMITTEE

I

INTRODUCTION

SCIENTISTS AND ENGINEERS: A NATIONAL ASSET

Scientists and engineers, through their discoveries and innovations, expand the range of choices open to a nation and its people. In the United States, we look to our scientists and engineers to help make the nation strong, to advance the prevention and cure of disease, to deepen our understanding of man and nature, to educate and train tomorrow's scientists and engineers, and in many other ways to help us attain our individual and national goals.

In the years ahead, the nation's needs for scientists and engineers unquestionably will increase, and probably at a faster rate than they have in the past. Although the supply of this manpower also will increase, it may not keep pace with all the possible needs to which domestic and international influences will give rise. Difficult choices will have to be made among the many alternatives to which our limited supply of skilled manpower might devote its efforts. The total number of its citizens that a nation can count as scientists and engineers is only a crude index of its capability to meet its needs in science and engineering. Truer measures are the number of able scientists and engineers whose services are effectively used and the quality and relevance of their training.

In this report, the Committee on Utilization of Scientific and Engineering Manpower is concerned with improving the utilization of scientists and engineers, irrespective of the shortages or surpluses that may exist at any particular time. At present, there are both unfilled positions and unemployed scientists and engineers. Conditions vary by region and specialty. There are unmistakable shortages of manpower in the advanced technologies of new engineering systems, of scientists and engineers with technical and administrative skills required for the effective management of large scientific and technological undertakings, of teachers of science and engineering, and of persons with doctorates in mathematics.

Also at the present time, there are identifiable surpluses resulting, for example, from industries changing from older to new technologies. As the aircraft industry has redirected its major effort from airborne vehicles to space vehicles, adjustments have become necessary in the deployment of engineers. Currently, changes in the programs of the Department of Defense are resulting in cutbacks in certain types of employment. A number of engineers face problems of adapting themselves to more advanced technologies as their older skills become obsolete. Thus, the employment situation remains mixed. Our concern for improved utilization must go beyond those now employed.

ORGANIZATION OF THE REPORT

Chapter II describes the nation's needs for scientific and engineering manpower and the resources available to serve those needs. Chapters III, IV, and V set forth the Committee's findings and recommendations, divided according to three sectors: the federal government, industry, and colleges and universities. Aspects of utilization associated with the federal government, covered in Chapter III, relate not only to scientists and engineers employed within the federal government, but also to those employed by industry and by colleges and universities, but engaged in work that is supported, in whole or in part, by federal funds.

Scarcely any aspect of manpower utilization has relevance exclusively to only one of the three sectors. Education of scientists and engineers, for example, is supplied largely by colleges and universities; but the education they receive affects, in critical ways, the utilization of manpower in the other sectors. Nevertheless, even though utilization links the three sectors, the content of these chapters is organized according to the sectors in order to make explicit the principal audience to which the Committee addresses each of its recommendations.

Chapter VI recommends and discusses research efforts needed to strengthen our understanding of manpower utilization.

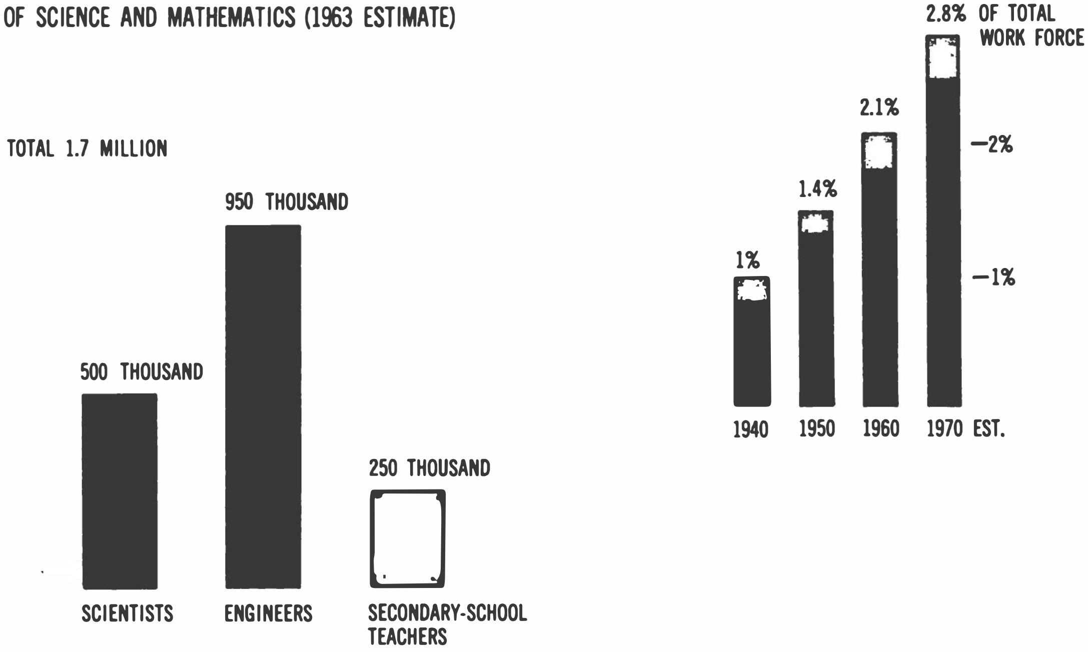
Chapter VII integrates the findings of the Committee, first by describing the major considerations that cut across all aspects of utilization, and then by drawing together, in summary form, all the recommendations introduced in the report. Throughout the report, the recommendations are marked by colored numerals and set in bold type.

II

NEEDS AND RESOURCES

In the United States, as in other economically advanced countries, the number of scientists and engineers has been growing rapidly. As Figure I shows, the proportion of scientists and engineers in the total work force doubled between 1940 and 1960. It now stands at more than two per cent. All together, about 1.7 million persons in the United States are now engaged in scientific and engineering work, including teaching, that requires a college degree or its equivalent. Of this total, about 950 thousand are engineers, 500 thousand are scientists, and the remaining 250 thousand are teachers of science or mathematics at the secondary-school level.

FIGURE I
NUMBERS OF SCIENTISTS, ENGINEERS, AND SECONDARY-SCHOOL TEACHERS OF SCIENCE AND MATHEMATICS (1963 ESTIMATE)



Based on "Profiles of Manpower in Science and Technology," National Science Foundation, 63-23.

A country's needs for scientists and engineers are reflected in the distribution of these persons among the several national purposes they serve. Figure II shows the deployment that has resulted from past priorities and goals.* Today, between two and three out of every ten scientists and engineers in the United States are engaged in work intended to strengthen the nation's security and to improve its position in space exploration. Approximately four out of every ten devote their efforts to commercial and industrial pursuits in the private sector of the economy, and about two out of every ten work in education. Clearly the demand for the services of scientists and engineers has been generated by domestic needs, but in substantial degree it has also been related to the international responsibilities of the United States.

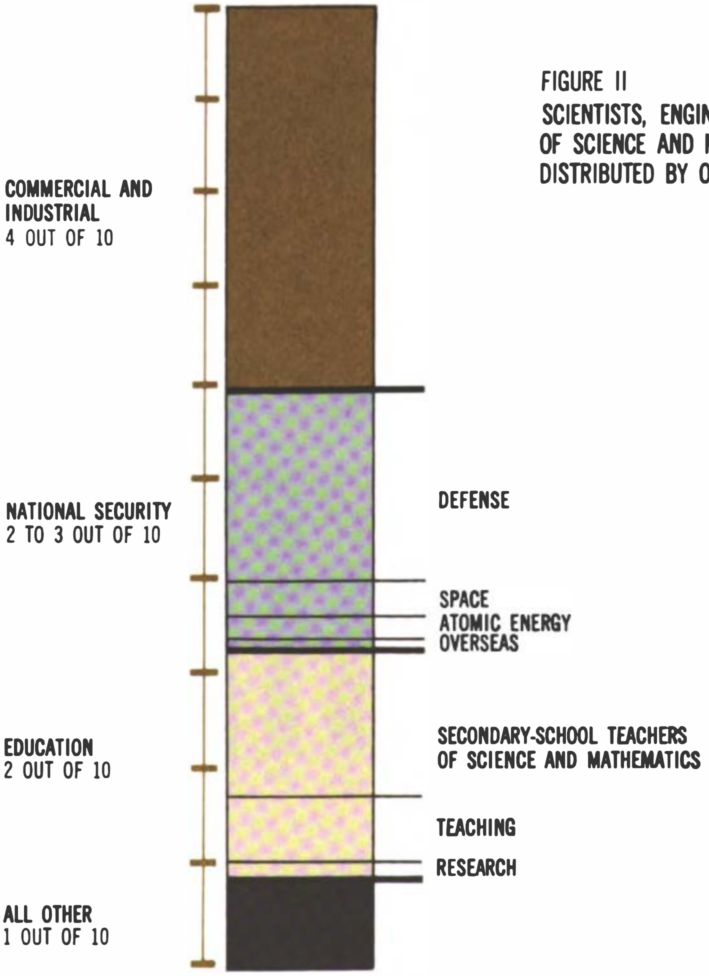


FIGURE II
SCIENTISTS, ENGINEERS, AND SECONDARY-SCHOOL TEACHERS OF SCIENCE AND MATHEMATICS, DISTRIBUTED BY OBJECTIVES (1963 ESTIMATE)

NOTE: THE PROPORTION OF ALL U.S. SCIENTISTS AND ENGINEERS WORKING TOWARD NATIONAL SECURITY OBJECTIVES IS MUCH LOWER THAN THE CORRESPONDING PROPORTION OF RESEARCH AND DEVELOPMENT SCIENTISTS AND ENGINEERS.

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* Estimate based on William D. Nordhaus and Wilbert Annis, "Scientists and Engineers by End Use," 1963. Since the government does not provide scientific and engineering manpower data by end-use or purpose, this study was sponsored by the Committee to provide order-of-magnitude comparisons.

During the past decade, such events as the swift growth of military capabilities not only have increased the demand for scientific and engineering manpower, but also have brought about profound changes in the way in which this manpower is deployed. In the years ahead, international developments will continue to influence the utilization of scientific and engineering manpower.

The Soviet Union already has as many scientists and engineers as the United States—each has about one fourth of the total world supply—and the number it adds each year is roughly twice the number added in this country. These facts suggest a continued growth in the Soviet Union's capacity to launch and sustain massive technological undertakings which the United States may feel impelled to anticipate with corresponding new programs of its own that could require tens of thousands of scientists and engineers.

The scientific and technological capabilities of western Europe also must be considered. Although there are somewhat fewer scientists and engineers in western Europe than in the United States, their number has been increasing more rapidly than in this country. Western Europe has already become a formidable commercial competitor of the United States. It is reasonable to assume that Western Europe's competitive strength, bolstered by the rapid progress it has been making in industrial technology, will continue to grow, and the United States, if it wishes to hold its ground, may have to invest more scientific and engineering talent in industrial research and development.

Finally, the United States may well find it advisable to invest more of its scientific and technological resources in the economic development of Asia, Africa, and Latin America, as well as to continue to expand its private investment in the more advanced countries.

The United States has for some years devoted a substantial teaching effort in science and engineering to the education of students from abroad. These foreign students have numbered approximately 30 thousand a year in recent years. Over the past decade, approximately five per cent of the United States' supply of new scientists and engineers have been of foreign origin. Many of these, of course, were trained in the United States and remained after completing their education. The interests of other countries and of the United States will both be served if the United States continues to be a training center for large numbers of foreign scientists and engineers.

Domestic needs for the contributions of scientific and engineering manpower have been eloquently expressed in recent years, and require no detailed reiteration here. Broadly viewed, these needs include improving the environment in which we live, work, and find recreation; increasing the national standard of living; maintaining a healthy rate of economic growth; and, of prime importance to our future, ensuring first-rate education in science, both for the scientist and engineer and for others.*

To sum up: In estimating future needs for scientists and engineers, we must first of all take into account the increased demand that will be generated by the normal growth of the economy. We must also allow for the hopeful possibility that ways will be found to channel more scientific and engineering talent into education, urban redevelopment, and other fields where the need is critical. In the military sphere, the demand for scientists and engineers, whether to develop instruments of destruction or systems for their control, seems likely to remain high. There may be a growing demand for scientists and engineers in research and development aimed at strengthening our competitive position in world trade. Finally, we must allow for greater use of scientific and engineering talent in programs of economic development, and eventually for its deployment in international undertakings aimed at controlling the physical environment of the world, and at improving social conditions.

The scientific and engineering manpower resources available to meet the needs of the nation have important characteristics that must be borne in mind in discussing utilization. Scientists and engineers are divided among many specialties, perform a number of different functions, are distributed unevenly throughout the main sectors of the economy, and are heavily dependent on federal financing for support. The figures that follow illustrate these characteristics.

Figure III shows how the nation's scientists and engineers are divided among fields of work. No major science specialty includes more than 7.5 per cent of the total number of scientists and no engineering specialty more than 15 per cent of all engineers. Figure III also shows the percentages of personnel working in each category who hold doctoral degrees. Each category includes dozens of sub-specialties. At any one time, of course, certain kinds of scientists and engineers may be in short supply while others are relatively plentiful.

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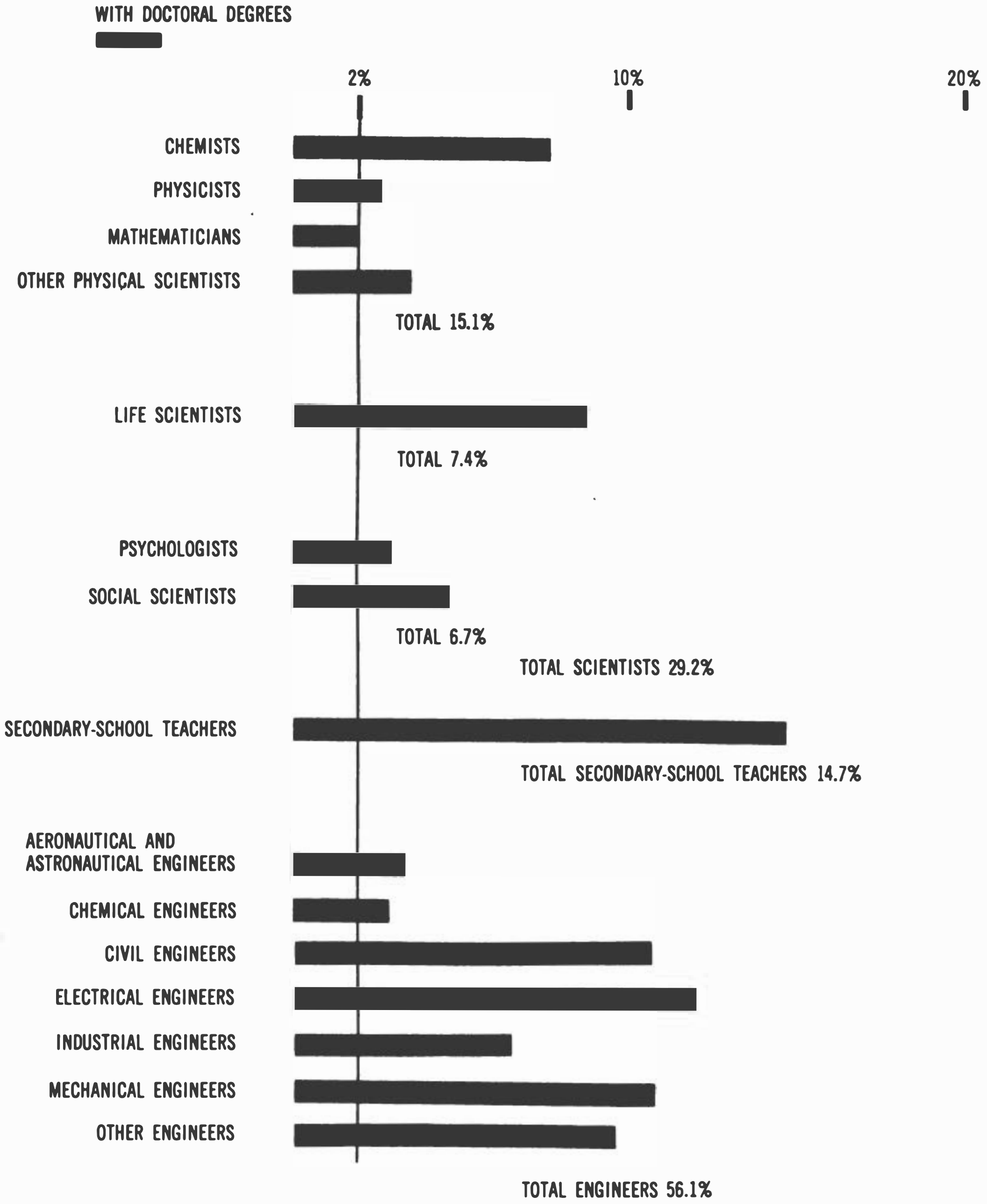
* For one set of projections prepared for the Committee, which take account of growth and national goals, see "Requirements for Scientific and Engineering Manpower in the 1970's." Colm and Lecht, National Planning Association, January 1964. pp. 71-82 of this volume.

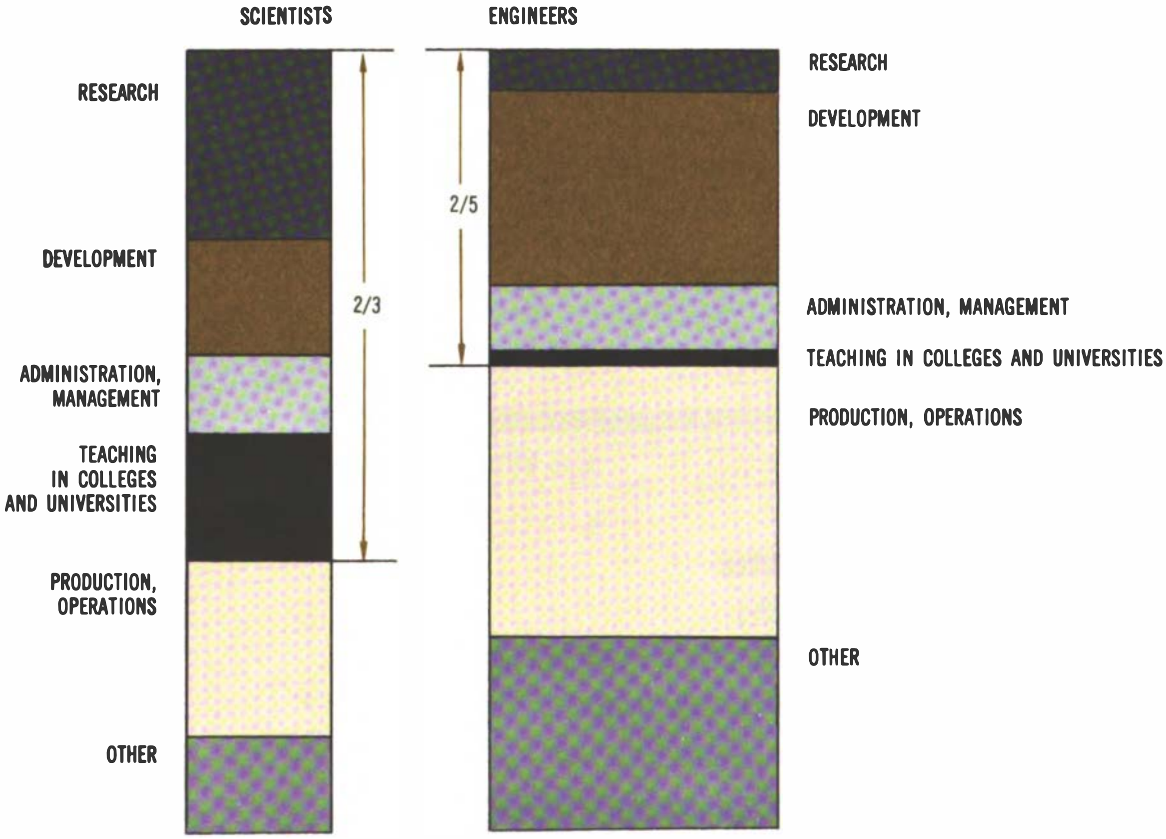
FIGURE III
SCIENTISTS, ENGINEERS, AND SECONDARY-SCHOOL TEACHERS OF SCIENCE AND MATHEMATICS, DISTRIBUTED BY FIELD OF WORK (1963 ESTIMATE)



Based on "Profiles of Manpower in Science and Technology," National Science Foundation, 63-23.

While this report deals with engineers and scientists of all kinds, it is particularly concerned with those upon whom the quality of scientific and engineering efforts most directly depends—that is, those who teach, those who manage, and those engaged in research and development. As Figure IV shows, this group includes two out of three scientists, and two out of five engineers.

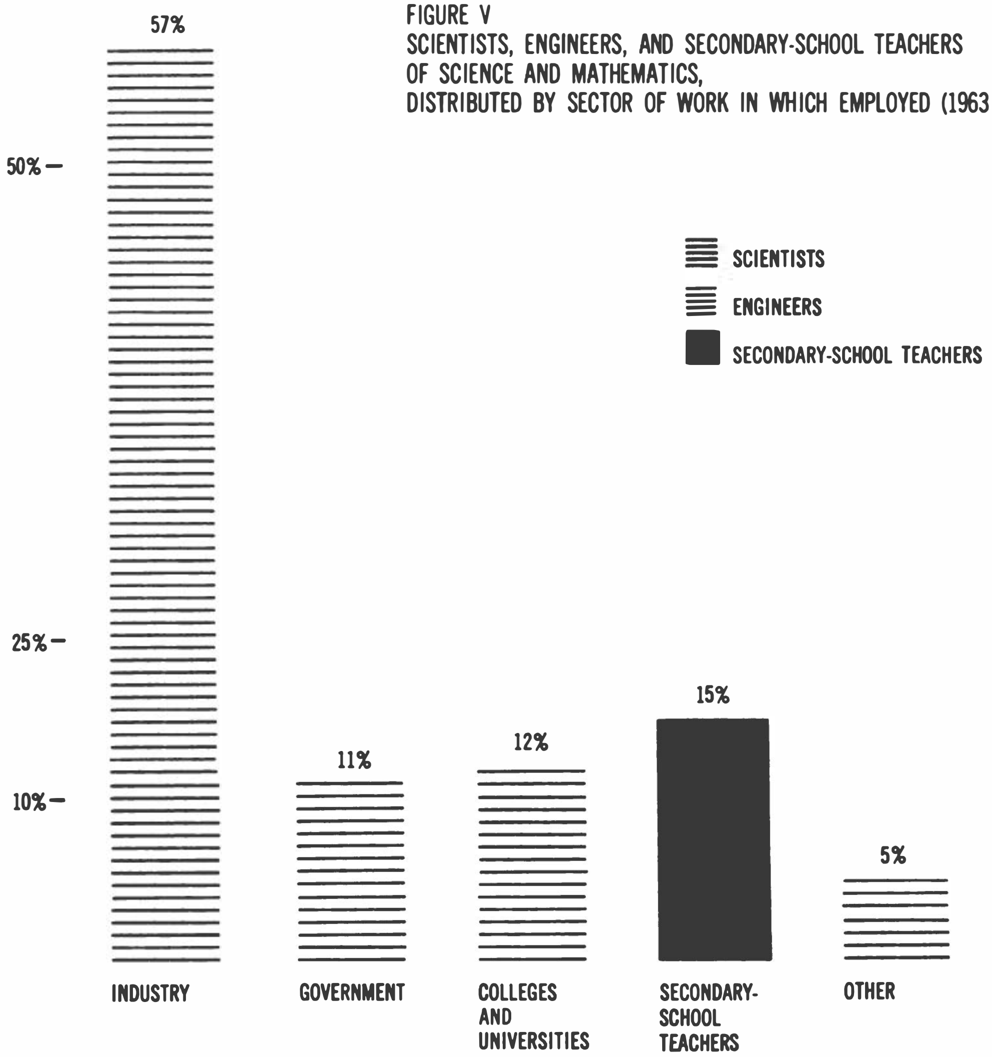
FIGURE IV
SCIENTISTS AND ENGINEERS,
DISTRIBUTED BY FUNCTION PERFORMED (1963 ESTIMATE)



(SECONDARY-SCHOOL TEACHERS NOT INCLUDED)

Based on "Profiles of Manpower in Science and Technology," National Science Foundation, 63-23.

FIGURE V
SCIENTISTS, ENGINEERS, AND SECONDARY-SCHOOL TEACHERS OF SCIENCE AND MATHEMATICS, DISTRIBUTED BY SECTOR OF WORK IN WHICH EMPLOYED (1963 ESTIMATE)



Based on "Profiles of Manpower in Science and Technology," National Science Foundation, 63-23.

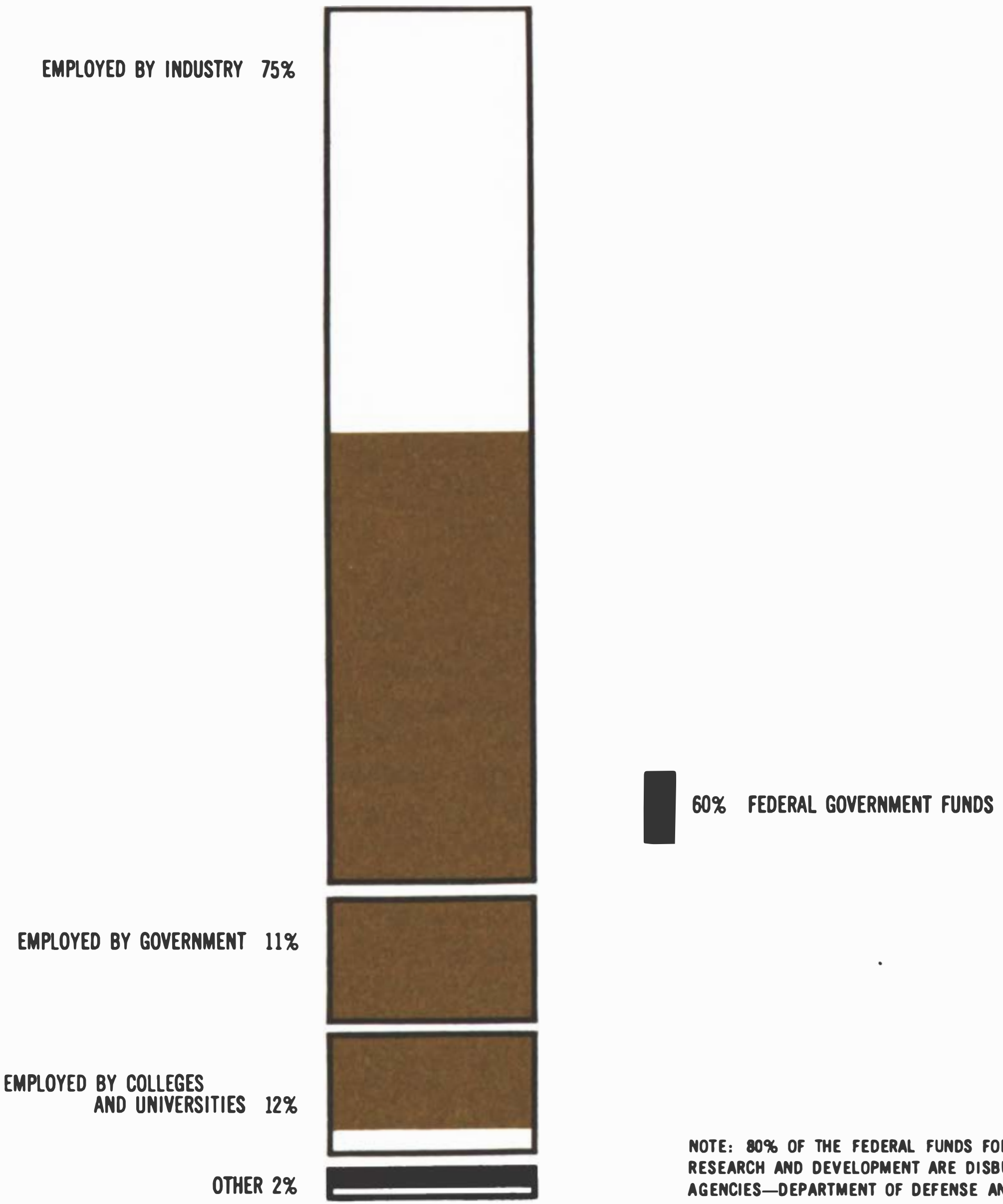
The Committee has focused its attention upon three kinds of institutions: the federal government, private industrial corporations, and colleges and universities. Together, as shown in Figure V, they employ the overwhelming majority of all scientists and engineers. Over half of all scientists and engineers are employed in industry. Colleges and universities account for nearly 12 per cent, and, together with the secondary schools, employ one fourth of the total. The government directly employs over one ninth of the total.

The distribution of scientists and engineers among these institutions does not, however, reveal two of the most important factors bearing on their deployment and utilization. One of these factors is the massive influence of the federal government. The government not only employs a large number of scientists and engineers, but also finances the work of a very substantial fraction of all those who do research and development work in private industry or at colleges and universities. Indeed, as Figure VI shows, the federal government now supports about three fifths of the nation's scientists and engineers engaged in research and development.

The other important factor that statistics alone do not fully reveal is the government's deep involvement in science and technology, creating a complex relationship involving the government, the universities, and private industry, which is both cooperative and competitive. To illustrate: the government helps to finance the graduate education of scientists and engineers, and then competes for their services with the universities that have educated them. Private corporations compete with the government in recruiting talent to perform research and development and other work that the government is paying for. At the same time, the efficiency with which scientific and engineering manpower is utilized in industry is determined in large part by the way in which the interests of the government and its industrial suppliers are contractually adjusted.

Improvement in the way we utilize scientists and engineers, and in the quality of our achievements in science and technology, can best be attained by close cooperation among all the three sectors. The responsibilities of the federal government, industry, and the universities for improved utilization of scientists and engineers are dealt with in turn in the next three chapters.

FIGURE VI
SCIENTISTS AND ENGINEERS WORKING IN RESEARCH AND DEVELOPMENT, EXTENT OF FEDERAL SUPPORT (1963 ESTIMATE)



NOTE: 80% OF THE FEDERAL FUNDS FOR RESEARCH AND DEVELOPMENT ARE DISBURSED BY TWO AGENCIES—DEPARTMENT OF DEFENSE AND NATIONAL AERONAUTICS AND SPACE ADMINISTRATION.

Based on "Profiles of Manpower in Science and Technology," National Science Foundation, 63-23.
and Reviews of Data on Research and Development, National Science Foundation #41, September 1963.

III

UTILIZATION AND THE FEDERAL GOVERNMENT

The federal government influences the deployment and utilization of scientific and engineering manpower in three principal ways. (1) At the policy level, it initiates major programs requiring a heavy investment of scientific and engineering talent. (2) In implementing its programs it purchases a major share of the nation's research and development effort, and of its end products. (3) It directly employs many scientists and engineers. In addition, the federal government is the largest supplier of information about scientists and engineers, and about the activities, such as research and development, in which they engage.

As the initiator of major national programs, over the past 15 years the government has determined the deployment of hundreds of thousands of scientists and engineers. Its decision to invest heavily in the development of missiles and of other advanced weapons systems, and more recently its decision to carry through the manned lunar project by 1970, are together largely responsible for the high proportion of scientists and engineers now engaged more or less directly in national security and space efforts.

Through contracts and grants, the government has an indirect but powerful influence on the utilization of a large fraction of the nation's scientific and engineering manpower employed by industry and the universities. This influence is exerted by the government in its definitions of work to be funded, its selection of the institutions where the work will be done and the individuals who will do it, in the conditions it writes into contracts and grants under which work will be performed, and in the skill and intelligence with which the work is supervised by government scientists, engineers, and administrators.

Finally, the government directly employs more than 120 thousand scientists and engineers, of whom one third are engaged in research and development.

The following series of recommendations is intended to help the government improve its performance in each of these roles.

THE GOVERNMENT AS AN INITIATOR OF MAJOR PROGRAMS

1 Before the government reaches a decision to undertake a great technological program (e.g., the lunar landing or the supersonic transport projects), it should make a careful assessment of the impact of the decision on the deployment and utilization of scientists and engineers.

In view of the way in which certain government decisions have radically altered the pattern of deployment of scientists and engineers in recent years, it might be supposed that major decisions had been preceded by careful studies of their probable impact on the market for scientific and engineering manpower, and, more broadly, of their effect on the general direction of scientific and technological effort in the United States. Yet, so far as we can learn, no adequate studies of the impact of these decisions were in fact made before the decisions were taken. Indeed, meaningful studies probably could not have been made, partly because the information on which to base them was not available.

Common sense suggests that there should be a careful calculation of the requirements for scientific and engineering manpower that will flow from each major decision of the federal government. When these requirements are large, the government should make an estimate of what the resulting redeployment of the nation's manpower is likely to cost in money and in scientific and engineering manpower diverted from other objectives.

Such calculations and estimates are difficult to obtain. At the present time, many different units of the federal government are involved in the collection, analysis, and publication of information on scientific and technical personnel. Even though considerable progress has been made toward the coordination of these disparate activities, officials at the top levels of the government still lack the kind of coordinated information they need if they are to assess accurately the impact their decisions are likely to have on the deployment and utilization of scientific and engineering manpower.

2 Responsibility should be assigned to a unit within the Executive Office of the President for (a) stimulating and coordinating planning by federal departments and agencies with respect to scientific and engineering manpower; (b) promoting research, both inside and outside government, that is likely to facilitate such planning and the solution of manpower problems; and (c) taking the lead in developing an integrated program for the continuing collection and analysis of information, relevant for operating and policy purposes, on scientific and engineering manpower. While the Committee does not recommend a specific location for this unit in the Executive Office, it notes the feasibility of placing it in the Office of Science and Technology.

Executive Office leadership and coordination are clearly essential, both to assess the impact of major decisions and to promote continuing improvement in the utilization of scientists and engineers. The Committee does not propose that the collection of information about scientific and engineering manpower be accomplished by a single agency; centralization of this kind, in fact, is to be avoided. It does propose that the data now being collected from various sources be made more compatible. In some areas, additional data must be obtained. In support of this objective, extensive and continuing analysis is needed to ensure that information related to scientific and engineering manpower is both adequate and useful for making major decisions in all sectors, and especially in the federal government.

Another task of Executive leadership should be to strengthen research in the field of scientific and engineering manpower. A considerable increase in expenditures for development of organized information would yield a high return in better utilization of scientists and engineers. Particularly urgent is the need for research that will identify and help to resolve certain critical problems. For example, convertibility and occupational mobility of scientists and engineers critically affect their utilization; yet there is little useful information on this subject.

The machinery and the precise arrangements required for the development of an integrated federal policy on all manpower are not the proper concern of this Committee. Nevertheless, it sees an acute need for a continuing assessment of the total impact of government policies and activities on the development and utilization of manpower in the United States. The Committee is encouraged by the recent establishment by the President of a cabinet-level Committee on Manpower.

THE GOVERNMENT AS PURCHASER

3 Each department and agency charged with major scientific or engineering activities should assign to one of its top officials responsibility for improving the utilization of civilian scientists and engineers, both those the agency employs and those whose work it finances. The duties of that official should include: (a) participating in government-wide scientific and engineering manpower planning activities; (b) bringing to the attention of his colleagues the implications, in terms of scientific and engineering manpower, of proposed new programs; (c) assessing the impact on manpower of cancellation, curtailment, or alteration of major programs; (d) analyzing the influence of various management practices and policies on the effectiveness with which scientific and engineering manpower is utilized; (e) providing for the collection and analysis of the information he needs to meet his other responsibilities. Specifically, the Committee recommends that an official be assigned these responsibilities in the Department of Defense in order to improve the utilization of civilian scientists and engineers working on defense programs both within and without the department.

Decisions made within the departments and agencies of the government are of key importance in determining how effectively a very large proportion of the nation's scientific and engineering manpower outside the government is utilized. At the present time, the direct attention paid to the utilization of scientific and engineering manpower varies widely from agency to agency. The National Aeronautics and Space Administration, for example, as required by statute, has actively sought and organized information on the numbers and kinds of scientific and engineering personnel that are involved in its programs, including those employed by its contractors. The Department of Defense has very little information of this kind. It has, however, actively examined the impact of various management policies and practices on project effectiveness, although not directly on utilization of manpower. Responsibility for efficient use of scientific and engineering manpower tends to be widely diffused within most agencies, and is regarded by most program managers as incidental to other tasks. If this responsibility is to be fulfilled effectively, it must be made the principal concern of designated officials at the highest level of department and agency management.

4 The Department of Defense, the National Aeronautics and Space Administration, the Federal Aviation Agency, the Atomic Energy Commission, and other agencies with major technological programs should continue to place great emphasis on improving the management of major projects by assigning to these projects identifiably top-quality managers with both technical and administrative skills, and giving them authority, responsibility, and resources necessary for successful completion of projects.

We particularly commend measures already taken to give both military and civilian personnel special training in project management; to form project teams that cut across conventional organizational lines; to use formal management techniques for the better coordination of complex programs; and to increase the technical competence of government project-management teams by encouraging them to draw on the resources of industrial contractors, non-profit companies, and universities.

More than half of all scientists and engineers employed by private industry in research and development are working on projects financed and supervised by the federal government. The effectiveness of their efforts depends in very large degree upon the skill with which the government manages these projects. A single unwise decision in the fixing of design objectives may delay by a year the development of a space vehicle or a weapons system, and add a thousand man-years of scientific and engineering effort to its cost. Conversely, an alert and technically competent project-management team can effect enormous savings in time and effort by skillfully coordinating the activities of contractors working on different but related phases of a major space or weapons system.

It appears that the successful development of two particular weapons systems, for which the Committee had case studies prepared, can be traced in part to skillful management for both the government and industry by strong project offices.

Many large government research and development projects have in fact been handled most competently. But we believe that the quality of management could be substantially improved by wider use of techniques such as those recommended above and by recognition and reward of exceptional work. It would be improved further by the passage of legislation raising the salaries of scientists and engineers in the upper civil service grades, from whose ranks the members of project-management teams are in large part recruited. The military services, also, need to give more attention to the development and retention of this kind of engineer-manager in their officer corps.

5 Government agencies responsible for development programs should continue to place great emphasis on accurate estimates of their cost and feasibility, and on the use of multi-phase contracts.

The Committee is impressed by evidence of the government's growing skill in estimating the cost of projected programs, and in determining their technological feasibility before large amounts of money and manpower have been committed. The government is also to be commended for increased use of multi-phase contracting, a system under which several companies, chosen in competition, are awarded contracts calling for preliminary study and task definition. The company that performs best in this early and relatively inexpensive phase is then awarded a development contract. One of the several advantages of multi-phase contracting is that it tends to reduce the number of prospective contractors submitting major proposals for a development program, thus reducing the investment of scientific and engineering talent in the preparation of proposals.

6 In development programs, the use of fixed-price and incentive contracts instead of cost-plus-fixed-fee contracts is to be commended. Great care must be taken by government agencies to establish meaningful and realistic performance criteria.

In general, the Committee favors the increasing use of fixed-price and incentive contracts for development work. It is clear that the payment of higher fees to contractors whose performance is superior is likely to result in over-all improvement in the efficiency with which scarce technical talent is utilized in government-financed research and development programs. There is a danger, however, in overemphasizing objective performance criteria in contracts, in such a way that a company's profits become related to the achievement of goals irrelevant to the central objective for which its services are secured. For example, early operational capability and low cost are usually desirable characteristics for military systems. But if the need is for a highly dependable back-up to a system already in the field, care must be taken lest a premium paid for speed of contractor performance, or an undue penalty for a cost overrun, divert attention and effort from the primary goal of reliability.

7 **The Committee commends federal contracting agencies in the fields of defense and space for their increasing ability to act at an early stage to cancel, curtail or materially alter major programs that do not appear to be worth their cost.**

Because of the necessarily speculative nature of development, it may often prove impossible to reach a desired goal by continuing to move along a particular line, or to reach it soon enough at an acceptable cost. Significant reductions in waste of money as well as manpower can be achieved if responsible government organizations are alert to the desirability of terminating or drastically modifying projects, or even entire programs, whenever there is convincing evidence of probable failure. Carefully considered action to terminate or redirect a program under such conditions is more often a sign of strength than a sign of weakness in the government's research and development management, and should be so interpreted by Congress and the public. Such action can be an important means of conserving scarce scientific and engineering manpower.

8 **Federal departments and agencies should work with industry to develop plans and programs for minimizing the dislocation and consequent malutilization of scientists and engineers as a result of program cancellation or redirection.**

Early cancellation or curtailment of major programs will not, by itself, improve utilization of scientific and engineering personnel unless the personnel inactivated by these decisions can go to work on other productive activities immediately. If they are thrown out of employment by the cancellation, or assigned to busy-work projects, their usefulness is actually reduced, of course, although money may be saved by reduced need for materials and facilities.

As noted at the beginning of this report, scientists and engineers can play a key role in creating new opportunities for the nation. If the burden of defense lightens, they should be involved in the conversion of defense industry to other national objectives or to civilian purposes. If their potential is to be utilized productively, cooperative action will be needed to facilitate the transition. Provisions are required to enable existing defense industrial contractors more readily to utilize their scientists and engineers in diversifying and transforming the enterprise. Incentives to facilitate the formation of new enterprises, based on the capabilities of creative groups wishing to apply technology with which they are familiar to the civilian economy, will also be of value.

It would be in the national interest if, during the periods of transition, attractive opportunities could be provided for individual scientists and engineers to replenish and augment their professional value through education and training, possibly at university centers as well as within the organizations in which they work.

The Committee recognizes that these objectives are difficult to achieve, and hastens to express its view that programs designed to minimize dislocation should not involve coercive methods that would curtail the freedom of individuals or encroach upon the proper prerogatives of responsible free enterprise.

9 Federal support of contractor-initiated technical effort by government industrial contractors should be maintained at a substantial level. Incentives should be developed for encouraging corporate managements to emphasize quality and continuity, and to orient work toward long-run objectives.

Companies engaged in research and development or production under government contract are usually permitted to devote some portion of their total effort to what has been called independent research and development, or, as it has more recently been designated, contractor-initiated technical effort. Its objectives are, as a rule, defined only in general terms, and it is treated as a recognized business cost. Independent research and development has provided scientists and engineers employed by industrial contractors the opportunity to develop advanced concepts that, in many cases, have been of great value to the government. In the current efforts to strengthen government contracting procedures, it would be unfortunate if government funding in this area were to be eliminated or even substantially reduced. While the Committee recognizes the need for limits on government funding for this purpose, it believes that the public interest would be better served by an increase than by a decrease in current allowances.

The government should seek to develop incentives to encourage the most effective use of the manpower supported by the funds it supplies. While detailed government controls over the specific activities of individual contractors are not desirable, a periodic review by responsible and competent technical people would be useful to determine whether the results of independent research and development effort are commensurate with its cost.

THE GOVERNMENT AS EMPLOYER

10 Greater emphasis should be placed on assuring a high level of professional competence in the federal scientific establishment. In support of this objective, the administration proposals for higher salaries at the upper levels of government service should be promptly enacted by the Congress.

Since World War II, the government's large and important scientific establishment has had continuing difficulty competing with industry and the universities for the services of talented scientists and engineers. Many groups, both inside and outside the government, have studied this problem and made recommendations. A number of the recommendations have now been adopted, and the government's competitive position is consequently stronger today than at any time in the past 18 years. But, as Table 1 shows, the salaries paid to scientists and engineers at the upper levels of government career service are far below those prevailing at comparable levels in private industry. The discrepancy is even greater in the top policy positions. Ironically, the government is often in the position of reimbursing a contractor for salaries the contractor has paid to scientists and engineers that are very much higher than the salaries the government can pay its own employees. Enactment of pending legislation authorizing higher salaries at the upper levels of government service would improve the government's competitive position.

TABLE 1 COMPARISON OF TOP GOVERNMENT CAREER SALARIES WITH THOSE IN PRIVATE BUSINESS FOR COMPARABLE WORK

FEDERAL GOVERNMENT		CORRESPONDING LEVELS IN PRIVATE BUSINESS
GS–16	$16,000-$18,000	$20,000-$30,000
GS–17	$18,000-$20,000	$27,500-$37,500
GS–18	$20,000	$32,500-$45,000

Source: THE COMPETITION FOR QUALITY, Vol. 1 Federal Council for Science and Technology, 1962. (The federal government salaries listed here reflect upward revisions enacted since that report.)

Raising salaries is only one of several measures that must be taken if the government is to attract and retain its fair share of the nation's best scientific and engineering talent. Managers of some federal laboratories should strengthen their recruiting programs, particularly at colleges and universities. The government should also take more positive steps to provide scientists and engineers employed in federal laboratories with a wider variety of opportunities for continuing their education and developing their professional competence. These opportunities should include work in private industry, at other government establishments, and at universities, and they should be available to scientists and engineers at reasonable intervals throughout their professional careers.

Federal laboratories and agencies should also encourage their scientists and engineers to participate in activities of professional societies. The personnel of these establishments have not always had the opportunity to participate on study groups and advisory panels, and in scientific missions representing the United States. They should be called upon more than they are now, and their participation should be encouraged by their employers. They have much to contribute.

As part of its study, the Committee had case studies made for it on the utilization of scientific and engineering manpower in the development of two military systems—Titan II and the Naval Tactical Data System. The first such comprehensive studies so far made, they highlighted the superior opportunities for advanced technical study that are given to military officers, in contrast with relatively meager opportunities available for civilian employees.

11 The U. S. Civil Service Commission should take the lead in working with government departments and agencies to improve the working environment of scientists and engineers employed by the federal government. It should also help to foster improved forecasting of their future requirements for scientific and engineering personnel.

Although improved utilization of scientific and engineering manpower is primarily the responsibility of agency and departmental managers, there is need for action that will cut across departmental lines. The Civil Service Commission should assist the individual agencies in their planning of how many scientists and engineers—of what types—the government is likely to require in the future.

The Civil Service Commission should, in addition, carefully review government personnel policies to determine which ones have or can have a significant effect on the environment in which research and development is carried out in government laboratories. Where changes in such policies seem advisable, authority to make them should be promptly sought. At the same time, the commission should aid and encourage agency heads and laboratory directors fully to use all existing authority to improve working environments.

12 The Department of Defense, the Atomic Energy Commission, the National Aeronautics and Space Administration, the Department of Health, Education and Welfare, the Department of

Agriculture, the Department of Commerce, and other government departments and agencies should periodically review the missions and programs of the mission-oriented research laboratories they finance in full, both those they operate directly and those operated under contract, in order to make sure

(a) that their resources continue to serve high-priority national needs and objectives, (b) that the arrangements for their management and location provide them maximum opportunity to be strong and creative, and (c) that their programs and administrative arrangements are compatible with the objectives of the institutions with which they may be linked. The Committee suggests that the resources of the President's Science Advisory Committee could be called upon in conducting these reviews and in arriving at decisions.

The great national research centers financed by the government utilize large numbers of scientists and engineers. The missions of some of them, especially of those related to defense, have changed since their establishment. It is important that their present and future missions be clear-cut and of high priority, and that their use of scientists and engineers be unmistakably in the national interest. In maintaining these major concentrations of manpower, the government has a special responsibility to appraise them in terms of both their contributions to urgent government needs and their impact on the over-all utilization of scientists and engineers, taking into consideration the needs of the private sector of the economy.

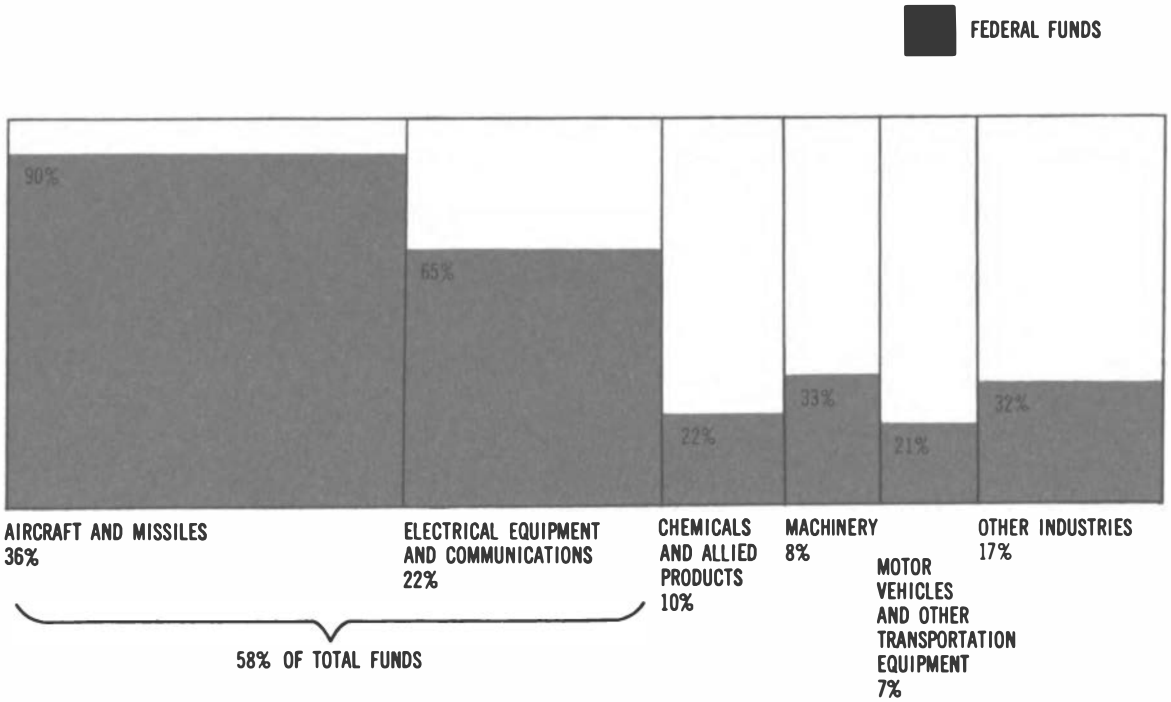
New ways to manage and house the large research laboratories of the federal government are needed. Some laboratories can be handled directly by the government, others by industry, by universities, and by non-profit corporations. It may be necessary to handle some of them in new ways. In the long future, it will probably be wise not to expect universities to manage such establishments unless there is no alternative for the government.

IV

UTILIZATION AND INDUSTRY *

The recommendations in this section are concerned primarily with scientists and engineers employed by private corporations but engaged in research and development, with emphasis on that half of the group whose work is paid for by the federal government. They are heavily concentrated in two industries—in aircraft and missiles, and in electrical equipment and communications. These two industries together received $5.4 billion of the $6.7 billion that the government spent in 1962 for research and development performed by private industry. As Figure VII shows, the two industries accounted for 58 per cent of all funds, both private and federal, invested in industrial research and development.

FIGURE VII
DISTRIBUTION OF FUNDS FOR PERFORMANCE OF RESEARCH AND DEVELOPMENT IN INDUSTRY, 1962



Based on Reviews of Data on Research and Development, National Science Foundation, #40, September 1963.

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* Report of Industrial Panel 1 by Augustus Kinzel deals with this sector. Its conclusions are contained on pages 135-136.

IMPROVING THE MANAGEMENT OF RESEARCH

13 **Corporate managers should identify their most promising scientists and engineers, and take action to enable them to fully develop and apply their competence.**

While the federal government, through its financial support and contracting practices, sets many of the conditions under which industrial scientists and engineers work, the firms that employ them retain the basic responsibility for using them well.

Each company employing large numbers of scientists and engineers has its complement of highly talented individuals, some of whom are able and eager to originate and carry forward large programs or projects, others of whom could make their greatest contribution in specialties or disciplines not directly bearing upon projects. Unless these individuals, and the groups they form, are recognized and enabled to exercise their special capabilities, both the firm and the individuals lose valuable opportunities. Some companies do search out and actively support their outstanding people. Others, however, tend to treat their scientists and engineers as a more or less homogeneous pool, to be drawn upon without due regard to qualitative differences. It is important for managers to recognize that scientists and engineers vary greatly, and that their working conditions should be correspondingly varied.

In virtually every phase of the work of scientists and engineers, good utilization also requires the availability of adequate numbers of well-trained technicians. Since the problem of technicians is under study by the President's Science Advisory Committee, it is not dealt with in detail by this Committee. Industry is doing much to improve the training and use of technicians, but, as has been pointed out by the National Science Foundation, there is a growing conviction that a major effort is required to meet the need for technicians. Additional programs and facilities will be necessary. Technicians are important not only to assist and thus improve the utilization of scientists and engineers, but also to contribute to the progress of all sectors of the economy.

14 **Corporate managers should strive to provide a climate for creativity and productivity of highly qualified scientists and engineers in keeping with their great potential value to their firms.**

Increasingly, corporate success in research and development will require that management personnel and research and development personnel achieve a better understanding of each other's problems, objectives, and capabilities.

Among the measures to be considered by managements in increasing the effectiveness of research and development work are more extensive and appropriately organized supporting services; more effective efforts to keep scientists and engineers apprised of objectives, plans, business conditions, and other matters relevant to selecting or directing their own efforts; and greater involvement of scientists and engineers in managerial decisions that affect them. The desire of scientists and engineers for professional achievement, if it is combined with understanding of corporate objectives and problems and augmented by proper management incentives and stringent, continuing, selection processes, can mitigate the need for a great many administrative controls that, traditionally applied, tend to frustrate consistently high-quality professional performance.

THE KEY ROLE OF MANAGEMENT

15 **A key to the success of a system-development "project" team is the quality of its central core of technical and administrative talent. This group should be given authority consistent with its objectives.**

The effectiveness of a project team appears to depend very largely upon the abilities of the few men who form its nucleus or core. As shown in the case studies of Titan II and the Naval Tactical Data System that were prepared for the Committee, the technical and administrative management of the system-development process at both government and industry levels was performed by a handful of key individuals. It would have been difficult to predict on the basis of their age or education that these individuals would be successful managers.

The early identification, development, and assignment of men capable of playing key roles in the technical direction of big projects is one of the most important responsibilities of top management in companies engaged in large-scale research and development. Another is the proper meshing of projects into the functionally organized parent companies or divisions, including the manner in which scientists and engineers are assigned to and from project teams.

16 **Industry, government, and the universities all share a responsibility to train and develop more managers and project engineers who combine thorough understanding of the technology they manage with mastery of the art of leadership.**

Large system developments require a combination of engineering skill and management coordination that is not commonly encountered. To an extent seldom required in other industrial undertakings, project managers are called upon to coordinate the activities of many technical groups, each of which is working on a problem whose solution—or non-solution—may vitally affect the work of other groups. The nation needs more managers who understand the interdependence of technical and managerial decisions, and are equipped to appreciate the technical as well as managerial issues in system development.

17 **Companies that use scientific and engineering manpower should actively seek ways to help their high-talent manpower augment and replenish their professional capabilities.**

Industry should provide opportunities and encouragement for its scientists and engineers to keep abreast of new developments in their professional specialties, and in some cases to enter new fields. Steps that may be taken to that end include provision of free time for basic research, leaves of absence for the purposes of broadening and updating knowledge, and subsidization of retraining in universities.

In this age of sweeping scientific discovery and rapid technological change, highly talented manpower must undergo continuous self-renewal if it is to maintain its creative potential. Some activities of scientists and engineers in industry tend to build, rather than deplete, their capabilities. For the most part, however, obsolescence is an occupational hazard against which the individual must guard; his corporation, or other organization, should provide attractive opportunities for education and development. Certainly employing institutions that use up high-talent manpower on narrowly focused tasks, without providing for the replenishment and expansion of skill and knowledge, are shirking a vital responsibility. It is important that industrial management be as much concerned with building the capacities of people as with assigning them to productive tasks. Although many companies do invest substantially in professional improvement of scientists and engineers, more would find it profitable to do so.

18 **Utilization of scientists and engineers in industry could be further improved if there were more systematic study of the art and science of research management. With industry taking the lead, private foundations, industry, and government should provide more stimulus and funds for this purpose. The Committee recommends intensive study of the experience of modern corporations that are heavily**

committed to research and innovation, or whose chief business is research and development rather than production.

The Committee believes that more definitive understanding regarding the innovative utilization of scientific and engineering talent is required. Current doctrine in this area is not comparable with the body of doctrine available for financial or production management.

The Committee concurs in the following observation stated in a study made for its use: "After a generation of intuitive platitudes concerning leadership, supervision and benign personnel practice, such broad areas as creativity, motivation, group dynamics, organizational behavior, and interpersonal communications remain today in the forefront of research in the social, behavioral, and management sciences."*

IS THERE A WASTE OF TALENT?

19 **The Committee recognizes the existence of some waste of scientific and engineering talents inherent in practices such as "goldplating," "brochuremanship," and "stockpiling" of manpower. This waste, in the Committee's view, can best be minimized by improved management in both government and industry along the lines suggested in this report, and does not demand a fundamental overhauling of government procurement methods or the imposition of extreme controls over contractors.**

Executives of companies deeply involved in the defense and space programs must contend with special problems. For example, their freedom to make management decisions often are curtailed to an excessive degree by the close monitoring of their internal operations exercised by government project officers. (There is hope that increasing reliance on incentives will minimize the need for detailed government supervision, but so far there has been little change.) Also, the volume of business done by individual firms may fluctuate violently, and managers often must try to maintain the integrity and capabilities of their organizations in the face of abrupt, though perhaps temporary, shifts in the amount of work they have on hand.

These and other related characteristics of the space and defense industries have led to certain practices widely seen as abuses. To cushion the impact of anticipated cutbacks, a contractor may engage in "gold-

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* Lawton M. Hartman, "Industrial Practice Affecting the Utilization of Scientific and Engineering Manpower." pp. 137-142, this report.

plating," that is, stretching out a production or development contract by introducing extensive design modifications.* A company may also keep more scientists and engineers on its payroll than the fulfillment of its current contracts requires, a practice known as "stockpiling" and aimed at making it easier to obtain and man new projects. Competition for new government contracts is also on occasion characterized by "brochuremanship," or the use of excessively elaborate and costly sales techniques.

Although the Committee recognizes that "goldplating," "brochuremanship," and "stockpiling" undoubtedly exist, it believes that to overemphasize their incidence would be a mistake, and it urges caution in deciding the point at which these practices are disproportionate to real requirements of the situation, and thus excessive. The Titan II and Naval Tactical Data System case studies, previously referred to, showed no positive evidence of such excesses. In one instance, a major re-design effort by the contractor materially improved the performance of a subsystem. Some might have regarded this effort as "goldplating," but the government clearly benefited from it.

Practices among contractors such as "stockpiling" or "goldplating" might be further curtailed by stricter controls, but the Committee believes the imposition of such controls would do more harm than good. "Goldplating" by contractors could be eliminated, for instance, if the government flatly refused to tolerate specification changes in the performance of contracts. Needless changes would thereby be avoided, but so would well-thought-out changes that might markedly improve system effectiveness or reduce costs. "Stockpiling," when not excessive, permits a company that is permanently committed to government-sponsored developmental work to keep some of its skilled teams of scientists and engineers at work anticipating future trends, considering possibilities raised by the changing state of the art, and writing preliminary proposals to stimulate the imagination of the civilian and military officials who are the company's principal customers.

In the Committee's opinion, the best means of minimizing abuses in the government's major procurement programs—and hence of minimizing the accompanying waste of scientific and engineering manpower—are the development of incentives to make the objectives of contractors and the government more congruent, and a steady improvement in the quality of the government and industrial teams that direct and participate in large research and development projects. It is their joint responsibility to reconcile the need for reasonable controls with the need for a considerable degree of autonomy in the performance of work.

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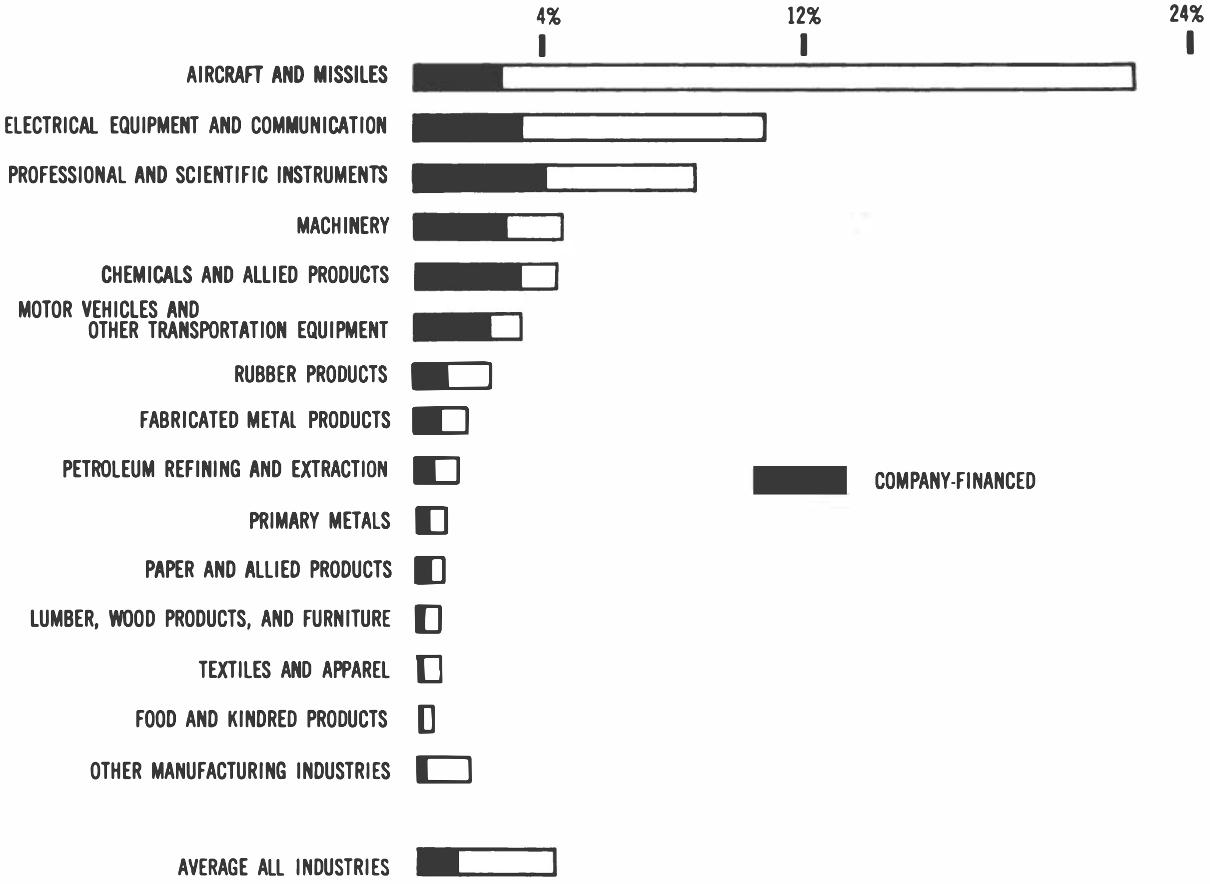
* "Goldplating" is sometimes used to describe any over-specification not worth its cost. This kind of goldplating is clearly the responsibility of the government's own contracting agencies. It can best be eliminated through better design and specifications.

STIMULATING INNOVATION

20 **Coordinated action by industry and government is needed to stimulate more research and development in areas of the economy where the rate of innovation has been relatively slow.**

Figure VIII shows the wide range of major industries in the United States in which only limited funds are used for research and development.

FIGURE VIII
FUNDS FOR RESEARCH AND DEVELOPMENT PERFORMANCE
AS PERCENTAGE OF NET SALES IN MANUFACTURING COMPANIES, 1960



Based on "Research and Development in Industry" 1960, National Science Foundation, January 1963.

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It is mainly to scientists and engineers in industry-financed research and development that we look for technological advances in the broad "civilian" sector of the economy. However, advanced research supported by private funds is concentrated mainly in a few industries in which a few large and stable firms are pre-eminent. While research in these industries has yielded a rich harvest of new and better goods and services—and cheaper ways of producing old ones—progress has been relatively slow in other industries. Government requirements for scientists and engineers do not appear to have been a prime factor; rather, the lag stems largely from the difficulty of making the necessary arrangements. In construction, for example, the problems include local building codes, labor practices, and the small-company pattern of the industry.

To facilitate research and innovation in such industries, the federal government should stimulate and support initiative shown by industrial and labor groups and communities in developing new arrangements that will open the way to more intensive application of research and technical knowledge. In addition, in the interest of accelerating the rate of innovation in these industries, more research should be undertaken under the joint auspices of government and industry. Proposals that have been made for the sponsorship of such research should be re-examined with a view to making them more acceptable to Congress and to the business community.

V

UTILIZATION AND THE COLLEGES AND UNIVERSITIES

Recent studies, notably those under the auspices of the President's Science Advisory Committee,* have given systematic attention to the education of scientists and engineers. Without going over the ground these reports have covered, and with no intention of treating education comprehensively, this section deals with those aspects of scientific and engineering education which affect utilization.

The growth in demand for teaching, research, and public service currently imposes a new order of responsibility upon our colleges and universities, both as users and as suppliers of scientific and engineering manpower. As our education system grows, it will need for its own use a substantial fraction of the total production of persons with graduate degrees, especially doctoral degrees in science and engineering. Colleges and universities are major users of scientists and engineers, and, along with government and industry, they are under obligation to use this scarce talent well. Currently, about 175 thousand scientists and engineers are employed by colleges and universities in their educational and research activities. As suppliers of scientific and engineering manpower, colleges and universities have a major influence on its availability and quality. These are but a few of the reasons why any study of utilization must include consideration of education.

While the Committee stresses the importance of strengthening science and engineering education, and of increasing the output of high-quality scientists and engineers, it does not believe that science and engineering should be, or need to be, promoted at the expense of other kinds of learning. Our society needs many kinds of skills, and the varieties of education required to produce them.

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* See selected bibliography.

THE COLLEGES AND UNIVERSITIES AS USERS OF SCIENTIFIC AND ENGINEERING MANPOWER

Colleges and universities face a number of recurring questions in the effective utilization of the scientists and engineers they employ. How can research be managed so that its proper relationship to teaching is preserved? In the effort to strengthen and expand graduate education, how can the quality of undergraduate education be maintained? How can the needs of "little science" be adequately met? How far should universities go in the performance of public service activities requiring large-scale applied research? How can salary equity and institutional loyalty be maintained when funds are provided from outside the institution? How can the freedom of the universities be protected while assuring adequate accountability for public funds used by them? These are only some of the questions that must be dealt with by the colleges and universities in their use of manpower resources.

21 **Colleges and universities engaged in scientific and engineering education must accept full responsibility for maintaining a proper balance among the claims of teaching, research, and public service. They should systematically seek the cooperation of the federal government in maintaining the proper balance.**

Since the scholar-teacher plays an indispensable role in the cultivation and development of first-rate minds, scientists and engineers who accept faculty membership should also, with few exceptions, assume an obligation to teach that is as clear and compelling as their commitment to research. We need better ways to recognize and reward distinguished teachers of science and engineering (who are not always distinguished in research). While this is a direct responsibility of the universities, professional and honorary societies, which recognize other distinctions by awards and memberships, have given far too little recognition to great teaching. These organizations, together with such national bodies as the President's Science Advisory Committee, might well suggest more effective ways of recognizing great teachers and creative contributions to the teaching process.

The partnership between the federal government and the universities has yielded very great benefits. It has helped universities to attract and hold first-rate scientists and engineers as members of their faculties. It has accelerated the increase of knowledge through basic and applied science. It has provided both faculty and students with facilities for research that the universities and colleges could not otherwise have afforded. It has permitted the expansion and strengthening of graduate education in science and engineering. In short, federal support has greatly strengthened our universities and has helped to give America world leadership in science.

However, the more than 400 per cent increase in federal funds obligated for research and development at colleges and universities, from under $200 million in 1956 to about $900 million in 1963,* has created problems that require the continuing attention of both government and universities to ensure that, in the long run, education will continue to be strengthened by the partnership.

The determination of the colleges and universities to adhere to their primary missions, to be constantly vigilant in protecting their independence, and to maintain their distinctive qualities as educational institutions is of vital importance.

More specifically, universities have a responsibility to make sure that research is conducted in such a way that it complements teaching. When university research becomes dissociated from education, both research and education can suffer. This does not mean that all research must be student-oriented; the pursuit of new learning is valuable in itself. It does mean that emphasis on research should not lead to neglect of the university's special mission—the nurturing of new talent.

The scholar-teacher plays an indispensable role in the cultivation and development of first-rate creative minds, and scientists and engineers who accept the privileges of faculty membership should also, with few exceptions, assume an obligation to teach that is as clear and compelling as their commitment to research. This obligation should include the teaching of undergraduates. University administrations, for their part, must undertake to provide greater rewards for devoted and distinguished teaching. Occasionally, the patterns of reward for academic work tend to remove scholars from their students. Where such patterns predominate, the best minds of this generation and the best minds of the next may not meet at all.

The growing scale and importance of graduate and post-doctoral study and research should not diminish the commitment of faculties to undergraduate teaching. It should be recognized that undergraduate, as well as graduate, education is enriched by research. One of the great educational opportunities now to be grasped is to make research experience more readily available to qualified upperclassmen in science and engineering.

Federal funds have made possible the growth of "big science," big

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* These totals do not include the cost of operating federal research centers such as Los Alamos or Lincoln, which are administered by universities under government contract.

projects, and big machines. Wisely planned and used, these great undertakings are valuable for the progress of science and engineering, but they must not lead to neglect of "little science." Universities and government must act to protect and to enhance support of the individual scholar with his cluster of students. When federal budgets for research are curtailed, big science, with its fixed cost and its glamor, must not be allowed to pre-empt the available funds, leaving the small group and the individual investigator without adequate support.

As the home of basic research, universities have been criticized for accepting funds for applied research and development. Some have said that this constitutes a malutilization of academic talent. The basic research end of the research-and-development spectrum must have overriding priority in colleges and universities, but the danger of oversimplification in categorizing research must be recognized. The real test is whether the research, basic or applied, contributes to the central missions of the university. University research must be closely related to the advancement of learning, to the education of students, or to a legitimate public service. Moreover, applied research, as it contributes, for example, to engineering education, has a fundamental function in professional schools.

American universities will be weakened if faculty members come increasingly to feel that their primary loyalty belongs not to the university but to some outside entity that represents their field of scholarship and provides it large support. Migratory research workers following available funds and having deep roots in no institution can hardly contribute to the coherence, unity, and spirit of commitment so essential to great educational institutions. They also miss the benefits that full devotion to the company of scholars in residence can provide. Devotion to a program or to a field of scholarship—which is admirable, of course—need not conflict with commitment to a university.

The administrations of universities must, in turn, take care that government contracts and grants do not distort appointment and compensation policies. Federal funds should not be allowed to make teaching less attractive. In inter-institutional competition for talent, federal funds should not be used to finance salaries and benefits that are inequitable with respect to personnel not receiving government funds. Where practices inimical to higher education occur, the universities, and not the government, should take the initiative for eradicating them.

Congress, as it reassesses the federal financing of research in the universities, can help achieve effective utilization of scientific manpower if it avoids requiring the Executive Branch to impose undue restrictions on personnel policies of universities, or excessive burdens of reporting and accounting on the researchers themselves. If the university is asked to adopt personnel practices foreign to the spirit of the university, or if the scientist is overburdened by fiscal procedures, malutilization occurs and creativity is reduced. Both the government and the country lose. The university must also recognize, however, that it has an obligation to provide adequate accounting for public funds. In stressing the importance of improving the management of federal research grants and contracts in our universities, we call attention to the recent report of the National Academy of Sciences, *Federal Support of Basic Research in Institutions of Higher Learning.*

THE COLLEGES AND UNIVERSITIES AS SUPPLIERS OF SCIENTIFIC AND ENGINEERING MANPOWER

As the nation's economy continues to grow, a large number of scientists and engineers will be needed in order merely to maintain their proportionate contribution. Furthermore, as long as research and development funds continue to grow at a faster rate than the economy, the proportionate need for scientists and engineers will increase accordingly, other things being equal. Fortunately, the undergraduate student population from which scientists and engineers can be drawn is also increasing more rapidly than the economy.

Contrary to some public statements, we run the risk of having too few, rather than too many, students elect to study science and engineering. Until this year, the proportion of the total college population electing engineering has been dropping for several years, and the shift into the sciences has been sufficient only to maintain the percentage of the total college population studying science and engineering. These facts are shown in Table 2.

TABLE 2 BACHELOR'S DEGREES[1] AWARDED
TOTAL AND SCIENCE AND ENGINEERING (IN THOUSANDS)
1950-51 TO 1961-62

ACADEMIC YEAR	ALL FIELDS TOTAL	ENGINEERING NUMBER	SCIENCE AND ENGINEERING[2] NUMBER	% OF TOTAL
1950-51	384	42	109	27
1951-52	332	31	79	24
1952-53	305	24	67	22
1953-54	293	22	64	22
1954-55	287	23	63	22
1955-56	311	26	68	22
1956-57	340	21	78	23
1957-58	366	31	87	24
1958-59	385	35	94	24
1959-60	395	38	98	25
1960-61	402	36	97	24
1961-62	420	35	100	24

[1] Includes bachelor's and first professional degrees.
[2] Excludes social sciences.
Source: "Earned Degrees Conferred: Bachelor's and Higher Degrees," U.S. Office of Education.

Comparison of the scientific and engineering student population of the United States with that of other advanced countries does not support the contention that the United States is overemphasizing science. In their book, *Education, Manpower and Economic Growth,* Frederick H. Harbison and Charles A. Myers develop significant indices comparing the manpower resources of countries in various stages of development. One of their comparisons, based upon UNESCO data, is the distribution of students between science and technology, on the one hand, and humanities, law, and the arts on the other. In percentage of students studying science and technology, the United States stands substantially below the mean of sixteen advanced countries. West Germany, France, the United Kingdom, Australia, and Russia, among others, have a higher percentage of students studying science and technology than does the United States.

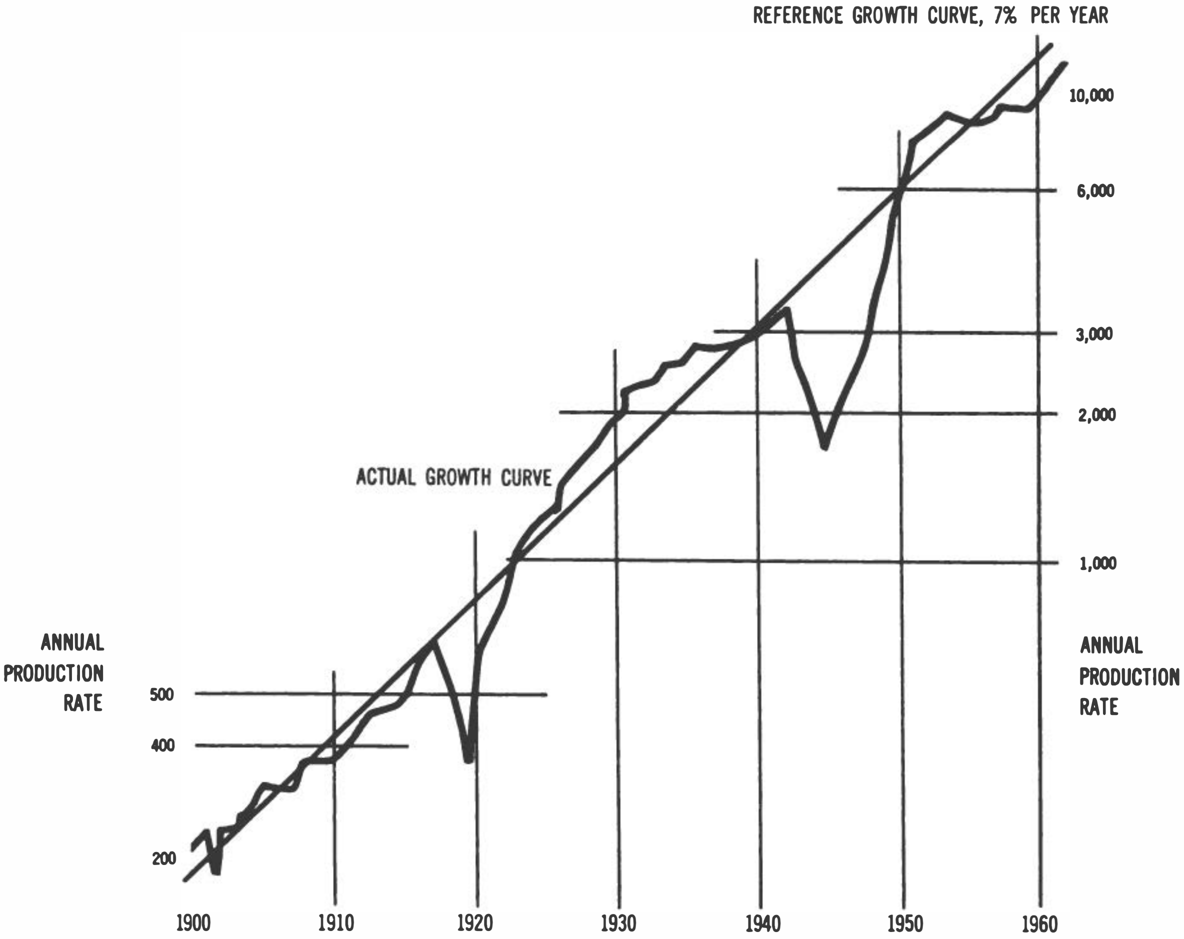
As Figure IX shows, the rate of doctoral-degree production by colleges and universities in the United States has been increasing seven per cent a year. This Committee concurs in the recommendation made in 1962 by the President's Science Advisory Committee that a major effort be made to increase our national output of doctorates in science, engineering, and mathematics. It also stresses the importance of maintaining rigorously high standards for graduate degrees, even if this means that the growth in the number of degrees will not meet the goals recommended. The overriding requirement is for higher quality.

22 **The nation needs not only to further the efforts of its present centers of educational excellence in science, but also to develop new ones that are as good as the best it now has.**

The swift expansion of research and development and the growth in the student population in recent years have not brought a corresponding increase in the number of universities that occupy front-rank positions in science and engineering. Federal funds have been channeled mainly to those institutions, relatively few in number, that traditionally have had the most distinguished science and engineering faculties. In 1963, ten universities received 38 per cent of all federal funds for research and development at institutions of higher learning; 25 universities received 59 per cent of the total. Furthermore, the universities where the bulk of scientific research is now conducted are almost all located on the West Coast, in the Northeast, and in the Great Lakes region.

If the educational system is to produce more scientists and engineers who have had the kind of graduate training that the leading

FIGURE IX
DOCTORATE PRODUCTION, U.S. UNIVERSITIES, 1900 TO 1963



Based on "Doctorate Production in U.S. Universities 1900-1962," (NAS-NRC 1142) 1963.

universities now offer—perhaps the finest offered anywhere in the world—more centers of true excellence in scientific research and education will be needed. Furthermore, centers of excellence located throughout the nation may also speed the economic development of other parts of the country.

It has been suggested that the best way to build such new centers is for the federal government to award more research and development money to institutions that now get little or none. The Committee is strongly opposed, however, to lowering the quality of government-sponsored research and development by awarding funds for research projects to people and institutions whose proposals would not qualify for support if they were judged strictly on their merits. In the Committee's view, it would be better for the government to make institutional grants that are not linked to specific research projects. These grants should be given to institutions that show particularly strong promise of emerging, through their own efforts and those of their communities, as important new centers of scientific research and education. The program to assist the development of new centers of strength recently initiated by the National Science Foundation accepts these objectives, but the funds presently available are inadequate.

More constituencies, communities, and states should determinedly set about strengthening their existing educational institutions and creating new ones. Then the federal government can help. The central objective must be improvement of education; we need carefully to distinguish this objective from that of promoting research and getting early research results.

23 Programs of curriculum development and reform that involve outstanding scholars in the universities working jointly with pre-college teachers should be encouraged and supported with greatly enlarged funding.

Major curricular changes and reforms undertaken mainly on the initiative of distinguished universities and scholars have greatly improved the quality of science teaching in pre-college schools. A scholar in the university, working closely with the teacher in lower schools, is finding it possible to make important contributions to the structure, the content, and the methods of pre-college science courses. He is also finding great satisfaction in contributing to the strengthening of teaching in the sciences. Inspired by the success of curriculum reform in the sciences, scholar-teacher groups are now beginning to develop new curricula in the social sciences and other subject areas. Universities and colleges have a big stake in these reforms, since they will permit—indeed demand—reform and enrichment of curricula at the college level. Joint work on curriculum development represents a marked advance in the effective utilization of our intellectual resources.

Preparation of new and more modern teaching materials, and large-scale retraining of teachers to handle new curricula and new materials, are essential parts of this process. Adoption of the "new" physics and the "new" mathematics, for example, has been slowed by the scarcity of teachers qualified to handle them effectively in the classroom. Even though approximately 90,000 of the 225,000 teachers of science and mathematics have attended training institutes sponsored by the National Science Foundation, the "new" mathematics is still being taught to only about ten per cent of the total secondary school population.

24 **Universities with strength in science should accept a responsibility to provide special study and research opportunities for faculty members of independent liberal arts colleges. Moreover, these colleges need to strengthen the quality of their science teaching through increased funds for salaries, research, and faculty leaves for professional development.**

Periodic opportunities for faculty members at liberal arts colleges to go on leave to engage in work and study at the frontiers of science in major centers will contribute to their professional development and to the strengthening of teaching in their institutions. This form of continuing professional education is of growing importance in many fields. It may well be practical for individual universities to provide such continuing educational opportunities to the faculties of one or more colleges in their communities or regions.

In the past, independent liberal arts colleges have been an important source of America's most distinguished scientists. As research opportunities have expanded, many scientist-teachers from the liberal arts colleges have preferred to move into research in industry, government, and the universities. This attrition has created continuing replacement problems for these institutions, and it has cut back the number of exceptional graduate students receiving their undergraduate education in these institutions.

At the same time, the rapid pace of science has created new problems for teachers. The task of keeping up to date is serious for all teachers, but is more serious for the liberal arts college science teacher if his teaching load is heavy and he is not within easy reach of a major research center.

The Committee views the problem of maintaining the quality of science teaching in both four-year and two-year independent liberal arts colleges as urgently calling for imaginative solution. The stakes are high enough to warrant a bold search for remedies. Obtaining additional funds to permit increases in salary, research opportunities, and leaves for professional development is an obvious move. Collaboration of nearby institutions in the development of graduate study, or in student exchange programs, without red tape, is another way of meeting the problem. The development and use of shared research facilities is still another. But acceptance of direct responsibility by the universities with strength in science is one of the most important aids to be sought.

IMPROVING THE QUALITY OF ENGINEERING EDUCATION

25 **Efforts now being made to improve the professional education of engineers should be augmented and accelerated along the following lines:**

(a) Strengthen and expand graduate study in engineering. (b) Continue the reform of engineering undergraduate education, reducing its rigidity and enriching its scientific content. (c) Continue to modernize the laboratory facilities of engineering schools.

The United States has schools of engineering unmatched in other parts of the world, but we need more that are as good as the top institutions. A variety of institutions are now attempting bold and imaginative improvements in engineering education. The number of these attempts should be multiplied in order to enable our engineering schools to pace, rather than follow, the rapid advance of technology, and to educate more engineers who are versatile, adaptable to rapid change, and capable of broad professional responsibility. By their creativity, such engineers will generate a demand for more engineers of their kind, and for many other types of skilled personnel as well.

In engineering, the need for exceptional competence and for mastery of the latest technologies is greater than the need for increased numbers. Yet numbers and quality are not unrelated. Graduate schools of engineering are not yet producing enough engineers of the quality and points of view required to upgrade and modernize engineering education.

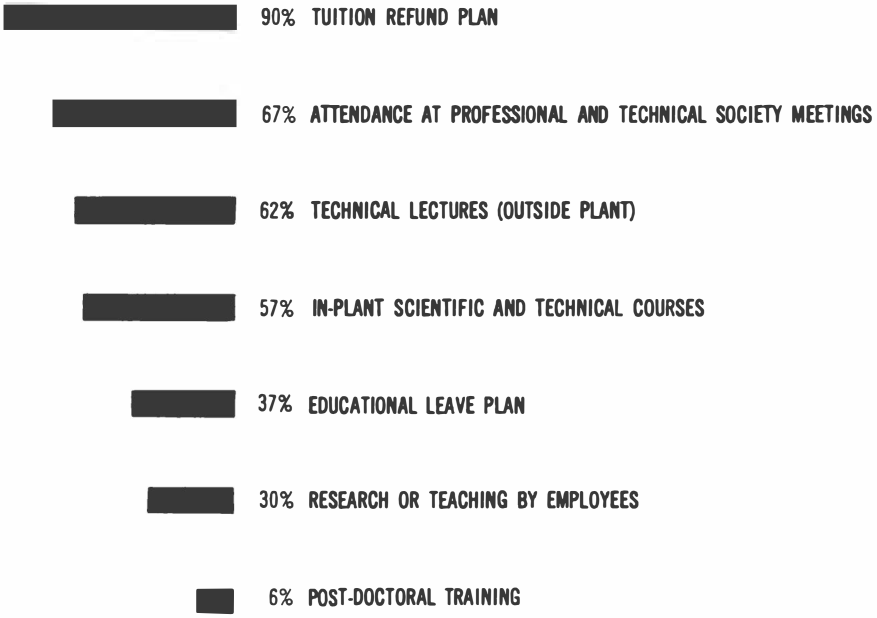
Continuing efforts are required to strengthen graduate schools of engineering. The limiting factor here is the availability of teachers who can master the most advanced technologies and put them to use. Graduate study in engineering must be conducted in intimate association with advanced engineering research that applies science to the frontiers of engineering. Some of the efforts to strengthen graduate education in engineering have been hampered by out-of-date instructional facilities. Modernization of these facilities is clearly required.

Engineering schools should emphasize science fundamentals, to give their graduates the versatility to adjust to our rapidly changing technology. However, engineering is not synonymous with science; the reason for including scientific fundamentals in engineering education is not to make scientists of engineers, but to enable engineers to use science effectively for engineering purposes.

MEETING NEW NEEDS

26 **Universities, in close cooperation with industry and government, should develop a concerted attack on the problem of updating engineering and scientific manpower.**

FIGURE X
EDUCATIONAL ACTIVITIES SPONSORED BY SELECTED INDUSTRIAL EMPLOYERS, PERCENTAGE OF COMPANIES SPONSORING EACH ACTIVITY



NOTE: OFFICE OF EMERGENCY PLANNING SURVEY—DATA BASED ON A SAMPLE OF 96 POSITIVE RESPONSES OUT OF 154 REPLIES TO SOLICITATIONS SENT TO 270 COMPANIES REPRESENTED AT TECHNICAL OBSOLESCENCE CONFERENCES. THESE COMPANIES MAY HAVE AN ABOVE-AVERAGE INTEREST IN TRAINING AND EDUCATION.

Based on "Educational Activities Conducted by Companies for their Scientists and Engineers," W. G. Torpey, January 1964.

Experienced engineers and scientists working for industry and government and wishing to update or improve their knowledge need more and better opportunities to do so. A growing acceptance by industry of its responsibility to help employees continue and broaden their education is suggested by the results of a recent survey, shown in Figure X.

Indeed, it is increasingly common—and increasingly necessary—for experienced professionals of all kinds to go back to school from time to time. The University of California, for example, now has on its rolls—as extension students—one out of every three lawyers in the state, and one out of every six physicians. Yet, despite the recognition by companies of the need to support the education of scientists and engineers, the survey also indicated that, thus far, company investment in such activities has not been large.

Similarly, although universities currently offer a number of first-rate programs designed to afford mature engineers, teachers, and others an opportunity to enhance their professional competence, more such programs are needed. Management-development programs that provide opportunity for business executives to return to the campus for fixed periods to learn about recent developments in managerial practice provide one model of a successful procedure. The new Center for Advanced Engineering Study at the Massachusetts Institute of Technology provides another.

A concerted program to meet the varied, substantial needs of scientists and engineers for updating seems to be required. While some persons view the limits of present programs as primarily fiscal in nature, the Committee's view is that, in the first instance, a concerted effort by universities, government, and industry is required to lay out high-quality programs for meeting the growing need. As this is done, industry should come to see its interests as requiring a substantial investment in the updating of its human resources.

27 **Universities should take the lead in expanding research on the educational process. Curriculum reform, improvement in engineering schools, expansion of teacher training, and the establishment of new centers of excellence all require a sound foundation in research.**

Education represents a national expenditure of about $30 billion. In contrast, the amount of research done to make education better is miniscule. Curriculum reform, improvement in engineering schools, expansion of teacher training, and the establishment of new centers of excellence all require a sound foundation in research. Moreover, there is a need for universities and other institutions to sponsor more research on human-resource development and use, and specifically on all the factors that significantly affect the use of professional talent, such as that of scientists and engineers. Schools of management should sponsor more systematic study of the art and science of management of research and development, and how they may be taught most effectively. Private foundations, industry, and government alike have opportunities to provide more stimulus and funds for this purpose.

VI

THE NEED FOR RESEARCH

The Committee views its deliberations and this report as marking only a beginning toward developing better policies for the utilization of scientific and engineering manpower.

It believes that the appended papers (see Part Two, page 65 ff.) are important contributions to understanding of problems relating to scientific and engineering manpower utilization. The case studies reported on by Paul Cherington, the projections of manpower requirements in terms of national goals by Gerhard Colm and Leonard Lecht, the discussion of the development of a national manpower policy by Frederick H. Harbison, the proposal for a manpower information system by Allen O. Gamble, and the other special papers included in this report represent significant points of departure for additional research. Within the scope of the Committee's report more questions are raised than are answered. In concluding its report, therefore, the Committee identifies some of the needs for further study, and recommends that vigorous attention be directed to research bearing upon this subject.

28 **The Committee recommends that the government, industry, and the universities expand or initiate research efforts that will provide the broader perspectives and increased knowledge needed for dealing more effectively with the issues of scientific and engineering manpower utilization. Examples of research areas include: (a) the economics and dynamics of scientific and engineering manpower, (b) unused potential in human resources, (c) technological aids, (d) the organization in its operating environment, (e) the scientist or engineer in his working environment, (f) scientific and engineering manpower and public policy.**

Topics that require study include:

The economics and dynamics of scientific and engineering manpower. We need to know more about qualitative as well as quantitative aspects of the supply of scientific and engineering manpower; about the dynamics of the market for this manpower; and about the sources of demand for it, including ways in which scientists and engineers themselves, through their own creative efforts, contribute to the demand for their services. We need urgently to know more about the contributions scientists and engineers are making and could make toward creating new ideas, products, and enterprises to help the nation adapt itself to changes, such as those that might be induced by reductions in defense expenditures or by introduction of automation. Also, we need to learn more about the geographical and professional mobility of scientists and engineers, so that we can, for example, influence this mobility more effectively in adapting to new requirements.

Unused potential in human resources. Our ability to draw talented people toward scientific and engineering pursuits varies greatly among different segments of the population. Women constitute a large reservoir of talent still not sufficiently encouraged to enter fields of science and engineering, and often not fully utilized when well educated. The talent latent in underprivileged minority groups should everywhere be openly welcomed and fully utilized. Unused capabilities are possessed by many persons who have retired, whose energy, skills, and wisdom remain unimpaired. Technicians constitute an already developed resource that could make a more substantial contribution. The nation will have to nurture the intellectual capabilities of all these groups, if they are to contribute their efforts effectively when called upon. Research is needed to identify the characteristics of these latent resources and to define the educational, social, and economic steps that must be taken to develop and use them wisely.

Technological aids. The possibilities inherent in new technologies for substantial augmentation of the abilities of scientists and engineers are great. More effective application of techniques for storing, retrieving, and disseminating scientific information is an obvious and well-recognized need. Improved communications can bring the community of science into closer and more mutually enriching interaction. It also can help disseminate education more effectively. New and better teaching aids, including programmed instruction, can enrich education and help relieve some of the pressure on the nation's educational plant and personnel. More extensive and imaginative use of computers in combination with scientists or engineers may greatly amplify the intellectual power than can be brought to bear on scientific or technological problems. Computer-aided engineering design may have profoundly beneficial effects on utilization. We need to push forward with these developments, and to encourage their wise use when and where they are available and applicable.

The organization in its operating environment. The organization, which may be a firm, a university or college, or a government agency, is the means by which the efforts of scientists and engineers are translated into products and services to satisfy society's needs. The response of an organization to influences in its operating environment can affect the numbers and the effectiveness of the persons working within the organization; and also can affect the relative distribution of those persons among different national needs. The development of large systems usually requires scientists and engineers in several different firms to interact successfully with each other and with their counterparts in one or more government agencies. The structure, policies, and financial condition of each firm, the capabilities of its management team, and the authority assigned to it can either facilitate or limit the interactions required. Incentives for firms to invest abroad can determine to a considerable degree the pattern of flow of scientists and engineers into or out of the United States. The decision of a government agency to terminate a program, or of a firm to shift from a military to a civilian product line, may make significant numbers of specialists available to a market not prepared to employ them. Research is needed on the organization's response to those internal and external environmental changes affecting utilization.

The scientist or engineer in his working environment. Although we have been counting scientists and engineers for years, we still do not adequately understand just what a scientist or an engineer does, what motivates him, what his objectives are, how his interests and his capabilities may be expected to change with time, or how he resembles or differs from his colleagues. Even less do we understand how creativity and innovation occur or how working conditions help or hinder these processes. We need to know how management decisions and practices affect the productivity of scientists and engineers; how shifts between project and functional forms of organization affect individual and group output; how project-core groups are formed and what makes them successful. We do not know how to express the cost in manpower utilization of major changes in programs, with their attendant dislocation and mobility. And we do not adequately understand how investment in the development and updating of human resources can be evaluated realistically. Although some of these questions are being studied, the Committee believes that a great deal more research is required to elucidate the ways in which utilization is affected by interactions between scientists and engineers and their working environments.

Scientific and engineering manpower and public policy. Research is needed to help provide a rational basis for judgment concerning issues of public policy. Issues requiring research are suggested by questions such as: What lines of action will meet most effectively the rapidly expanding requirements of higher education during the next several years? How can scientists and engineers be brought to bear most effectively in the development and support of our foreign policy and foreign trade? What new measures could improve the preparation of young persons for a world that is likely to be substantially changed, technologically and perhaps socially, by the time they enter the labor market? How can defense and space technology best make its contribution to the civilian economy? In turn, how can scientists and engineers in defense best be utilized to ease the transitions of defense industry as defense expenditures stabilize or decline? What part can scientists and engineers play in solving the problems of technological unemployment? These are but a few examples of the issues of utilization to which research may make a contribution in the period immediately ahead.

The United States is fast becoming a research-oriented society. Rational problem-solving is replacing decision by random trial and error. Growing pains unavoidably accompany such change, but we can reduce them by strengthening our understanding of this key group, the scientists and engineers, and of the environment in which they work.

VII

CONSOLIDATED CONCLUSIONS AND RECOMMENDATIONS: A PROGRAM TO IMPROVE THE UTILIZATION OF SCIENTIFIC AND ENGINEERING TALENT

In the course of this study, certain themes clearly emerged in our discussion and played a central role in shaping our recommendations. These major considerations are presented below and are followed by a consolidated list of the recommendations presented in the preceding pages.

Seven in number, these themes are:

1 *The massive influence of the federal government on the deployment and utilization of scientists and engineers. This influence imposes on government an entirely new order of responsibility to prevent malutilization. Government must assess in advance the effects of its decisions on the deployment of large numbers of scientists and engineers, both in undertaking new projects and in discontinuing old ones.*

2 *The need to strive consciously for a balanced allocation of scientific and engineering talent. For example, we should avoid emphasizing "big science" to the detriment of the individual investigator or scholar-teacher. The government should be mindful of the manpower needs of the civilian economy in considering great technological projects.*

3 *The pressing national need for meaningful, reliable data, expertly analyzed and coordinated, on the allocation and utilization of scientists and engineers. Because of the inadequacy of such data, decisions affecting utilization have so far been based largely on hunches, intuition, and fragmentary information.*

4 *The key role of managerial leadership in achieving a wise allocation and utilization of scientists and engineers. In our innovative society we need more managers with a new dimension: managers who can match comprehension of a complex, changing technology with mastery of the arts of leadership.*

5 *The central importance, in any manpower policy, of maintaining high standards of accomplishment. Increasing the supply of scientists and engineers at the expense of quality may be more harmful than helpful, while overcommitment of the existing manpower in any field may seriously lower standards of performance.*

6 *The importance of carefully thought-out policies and strategies for human resources development and use. We must do more than preach that investment in men is more important than investment in things. We must carry this view into practice.*

7 *The need for institutions and individuals to be adaptive to change. Individuals must have a deep commitment to innovation and self-renewal. Institutions must continually adapt their policies and procedures to new tasks. They also have an increasing responsibility for encouraging personnel, especially those in the professions, to renew, update, and extend their skills throughout their careers, and for providing them opportunities to do so.*

These seven themes provide the perspective from which the Committee's recommendations for improved utilization of scientific and engineering manpower emerged. These recommendations, discussed in the preceding sections, are brought together in a consolidated program in the following pages.

UTILIZATION AND THE FEDERAL GOVERNMENT

1
page 13

Before the government reaches a decision to undertake a great technological program (e.g., the lunar landing or the supersonic transport projects), it should make a careful assessment of the impact of the decision on the deployment and utilization of scientists and engineers.

2
page 14

Responsibility should be assigned to a unit within the Executive Office of the President for (a) stimulating and coordinating planning by federal departments and agencies with respect to scientific and engineering manpower; (b) promoting research, both inside and outside government, that is likely to facilitate such planning and the solution of manpower problems; and (c) taking the lead in developing an integrated program for the continuing collection and analysis of information, relevant for operating and policy purposes, on scientific and engineering manpower. While the Committee does not recommend a specific location for this unit in the Executive Office, it notes the feasibility of placing it in the Office of Science and Technology.

3
page 15

Each department and agency charged with major scientific or engineering activities should assign to one of its top officials responsibility for improving the utilization of civilian scientists and engineers, both those the agency employs and those whose work it finances. The duties of that official should include: (a) participating in government-wide scientific and engineering manpower planning activities; (b) bringing to the attention of his colleagues the implications, in terms of scientific and engineering manpower, of proposed new programs; (c) assessing the impact on manpower of cancellation, curtailment, or alteration of major programs; (d) analyzing the influence of various management practices and policies on the effectiveness with which scientific and engineering manpower is utilized; and (e) providing for the collection and analysis of the information he needs to meet his other responsibilities. Specifically, the Committee recommends that an official be assigned these responsibilities in the Department of Defense in order to improve the utilization of civilian scientists and engineers working on defense programs both within and without the department.

4 *page 16* The Department of Defense, the National Aeronautics and Space Administration, the Federal Aviation Agency, the Atomic Energy Commission, and other agencies with major technological programs should continue to place great emphasis on improving the management of major projects by assigning to these projects identifiably top-quality managers with both technical and administrative skills, and giving them authority, responsibility, and resources necessary for successful completion of projects.

5 *page 17* Government agencies responsible for development programs should continue to place great emphasis on accurate estimates of their cost and feasibility, and on the use of multi-phase contracts.

6 *page 17* In development programs, the use of fixed-price and incentive contracts instead of cost-plus-fixed-fee contracts is to be commended. Great care must be taken by government agencies to establish meaningful and realistic performance criteria.

7 *page 18* The Committee commends federal contracting agencies in the fields of defense and space for their increasing ability to act at an early stage to cancel, curtail, or materially alter major programs that do not appear to be worth their cost.

8 *page 18* Federal departments and agencies should work with industry to develop plans and programs for minimizing the dislocation and consequent malutilization of scientists and engineers as a result of program cancellation or redirection.

9
page 19

Federal support of contractor-initiated technical effort by government industrial contractors should be maintained at a substantial level. Incentives should be developed for encouraging corporate managements to emphasize quality and continuity, and to orient work toward long-run objectives.

10
page 20

Greater emphasis should be placed on assuring a high level of professional competence in the federal scientific establishment. In support of this objective, the administration proposals for higher salaries at the upper levels of government service should be promptly enacted by the Congress.

11
page 21

The U.S. Civil Service Commission should take the lead in working with government departments and agencies to improve the working environment of scientists and engineers employed by the federal government. It should also help to foster improved forecasting of their future requirements for scientific and engineering personnel.

12
page 21

The Department of Defense, the Atomic Energy Commission, the National Aeronautics and Space Administration, the Department of Health, Education and Welfare, the Department of Agriculture, the Department of Commerce, and other government departments and agencies should periodically review the missions and programs of the mission-oriented research laboratories they finance in full, both those they operate directly and those operated under contract, in order to make sure

(a) that their resources continue to serve high-priority national needs and objectives, (b) that the arrangements for their management and location provide them maximum opportunity to be strong and creative, and (c) that their programs and administrative arrangements are compatible with the objectives of the institutions with which they may be linked. The Committee suggests that the resources of the President's Science Advisory Committee could be called upon in conducting these reviews and in arriving at decisions.

UTILIZATION AND INDUSTRY

13 *page 24*

Corporate managers should identify their most promising scientists and engineers, and take action to enable them to fully develop and apply their competence.

14 *page 24*

Corporate managers should strive to provide a climate for creativity and productivity of highly qualified scientists and engineers in keeping with their great potential value to their firms.

15 *page 25*

A key to the success of a system-development "project" team is the quality of its central core of technical and administrative talent. This group should be given authority consistent with its objectives.

16 *page 25*

Industry, government, and the universities all share a responsibility to train and develop more managers and project engineers who combine thorough understanding of the technology they manage with mastery of the art of leadership.

17 *page 26*

Companies that use scientific and engineering manpower should actively seek ways to help their high-talent manpower augment and replenish their professional capabilities.

18 *page 26*

Utilization of scientists and engineers in industry could be further improved if there were more systematic study of the art and science of research management. With industry taking the lead, private foundations, industry, and government should provide more stimulus and funds for this purpose. The Committee recommends intensive study of the experience of modern corporations that are

heavily committed to research and innovation, or whose chief business is research and development rather than production.

19
page 27
The Committee recognizes the existence of some waste of scientific and engineering talents inherent in practices such as "goldplating," "brochuremanship," and "stockpiling" of manpower. This waste, in the Committee's view, can best be minimized by improved management in both government and industry along the lines suggested in this report, and does not demand a fundamental overhauling of government procurement methods or the imposition of extreme controls over contractors.

20
page 29
Coordinated action by industry and government is needed to stimulate more research and development in areas of the economy where the rate of innovation has been relatively slow.

UTILIZATION IN THE COLLEGES AND UNIVERSITIES

21
page 32
Colleges and universities engaged in scientific and engineering education must accept full responsibility for maintaining a proper balance among the claims of teaching, research, and public service. They should systematically seek the cooperation of the federal government in maintaining the proper balance.

Since the scholar-teacher plays an indispensable role in the cultivation and development of first-rate minds, scientists and engineers who accept faculty membership should also, with few exceptions, assume an obligation to teach that is as clear and compelling as their commitment to research. We need better ways to recognize and reward distinguished teachers of science and engineering (who are not always distinguished in research). While this is a direct responsibility of the universities, professional and honorary societies, which recognize other distinctions by awards and memberships, have given far too little recognition to great teaching. These organizations, together with such national bodies as the President's Science Advisory Committee, might well suggest more effective ways of recognizing great teachers and creative contributions to the teaching process.

22 *page 36*

The nation needs not only to further the efforts of its present centers of educational excellence in science, but also to develop new ones that are as good as the best it now has.

23 *page 38*

Programs of curriculum development and reform that involve outstanding scholars in the universities working jointly with pre-college teachers should be encouraged and supported with greatly enlarged funding.

24 *page 39*

Universities with strength in science should accept a responsibility to provide special study and research opportunities for faculty members of independent liberal arts colleges. Moreover, these colleges need to strengthen the quality of their science teaching through increased funds for salaries, research, and faculty leaves for professional development.

25 *page 40*

Efforts now being made to improve the professional education of engineers should be augmented and accelerated along the following lines:

(a) Strengthen and expand graduate study in engineering. (b) Continue the reform of engineering undergraduate education, reducing its rigidity and enriching its scientific content. (c) Continue to modernize the laboratory facilities of engineering schools.

26 *page 40*

Universities, in close cooperation with industry and government, should develop a concerted attack on the problem of updating engineering and scientific manpower.

27 *page 42*

Universities should take the lead in expanding research on the educational process. Curriculum reform, improvement in engineering schools, expansion of teacher training, and the establishment of new centers of excellence all require a sound foundation in research.

THE NEED FOR RESEARCH

28
page 43

The Committee recommends that the government, industry, and the universities expand or initiate research efforts that will provide the broader perspectives and increased knowledge needed for dealing more effectively with the issues of scientific and engineering manpower utilization. Examples of research areas include: (a) the economics and dynamics of scientific and engineering manpower, (b) unused potential in human resources, (c) technological aids, (d) the organization in its operating environment, (e) the scientist or engineer in his working environment, (f) scientific and engineering manpower and public policy.

IN CONCLUSION

These recommendations should not be taken as harsh criticism of government, industry, and the universities, to which they are mainly directed, but rather as an expression of the Committee's conviction that our society can adjust to new conditions and requirements. The Committee has confidence in the ability of our institutions to adapt to change, and it is this adaptation that it seeks to facilitate by the program of action recommended above.

Our goal should be to encourage the flowering of individual skills and to open new avenues of individual fulfillment. In our research-oriented, innovative society we have an unprecedented opportunity to encourage all our citizens to be creative, each in his own way. Science and technology can hasten the achievement of this goal if we deploy and use our creative talent wisely.

SELECTED BIBLIOGRAPHY

GOALS FOR AMERICANS. Report of the President's Commission on National Goals. Spectrum Book, 1960

COUNTRY REPORT ON THE ORGANIZATION OF SCIENTIFIC RESEARCH—UNITED STATES. Organization for Economic Cooperation and Development, 1962

SCIENCE AND THE POLICIES OF GOVERNMENT. Organization for Economic Cooperation and Development, 1963

MANPOWER REPORT OF THE PRESIDENT AND A REPORT ON MANPOWER REQUIREMENTS, RESOURCES, UTILIZATION, AND TRAINING. U. S. Department of Labor, 1963

EDUCATION, MANPOWER, AND ECONOMIC GROWTH: STRATEGIES OF HUMAN RESOURCE DEVELOPMENT. Harbison, Frederick H. and Myers, Charles A., McGraw-Hill Book Co., 1964

HUMAN RESOURCES: THE WEALTH OF A NATION. Ginzberg, Eli, Simon and Schuster, 1958

THE DEMAND AND SUPPLY OF SCIENTIFIC PERSONNEL. Blank, David M. and Stigler, George J., National Bureau of Economic Research, Inc., 1957

THE RATE AND DIRECTION OF INVENTIVE ACTIVITY: ECONOMIC AND SOCIAL FACTORS. National Bureau of Economic Research Conference, Princeton University Press, 1962

AMERICA'S RESOURCES OF SPECIALIZED TALENT. Wolfle, Dael, Harper & Brothers, 1954

PROFILES OF MANPOWER IN SCIENCE AND TECHNOLOGY. National Science Foundation (NSF 63-23), 1963

THE DISTRIBUTION OF SCIENTISTS & ENGINEERS BY END USE CATEGORIES. Wilbert Annis, William D. Nordhaus, National Science Foundation, December, 1963 (Unpublished paper)

DOCTORATE PRODUCTION IN UNITED STATES UNIVERSITIES 1920-1962. National Academy of Sciences—National Research Council (NAS-NRC 1142), 1963

SCIENTISTS, ENGINEERS, AND TECHNICIANS IN THE 1960'S—REQUIREMENTS AND SUPPLY. National Science Foundation (NSF 64-34), 1964

THE LONG RANGE DEMAND FOR SCIENTIFIC AND TECHNICAL PERSONNEL—A METHODOLOGICAL STUDY. National Science Foundation (NSF 61-65), 1961

EARNED DEGREES CONFERRED: BACHELOR'S & HIGHER DEGREES. U. S. Office of Education. Published yearly since 1947-48

REVIEWS OF DATA ON RESEARCH AND DEVELOPMENT. National Science Foundation Nos. 1-43 (Published occasionally since December 1956)

SCIENCE, GOVERNMENT AND INFORMATION. President's Science Advisory Committee, 1963

STATUS OF THE PROGRAM FOR NATIONAL INFORMATION ON SCIENTIFIC AND TECHNICAL PERSONNEL. National Science Foundation, 1963

THE WEAPONS ACQUISITION PROCESS: AN ECONOMIC ANALYSIS. Peck, Merton J. and Scherer, Frederic M., Harvard University, 1962

THE INDUSTRY—GOVERNMENT AEROSPACE RELATIONSHIP. Stanford Research Institute, 1963

THE IMPACT OF GOVERNMENT RESEARCH AND DEVELOPMENT EXPENDITURES ON INDUSTRIAL GROWTH: PROCEEDINGS OF SYMPOSIUM. National Security Industrial Association, 1963

REPORT TO THE PRESIDENT ON GOVERNMENT CONTRACTING FOR RESEARCH AND DEVELOPMENT. Bureau of Budget, Senate Document #94, 87th Congress, 1962

THE COMPETITION FOR QUALITY—VOL. 1, THE EFFECT OF CURRENT SALARY LEVELS. VOL. 2, THE EFFECT OF NON-SALARY FACTORS. Federal Council for Science and Technology, 1962

THE FEDERAL GOVERNMENT AND EDUCATION. Special Subcommittee on Education, House of Representatives, House Document #159, 88th Congress, 1963

MEETING MANPOWER NEEDS IN SCIENCE AND TECHNOLOGY REPORT NUMBER 1: GRADUATE TRAINING IN ENGINEERING, MATHEMATICS AND PHYSICAL SCIENCES. President's Science Advisory Committee, 1962

SCIENTIFIC PROGRESS, THE UNIVERSITIES, AND THE FEDERAL GOVERNMENT. President's Science Advisory Committee, 1960

EDUCATION FOR THE AGE OF SCIENCE. President's Science Advisory Committee, 1959

FEDERAL SUPPORT OF BASIC RESEARCH IN INSTITUTIONS OF HIGHER LEARNING. National Academy of Sciences, Washington, D. C., 1964

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While acknowledging its indebtedness to many people, the Committee assumes full responsibility for the report.

PART TWO STUDY PAPERS

TOWARD THE DEVELOPMENT OF A COMPREHENSIVE MANPOWER POLICY

Frederick H. Harbison *

In this era of dramatic forward strides in science and technology, it is well to remember that human beings are of all resources the most critical for the nation's economic, social, and political development. In the long run the wealth, strength, and leadership position of the United States is tied to its ability to develop and effectively utilize human resources. It is appropriate, therefore, to examine the elements of a national manpower policy and to discuss the possible contributions of the federal government in building it.

THE ELEMENTS OF A COMPREHENSIVE MANPOWER POLICY

A comprehensive manpower policy for the federal government would logically include consideration of: (1) an employment policy; (2) a human-resource-development policy; and (3) a manpower-allocation policy.

Under the heading of *employment policy* we could list measures aimed at providing employment opportunities for all persons able and willing to work. These would include the increasing of aggregate employment by monetary and fiscal measures, the deliberate attempt to create more employment in so-called distress areas, and other measures designed to make jobs available for those needing them.

Under the heading of *human-resource-development policy,* we would group all measures designed to increase the skills, knowledge, and capabilities of the present and future labor force. Such measures would include the expansion and improvement of education at all levels in order to raise the qualifications of people to meet changing job requirements, as well as the continuous training and retraining of the employed and the unemployed to provide the right skills at the right places. Both *education policy* and *training policy,* therefore, are integral components of human-resource-development policy.

Under the heading of *manpower-allocation policy,* we might include all measures specifically aimed at matching men and jobs. These would encompass the provision of employment and placement services, labor-market information, and incentives to attract persons into useful and productive activities. Here the underlying objective is to maintain "an employment climate" based upon free institutions to promote productivity and reward creativity. Also included in this category are measures for eliminating discriminatory hiring and utilization practices.

A comprehensive manpower policy, obviously, is concerned with the effective employment, development, and utilization of all human resources—the skilled as well as the unskilled, scientific and engineering manpower as well as administrative and managerial personnel, those in public and in private employment, those who are employed as well as those who are seeking work, and the new generations preparing for employment as well as those presently in the labor force.

THE INVOLVEMENT OF THE FEDERAL GOVERNMENT

In a pluralistic society such as ours, the bases of manpower policy are quite properly widely diffused. Education is largely the responsibility of thousands of local school boards, publicly and privately financed colleges and universities, and a multitude of other special-purpose educational institutions that draw their support and inspiration from a great variety of sources. Yet,

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the responsibility of the federal government for expansion and improvement of education throughout the nation is growing rapidly.

This is not to suggest that the United States must consciously develop a "master strategy" for manpower development and utilization. Our government does not, and should not, direct people to follow particular careers; it does not tell them what they must study; it does not prescribe training courses in either private or public employing institutions; and it does not tell universities what to teach or what areas of research to pursue. The reliance upon and faith in decentralized decision-making is basic to our pluralistic society and is a major source of its strength and vitality. Thus the main objective of any national manpower policy is not to regulate but rather *to energize the activities of thousands of decision-making organizations by providing them with information, tools, and ideas for better assessment of the total impact of their decisions.*

A national manpower policy does not require an expansion of the role of the federal government, for it already has far-reaching influence upon manpower policy, as can be seen from these few examples of its present involvement:

1 The federal government is the largest single employer of manpower in the nation. In its civilian activities it employs over two and a half million people. Of these about 10 per cent work in Washington, and the remainder is scattered through all the states of the union as well as many foreign countries. Equally significant are the two and a half million members of the armed services, in whose ranks are many thousands of highly qualified technical specialists and skilled tradesmen. The building of military bases in certain localities may transform employment patterns in whole regions or states. And the closing of a major military establishment can create serious unemployment in a particular area.

2 The federal government finances about two thirds of the nation's scientific research and development. As the largest customer of research and development in private industry (60 per cent) and the main patron of basic research in universities (65 per cent), it has a tremendous influence on the relative amounts of effort going into basic and applied research and development as well as on the proportion of scientific and engineering manpower assigned to defense and space exploration and to civilian technology. Because it is, directly and indirectly, the dominant buyer, it cannot avoid being a major force in determining scientific and engineering salaries.

3 Today, the federal government, through at least 17 departments and agencies, is significantly involved in education. Its programs can be divided into these categories:

1 Facilities and equipment
2 Support of students
3 Support of teachers
4 Strengthening of curricula
5 Research in educational institutions
6 Support to federally impacted schools
7 Miscellaneous education programs

The government's involvement in support of students is worth exploring. In 1962, over 250,000 students, or about seven per cent of our college population, received some sort of federal support, which was handled by more than ten federal agencies.[1] Of this number, over 65,000 received direct support, or grants, and about 185,000 received loans. The direct support is concentrated at the graduate level (over 80 per cent) and in the scientific and engineering fields (over 85 per cent). There is also concentration of funds at 100 institutions (over 90 per cent).[2] These programs may serve the purposes of the agencies that administer them, but in some cases they may cause serious problems in the educational community. For example, if the best faculties in science and engineering are being attracted by the availability of federal funds to the 100 major universities, it becomes increasingly difficult for the other 1,800 institutions of higher learning to develop or maintain academic excellence in these areas.

4 The Employment Act of 1946 places upon the federal government the responsibility to foster and promote conditions under which there will be useful employment opportunities for all persons able and willing to work. Thus, a major responsibility of the Council of Economic Advisers is to recommend broad economic policy to promote maximum employment, production, and purchasing power. In recent months, the Council has advocated an increase in

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[1] THE FEDERAL GOVERNMENT AND EDUCATION. Special Subcommittee on Education, U.S. House of Representatives. House Document #159, 88th Congress 1963.
[2] Ibid.

effective demand, through tax cuts, as the principal employment-expanding device.

5 Congressional passage of the Manpower Development and Training Act (MDTA) in 1962 indicates that the government will make a direct assault on the problem of unemployment. This legislation provides for federally supported retraining of the unemployed on a broad national scale, as well as providing for a comprehensive, unified, manpower research and development program. Since the start of the program, over sixty thousand workers have received some training under provision of MDTA. In addition, the Secretary of Labor envisions the development of a labor-market program with the following components:

A current labor-market information service providing information on job vacancies, occupational needs, and availability of workers;

An early-warning system of impending changes in employment, especially layoffs, so that action can be taken immediately to place workers or put them into training;

An effective vocational guidance and counseling program beginning in the elementary school;

A program of research and the implementation of its findings throughout the educational system which will help make the system fully responsive to manpower needs, current and prospective;

A nationally oriented placement service;

A program of training and retraining for unemployed and underemployed workers; and

A program for aiding the mobility of workers, responsive to the changing geography of employment opportunities.

6 The federal government is also deeply involved in the area of health services. The National Institutes of Health has provided a total of $160 million in the past six years to educational institutions for the creation of facilities for research and research training in the medical sciences. In 1962, it was supporting over 10,000 graduate students in health-related fields.

7 Finally, in addition to the above functions, the federal government has a major task of collection and dissemination of manpower information. It is the principal supplier of information concerning manpower and its education, location, age, employment, utilization, wages, and fringe benefits. Since this information is vital to most governmental as well as non-governmental decisions involving manpower, its availability or lack of availability is often a major limiting factor.

Through these and other far-reaching programs, the federal government obviously is the maker of key decisions affecting the employment, development, and utilization of manpower. Its actions significantly influence, and in some cases actually determine, whole chains of decisions by private employers, state and local governments, and non-profit institutions. Because the programs are scattered through so many agencies, and because legislation is channeled through so many congressional committees, inconsistencies and even contradictions have arisen.

In summary, many different agencies are concerned with pieces of manpower policy, some of which are consciously formulated and many of which are simply indirect consequences of policy decisions made in other areas. There is need for the government to develop greater awareness of the total impact of its actions on the employment, development, and allocation of the nation's manpower. There is a need also to develop a consistent set of goals for manpower, some commonly accepted criteria for measuring progress toward such goals, and plausible programs for attaining them.

MACHINERY FOR DEVELOPMENT OF A NATIONAL MANPOWER POLICY

It has been suggested that the solution lies in the establishment of appropriate machinery to coordinate the activities of the federal government that influence manpower development and to relate them to general economic policy. Among the more frequently discussed proposals are the following:

1 The establishment of a Council of Manpower Advisers in the Executive Office of the President. Such an organization would have responsibilities relating to manpower parallel to those of the present Council of Economic Advisers in economic affairs. The creation of such a council would require new legislation, and it is doubtful whether the issues involved in national manpower policy are as yet clearly enough defined to command the support of the Congress for a council of this kind.

2 A somewhat related proposal is for the creation of a Directorate of Manpower in

the Executive Office of the President. Such a directorate would have the power to coordinate all the activities of the various government agencies having a substantial impact on manpower. During World War II, the War Manpower Commission was in some respects an organization of this kind. However, there are few supporters of this proposal as a peacetime solution. It would require new legislation, and it would almost certainly encounter stiff resistance from many of the major federal agencies.

3 A more feasible proposal would be to extend the functions of the present Council of Economic Advisers to include the appraisal and coordination of the manpower policies of the various agencies. This arrangement would probably not require new legislation. And, since the major function of the Council might be to appraise, rather than coordinate, the manpower activities of the various agencies, it would be more readily acceptable to the present governmental hierarchies.

4 The other widely discussed proposal is for the establishment of a cabinet-level committee on manpower policy (headed presumably by the Secretary of Labor) to appraise, integrate, and coordinate the activities of the various agencies insofar as they have manpower responsibilities. This proposal, like the preceding one, would require no new legislation. Its major objective would be to organize a cooperative effort by the agencies concerned to develop a national manpower policy. Since this proposal would probably offer the easiest and quickest solution, at least in the immediate future, I shall discuss it in more detail.

A committee on manpower could be set up by a simple executive order of the President. Its membership should probably include: the Secretaries of Defense, Health, Education and Welfare, Agriculture, Commerce, and Labor; the Chairman of the Council of Economic Advisers; the Director of the Bureau of the Budget; the Chairman of the Atomic Energy Committee; the Director of the National Science Foundation; the Administrator of National Aeronautics and Space Administration; the President's Special Assistant for Science and Technology; the Director of Selective Service; and the Chairman of the U.S. Civil Service Commission. The general function of the Committee would be to study and appraise the total impact of activities of the federal government on employment, human resource development, and manpower allocation, and to achieve some coordination of these activities. A more specific function would be to prepare the annual manpower report of the President.

Certainly, it would be wise to broaden both the scope and the concept of the President's annual message on manpower. In 1963, this report, which was prepared by the Department of Labor, concentrated on measures to increase job opportunities and to retrain the unemployed. In his message, the President said that "unemployment is our number one economic problem." But there are other manpower problems of high priority. There is the problem of shortages of particular kinds of strategic, highly talented manpower—mathematicians, physicists, teachers, key managerial personnel, and physicians. There are major deficiencies in education at all levels. The President's manpower message could, therefore, logically be expanded to include policy statements on highly talented manpower, on aid to education, on technological obsolescence, and on related problems, and proposals to augment job opportunities and alleviate unemployment. This would allow the various government agencies to participate in the preparation of a consolidated statement on manpower, and would encourage these agencies to examine the consistency of their far-flung activities and to focus their attention on a number of interlocking policy-making areas. It would also dramatize for the American people the importance of building many kinds of human capabilities to prepare ourselves to face all problems—domestic and international. It would represent a point of departure for information-gathering, research, and strategy-building in the broad area of human-resource policy.

The Committee would need a small, but competent, professional staff. And it would be necessary for the President to direct all executive agencies of the government to assess the manpower implications of their respective programs and to report their findings to the Committee on Manpower. Finally, it would be essential to make a clear distinction between the functions and staff of the Committee and those of the Department of Labor as one of the principal agencies represented. In no sense should the designation of the Secretary of

Labor as chairman of the committee imply that the Labor Department as such would take over and assume control of the development of a national manpower policy.

THE GENERATION OF NEW IDEAS

The establishment of coordinating machinery, such as that outlined above, would be only a first procedural step in the development of a national manpower policy. The ultimate success of the venture would depend upon the generation of new ideas, concepts, and workable programs. This would require a major research effort coupled with a program of interchange between "practitioners" and "idea men."

Until a few years ago, relatively little research effort went into studies of manpower and educational development. Indeed, although education is the largest single industry in the United States (employing over 2.5 million people and costing nearly 30 billion dollars annually), less than one per cent of total expenditures for education is devoted to research. And, in comparison with studies of unionism and collective bargaining, the attention given to research on the labor force, on unemployment, on the operation of labor markets, and on manpower development has not been very great. Finally, the Council of Economic Advisers, until very recently, has concentrated its thinking on general problems of aggregate employment rather than on specific questions of education and manpower-development policy. Within the last few years, however, there has been a noticeable burst of interest in manpower and education problems, and now the rate of generation of new ideas in this field is quite impressive.

Professor T. W. Schultz, for example, has effectively mobilized the interest of general economists in the concepts of "investment in man," returns to education, and the contribution of education to economic growth. The Conservation of Human Resources Project at Columbia University has turned out several significant studies in the manpower-development field. A Commission on Human Resources has just been established by the Conference Board of Associated Research Councils to make a broad study of the changing demand for high-talent manpower and the sources from which it may be drawn. The Institute of Industrial Relations at the University of California (Berkeley) is making a comprehensive study of unemployment in the United States. The Brookings Institution is currently launching a major research effort on the economics of education. And, in a growing number of places, there is a rapidly expanding interest in studies of the manpower implications of automation. It is clear, therefore, that the generation of ideas in this field is increasing quite significantly.

There are now many important areas for research on education and manpower. Without attempting to be all-inclusive, the following are perhaps among the most important:

The composition and growth of the labor force in the United States, and the factors that determine the participation of various categories of personnel in it.

The changing occupational structure of the labor force, and the factors that influence occupational choice (particularly in the high-talent manpower categories).

The basic relationships between employment, educational attainment, and the wage and salary structure.

Assumptions, methods, and procedures of making long-term estimates of future requirements and supply of manpower, with particular reference to the high-talent occupational categories.

The factors that account for and promote mobility of human resources, both occupationally and geographically.

The achievements, shortcomings, and potentialities of employing institutions (both public and private) as trainers, developers, and retrainers of skilled manpower.

The critical examination of the role of vocational schools for pre-employment training of skilled manpower.

The concept and the mechanisms of "continuous education" as a means of stimulating "self-renewal" of human resources in a rapidly changing economy.

Changing technologies of education and the learning processes.

Cost-benefit analyses of education and training.

The contribution of training in the armed forces to development of skills and capabilities in the civilian labor force.

The identification of critical gaps in highly talented manpower, and measures for building the talent to fill them.

The dimensions, causes, and alternative remedies for persistent unemployment and underemployment in prosperous economies.

The relationship of various kinds of social insurance to the productivity and flexibility of the labor force.

The concept and practical feasibility of a "national manpower budget."

Obviously, the areas listed above could easily be expanded. The central objective is to encourage some of the nation's best brainpower to make studies and generate new ideas in this broad field. Few other fields are as "underdeveloped" as this one, and few hold better prospects for high returns in the form of contributions to strategic knowledge.

It is vitally important, moreover, to build systems of communication between the generators of new ideas and the practitioners in government and industry who could make use of them. In formulating a national manpower policy, ideas are even more important than appropriate government machinery. Accordingly, I would advocate the establishment of a continuing "Manpower Research and Policy Seminar" to serve as a communications belt between idea men and the practitioners. Although the seminar should have the support and constructive participation of federal government representatives, it should be organized and managed by a non-government institution to emphasize its concept-developing rather than decision-making role. Its function would be to suggest solutions to pressing problems, to foster new thinking, and to explore interrelated policy issues. It would provide a forum for selected persons with knowledge and interest in the manpower field, who could be drawn together from government agencies, universities, industry and labor on a regular basis. The major focus of the seminar would be to identify major interlocking policy-making areas, to build unifying concepts aimed at solutions, and to chart areas for further research and investigation by appropriate organizations on a cooperative basis. In such a policy seminar, the government participants would not be expected to defend the official positions of their respective agencies. Nor would they be under obligation to accept any of the findings of the seminar. Some discussions, indeed, might well be completely off the record, while, in other cases, policy statements might be issued as appropriate. In any case, a seminar of this kind would be indispensable for the productive operation of any governmental apparatus concerned with the development of a national manpower policy.

CONCLUSION

Even in our pluralistic society, the federal government now has far-reaching influence on employment, human-resource development, and the allocation and utilization of the nation's manpower. At present it has no means of assessing its total impact in this vital area. Accordingly, measures should be taken to enable the government to evolve a logical and consistent national manpower strategy.

The measures discussed and advocated in this paper are the following:

(1) Establishment by the President of a cabinet-level Committee on National Manpower Policy to appraise, integrate, and coordinate the activities of the various government agencies that influence, directly or indirectly, the employment, development, allocation, and utilization of the nation's human resources. Such a committee should be given authority to secure information relating to manpower activities from the constituent agencies; it should have a small but highly competent staff.

(2) The scope of the annual Manpower Report of the President should be broadened so as to make it, in effect, a consolidated statement on manpower policy of the federal government.

(3) Both government and private organizations should attempt to stimulate research and the generation of new ideas in the broad area of employment, education, allocation, and utilization of manpower throughout the nation.

(4) A Manpower Research and Policy Seminar should be established, on a national basis but under private sponsorship, to build a communication channel between "idea men" throughout the country and practitioners in the government service.

It would be wise to experiment with these rather simple steps before attempting to establish more elaborate government machinery for building a strategy of human-resource development. The proposals set forth in this paper can be implemented without new legislation and without the building of a new governmental bureaucracy. Although the task is formidable and its precise dimensions still unclear, there are people both within and outside the government who are willing and able to take it on.

REQUIREMENTS FOR SCIENTIFIC AND ENGINEERING MANPOWER IN THE 1970'S

Gerhard Colm and Leonard A. Lecht

I

This report is based on work in progress by the National Goals Project of the National Planning Association's Center for Priority Analysis. The report presents the findings of a pilot study of scientific and engineering manpower requirements for achieving national goals in the 1970's.

The Goals Project has taken the work of President Eisenhower's Commission on National Goals as a point of departure. The goals for which manpower needs have been estimated are the same goals insofar as they could be quantified. Space goals were added after the late President Kennedy proposed in 1961 that it become a national objective "to put men on the moon and bring them back." This we interpret to mean embarkation on a sustained space-research program.

The standards costed by the Goals Project are standards for adapting American society to the challenges created by changing technology, urbanization, and our role as a leader in the non-communist world. The expenditures required are a measure of the magnitude of the problem our nation faces in supplying resources for a variety of aspirations ranging from elimination of slums to the conquest of space. The estimates of the costs of achieving the goals are only a first step in developing targets that are attainable within the constraints imposed by our resources. The elements entering into the standard for each goal are defined in the appendix to this report.

The over-all findings of the study can be summarized as follows:

1 If the trends of the past decade continue, our nation would require approximately 1.9 million scientists and engineers in 1970 and 2.3 million in 1975 to provide for a growing economy. Approximately nine tenths of the total in 1970, and four

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fifths by 1975, would be preempted in maintaining present standards. To reach the more ambitious objectives in the goals, the demand for technical manpower would rise to 2.1 million in 1970 and 2.6 million in 1975.

2 Assuming that these trends continue, there would be a deficit of approximately seven per cent of the gross technical personnel requirements for a growing economy. For the higher performance levels in the goals, the shortage would diminish from about one sixth of the scientists and engineers needed by 1970 to slightly over one tenth by 1975.

3 The estimates of shortage presuppose that the institutional arrangements influencing the supply of and demand for technical manpower will remain as they are at present. If these arrangements were to be changed through planning by business, education, and government, the prospective shortage could be substantially reduced or even eliminated.

4 There are major gaps in our understanding of the forces affecting the labor market of scientists and engineers, especially on the supply side. The gaps could be narrowed by research aimed at establishing the relevant facts and creating the conceptual tools for relating these facts to the needs of business and public programs.

II

The manpower projections in this report relate to the economic framework associated with the estimates of the dollar costs of the nation's goals prepared by the Goals Project. The projections for 1970 refer to a society in which the gross national product has risen to $780 billion, while those for 1975 pertain to a gross national product of $980 billion. The annual rate of growth in both estimates is approximately four per cent a year. This is in line with the target rate agreed upon by the United States in discussions with the Organization for Economic Cooperation and Development. These levels of output support a population estimated to increase to 209 million persons by 1970 and to 226 million by 1975.

The expenditures for the individual goals and the manpower requirements they imply are based on comparison of three cost figures for each goal. One is the current level of costs. The second is an estimate of

TABLE 1 GROSS COSTS FOR INDIVIDUAL GOALS (in millions of 1962 dollars)

GOAL	GROSS COST IN BASE YEAR 1961 or 1962	PROJECTED COSTS IN 1970		PROJECTED COSTS IN 1975	
		to maintain present standards	for goals	to maintain present standards	for goals
1 Health	$ 30,200	$ 34,800	$ 68,800	$ 38,200	$ 78,600
2 Education	25,074	33,778	66,611	37,364	92,320
3 Social Welfare	34,800	46,672	66,318	52,413	83,082
4 Consumer Goods and Services	355,400	405,692	518,235	444,596	637,049
5 Housing	21,300	32,170	49,690	37,450	61,650
6 Community Redevelopment	36,300	49,144	54,037	56,068	77,586
7 Research and Technology	15,000	22,350	32,170	27,900	37,520
8 Natural Resources	3,760	4,317	7,250	4,741	7,250
9 Industrial and Commercial Tools and Plant	45,200	81,800	92,838	102,300	142,418
10 Transportation	22,786	32,477	37,801	39,341	50,699
11 National Defense	50,823	47,765	59,732	43,295	68,869
12 International Relations	3,946	3,668	13,419	3,668	16,688
13 Agriculture	7,232	4,916	8,743	4,877	9,722
14 Retraining	35	131	1,748	158	2,049
15 Area Redevelopment	9	180	332	149	364
16 Space Program	2,390	4,500	9,600[a]	3,500	10,390[a]
TOTAL GROSS COST	$654,255	$804,360	$1,087,319	$896,020	$1,371,101

[a] Space estimate includes the projected cost of programs carried out by NASA, AEC, NSF, Weather Bureau, COMSAT.

the costs in the 1970's to maintain existing standards for the larger anticipated population and to provide the means for attaining the growth in gross national product assumed in the study. These costs differ from current expenditures because of the additional expenditures required to support present standards of living or health for more families and to create the additional capital equipment needed for a growing economy. The last of the cost estimates refers to the higher level of expenditures for the improvements beyond current performance represented by the standards for each goal. The standards have been derived, wherever possible, from the findings of expert studies or public bodies. The cost of implementing the recommendations of President Eisenhower's Commission on Higher Education serves as an example. Where there are widespread differences in informed opinion as to the program required for achieving a specific goal, or the speed with which it should be pursued, alternative standards have been costed.

The cost estimates for the individual goals are presented in Table 1. Where alternatives are available, the table presents the costs for the high cost standards for each goal. They have been selected to indicate an upper limit to the prospective manpower demand.

Consumer spending is by far the largest single item in the projected expenditures. Maintaining current living standards for the larger population in the 1970's would require $50 billion more spending in 1970 than in 1960, and $90 billion more in 1975. Expenditures for research and development in the goals rise to approximately four per cent of the gross national product in the 1970's as compared to 2.8 per cent in the early 1960's. Spending for defense, as projected in the high standard for the defense goal, involves an increase to $60 billion in 1970 and $64 billion in 1975, or about 25 per cent more than the 1962 level by 1975. It is estimated that partial disarmament, following the lines of Part I of the United States disarmament proposals at Geneva in 1962, included as the basis for the minimum defense expenditures in the study, would reduce defense spending by $12 billion below the high-standard level in 1970 and by approximately $20 billion in 1975. The alternative standards costed for space differ mainly in the pace they assume in the pursuit of our space objectives. The more ambitious and costly standard involves an estimated expenditure of $9 billion in 1970 and $10 billion in 1975. The slower space program and the one less concerned with investigating planets other than the moon before 1975 would cost approximately $2 billion less in 1970 and about $5 billion less in 1975. (All figures are in 1962 dollars.)

III

Requirements for scientists and engineers are derived for the goals by relating their cost figures to estimates of the output and employment they imply in each of the major sectors of the economy in 1970 and 1975. The estimates for growth refer to manpower needs for the output in each of the sectors corresponding to the levels of gross national product projected in the study. Past trends and current developments in the percentage of total employment made up of scientists and engineers in each sector provide a basis for estimating demand for technical manpower by sector. Estimates of actual employment in 1960 and projections for 1970 and 1975 are presented in Table 2.

The estimates add up to a demand for approximately 1.9 million scientists and engineers in 1970 and 2.3 million in 1975 for a growing economy. These requirements represent an increase over 1960 levels of 60 per cent for 1970, and 95 per cent for 1975. Another 215,000 would be needed by 1970 and 330,000 by 1975 to replace losses due to normal attrition, making for a projected total increase in manpower demand of 900,000 by 1970 and 1.4 million by 1975. The estimates for growth can be translated into manpower needs for maintaining current standards of performance in the next decade. Continuing the present standards for consumer spending, or health, or urban renewal, will absorb approximately the same share of technical employment in 1970 and 1975 as the share of output these activities are collectively projected to absorb. The number of scientists and engineers needed for extending the status quo is estimated to grow to 1.7 million by 1970 and to 1.9 million by 1975. The increase from 1970 to 1975 is due primarily to population growth.

An additional quarter-million scientists and engineers would be needed in 1970, and

TABLE 2 PROJECTED REQUIREMENTS FOR SCIENTISTS AND ENGINEERS, 1970 AND 1975[a]

		PROJECTED REQUIREMENTS			
		1970		1975	
SECTOR OF ECONOMY	ESTIMATED ACTUAL EMPLOYMENT IN 1960	to maintain growth	for goals	to maintain growth	for goals
BUSINESS	855,400	1,391,800	1,510,800	1,702,000	1,868,300
1 Mining	31,500	46,200	50,900	58,900	62,200
2 Construction	55,100	106,500	118,800	128,500	139,900
3 Manufacturing	613,500	1,011,700	1,075,900	1,231,200	1,339,800
4 Transportation, Communication and Public Utilities	61,500	71,200	76,100	87,200	98,500
5 Engineering and Architectural Services	56,900	96,100	103,600	121,800	129,600
6 Other Non-Manufacturing	36,900	60,100	85,500	74,400	93,300
NONPROFIT ORGANIZATIONS	6,500	11,100	13,200	15,000	18,100
GOVERNMENT	170,200	231,700	292,900	276,200	365,400
1 Federal	99,200	135,700	184,200	161,200	215,100
2 State-Local	71,000	96,000	108,700	115,000	150,300
COLLEGES AND UNIVERSITIES	125,100	220,000	305,000	261,000	345,000
TOTAL	1,157,200[b]	1,854,600	2,121,900	2,254,200	2,591,800

[a] These figures are estimates of the total demand in 1970 and 1975. They are net of the manpower needs between 1960 and 1969 and between 1971 and 1974 to replace losses created through normal attrition.
[b] The figure 1,157,200 is based on a definition of "scientists and engineers" that excludes all categories of social scientists and certain categories of medical scientists. A broader definition including all categories of scientists underlies the number used in Part I of this report and yields for 1960 the figure 1,295,000 scientists and engineers.
(See PROFILES OF MANPOWER IN SCIENCE TECHNOLOGY, National Science Foundation Report 63-23.)

over a third of a million more in 1975, to make possible the increases in production, construction, research, and teaching for achieving our goals at the higher levels proposed in the standards. The total increase in manpower requirements for achieving the goals, including attrition, would approximate 1.2 million by 1970 and 1.8 million by 1975. The manpower needs for the goals in 1970 are 83 per cent greater than those in 1960, and 124 per cent greater in 1975.

In terms of specific goals, the total of 2.1 million scientists and engineers projected for 1970 includes an estimated increase of about 13 per cent in defense in the high standard—from under 300,000 in 1960 to 340,000 in 1970.[1] Supplying faculty for the college enrollment anticipated in the 1970 education goal would require an additional 180,000 scientists and engineers over the 1960 level, or a growth of about 150 per cent. Expansion of research activities in health would create an estimated demand for 77,000 additional scientific workers. The largest proportionate increase is projected for the space program, with the 15,000 engineers and scientists in 1960 rising to about 135,000 in 1970 in the high standard. An alternative standard assuming a slowing down in the rate of growth of space activities reduces the expected total to 110,000. This figure compares with an estimate by the National Aeronautics and Space Administration of 43,500 scientific and engineering employees in its programs in 1963 and a forecast of 64,000 in 1964.[2] Less spectacularly, the goals concerned with housing, industrial plant, or public buildings are estimated to require 65,000 technical personnel in construction, an increase of over 100 per cent and largely made up of engineers. Similarly, the goal in research and development projects an increase in the number of research workers in all fields to approximately 825,000 by 1970.

The changes in manpower needs projected for the goals in 1975 follow the 1970 pattern, but with important exceptions in defense and space. It is assumed in the defense goal that the early 1970's are largely devoted to adding technological advances perfected earlier into the existing defense capabilities. Accordingly, the number of scientists and engineers employed in defense activities increases by only 18,000 or

PERCENTAGE CHANGE IN REQUIREMENTS

1960 to 1970		1960 to 1975		
to maintain growth	for goals	to maintain growth	for goals	
62.7%	76.6%	99.0%	117.8%	
46.7	61.6	87.0	97.5	1
93.8	115.6	138.2	153.9	2
64.9	75.4	100.7	118.4	3
15.8	23.7	41.8	60.2	4
68.8	82.1	114.1	127.8	5
62.9	131.7	101.6	152.8	6
70.8	103.1	130.8	178.5	
36.1	72.1	62.8	114.7	
36.8	85.7	62.5	116.8	1
35.2	53.1	61.9	111.7	2
75.9	143.8	108.6	175.8	
60.0	83.4	94.8	124.0	

about five per cent, from 1970 to 1975. If partial disarmament following the lines of Part I of the 1962 United States proposals were in force in 1975, the technical manpower needed would be less by a third of the total projected in the high defense standard. The largest proportionate decreases in the event of disarmament are projected to take place in personnel engaged in activities other than research and development. Manpower needs for the space program are estimated to taper off more sharply than those for defense, with an increase of only 2,000 between 1970 and 1975 in the high space alternative. The less costly space alternative projects a decline in the number of scientists and engineers of 6,500 between 1970 and 1975. The underlying assumption is that the space program in the early 1970's will consist mainly of exploiting the technological changes developed in the previous decade. Scientists and engineers for college faculty in the education goal grow by 40,000 to a total of 345,000 in 1975. For the entire 1960-1975 period, the largest rates of increase in demand for technical manpower are in education and space.

IV

Corresponding to the estimated increases in demand are expectations of considerably lesser increases in supply. The supply figures are derived from estimates of enrollments and earned degrees by public agencies such as the U.S. Office of Education, and from projections of other components of supply, including foreign scientists moving to the United States and persons without degrees qualifying as engineers. The total increase in supply expected from growth in population and enrollments is estimated to exceed three quarters of a million by 1970 and one and a quarter million by 1975. If the goals in education began to be implemented in the mid-1960's, the increase in supply would rise slightly by 1970, to over 800,000, and more substantially by 1975, to almost 1.5 million.* These data, the manpower requirements, and the estimated deficits they imply are listed in Table 3.

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* See Appendix Table G-2 for the basis of estimate for the Education goal.

TABLE 3 PROJECTED DEFICIT OF SCIENTISTS AND ENGINEERS IN 1970 AND 1975

	1960 to 1970		1960 to 1975	
	to maintain growth	for goals	to maintain growth	for goals
Increase in Demand for Scientists and Engineers from:				
a) Growth in Requirements	697,400	964,700	1,097,000	1,434,600
b) Normal Attrition	215,100	215,100	333,400	333,400
c) Total Increase in Demand	912,500	1,179,800	1,430,400	1,768,000
Increase in Supply of Scientists and Engineers	764,800	801,800	1,264,400	1,459,850
Deficit	147,700	378,000	166,000	308,150
Deficit as % of Gross Personnel Needs Including Attrition	7%	16%	6.5%	10.5%

The projected deficit for scientists and engineers to support growth rises from 148,000 in 1970 to 166,000 by 1975. These figures represent approximately seven per cent of the gross personnel requirements by 1970 and 1975 to provide for the larger number of positions and to replace losses in the technical work force created by attrition. The estimates for the more ambitious objectives in the goals project a shortage decreasing from 378,000 by 1970 to 308,000 by 1975. As a percentage of gross manpower needs for the goals, the shortage diminishes from 16 per cent by 1970 to 10½ per cent by 1975. The decline is attributable to the inclusion of a substantial expansion of educational opportunities as an important national objective. As defined in this study, the expansion involves an increase of 50 per cent in the share of the eligible age groups enrolled in colleges and universities between 1960 and 1975. Implementing the standard for our education goal would add some 200,000 scientists and engineers to the available supply by 1975.

V

The data in the tables listing requirements for scientific and engineering personnel are consistent with other estimates for 1970 published by the National Science Foundation and the Bureau of Labor Statistics.[3] They are also consistent with experience in the 1950's. In the 1950-60 decade, the percentage of civilian non-agricultural wage and salary employment accounted for by scientists and engineers increased from 1.6 per cent to 2.1 per cent of the total. The estimates for 1970 indicate that scientists and engineers would make up about 2.8 per cent of the corresponding employment figure for that year, while in 1975 the ratio would rise to three per cent or slightly higher. Less apparent are the underlying economic, political, social, and technological forces the projections presumably reflect.

The strategic variables in the projections are factors subject to planned and unplanned changes before 1970 or 1975. On the demand side of the market, these variables include the share of employment made up of scientists and engineers, or the manner in which employers utilize their technical personnel. On the supply side, the critical elements are enrollments, degrees earned, the percentage of persons earning degrees entering the scientific and engineering labor market, and the ease with which persons without degrees may qualify as engineers.

The ratio of employment by economic sector accounted for by scientists and engineers includes a built-in factor extrapolating most of the growth of research and development in the past decade into the future. To a very large degree, this growth has been the result of public policy decisions reflected in government expenditures. These decisions sometimes introduce discontinuous changes in the demand for technical manpower or in the distribution of the demand for different programs and objectives. The space program in the early 1960's supplies an illustration. As needs are redefined in public policy, it is possible that other discontinuous changes that are difficult to anticipate at present may introduce new elements that would outmode the assumptions in our projections. The impact of disarmament on the manpower estimates in our defense goal is an instance.

The estimates of demand in the projections are heavily weighted by the events of the recent past because they are derived from empirical data covering a narrow time span. Extensive and accurate information describing the employment of technical manpower by industry is generally available beginning in 1954. In so short a time period, cyclical fluctuations in business activity or accidental factors are likely to influence the level of employment or the share of employment composed of engineers and scientists. For a majority of industries, this ratio increased in 1957, a recession year, and it decreased in 1958 as employment recovered.[4] It is difficult to obtain a reliable measure of trend from so short, and often unstable, a basis in experience.

The expected demand for engineers would rise less sharply in the coming decade if the precedent of medicine were followed in economizing the use of highly trained professional personnel. The great strides in health in the United States in the past generation have taken place without a substantial increase in the ratio of physicians to population. Many of the routine tasks in medicine have been turned over to medical technologists and trained nurses. It is likely that technicians also could take over much of the routine testing, design implementation, and production-control work currently performed by engineers. Developing a supply of trained technicians would make new demands on our educational system. In much of Europe, technical training of this type is conducted in schools offering two years of post-high school instruction in basic science and applied techniques. The success of the program in the United States would be facilitated by cooperation of educational institutions and the industries utilizing engineers and scientists.

One of the elements in the estimates of supply is the expectation that the number of bachelor degrees in engineering as a proportion of all bachelor degrees will continue to decline in the 1960's as they have since 1959. Engineering degrees, which composed more than nine per cent of all bachelor degrees in 1960, are projected to fall to less than five per cent of the total in 1969.[5] If bachelor degrees in engineering increased proportionately among bachelor degrees generally through 1975, the anticipated shortage of scientists and engineers would be substantially reduced, although not eliminated.

The share of college freshmen selecting engineering is the end result of all the factors that influence occupational choice in a free society. They include economic incentives such as salaries, fringe benefits, and opportunities for promotion for engineers in comparison with the alternatives in business, science, and medicine. Similarly, engineering enrollments are affected by public and private programs reducing the financial burden of obtaining an education. The National Defense Education Act or the NASA followships are examples. Also present in the mix are non-economic elements including the chances for professional fulfillment in work, or the status of engineers in American society. The projections of degrees would provide more useful guides for manpower policy if our understanding of the processes by which these incentives motivate individuals to make educational and career choices were improved by research.

The estimates of future supply and demand treat engineers and scientists as homogeneous units which remain constant in quality through time. Yet the content of engineering and scientific education has been shifting in the direction of more emphasis on graduate study and theoretical training. The growth in demand for individuals with this training indicates a good possibility that the future shortages may be concentrated in the aspects of science and engineering demanding graduate study rather than being evenly distributed along the spectrum of training and ability.

In higher education, the statistics projecting needs for college faculty in the 1970's presuppose the current technology of teaching with something close to the prevailing ratios of students to faculty. Yet the pressures of rising enrollments will hasten acceptance of new techniques in teaching. Teaching machines or closed-circuit television are outstanding instances.

APPENDIX TABLE A.

SCIENTISTS AND ENGINEERS AS PERCENTAGE OF TOTAL NON-AGRICULTURAL WAGE AND SALARY EMPLOYMENT

YEAR	TOTAL, NON-AGRICULTURAL EMPLOYMENT	TOTAL EMPLOYMENT SCIENTISTS & ENGINEERS	SCIENTISTS & ENGINEERS AS % OF TOTAL EMPLOYMENT	NUMBER OF EMPLOYED WORKERS PER SCIENTISTS & ENGINEERS
1950	45,222,000	702,700	1.6%	64
1960	54,847,000	1,157,200	2.1	47
1970 Projection to maintain growth	67,955,000	1,854,600	2.7	37
1970 Projection for goals	74,558,000	2,121,900	2.8	35
1975 Projection to maintain growth	74,449,000	2,254,200	3.0	33
1975 Projection for goals	84,305,000	2,591,800	3.1	32

APPENDIX TABLE B. PROJECTED REQUIREMENTS FOR ENGINEERS, 1970 AND 1975[a]

		PROJECTED REQUIREMENTS			
		1970		1975	
SECTOR OF ECONOMY	ESTIMATED ACTUAL EMPLOYMENT IN 1960	to maintain growth	for goals	to maintain growth	for goals
BUSINESS	683,600	1,120,000	1,211,300	1,373,800	1,503,200
1 Mining	19,100	30,900	34,100	41,500	43,800
2 Construction	52,700	102,100	113,800	123,200	134,100
3 Manufacturing	472,800	783,100	832,700	954,300	1,038,500
4 Transportation, Communication and Public Utilities	58,700	68,100	72,800	83,400	94,200
5 Engineering and Architectural Services	54,300	92,300	99,500	117,400	124,900
6 Other Non-Manufacturing	26,000	43,500	58,400	54,000	67,700
NONPROFIT ORGANIZATIONS	1,800	3,000	3,600	4,100	4,900
GOVERNMENT	109,500	142,900	178,000	166,900	220,300
1 Federal	56,200	71,900	97,600	82,700	110,300
2 State-Local	53,300	71,000	80,400	84,200	110,000
COLLEGES AND UNIVERSITIES	27,000	47,500	65,900	56,500	74,700
TOTAL	821,900	1,313,400	1,458,800	1,601,300	1,803,100

[a] These figures are estimates of the total demand in 1970 and 1975. They are net of the manpower needs between 1960 and 1969 and between 1971 and 1974 to replace losses by normal attrition.

APPENDIX TABLE C. PROJECTED REQUIREMENTS FOR SCIENTISTS, 1970 AND 1975[a]

		PROJECTED REQUIREMENTS			
		1970		1975	
SECTOR OF ECONOMY	ESTIMATED ACTUAL EMPLOYMENT IN 1960	to maintain growth	for goals	to maintain growth	for goals
BUSINESS	171,800	271,800	299,500	328,200	360,100
1 Mining	12,400	15,300	16,800	17,400	18,400
2 Construction	2,400	4,400	5,000	5,300	5,800
3 Manufacturing	140,700	228,600	243,200	276,900	301,300
4 Transportation, Communication and Public Utilities	2,800	3,100	3,300	3,800	4,300
5 Engineering and Architectural Services	2,600	3,800	4,100	4,400	4,700
6 Other Non-Manufacturing	10,900	16,600	27,100	20,400	25,600
NONPROFIT ORGANIZATIONS	4,700	8,100	9,600	10,900	13,200
GOVERNMENT	60,700	88,800	114,900	109,300	145,100
1 Federal	43,000	63,800	86,600	78,500	104,800
2 State-Local	17,700	25,000	28,300	30,800	40,300
COLLEGES AND UNIVERSITIES	98,100	172,500	239,100	204,500	270,300
TOTAL	335,300	541,200	663,100	652,900	788,700

[a] These figures are estimates of the total demand in 1970 and 1975. They are net of the manpower needs between 1960 and 1969 and between 1971 and 1974 to replace losses by normal attrition.

PERCENTAGE CHANGE IN REQUIREMENTS

1960 to 1970		1960 to 1975		
to maintain growth	for goals	to maintain growth	for goals	
63.8%	77.2%	101.0%	120.0%	
61.8	78.5	117.3	129.3	1
93.7	115.9	133.8	154.5	2
65.6	76.1	101.8	119.6	3
16.0	24.0	42.1	60.5	4
70.0	83.2	116.2	130.0	5
67.3	124.6	107.7	160.4	6
66.7	100.0	127.8	172.2	
30.5	62.6	52.4	101.2	
27.9	78.7	47.1	96.3	1
33.2	50.8	58.0	106.4	2
75.9	144.1	109.3	176.7	
59.8	77.5	94.8	119.4	

PERCENTAGE CHANGE IN REQUIREMENTS

1960 to 1970		1960 to 1975		
to maintain growth	for goals	to maintain growth	for goals	
58.2%	74.3%	91.0%	109.6%	
23.4	35.5	40.3	48.4	1
83.3	108.3	120.8	141.7	2
62.5	72.9	96.8	114.1	3
10.7	17.9	35.7	53.6	4
46.2	57.7	69.2	80.8	5
52.3	148.6	87.2	134.9	6
72.3	104.3	131.9	180.9	
46.3	89.3	80.1	139.0	
48.4	101.4	82.6	143.7	1
41.2	59.9	74.0	127.7	2
75.8	143.7	108.5	175.5	
61.4	97.8	94.7	135.2	

In many areas these innovations will permit individual teachers to reach a larger number of students without reducing the quality of instruction. Their net effect will be to slow down the estimated increases in requirements for college faculty, and to increase the potential supply of scientists and engineers.

VI

The over-all bearing of this pilot study is to emphasize the range of alternatives affecting the future demand and supply for scientists and engineers. The projections of shortage represent an extension in time of one of these alternatives—the changes of the recent past.

It is unlikely that the attainable rates of growth would enable us as a nation to fully achieve the targets for all our goals in the 1970's. If this were our objective, the anticipated shortages of highly trained manpower would be paralleled by similar deficits in, for example, water, timber, or in transportation and industrial plant.

The important problem is not so much the over-all shortages likely to occur from projecting current tendencies as it is a question of the relevant choices in matching our resources, including scientists and engineers, with a multitude of needs. Will the rate at which additional scientists are employed in industry diminish the supply needed for college teaching? Should the railroads build up staffs to engage in more research and development or should they continue to rely on their supplying industries for innovation? Do our international objectives indicate a need for encouraging more American scientists and engineers to work in the developing countries? If they do, how much is enough? Should the proportion of our scientific work force occupied in basic research be increased, and need this imply a diminution of resources for applied research and development? And, how can we significantly increase the supply of scientists and engineers without reducing the flow of high-calibre personnel to other professions or for administration in corporations and public agencies? It is in these areas that research and planning by business and government can alter present tendencies and obsolete the projections of shortage before the 1970's.

APPENDIX TABLE D.

PROJECTED INCREASES IN SUPPLY OF SCIENTISTS AND ENGINEERS, 1970 AND 1975

	1960 to 1970		1960 to 1975	
Source	to maintain growth	for goals	to maintain growth	for goals
New entrants				
—with degrees in field	550,907	571,300	910,944	1,061,129
—with degrees in other fields	134,200	151,300	221,803	270,480
—other new entrants[a]	113,300	113,300	174,600	174,600
Total, new entrants	798,400	835,900	1,307,347	1,506,209
—minus losses of new entrants to other fields	33,600	34,100	42,941	46,359
Net Increase in Supply	764,800	801,800	1,264,400	1,459,850

[a] Other new entrants include scientists and engineers moving to the United States from other countries and persons qualifying as engineers without college degrees.

APPENDIX TABLE E.

PROJECTED NUMBER OF BACHELOR'S DEGREES IN SCIENCE AND ENGINEERING, TO 1974

	ASSUMING GROWTH CONDITIONS			ASSUMING EDUCATION GOAL		
PERIOD	Bachelor Degrees in Science & Engineering	Bachelor Degrees in Engineering	Bachelor Degrees in Science	Bachelor Degrees in Science & Engineering	Bachelor Degrees in Engineering	Bachelor Degrees in Science
1960 (Actual)	89,435	37,800	51,635			
1960-69, Total	1,058,800	346,600	712,200	1,098,130	359,130	739,000
Annual Average	105,900	34,700	71,200	109,800	35,900	73,900
1970-74, Total	727,600	200,200	527,400	989,900	272,400	717,500
Annual Average	145,500	40,000	100,500	198,000	54,500	143,500
1960-74, Total	1,786,400	546,800	1,239,600	2,088,030	631,530	1,456,500
Annual Average	119,100	36,500	82,600	139,200	42,100	97,100
1974 (Projected)	152,700	42,000	110,700	212,600	59,100	153,500

Sources: Bureau of Labor Statistics, USDL for projections of science and engineering degrees awarded through 1969. Office of Education, USDHEW, projections of total bachelor degrees awarded were used to derive bachelor degrees in Science and Engineering 1970 through 1974.

APPENDIX TABLE F.

PHYSICIANS, NURSES, MEDICAL TECHNICIANS, AND ENGINEERS PER 100,000 POPULATION, 1920-1960

YEAR	PHYSICIANS[a]	GRADUATE NURSES	MEDICAL TECHNICIANS	ENGINEERS
1920	137	98	n.a.	126
1930	125	175	n.a.	176
1940	133	216	15	225
1950	134	249	20	358
1960	133	282	38	478

n.a. Not available

[a] M.D.'s only

Sources: STATISTICAL ABSTRACT OF THE UNITED STATES, 1963, p. 75; HISTORICAL STATISTICS OF THE UNITED STATES, 1961, pp. 34, 75.

APPENDIX TABLE G.

BASIS FOR COST ESTIMATES IN GOALS, NATIONAL GOALS PROJECT

1 *Health* Proposes major expansions in community health services and in federal financing of health-related education and research. Objectives include development of the Community Mental Health Program proposed in recent Presidential Messages, and expansion of environmental health services recommended in Gross Report. Comprehensive personal medical care coverage to be provided by expansion of public and private programs for financing health expenditures.

2 *Education* Costs derived from enrollment objective specifying that 100% of eligible age group attend school through high school, and that proportion of 18-24 year old group enrolled in higher education increase by approximately 50% from 1960 to 1970 and 1975. Costs include increases in faculty salaries proposed by President Eisenhower's Commission on Higher Education, with corresponding increases for the faculties at other educational levels, plus costs of increasing teacher-supporting staff, expanding plant and equipment, and doubling loan and scholarship funds per student in higher education.

3 *Social Welfare* Concerned with programs for maintaining income against hazards which destroy earnings—old age, illness, disability, loss of family breadwinner, loss of employment, etc. Provides for expansion of coverage of public programs such as OASI plus expansion of private programs including collectively bargained benefits for income protection during illness. Includes increases in benefits as proposed in recent government and private expert studies.

4 *Consumer Expenditures* Goal specifies that living standards rise to limit set by long-term savings rate of 7% of disposable personal income. To this expenditure is added the cost of increasing the incomes of 75% of the families in 1970 and 90% in 1975 with incomes below the poverty line as defined in study to income just above poverty limit. Expenditures also include increase for consumer expenditures in other goals such as health, education, transportation.

5 *Housing* Expenditures to provide adequate housing for Americans which will take into account population increase, rise in personal income, and objective of eliminating substandard housing. Costs include emphasis on both rehabilitation and demolition in urban blighted areas. Substandard defined in terms of housing space per family and following census definitions.

6 *Community Redevelopment* Emphasis is on transportation as strategic variable in urban redevelopment. Costs of providing adequate metropolitan transportation systems, plus costs of providing cultural and recreational facilities, public utilities, and coping with problems such as water pollution. Standards are as defined by various public and private authorities such as Isaacs and Dyckman, Dewhurst, New York Regional Plan, Rockefeller Bros., and congressional committees.

7 *Research and Development* Assumptions that R & D expenditures as percentage of GNP will increase in a decade from about 2.8% to 4% which implies increase at a decreasing rate. Government financed R & D assumed to increase at half its 1953-61 rate with industry and non-profit R & D continuing to increase at roughly earlier rates. Objective is that industries not presently participating in R & D to any degree will be participating at over-all national rate for all industry, and that expenditures on basic research will increase.

8 *Natural Resources* Cost of private research and development to increase supply and develop substitutes for scarce natural resources, plus the public cost of conserving and developing timber, water, minerals, fish and game, and recreational land. Standards as proposed in public studies and private research findings.

9 *Industrial and Commercial Plant* Significant increases here are those in the plant and equipment needs to sustain the economic growth in the early 1970's. The additional expenditures for the goals are primarily those for private plants and equipment specified in other goals—utilities in community redevelopment, transportation equipment in tranportation, etc.

10 *Transportation* Expenditures in 1970 if changes in transportation resource use were to follow the objectives in President Kennedy's Transportation Message to Congress in 1962. These include the costs for R & D and initial commercial application of technological changes in transportation such as supersonic planes, nuclear ships, hydrofoils, gas-turbine engines, etc.

11 *Defense* Minimum costs listed for maintaining present standards of national security assume partial disarmament following Phase I of U. S. 1962 disarmament proposals. Additional expenditures for goal are those needed to maintain present level of defense capabilities plus expenditures for utiliz-

ing possibilities of technological advance including anti-missile missiles, nuclear ships, etc.

12 *International Relations* Goal concerned with relationships to newly developing nations and to international organizations. It assumes institutional changes encouraging resumption of private capital exports to developing countries on large scale plus public grants and loans, following UN proposal, pegged at 1% of GNP. To this is added present level of defense support for developing countries plus expansion of contributions to international organizations such as UN or WHO to provide for rising populations and new functions including a UN permanent peace force as on the Israeli border.

13 *Agriculture* The most costly of the alternatives is that of continuing the present price-support program. To this is added the cost of programs for encouraging the movement of low-income farmers from agriculture to non-farm employment through manpower retraining, rural renewal programs, or payment of moving costs.

14 & 15 *Manpower Retraining and Area Redevelopment* Cost of programs for depressed areas following the outlines and objectives of the Area Redevelopment Act and the Manpower Retraining Act.

16 *Space* Cost included in growth estimate is an extrapolation of cost of continuing present-type programs including manned lunar landings, Telstar, etc. Estimate for goal includes other programs proposed by public and private bodies such as exploration of other planets, space platforms, expansion of weather and communication programs, etc.

REFERENCES

1 The writer is indebted to William D. Nordhaus' paper prepared for the National Academy of Sciences, "Employment of Scientists and Engineers By End Use Categories," for estimates of the employment of scientists and engineers in defense in 1960.

2 See "Requirements for Scientists and Engineers," submitted by the National Aeronautics and Space Administration to the Subcommittee on Employment and Manpower, Committee on Labor and Public Welfare, U. S. Senate, November, 1963.

3 See "The Outlook for Scientists and Engineers," by Howard V. Stambler, MONTHLY LABOR REVIEW, November, 1963, p. 1275ff; THE LONG-RANGE DEMAND FOR SCIENTIFIC AND TECHNICAL PERSONNEL, National Science Foundation, 1961; and PROFILES OF MANPOWER IN SCIENCE AND TECHNOLOGY, National Science Foundation, 1963. The estimates in this report of the 1970 requirements to maintain growth are 100,000 less than in the MONTHLY LABOR REVIEW article. The estimate of the number of scientists and engineers needed in 1970 for the goals are 70,000 greater than the projections of employment of scientists and engineers in the PROFILES study. The writer has gained many welcome insights from these pioneering studies.

4 See THE LONG RANGE DEMAND FOR SCIENTIFIC AND TECHNICAL PERSONNEL, op. cit., p. 40.

5 For a discussion of these projections, see SCIENTISTS, ENGINEERS AND TECHNICIANS IN THE 1960's—REQUIREMENTS AND SUPPLY, prepared by the Bureau of Labor Statistics for the National Science Foundation, 1964.

HOW DO WE USE OUR ENGINEERS AND SCIENTISTS?

Arthur M. Ross

I INTRODUCTION

Perhaps it won't happen this way, but it could: In 1965 the race to the moon accelerates. America launches a "total effort" to get there first. Some 425,000 engineers and scientists, together with several production workers, are mobilized to telescope the remaining steps of the Apollo program. By dint of this endeavor, the American spacecraft reaches the moon on July 4, 1969, eight full months ahead of the Russian entry. The President announces the good news. Millions of Americans hear his words on their Japanese "Panasonic" television sets, which took over the civilian market in 1966. The people don their "smog resistant" suits (made in Italy), adjust their "neue welt" gas masks (made in Germany), and pour out of their automobiles, in which they have been living since traffic congestion passed the saturation point in 1967. Between the rows of cars they sing and dance in joyous abandon.

Perhaps it won't happen that way, but if it did it would represent the result of a certain allocation of technical manpower. For this is the age of technology. There were times when priests, or soldiers, or lawyers, gave shape to human life. Today it is the scientists and engineers; the rest of us try to adjust and to understand. Hence the importance of allocation, which determines what the scientists and engineers do.

The principal themes of this paper are that the federal government plays a dominant role in the utilization of scientific and engineering manpower; that the results are not fortunate in all respects; that the government must have greater awareness of the consequences of its actions; and that a coherent program relating to the use of this decisive resource is needed.

II WHAT IS ALLOCATION?

Manpower allocation may be viewed either as a *process* or as an *end result*. The process of allocation takes place in the labor market; the end result of this process is the distribution or deployment of manpower among alternative uses. In appraising the allocation of scientists and engineers, the operation of the labor market in which these persons find employment might be studied. Alternatively, an analysis might be made of their distribution as between research, development, production, teaching, and other functions; as between the civilian economy, the educational system, defense and space projects; as between the various specialized fields of work.

Evaluation of the scientific and engineering labor market, as a technical mechanism for bringing together current supply and current demand, involves questions such as the extent of competition among employers and among employees, the mobility of labor, the rationality with which decisions are made, and the availability of information to those who make the decisions. Certainly it is a competitive labor market. Despite the dominant influence of the federal government in an ultimate sense, proximate manpower demand is exercised through hundreds of employers, none of whom directly hires any large percentage of the total supply. Scientists and engineers have high geographical mobility. They engage in long-term career planning and endeavor to make careful and rational job choices.

The principal defect in the labor market mechanism is the paucity of information

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concerning this field of employment. Federal and state statistical programs have lagged badly behind changing patterns of economic activity, and university social scientists are still excessively preoccupied with production workers, hourly wages, trade unions and other aspects of the more traditional fields of work. Reports and monographs about scientists and engineers are accumulating, it is true, but since the study of the subject is still in its early stages, having begun on any scale only during the past decade, relatively little "hard" information has been established. Definitions and classifications are not yet standardized, so that to the query of how many scientists and engineers were working in 1960, several answers over a range of about 20 per cent or more can be obtained. It is ironical that the Bureau of Labor Statistics knows much more about the wages of streetcar motormen than about the salaries of research scientists. Excellent information is available concerning quit rates of production workers in the tobacco industry, but next to nothing is known about labor turnover among scientists and engineers.

One of the most serious informational deficiencies is the lack of knowledge concerning future trends in specialized demand within the profession. A young man entering engineering school in 1964 and planning to obtain a master's degree has no reliable way of knowing which of the present engineering fields will still be attractive in 1970, which new specialties will have developed, and similar questions. In view of long training periods, and the "trained incapacity" of specialists in one field to perform the work of another field, a shadowy knowledge of occupational trends is a serious defect in the labor market for scientists and engineers.

All of this clearly indicates that fact-gathering and analysis must be improved as a matter of first importance; that facilities for counseling and guidance of students should be strengthened; and that educational programs should emphasize theoretical understanding so as to improve flexibility and "convertibility" in the course of professional careers.

Shortage of information not only impairs the operation of the labor market but also complicates the task of appraising the distribution of scientists and engineers. Although concern has been expressed regarding the adequacy of research and development in the civilian sector, the information needed to assess this concern is not available.

How does a firm decide to initiate, terminate, accelerate, or decelerate research and development? Although many statements are made about stockpiling, hoarding, and squandering of technical manpower by defense contractors (see Section IV of this paper), the first empirical studies of the problem are, so far as I am aware, included in this volume.

Eventually we will have better information, but meanwhile we must do what we can with what we have. Using the information presently at our disposal, we must try to assess the distribution of scientific and engineering manpower among its major uses: governmental defense and space programs, civilian research and development in private enterprise, university research and teaching, and other civilian activities in the public sector.

III ALLOCATION AND MANPOWER SHORTAGES

Whether a given resource presents a serious problem in allocation depends on the degree of scarcity of the resource. In a tropical rain forest there is no need to worry about the allocation of water because there is enough to go around. Is there a shortage of scientists and engineers? On this point the economists and non-economists have talked so much at cross purposes that a good deal of mutual exasperation has resulted.

The difficulty is that the term "shortage" is used in a number of different senses. It may mean that professional salaries are rising faster than other incomes in order to achieve a running balance between an increasing demand and an inelastic supply. Salary surveys in the field of engineering, conducted by the Bureau of Labor Statistics and the Engineering Manpower Commission, do not indicate a current shortage in this sense. Not enough information is available about salaries of industrial scientists to indicate whether the current increases are greater or less than average. It is known that university salaries have been rising with unusual rapidity in recent years. Thus, if income trends are used as a criterion, there are indications of selective but not generalized shortages.

"Shortage" may refer also to a condition in which many vacancies remain unfilled at current salary levels. To the layman, this is certainly the most common meaning of the term, but, despite the attractiveness of the concept from a common-sense standpoint, it is not easy to apply. There is no comprehensive register of vacancies in scientific and engineering employment; help-wanted advertising sometimes gives a misleading impression of the extent of demand; employers often complain of shortages in a relatively well-balanced labor market. Furthermore, the number of vacancies is not independent of supply conditions. In an activity such as research, somewhat removed from production urgencies, a "vacancy" may not materialize until a satisfactory candidate comes into sight. Even then the employer may be reluctant to offer a salary at which new hirings are being made because he is afraid of unstabilizing the salaries of existing employees who were hired for less. Thus the concept of job vacancies has serious ambiguities. Nevertheless, it is desirable that greater efforts be made to develop job-vacancy statistics and other indicators of labor demand. This was one of the principal recommendations of the late President Kennedy's Committee to Appraise Employment and Unemployment Statistics,[1] and it certainly applies with particular force in the field of scientific and engineering manpower.

If the demand for some type of employee is regularly increasing more rapidly than the supply, and there are time lags in the adjustment of salary levels and hiring decisions, then it is possible to have a chronic shortage in the sense of unfillable vacancies. Kenneth J. Arrow and William M. Capron, writing in 1958, referred to this as a "dynamic shortage." In such a situation, they stated, "the price will increase steadily and indefinitely but always remain behind the price that would clear the market." Arrow and Capron argued that a "dynamic shortage" was then prevailing in the engineer-scientist labor market.[2]

More recent evaluations indicate that selective difficulties are experienced in filling vacancies. For example, the following has been reported:

"**ENGINEERS** From the latter part of 1961 through the beginning of 1962, there has been a persistent demand for experienced electrical, mechanical and chemical engineers with specialties in such areas as communications, electronics, materials, systems technology, and aerospace activities. *Shortage* of engineers with advanced degrees in all branches of engineering remains a problem, particularly for colleges and universities, and in the area of research and development. Overall, there appears to be a *balance* between the supply of new college graduates with the bachelor's degree in most branches of engineering and the need for such personnel, although there are signs that the continued upswing in demand may be greater than the forthcoming available new supply.

"**PHYSICAL SCIENTISTS** Generally, the greatest *imbalance* in the supply-demand situation exists in those fields where there is a shortage of experienced scientists with advanced degrees, particularly at the doctorate level. The demand for inexperienced chemists at the undergraduate level is generally being met by new graduates, but well-qualified personnel with advanced degrees are in short supply for work in defense-related activities and in some areas of medical research. Physicists and mathematicians are in demand at all levels of education and experience, especially at the doctorate level. Earth scientists appear to be in sufficient supply to meet present demands, except for those in the areas of meteorology and oceanography with experience and advanced degrees.

"**LIFE SCIENTISTS** The supply of biological and agricultural scientists is generally sufficient to meet requirements of employers, except for those with advanced degrees and in some specialties, both experienced and inexperienced. Life scientists are particularly in demand for research work in areas related to the medical and health fields."[3]

The picture conveyed is of a shortage of experienced engineers in those specialties most heavily used in missile and aerospace activities; a shortage of research personnel with advanced degrees, especially Ph.D's; and a balanced labor market in other respects. It is significant that shortages are *not* reported in those occupations and specialties which are concentrated in civilian industry—chemistry and civil engineering, for example.

NASA states that its requirements for scientists and engineers will increase sub-

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[1] MEASURING EMPLOYMENT AND UNEMPLOYMENT (Washington, 1962), pp. 25-26.

[2] "Dynamic Shortages and Price Rises: The Engineer-Scientist Case," prepared for RAND Corporation, May 7, 1958 (ditto).

[3] OECD, Resources of Scientific and Technical Personnel in the OECD Area, Paris, 1963, p. 201.

stantially between 1963 and 1970. In the scientific and engineering specialties where the increase will be concentrated, the increase may well be greater than the total new supply. The NASA program will accentuate the shortage of personnel with specialties such as systems technology, stability and control, guidance systems, and internal flow dynamics. Furthermore, there will be a pronounced effect on the market for less experienced mechanical, electrical, and aeronautical engineers and for physicists and mathematicians. Probably there will be many unfilled vacancies in these occupations during the next three years or so; and, although civilian industry has apparently not been suffering from shortages in the recent past (except for personnel with advanced degrees), this situation may well change.

The third concept of "shortage" is the most difficult to apply quantitatively and, at the same time, is the most significant. The country is short of scientists and engineers if tasks which are essential to national progress and welfare are not being performed for lack of them. It should be emphasized that this definition cannot be applied by examining the condition of the labor market. Essential tasks may be unfulfilled, for lack of effective monetary demand, even though there is enough manpower to go around.

A corresponding concept of allocation may be stated. Scientists and engineers are properly distributed if they make a maximum contribution to the national welfare in their present activities. They are misallocated if national welfare could be increased by a redistribution.

It will be objected that "national welfare" is an elusive, impalpable criterion. Is there no operational test? In theory, the operation of supply and demand in a competitive labor market will distribute workers so as to yield maximum advantage. But this assumes that the relative strength of monetary demand accurately reflects the relative urgency of alternative uses, and that the reaction threshold is not too high when there are changes in demand. It hardly needs emphasis that the first assumption does not prevail when it comes to employment of scientists and engineers. A large proportion of scientific and engineering activity (when traced back to its original source) is not motivated by profit and loss. Almost two thirds of research and development work is financed by the federal government; over half of all scientists are employed by universities, government agencies and other non-profit institutions; and the majority of Ph.D's are in the universities. Reliance cannot be placed on market criteria in assessing the use being made of this resource. It may well be true that the distribution of manpower corresponds with the push and pull of market pressures. But it may be equally true that the market pressures are not a reliable indication of national welfare.

This discrepancy between market incentives and national welfare, where civilian research and development is concerned, has been ably analyzed by Richard R. Nelson:

> "There are good reasons to believe that market incentives tend to cause business firms to spend much less than is socially desirable on research and experimental development exploring advanced concepts and designs. This work is risky—in many cases the information created will not be sufficient in itself to permit the design of a marketable product or process, but rather will suggest additional research and development, or will be of no value whatsoever to the firm. In all save the largest and most secure firms the time horizons are too short and the possibilities of spreading the risk too limited to give a firm strong incentives to do this kind of work. . . . There is a bias toward marginally improving old ways rather than experimenting the radically new ways of satisfying needs. . . . The returns might be very great if there were considerably more research and development aimed at creating and testing prototypes of radically new products and processes. Unless the Government directly or indirectly supports more of this work, not much more will be done. Our enterprise system also tends to fail badly in situations where one company takes the risks and covers the costs but many companies share widely in the benefits. The whole area of process improvements are subject to patenting (a major source of productivity growth), of testing and evaluation techniques, and of analysis of materials and methods are cases in point. Research on standards and user safety also is unlikely to yield a private firm profits commensurate with the benefits to society. Unless cooperative or public programs are established, these scientific activities will not draw an appropriate quantity of resources."[4]

The hard fact is that the allocation of

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[4] R. R. Nelson, "The Allocation of Research and Development Resources," (mimeo), September 4, 1962.

technical manpower cannot be appraised in precise quantitative terms. Certainly better information of all kinds concerning scientist and engineer employment is needed, but such information will not in itself supply the answer. It will serve as an aid to informed qualitative judgments but not as a substitute for such judgments.

Some economists have proposed to quantify the problem by assigning "shadow prices" to scientists and engineers. The shadow price would reflect the estimated true social value of an employee's potentially most productive use, as distinguished from the salary he actually receives for the work he actually performs. Suppose, for example, that a scientist earns a salary of $20,000 per year at General Electric but that he might alternatively contribute $100,000 to the social welfare if assigned as a professor at the University of California. In that event he should be "priced" at $100,000 per year for purposes of accounting and planning.

Shadow prices are helpful when a value can be placed on the alternative use. Suppose that the United States lends money to Brazil at one per cent per annum, and that the money could otherwise be used to pay off some four per cent bonds. In that case the Brazilian loan really costs three per cent. But the proposal to assign shadow prices to technical personnel begs the question of how the "real" contribution of the General Electric scientist in a hypothetical professorship can be measured, as compared with the $15,000 the University of California will actually pay him. Despite the popularity of mathematic models in social science, most of the crucial problems of human society are not now reducible to precise quantitative terms.

IV DEFENSE AND SPACE

About 70 per cent of all research and development is performed in private industry, but two thirds of the total is financed with federal money. Whereas industry financed more than half of its research and development activity as late as 1955, the federal government now supplies the bulk of the funds. Industrial research and development performance was valued at $11.6 billion in 1962, of which $6.7 billion came from the government. About 60 per cent of all industrial research and development is done in the aircraft and missiles industry and the electrical equipment and communications industry. Seventy-five per cent of the research and development in these industries is financed by the federal government. Federal expenditures are related principally to space and defense programs. *In fact, federal funds supplied to the aircraft and missile, and electrical equipment and communication industries accounted for almost half of all research and development work conducted anywhere in private industry, for any purpose and under any sponsorship, during the year 1962.*

I am not in a position to make authoritative statements concerning the utilization of scientific and engineering manpower in defense and space.

One would expect an unusually high consumption of research and development manpower in space and defense because the whole emphasis has shifted to advanced development rather than mass production. So rapidly does military technology change that it may be entirely rational never to produce an item after spending billions to develop it. Moreover, this is a situation where the customer does not know in advance exactly what he wants; the supplier does not know in advance what he can really deliver; the serviceability of the product will not be entirely clear until it has been developed and tested. Under these circumstances a good deal of apparent waste motion is inevitable, especially when judged in retrospect. I can only state my impressions based on what I have seen, heard, and read. Nevertheless, there is a good deal of evidence pointing in the direction of prodigality, indicating that while the federal agencies have been operating under budgetary constraints, first-rate manpower has been pre-empted by contractors as if the supply were unlimited. These indications give rise to a number of important issues:

(a) *Large number of weapons systems developed at great cost but never put into production.* Some of this must be expected in modern military technology, but one wonders whether a sufficient margin of advantage is required before shifting from one system to another, and whether feasibility decisions are made at the earliest possible date.

(b) *Large number of companies competing for research and development or production contracts in special fields such as orbital-*

guidance equipment. Each company must have its own staff of scientists and engineers. While competition is desirable, has not a great deal of overcapacity been generated? The financial cost of maintaining duplicate capability in specialized fields is not the issue here; but unless space and defense have an unlimited priority, which has never been asserted in time of peace, attention must be paid to the cost in terms of scarce manpower resources.

(c) *Consumption of scientific and engineering manpower in preparing and selling proposals.* Some of this is an essential part of program determination. But if it is true that 5-10 per cent of all research and development personnel in defense industries are occupied in this fashion, there is justification for suspecting that wasteful competition has been stimulated.

(d) *Assignment of scientists and engineers to sub-professional and administrative duties.* Inability to exercise professional skills is one of the evident and most chronic complaints of employed professionals. It is a persistent theme in surveys of scientific and engineering work. I might add that I have seen a great deal of it myself, in the course of arbitrating industrial disputes in private industry during the past 15 years. In the aerospace industry there were 42 technicians for every 100 scientists and engineers in 1955, but only 37 in 1961. After so much talk about manpower utilization, greater sub-professional support would be expected, but actually it declined.

(e) *Manpower "loading" or "hoarding" in order to be in a position to accept new contracts.* This is a frequently noted phenomenon closely related to the competitive conditions discussed above. If expiring projects and new projects are nicely dovetailed, waste of manpower may be avoided. Otherwise the excess personnel must be assigned to some project or other. I am not suggesting that it would be desirable or practical to demobilize and remobilize research organizations in response to irregularities of manpower demand. The point is that procurement authorities should regularize demand to a greater extent so that excess capacity can be minimized. This implies that the same amount of research and development can be done by fewer people.

(f) *Lack of pressure on the contractor to minimize cost.* Generally he is selected for reasons of technical and design superiority. A cost-type contract is then negotiated. At this point, the contractor has every reason to negotiate the highest cost target that the government agency will accept, and his bargaining power is superior because he has greater knowledge of what will be involved in producing the item. Once a cost target has been negotiated, there is no strong incentive to under-run the target.

Thus the factors that encourage wasteful use of scientific and engineering manpower in defense and space activities are much more fundamental than the adequacy of personnel management or the quality of human relations. They are inherent in the system of program determination, contractor selection, contract negotiation and administration. In my judgment, consumption of scientists and engineers might be significantly reduced without sacrificing the program goals.

If procurement procedures are to be revised and better controls developed, the first step is a greater awareness of the manpower consequences of important decisions.

V CIVILIAN RESEARCH AND DEVELOPMENT IN PRIVATE ENTERPRISE

The growth of research and development in the postwar period was so phenomenal that a progressive intensification has been taken for granted. Professor Machlup of Princeton, author of a treatise on "The Production and Distribution of Knowledge in the United States," tells us that research and development grew at an annual rate of 19.8 per cent between 1940 and 1960. He states that "even relative to the gross national product the increase has been remarkable: the expenditures were 0.09 per cent of GNP in 1920, 0.14 per cent in 1930, 0.37 per cent in 1940, 1.01 per cent in 1950, and 2.78 per cent in 1960."[5]

Federal expenditures related to defense and space purposes account for much of the increase. The build-up of company-financed research and development (primarily but not exclusively related to civilian production) has been less spectacular. Furthermore, the intensification of company-financed research and development seems to have tapered off to a considerable extent after 1957. Company research and develop-

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[5] Fritz Machlup, THE PRODUCTION AND DISTRIBUTION OF KNOWLEDGE IN THE UNITED STATES (Princeton, 1962), pp. 155-156.

ment funds amount to 0.61 per cent of gross national product in 1953, 0.81 per cent in 1958, and 0.86 per cent in 1962. Likewise, the trend toward ploughing back an increasing share of corporate profits into this form of investment has slowed down. Company-financed research and development equaled 5.7 per cent of corporate profits in 1953, 9.6 per cent in 1958, and 10.3 per cent in 1962.

Aside from this retardation, there are other sobering facts that cast doubt on ebullient statements concerning the extent to which research and development has penetrated American industry. Only seven industries spent as much as $200,000,000 of their own money for research and development in 1962.

Chemicals and allied products	$894,000,000
Electrical equipment & communications	$887,000,000
Motor vehicles & other transportation equipment	$675,000,000
Machinery	$633,000,000
Aircraft & missiles	$412,000,000
Petroleum refining & extraction	$281,000,000
Professional and scientific instruments	$231,000,000
Total, seven industries	$4,013,000,000

Although these industries were responsible for 83 per cent of all company-financed research and development, they represented only 10 per cent of total employment and 35 per cent of manufacturing employment.

At the other end of the spectrum, consider the following six industries: food and kindred products; textiles and apparel; lumber, wood products and furniture; paper and allied products; primary metals; and fabricated metal products. These industries are much larger than the other seven, accounting for 14 per cent of total employment and 49 per cent of manufacturing employment. However, in 1960 they spent only $424,000,000 of their own funds for research and development, less than 10 per cent of the total.

It should be added that very little research and development work is conducted in non-manufacturing industries, where the bulk of the gross national product is produced; and that 200 firms account for over three fourths of all company-financed research and development.[6]

Thus the status of civilian research and development in the United States is not too reassuring. Most of it is done by large firms in a few manufacturing industries. In relation to total output it has not grown much since 1957.

Persistent complaints are voiced that civilian research and development is being hampered by the shortage of competent engineers and scientists and the rising level of salary costs. But the available evidence does not support the explanation for the slowdown. It is true that selective shortages are reported, but these are mainly in the specialties most closely related to space and defense programs. It does not appear that civil engineers, chemical engineers, chemists, geologists, or biologists are in short supply (except for those with advanced degrees).

If there were serious shortages in the labor market, we would expect salary increases to be somewhat higher than average. Available information concerning engineering salaries, however, indicates that recent increases have been below average.

It is sometimes argued that, although engineers as a whole may be in adequate supply, there is a real shortage of the more creative and capable individuals. In a certain sense, there is always a shortage of highly creative individuals in any field. Yet it is significant that, according to government salary surveys, the more highly remunerated groups of engineers (generally in the $15,000 - $25,000 class) did not receive higher increases than the other groups.

Additional doubt is cast on claims of an engineer shortage by declining enrollments in engineering schools during recent years. Prospective earnings are not the only consideration, of course, that leads a talented young person with a scientific turn of mind to make his choice among engineering, medicine, physics, chemistry, and other professions utilizing that type of ability. There are also changes in the prestige hierarchy of professionals, differences in the availability of educational facilities, and other related factors. But, by and large, the economic influences continue to operate. If a profession is in great demand, jobs are plenti-

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[6] Research and development statistics in the preceding four paragraphs are from National Science Foundation, RESEARCH AND DEVELOPMENT IN INDUSTRY 1960 (Washington, 1963). Employment statistics are calculated from B.L.S. data.

ful, relative earnings rise, and young people are drawn into it.

National Science Foundation statistics on "performance cost" per research and development scientist and engineer (which includes materials, equipment and facilities as well as personnel) show a relatively modest increase, from $33,300 in 1957 to $34,700 in 1961. There have been substantial increases in certain industries, including food and kindred products; textiles and apparel; lumber, wood products, and furniture; and primary metals. These industries never have done a large amount of research and development, however, even when their costs were lower.

My over-all judgment is that the retardation of civilian research and development must be explained by reasons other than manpower shortages.

Probably the principal reason is the slowdown in economic growth. This is not the place to discuss that complicated subject at any length. But can it be a coincidence that the intensification of civilian research and development activity began to falter in the late 1950's, at the same time the period of ebullient postwar prosperity reached an end? The connection seems particularly evident in the relative movements of the major components of gross national product. Spending by consumers and by federal, state, and local governments has increased at a substantial rate; they have done their share, so to speak. It is private investment that has lagged badly, particularly investment in plant and equipment. After allowing for price changes, gross private domestic investment hardly increased at all between 1956 and 1962. Investment in producers' durable equipment actually declined.

Investment in plants and facilities depends upon the anticipated profitability (or "marginal efficiency") of such investment, together with the cost and availability of funds. There is no indication that industry is short of funds; in fact, the evidence is to the contrary. The prospective reduction in individual and corporate income taxes will probably stimulate private investment. If so, it can be anticipated that civilian research and development will then begin to accelerate once more.

But even when this happens, research and development will still be concentrated in a relatively confined sector of the economy—the larger companies in certain manufacturing industries. Smaller companies—aside from specialized research organizations—typically do not have the resources for this type of work, which is inevitably speculative and must be projected toward a distant time horizon. It follows that in industries (such as furniture and apparel) in which small firms predominate, research and development will have to be done by cooperative associations or by government support if it is to be done on any substantial scale.

The idea of government-supported civilian research and development will inevitably encounter strenuous opposition. Such activity may well undermine the value of existing patents, processes, and capital equipment. There are also objections based on principle, but, in view of the already dominant position of the federal government in agricultural and medical research, the entry of the government into other fields would hardly constitute a precedent.

VI COLLEGES AND UNIVERSITIES

Education is one of the nation's largest industries, and certainly the fastest-growing major industry. Expenditures for elementary and secondary schools and for institutions of higher education increased from $3,400,000,000 in 1940 to $24,800,000,000 in 1960.[1] The colleges and universities saw their enrollment grow from 1,500,000 to 3,750,000 during this period, or from 15.2 per cent to 33.5 per cent of the 18-21 age cohort. Some education specialists predict that eventually 50 per cent of the young people will attend colleges and universities.

Some 176,000 scientists and engineers were employed at colleges and universities in 1961, of whom 80,000 were engaged in teaching, 49,000 in research and development, and the remainder in other capacities. These institutions have about 12

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[1] Statistics in this section of the paper are from Office of Education; National Science Foundation; U.S. Dept. of Health, Education & Welfare; Bureau of Labor Statistics; National Education Association. Fritz Machlup, op. cit.; W. Robert Bokelman, "Higher Education Planning and Management Data, 1960-61"; John L. Chase, Doctoral Study: FELLOWSHIPS AND CAPACITY OF GRADUATE SCHOOLS.

per cent of all research and development personnel; they perform about nine per cent of all research and development work, and approximately 47 per cent of all basic research.

The principal functions of colleges and universities, of course, are teaching and basic research: the transmission of existing knowledge in order to create an educated citizenry and the discovery of new knowledge concerning the physical world, our human society and the various expressions of the human spirit. Appraisal of scientific and engineering manpower in higher education must be made in terms of how adequately these functions are presently performed and how adequately they will be performed in the future.

The problem of allocation is particularly acute in this sector because there are persuasive indications of manpower shortage, not only in terms of "opportunity cost" but also in terms of labor-market phenomena such as recruitment difficulties and salary increases.

Competition for high-level manpower is centered on doctorate holders. Educational institutions struggle with industrial research organizations and government laboratories over an inadequate supply of scholars, who are proselytized with the same diligence formerly devoted to the recruitment of football players. Top colleges and universities are able to maintain degree requirements, but higher education as a whole presents quite a different picture. The proportion of new full-time faculty members with Ph.D.'s, never very high, has declined substantially in recent years. According to the National Education Association, it fell from 31.4 per cent in 1954-55 to 28.8 per cent in 1960-61. While engineering schools have upgraded their faculties, contrary to the general trend, scientific fields have undergone a deterioration along with most others. The proportion of doctorate holders fell from 34.2 per cent to 22.2 per cent in mathematics, 54.5 per cent to 48.2 per cent in biological sciences, 53.0 per cent to 47.4 per cent in physical sciences, and 34.2 per cent to 18.9 per cent in health sciences (excluding dentistry and medicine).[8] Although some new faculty members without doctorates will eventually obtain them, it seems rather clear that the incidence of the Ph.D. among faculty members is declining.

Examination of some of the aggregate statistics confirms this impression. In 1954 there were 2,500,000 college and university students and 247,000 faculty members, producing a student-faculty ratio of approximately 10:1. Four years later, enrollments had grown to 3,259,000, while the number of faculty members had increased to 345,000. Thus the student-faculty ratio was somewhat improved. But, whereas there was a net increase of 98,000 faculty members during this period (the gross increase must have been considerably larger), only 38,000 Ph.D. degrees were awarded. And undoubtedly many of these 38,000 accepted positions outside of higher education.

Project this situation a few years into the future: the Office of Education tells us that 7,000,000 students will enroll in colleges and universities in the fall of 1970. If a student-faculty ratio of 10:1 is maintained, 700,000 faculty members will be needed—about 350,000 more than in 1958. This, of course, is only the net increase after replacement of all losses from death, retirement, and other attrition factors. The National Science Foundation predicts that only 174,000 doctorates will be awarded between 1958 and 1970. Even without knowing what proportion can be drawn into colleges and universities (in 1960 about 44 per cent of doctorate holders in science and engineering were employed elsewhere), it is evident that the problem of maintaining standards in higher education will be most difficult.

Another indication of manpower shortage is found in the movement of college and university salaries. The historical lag is notorious enough to require no comment, and even today there remains a substantial differential between the college and university salaries and those for equivalent education, experience, and ability in private industry. In 1960-61, average salaries of full professors in large public and private universities were somewhat over $11,000. Full professors average about $8,000 in private liberal arts colleges and $8500 in publicly supported

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[8] Statistics on proportion of doctorate holders: National Education Association, Research Division.

teachers' colleges. Assuming that professors have an opportunity for two months of additional employment during the summer, these may be regarded as ten-month salaries. In contrast, average salaries for the top three grades of chemists and engineers, as classified by the Bureau of Labor Statistics, ranged from $1,122 to $1,631 per month in 1961-62, or $11,220 to $16,310 for an equivalent ten-month period.

It is true that professors in some fields have attractive consulting opportunities. It is also true that the top universities, by dint of extraordinary efforts to recruit and retain personnel, can hold their own in this unprecedented seller's market for intellectual manpower. Nevertheless, most institutions of higher education face real difficulties.

Perhaps it will be questioned whether the "seller's market for intellectual manpower" is really "unprecedented." But salary trends must surely resolve any doubt. I never thought to see the day when college salaries would advance more rapidly than earnings of production workers in manufacturing industries. This is precisely what happened in the 1950's; and, although the differential for the entire decade was rather slight, it has been widening in recent years. According to the U. S. Office of Education, full professors received salary increases averaging 6.5 to 7.0 per cent annually during the four academic years ending in 1962.[9] Average earnings in manufacturing advanced about 3.3 per cent annually during this period.[10] Faculty salaries also increased much more rapidly than earnings of employed professionals in private industry, and of self-employed professionals.

Concentrating now on scientists and engineers in higher education, we see once more the prodigious influence of federal government programs. Seventy-five per cent of all research and development work conducted by colleges and universities is now supported by federal funds ($1,050,000,000 out of $1,400,000,000 in 1961-62, according to the National Science Foundation). In fact, the federal government even pays for about two thirds of the basic research. A substantial proportion of all graduate and post-doctoral fellowships is supplied by the Office of Education (under NDEA), NSF, NIH, NASA, AEC, and other federal agencies.[11] Then there are the construction grants and loans. It is estimated that the federal government now defrays 22 per cent of the total costs of higher education, but the percentage is higher for some of the more important institutions.

To assess the impact of federal programs upon colleges and universities is extraordinarily difficult because there are numerous ambiguities and uncertainties in the situation. For example, scientific research tends to be concentrated in those areas of greatest interest to the federal agencies. It would be something of a coincidence if those were the most strategic areas from the standpoint of the unfolding of knowledge. But is anyone in a position to establish a better set of priorities? Again, federal support results in large numbers of scientists being employed full-time in research laboratories and contract research centers, out of contact with students except for graduate students who may be assigned to assist them. Opinions will certainly differ as to whether this is healthy. It is evident that traditional standards of faculty qualifications are under pressure in many institutions as the shortage of Ph.D.'s intensifies. This might suggest that too many doctorate holders are being drawn away from the universities—largely with federal money—into other activities. But it is also possible that traditional standards will be altered as changes take place in educational organization and technology. Perhaps the Ph.D. will be required only of faculty members in graduate-level institutions where research is concentrated. Perhaps an augmented master's degree will be deemed sufficient for faculty members in the remaining institutions, who will be expected to be familiar with the results of research but not to

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[9] U.S. Office of Education, Press Release HEW-T85.

[10] ECONOMIC REPORT OF THE PRESIDENT (Washington, 1963), p. 204.

[11] John L. Chase: Doctoral Study: FELLOWSHIPS AND CAPACITY OF GRADUATE SCHOOLS, Office of Education (OE-54016). This monograph is based on questionnaires sent to all institutions granting doctoral degrees with the exception of a few awarding degrees in only one field. Questionnaires were sent to 155 institutions, and 139 usable replies were received. Fellowship support in these institutions totalled $35,041,000 in the academic year 1959-60. University fellowships accounted for $20,890,000, governmental fellowships for $9,265,000, and other fellowships for the remaining $4,866,000. Fellowships were classified as being granted by the university so long as recipients were selected by the university, even though the money may have come from the outside.

conduct it themselves. Perhaps television, teaching machines, and other automated devices will greatly augment the productivity of distinguished faculty members so that the student-faculty ratio can be increased without undue loss of teaching effectiveness. These are only a few of the open questions.

Furthermore, in appraising the total impact of federal participation, imbalances and distortions must be viewed in the light of the immense quantitative increase in activity. Critical judgments should not hide the fact that federal support has been of great value in attracting good students and able faculty members, building up research facilities, and in other improvements. Were it not for the increase in federal support during the past decade, the volume of research and development in educational institutions would be only half of what it is today. It may well be that a big, lopsided program is better than a small, balanced one.

But when all is said and done, the allocation of intellectual effort is so important that a large, balanced program must be earnestly sought. I see no reason to reduce the total amount of federal support. At the same time, there is every reason for the government to develop greater awareness of secondary effects, and to lay greater stress on achieving a proper balance of activities.

Here are a few of the more disturbing questions:

1 The Ph.D. is a scholarly degree, but almost 50 per cent of scientists and engineers holding doctorates are employed outside of colleges and universities. Considering the critical shortage of qualified faculty members during the current decade, does this represent good allocation? Educational institutions have never possessed exclusive jurisdiction over Ph.D.'s. If the manpower problems of colleges and universities have been aggravated by large-scale recruitment of Ph.D.'s into industry, the reverse is equally true. It appears that the proportion of Ph.D.'s "ploughed back" into higher education has not changed significantly during the past decade. Nevertheless, a good argument can be made that the proportion should have increased. Higher education is our fastest-growing industry; enrollments have risen from 2,100,000 in 1952 to 4,100,000 in 1962, and the Office of Education estimates that there will be 6,959,000 college and university students in 1970. While an industry or government scientist can produce more knowledge, a university scientist can produce more scientists as well as more knowledge. In this connection a presidential advisory committee has stated:

> "The most critical bottleneck to the expansion and improvement of education in the United States is the mounting shortage of excellent teachers. Unless enough of the nation's ablest manpower is reinvested in its education enterprise, its human resources will remain underdeveloped and specialized manpower shortages in every field will compound . . . Our nation, like the prodigal farmer, is consuming the seed corn needed for future harvests."

2 Where university scientists are employed in full-time research positions, they are not being "reinvested in educational enterprise." In 1961, only a minority of the scientists and engineers at colleges and universities were actually teaching. The remainder were engaged in research and development, administration, and other activities. Of the latter group, many were employed at contract research centers such as Argonne National Laboratory and Lawrence Radiation Laboratory. The percentage assigned to full-time research and development was particularly high in aeronautical, chemical, and electrical engineering, physics, biochemistry, microbiology and agriculture, all of which are heavily supported by the federal government.

Perhaps the dissociation of teaching and research represents a desirable division of labor and makes for greater efficiency. I doubt it. In my opinion, good students need to have contact with creative individuals, and research workers need to retain an inclusive view of their disciplines. This appears to have been the opinion of the President's Science Advisory Committee, which said:

> "The process of graduate education and the process of basic research *belong together* at every possible level. We believe that the two kinds of activity reinforce each other in a great variety of ways, and that each is weakened when carried on without the other."[12]

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[12] SCIENTIFIC PROGRESS, THE UNIVERSITIES, AND THE FEDERAL GOVERNMENT, November 16, 1960.

3 A related question is whether research and development should be so heavily concentrated in a relatively small number of institutions. Among the 306 graduate-level institutions, the top ten do 32 per cent of all research and development work, the top twenty do 50 per cent, the top fifty do 75 per cent, and the top 100 do 90 per cent. Doubtless these institutions are chosen on the ground that the highest quality work can be obtained there. But several counter-effects must be weighed in the balance. Scientific research is heavily concentrated in certain regions, particularly the West Coast, the East Coast, and the Great Lakes. Aspiring "centers of excellence" find it difficult to get started. The majority of college and university students are not educated in a research atmosphere.

Noting that only 200 institutions are capable of conducting major research programs, and that most of the money goes to the top 100, Congresswoman Edith Green (Chairman of the Special House Committee on Education) has observed that the remaining 1,900 institutions "also play a vital role in meeting the Nation's requirements, even for the production of the next generation of top scientific research talent . . . If the best science faculty is increasingly attracted by the availability of Federal funds to the major universities, it should be a matter of concern as to how well the other institutions can maintain academic excellence and this productivity."[13] In this connection Dr. Wiesner has proposed that federal money should be used for building up new centers of excellence in graduate education and research, "particularly in geographical areas aspiring to acquire a technological base."[14]

4 The federal government must recognize the decisive role it plays in determining not only the location of scientific activity but also the kinds of research and development work done. The policy of concentrating support in a relatively small number of institutions has its *pro's* and *con's*, but the policy of loading up the universities with applied research and development, as distinguished from basic research, is more difficult to defend. *More than half of all research and development at colleges and universities is currently classified as non-basic.* Practically all the applied research and development is financed by the federal government. Surely this is wrong. It serves the immediate interests of the government but misuses the educational institutions. The central function of the university—aside from teaching—is to extend man's knowledge, not to develop useful applications of existing knowledge.

Historically the United States has not been in the forefront of scientific progress. Since the time of de Tocqueville, observers have frequently noted the aversion to theory and abstraction and the preference for practical arts in this country. "A few instances of . . . basic ideas that have originated abroad are the steam turbine, the generation of electric power, the automobile, the diesel engine, wireless communication, x-rays, radioactivity, the electron, nuclear transmutation, isotopes, the quantum theory, mass-energy relationships, catalysis."[15]

Our attitude has been changing; the amount of basic research in the United States has more than trebled since 1953 (in current dollars). Nevertheless, it is not healthy for basic research to remain in the back seat at colleges and universities . . . I squirm when I read in the advertisements that "eminent university scientists" have produced amazing breakthroughs in cigarette filters, inspiring miracles of mattress design, and similar triumphs. But the fact is that *the federal government finances twenty times as much non-basic university research as private industry does.*

5 Within the area of basic research, federal support produces emphasis on certain fields of study of particular interest to the agencies dispensing the money. Many university administrators are disturbed because the academic community has lost control over the direction of research. If government agencies regard high-energy physics and space science as most important, these subjects will be emphasized. It is true that advisory panels from the scientific community play an

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[13] THE FEDERAL GOVERNMENT AND EDUCATION, House Document No. 159, 88th Congress, 1st session.

[14] NEW YORK TIMES, October 24, 1963.

[15] Eugene Ayres, "Social Attitudes Toward Invention," AMERICAN SCIENTIST, Vol. 43 (October 1955), p. 533.

important part in disbursing the money. Panel members know who are the good workers in their fields, and can judge whether a particular proposal is promising; but in the nature of the case they cannot handle the broader issues of scientific choice. "Panels usually consist of specialized experts who inevitably share the same enthusiasms and passions. To the expert in oceanography or in high energy physics, nothing seems quite so important as oceanography or high energy physics." [16]

One of the saving features of the situation is that there are now so many agencies supporting university research that a fairly good balance among the various fields of science and engineering may result, willy-nilly. But the great bulk of research support is directed toward physical sciences, life sciences, and engineering. The same is true of fellowship support. A recent study of 139 major universities showed 73.8 per cent of all governmental fellowships (in terms of dollar value) were awarded to students in these three fields. Only 26.2 per cent went to students in the social sciences, humanities, education, and other fields. Yet the latter group was awarded more than half of the doctorates.

If this represents a proper distribution of support, the result would appear to be accidental. It reflects the several interests and requirements of numerous agencies rather than a coordinated federal policy for support of higher education and research.

I do not claim any competence in judging among potential lines of scientific inquiry. But ways and means must be found to make such judgments. It does little good to talk about giving free rein to the idle curiosity of the individual scientist. When research moves from the bathtub to the million-dollar laboratory, inevitably it becomes institutionalized and bureaucratized.[17] Planning and programming cannot be escaped.

VII OTHER RESEARCH AND DEVELOPMENT IN THE PUBLIC SECTOR

David E. Lilienthal observes that "of all our national resources, minds are the most precious." He continues:

> "Two-thirds of our trained minds available for exploring scientific and technical frontiers . . . are absorbed by the space, defense, and atomic energy activities of our country. The rest of America's needs are relatively impoverished—neglected and starved . . . The Country is beginning to realize that we cannot have a satisfactory rate of economic growth if this disproportionate allocation of our trained intellect continues . . . The 'civilian sector' is a colorless term in economics for what it is that keeps America going." [18]

I stated in Section III that demand-and-supply, profit-and-loss criteria cannot be decisive in judging whether the distribution of scientific and engineering manpower is consistent with the national welfare. This statement applies not only as between military and civilian research, but also within the civilian sector.

The government has already undertaken vast programs of research in two civilian activities, medicine and agriculture. In the nature of the case this research has to be done under public auspices (directly or indirectly) if it is to be done on a large scale. But there are other kinds of research and development, not profitable to private industry, which appear equally important from the standpoint of public welfare.

(a) It is hardly necessary to dwell on the seriousness of traffic congestion in metropolitan areas. Evidently this problem cannot be solved by proliferation of cars and freeways. It is estimated that in fiscal 1952 some $25,000,000 of research and development money was spent on railroads, subways, and monorails. This contrasts with $196,000,000 for motor vehicles, $1 billion for space, and $8 billion for defense hardware (research and development only).[19] Is this good allocation?

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[16] Alvin M. Weinberg, "Criteria for Scientific Choice," MINERVA (Vol. 1, Winter 1963), p. 161.

[17] In the article already cited, Alvin M. Weinberg makes an interesting attempt to expound criteria for scientific choice. He proposes to use "internal criteria": is the field ready for exploitation, and are the specialists in the field really competent? But since no group of specialists can be permitted to write their own ticket, he adds three "external criteria": does the research have technological relevance; does it illuminate neighboring scientific disciplines; does it contribute to human welfare and social values? *Ibid*, pp. 163-67.

[18] "Whatever Happened to the Peaceful Atom?" HARPERS (Vol. 227, October 1963), p. 46.

[19] Estimates of research and development expenditures in this section are from J. Herbert Holloman, "Technical Policies in the Context of Economic Needs" (mimeo. July 18, 1963), prepared for Federal Council of Science and Technology.

(b) About $63,000,000 was spent for research on the "physical environment," including smog control and air-conditioning—one dollar devoted to man's own living space for every 16 dollars to explore outer space. Obviously little or no progress in smog control is being made. Can it be doubted that a really massive research and development effort would be successful?

(c) Our merchant marine has not yet entirely disappeared, a remnant surviving largely by virtue of government subsidies. Japan and other maritime nations are experimenting with radically new vessel designs. It is estimated that, in fiscal 1962, approximately $18,000,000 was spent for research and development in merchant shipping. During the same year, maritime subsidies totaled several hundred million.

(d) Or take education, a $25,000,000,000 industry with the fastest growth rate of any in the country. One might expect to see a great deal of research and development work on educational plant, methods, techniques, etc. The figures show $12,000,000 for curriculum studies of science and technology; $14,000,000 for teaching aids; and $6,000,000 for studies of plant and safety relating to schools and hospitals. It seems almost inconceivable that an industry of this size, undergoing such rapid growth, would have the benefit of so little research and development.

On this point Congresswoman Green observes,

> "The Federal Government supports research in many different areas but very little money is spent on research on education, *per se*. In a period of tremendous growth in school population there has been little change in the design of education, in the size and structure of classes, in the required 'nine months' for each student for each grade, in the use of school buildings, etc. Should immediate attention be given to an increase in research in regard to education and the learning process?"[30]

(e) I will not belabor other deficiencies closely related to national goals and problems. Suffice it to mention that in fiscal 1962 some $4,000,000 was spent for technical research, development, and applications in the field of area redevelopment; $13,000,000 for technical studies relating to foreign aid; a great deal on agricultural chemicals and very little on other methods of pest control; and, so far as the records indicate, nothing at all on traffic safety and accident control. Like education, highway construction is a huge industry which undoubtedly would have the benefit of more research and development if it were in the private sector rather than the public sector.

I do not know of any easy solution to these imbalances because they are deeply rooted in our economic and political institutions. However, they have to be dealt with in analyzing the distribution of scientific and engineering manpower. The issue is not really private versus public activity, since the federal government already finances two thirds of all research and development. The issue is, rather, *what forms* of public activity. It is a problem of allocation.

IX POLICY FOR SCIENTIFIC AND ENGINEERING MANPOWER

In discussing the policy implications of this analysis, I emphasize federal policies since the federal government decisively affects the deployment of trained scientists and engineers and strongly influences the production of new ones.

1 The most obvious implication is that the federal government should have greater awareness of what it is doing. The total impact on demand and supply of technical personnel should not emerge accidentally from uncoordinated agency programs, but should reflect conscious and considered policy conclusions. There is no need for centralized manpower assignment or budgeting; individuals will respond to market pressures and universities will take advantage of available support. By and large, the power of the purse is sufficient control; all that is needed is that manpower objectives and manpower effects be taken into account when that power is exercised. For this purpose a Federal Council on Scientific and Technical Manpower might provide a medium for the continuing study and consultation that is needed. The personnel of such a council should be sufficiently authoritative so that its conclusions will be genuinely influential.

2 Government agencies and universities should collaborate in gathering and analyz-

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[30] THE FEDERAL GOVERNMENT AND EDUCATION, House Document No. 159, 88th Congress, 1st Session, p. IX.

ing information about scientific and engineering manpower. The government has the best facilities for fact-gathering; the universities are in the best position for independent social-science analysis. Many agencies already collect information about technical manpower, but there are still serious gaps and inconsistencies. Much of the information has not been made available to the scholarly community. As for the universities, I would be the first to concede that this is a neglected area of labor economics and labor-market analysis. So much has been written about hourly wages and so little about professional salaries; so much about the turnover of factory workers and so little about mobility of scientists; so much about trade unions and so little about professional associations. Fact-gathering and analysis are mutually dependent and mutually supporting; it can be assumed that if government agencies develop an adequate information program, university social scientists will take advantage of it.

3 While every educated citizen should have a good grounding in science, I do not believe that our technical manpower problems can, or should, be solved by drawing a much greater proportion of college and university students into the technical professions. Their relative share has already increased substantially (except at the doctorate level). In 1954, 12.8 per cent of bachelors degrees were in mathematics, physical science, and engineering. The proportion increased to 16.8 per cent in 1960, and the Office of Education estimates that it will be 20.0 per cent (of a much greater total) in 1975. An almost identical increase is indicated at the masters level, although there seems to be greater stability in the proportion of doctorates.[21] Actually the real competition is for quality, and it is well established that an unusually high proportion of the more talented students are majoring in mathematics, science, and engineering.[22] The great bulk of governmental fellowship support is already directed into these fields. And society has many problems in other realms.

4 In any event, there is a huge reservoir of talented persons who do not enter college or do not graduate. Suppose that we classify all young people into deciles according to level of ability. As of 1954, 44 per cent of the boys and 60 per cent of the girls in the top decile were not receiving bachelor degrees. Within the upper three deciles, two thirds were not completing a college education.[23] Today the situation has undoubtedly improved, but a considerable portion of the high-ability group still fails to receive bachelor degrees. If the country's greatest shortage is educated, high-level manpower, this situation is really intolerable. It should be an objective of government policy that most of this group obtain the baccalaureate, and that as many as possible obtain advanced degrees. If this is done, science and engineering will automatically receive a large infusion of additional talent.

5 If a conscious federal policy in science and engineering manpower is developed, consideration should be given to the question of whether it is healthy to have such a large proportion of research concentrated in a relatively few institutions. Perhaps the notion that teaching and research are inseparable aspects of good education needs reinforcing. If so, matters should be arranged so that a much higher proportion of college and university students come into contact with research and with those who conduct it. On the other hand, perhaps a clearcut distinction needs to be made between research institutions and teaching institutions, associating graduate students with the former and undergraduate students with the latter. The research institutions would not require undergraduate teaching ability and the teaching institutions would not require the Ph.D. The second alternative would be easier because it is in line with the current drift. I think there would be a heavy sacrifice in quality of education, but opinions will differ on that point.

6 The universities must regain control over the balance and direction of their academic programs, and the federal government should aid and encourage them to do

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[21] Admittedly these projections are rather speculative as can be seen from the great variations. For example, NSF predicts that 30,500 Ph.D.'s will be awarded in 1975 (all fields), while the Office of Education expects 24,300. The Bureau of Labor Statistics estimates that 34,000 bachelors degrees in engineering will be awarded in 1969, but the Office of Education predicts 66,055 for 1970.

[22] American Council on Education and Educational Testing Service.

[23] Adapted by the National Science Foundation from AMERICA'S RESOURCES OF SPECIALIZED TALENT and THE DURATION OF FORMAL EDUCATION FOR HIGH ABILITY YOUTH (Office of Education).

so. Since federal agencies have specialized interests, their fellowships and research contracts will have a distorting effect unless corrective action is taken. When a research contract is presently awarded, an allowance is made for overhead costs, including space, administration, and similar items. Much thought has been given to the proper overhead allowance. But a larger sum should be added, with no strings attached, for the purpose of maintaining balance. Perhaps the university will use it to promote some other field of physical science, or to stimulate research in the humanities, or to provide undergraduate fellowships, or to support research in some new scientific field which is not of interest to the agencies, or to establish a Department of Religious Studies. This would be for the university to decide.

7 Steps should be taken to reverse the "flight from teaching" and to bring full-time researchers at colleges and universities into contact with students. New types of teaching appointments may have to be devised, and certain other standards and procedures of the academic community may need to be reviewed. In my opinion, scientists who also teach are likely to do more effective research.

8 It is absolutely wrong for universities to be doing less basic research than applied research and development. Most of the latter is financed by the federal government. If these government funds could be shifted into basic research, the universities could almost double the amount of basic research they are currently performing. This would not only constitute a return to their proper research function, but also make for much healthier graduate teaching.

9 Turning to space and defense, it is my belief that improvements in requirements determination, program definition, contractor selection, and contract administration would yield important economies in the use of scientific and engineering manpower. Such economies are particularly necessary in the case of experienced scientists with advanced degrees.

10 The build-up of civilian research and development has been tapering off in recent years. Tax incentives may be of some help in reviving it, but probably there will not be a decisive change until a more rapid rate of economic growth is reestablished. But even in its most dynamic phase, civilian research and development was concentrated in large firms and in a relatively small number of industries. To broaden the base of this activity, a program such as the Commerce Department's proposed Civilian Industrial Technology Plan may be essential.

11 Finally, the "public sector" of civilian research and development urgently needs attention. The government should consider whether brains and money cannot be shifted from space, defense, and atomic energy into this sector, without loss of effectiveness. Furthermore, a better balance must be achieved. Agriculture and medicine should not remain virtually the only major claimants. Smog control, rapid transit, water depollution, educational organization, and urban redevelopment, for example, are also integrally related to the national welfare and could benefit from the allocation of more technical manpower.

In an age of technology, the way in which a society uses its technical manpower is a pretty good indication of its values. If the United States is to have a rational policy on allocation of scientists and engineers, some basic value judgments will have to be made. This country is large, wealthy, and powerful. If we decide what we want, we can have it.

PROPOSAL FOR DEVELOPMENT OF AN IMPROVED MANPOWER-RELATED INFORMATION PROGRAM

Allen O. Gamble

INTRODUCTION

Adequate and timely information is needed for decisions concerning allocation of national resources that support scientific and technical work, the utilization of scientists and engineers, and the education and training that replenish and enrich their numbers and quality. The required information is of many kinds. It ranges from simple counts of scientists and engineers to information concerning individual creativity and productivity. It covers effects of working environments, interactions of team-workers, characteristics of research leadership, the nature and nurture of creativity, the dynamics of the research and development cycle, and many other aspects.

The present paper does not attempt to cover this full range. It is limited to a consideration of the statistical information that forms the essential base not only for many important decisions, but for additional studies in depth and in variety. The information includes manpower data and also manpower-related factors such as funds, organizations, and facilities for technological work, intimately associated with manpower.

Each scientist or engineer is a unique and complex individual with respect to his background, characteristics, and potentials, and his working environment vitally affects his performance. His work, when viewed in detail, is almost equally unique. Classifying and categorizing him or his work inevitably does some violence to reality. Yet when many hundreds of thousands are to be understood, it is essential to categorize and classify, and to analyze statistically so that generality can be gleaned from individuality.

NEED FOR INFORMATION BY DECISION-MAKERS AT MANY LEVELS

In our society, decisions affecting scientists and engineers are made at many levels and in all sectors. These decisions involve federal appropriations, corporate allocations for research and development, management utilization of scientists, engineers, and supporting personnel, levels of support for fellowships and scholarships, university curricula and facilities, and a wide range of other matters.

Specific examples of federal policy decisions might relate to the establishment of a major new program, such as attaining a manned lunar landing, or a major expansion of an existing program, such as health research or the interstate highway system. Specific questions might ask what would be the probable requirements for scientists and engineers and related resources, in addition to funds, and what is likely to be the impact of these requirements on competing national programs and on total national manpower and related resources. In a different decision-making area, policy questions could ask what academic fields of doctoral education should be federally supported, at what levels of support, and whether doctoral support should take priority over baccalaureate support. Universities might ask what should be the direction of change in curricula to meet the actual needs of federal and industrial installations for specific types of college graduates. An industrial corporation might ask whether its numbers of dollars per professional for research, for development, or for production, and also its ratios of supporting personnel to scientists and engineers, are out

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of line with those of competing companies.

Numerous and varied policy questions such as these point directly toward the need for specific types of integrated statistical information concerning manpower and related matters; for information structured to meet decision-making needs; for reasonably dependable information, including indications of probable error where feasible; for current as well as historical data; and for informational studies that are or can be made rapidly available when needed for actual decision-making.

The basic objective of gathering and analyzing statistical information should be to provide a sound basis for informed decision-making. The information is not an end in itself. The first step in proposing improvements in the existing systems should therefore be an identification of the major decision-makers, their major types of decisions, and the types of information that can contribute most to the facilitation and improvement of the decisions.

The following sections present a tentative structuring of three major types of decision-makers, their decisions, and their informational requirements. Further inquiry is needed to validate, refine, and make more specific this preliminary analysis. After such inquiries, specific detailed plans may be made for improvements or changes in present informational systems.

Decisions by "Resource-Allocating" Organizations

Major program decisions at the national level are, of course, made jointly by the Congress and the Executive branch. These result in appropriations of funds, related legislation, executive orders, and the regular management of operations. Such decisions constitute primarily an allocation of federal support among competing broad programs such as defense, non-military space, atomic energy, health, and food, and, secondarily, choices among specific alternatives within these programs. These allocations have major effects on the direction and distribution of scientific and engineering effort.

Traditionally these major allocations are based primarily on consideration of available dollar resources, but vaguely, if at all, on present or future availability of manpower and related resources. The dollars expended per scientist or engineer are not the same from one function to another, but vary from about $20,000 per professional in basic research in universities to about $800,000 in the construction industry. The relationship of dollars to manpower is thus far from simple, and must be based upon collected factual information.

Underlying the requests for funds for each major federal program are numerous contributory estimates of requirements for various components of the program. These subsidiary decisions also tend to be made primarily in dollar terms, though they may involve some estimating of total manpower requirements.

Rarely do estimates start with a schedule of requirements by type of manpower, and move from these projections into dollar terms. Yet it seems to be feasible to use records of the manpower and other resources actually applied in the work on an earlier project, such as a less complex launch vehicle or aircraft or a public works program, to provide guidance for planning new projects and programs. These data can be usefully broken down into such segments as in-house research and development, in-house fabrication and production, contracted or subcontracted research and development, purchase of materials and standard components, and construction work, to provide guidance in estimating future requirements for related projects and programs.

This "manpower-related budget" approach starts with the nature of the work to be done or mission to be accomplished, and ends with what should be more valid estimates of the array of requirements—specific types and quantities of manpower, funds, facilities, materials, energy, and other resources—all scheduled by periods of time. The requirements in each category can then be compared with corresponding resources, present and projected.

Included in this approach is consideration of the work cycle, including such phases as research, development, fabrication of prototypes, testing, short-run production, long-run production, operation, and maintenance. Both the numbers and the proportions of scientists and engineers required for the early stages of this cycle are greater than for the later stages, while production workers and other less highly trained personnel increase in the later stages. Thus considerable numbers of scientists and engineers who are involved in the early stages of a specific project may become reassignable to other projects during later stages. On the other hand, the onset of a "new start" or a major modification increases the scientific and engineering manpower requirements.

The converse of such considerations is the impact of cut-backs and terminations of ongoing projects. In industry as well as in federal installations, the effects are different with respect to various types of manpower during the cycle of retrenchment.

It must also be emphasized that decisions concerning allocation of resources at the federal level have their counterpart in virtually all types of organization.

Particularly at the level of the Congress and the Executive, but also at the corporate board and similar levels, "resource allocators" need adequate information concerning at least the following:

—Current levels and distributions of funds, manpower, facilities, and other resources by end-objectives or missions.

—Projections of future levels and distributions of the same factors based on a variety of assumptions such as would relate to various contemplated additions to, changes in, and terminations of specific projects and major programs.

—Projections of future resources. Past projects and programs are never perfectly matched with future ones. Just as clearly, projections of future available resources are subject to much uncertainty. Even the available data concerning past situations and events may often be incomplete or inaccurate. But studies of the types listed can nevertheless provide highly useful guidance, now largely lacking, for the making of resource-allocating decisions.

Decisions by "Performing Organizations"

A useful distinction may be made between "resource-allocating" and "performing" organizations. Actually, of course, many organizations have both allocating and performing functions; different segments or echelons usually perform the two distinct functions separately.

The term "performing organization" is here used to mean one that utilizes allocated resources in research, development, design, testing, fabrication, production, or other activities requiring scientists, engineers, and specialized supporting personnel and facilities. While this includes the research done in the universities, it excludes the teaching function, which is considered to be "resource-producing."

The types of management decisions that may be facilitated or improved in performing organizations by good manpower-related information systems are numerous and varied, and may be made at many different echelons. But all such decisions have the common objectives of maximizing the efficiency and productivity of skilled personnel, minimizing the costs of operations, estimating future requirements, and so on. Attainment of these objectives may be helped by comparative data concerning groups of similar organizations for matching with patterns of in-house information showing ratios of staffing, costs, and the like. Some examples are listed below.

—Ratios of dollars to scientist or engineer and dollars to employee for functions such as basic research, applied research, development, and production, and for various specialties such as instrumentation for spacecraft, solid-propellant engines, friction and lubrication, or broader fields such as oceanographic exploration.

—Ratios of various types of supporting personnel (e.g., technicians, administrative professionals, clerical personnel, shop workers) to professional scientists and engineers for such functions and specialties as those listed above.

—Patterns of education and experience of scientists and engineers in various work functions and specialties, particularly in new and short-supply specialties, to provide guidance in recruiting, reassignments, training, and retraining.

—Specific manpower-related costs by types of employer and work-oriented functions and specialties, including recruiting costs, entrance salaries and salary schedules, costs of in-service and employer-supported training and retraining, and turnover data and costs.

—Comparative information on organizational structures and interrelationships.

—Domestic versus foreign comparisons for such as the above, where available.

—Trends and projections for all the above variables, and for other variables and their interrelationships.

As experience is accumulated in the development of trends and projections, and also in the making of estimates of manpower where there are inadequate data, techniques must be developed for interpreting and evaluating the data. Analytical techniques and mathematical models already developed should be made available to "resource-allocating" and "performing" organizations, and also to the "resource-producing" organizations discussed below.

Decisions by "Resource-Producing Organizations"

Organizations that may be classed as "resource-producing" are engaged in the production of the manpower, material, and monetary resources required for scientific and engineering work. While this is their main function, they resemble "performing" organizations in utilizing resources allocated to them, and "resource-allocating" organizations in allocating internally the resources that they receive.

The educational system, in particular, requires comprehensive and dependable manpower-related information for wise and timely planning and decision-making, such as the following:

—Decisions by faculties concerning changes in the content and structure of curricula and courses.

—Decisions by college and university officials concerning changes in existing facilities, construction of new facilities, and faculty expansion and development.

—Decisions by funds sources (federal, foundation, corporate, and individual) concerning support levels and subject-field distributions of scholarships, fellowships, and related grants and donations.

—Decisions by career advisers (vocational guidance counselors, placement officers, faculty, and others) concerning relative emphasis on behalf of the various fields of education and types of employment.

Such decisions may be guided by three types of information: projections of demand for education; projections of demand for specific types of college and university graduates expressed in terms of the work-oriented fields and functions of science and engineering, translated into probability terms of the academically oriented fields that feed differentially into them; and projections of demand for additional training and retraining of experienced professionals.*

Decisions by Individual Students, Scientists, and Engineers

Many types of presently available manpower-related information also are useful to individual students, scientists, and engineers. Improved and more timely information would provide better guidance in the making of a variety of personal decisions such as the following:

—Educational choices including field of major study, level of degree, and even specific courses.

—Selection of employer when entering the work force and when changing employers.

—Selection of field and function of work.

—Decisions concerning additional training or retraining.

—Decisions to enter or reenter the work force, as by women upon graduation or when relieved from family responsibilities, by professionals who have transferred to different fields or functions of work, and sometimes by retired professionals.

The types of information required to facilitate and improve such personal decisions overlap considerably the three types covered in the preceding sections. This is because the individual is "resource-allocating" when he decides to work toward a given objective, and also when he invests or contributes his personal funds; is "performing" when he engages in scientific or engineering work; and is "resource-producing" insofar as he progressively improves his own knowledges and skills through education, formal and informal training, and work experience. His decisions differ in level perhaps more than in kind from those of organizations. His informational needs must not be overlooked.

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* This last is an emerging demand generated by the rapidity of growth of new scientific and technological knowledge, which produces a corresponding obsolescence in the knowledges and skills of practicing scientists and engineers. A recent estimate puts the "half-life" of an engineer's knowledges and skills at ten years. Universities can expect an increasing demand to share to a greater extent the meeting of the need for updating practicing professionals, now being largely met on the job by federal and industrial laboratories, technological organizations, and individual scientists and engineers, through both formal and informal programs. The university response to this need is likely to differ substantially from their usual programs: especially as to scheduling; considerably as to presentation techniques and content; and also as to faculty, due to more extensive use of the frontier knowledge of practicing professionals.

The informational needs of these numerous decision-makers, of many kinds at many levels, comprise a growing national requirement for adequate, readily available, and timely information concerning scientific and engineering manpower and related factors.

But there is also a growing recognition of inadequacies in the present flow and structure of manpower-related information. Perhaps this recognition is stimulated by the mounting urgency of the needs of decision-makers for improved informational guidance, caused by the phenomenal growth of the importance, size, cost, and complexity of the nation's scientific and technological efforts, work force, and educational system.

There is a record of considerable dissatisfaction during the years 1957 to 1959. In this period six reports were issued concerning scientific and technical manpower problems, and all six emphasized informational inadequacies. Much of what was then concluded is still applicable, including many of the proposals for improvement.[1]

Although considerable improvement has occurred since these six critical reports of 1957-59, comments made during recent months show that major inadequacies remain.[2]

Some Key Inadequacies

Many of the comments concern special informational inadequacies of interest to the critics. Relatively few have been critical of the information *systems* as such.

The key inadequacies of present manpower information systems are the multiple and fragmented compilation of data; unbalanced and inadequate coverage; insufficient longitudinal study of complex entities; and inadequate funding and administrative support.

Multiple, Fragmented Compilation

A recent survey showed 29 federal organizations engaged in collection of information on scientific and engineering manpower and related matters, of which ten were designated as "major federal collectors, compilers, and publishers," and eight were listed as "major federal coordinating organizations." This particular listing was tentative, subject to revisions in both structure and content. But the fact of multiple involvement in informational studies is strikingly evident.

Actually many more than 29 federal organizations could properly be listed if three additional headings were used: "major federal employers of scientists and engineers," "major federal funders of contracted scientific and engineering work," and "major federal funders of scientific and engineering education." Organizations within these three groups must collect, analyze, and use considerable manpower and related information to guide and also to report upon their program functions.

In addition there are many non-federal organizations engaged in the collection, compilation, analysis, evaluation, use, and publication of such information. Among them are congressional committees, Presidential committees, the Engineering Manpower Commission, the Scientific Manpower Commission, various scientific and engineering professional societies, state and regional organizations, colleges and universities, other non-profit organizations, industry associations, professional and trade journals, and others.

The informational structure resembles an array of fishlines rather than a fish net, or a texture with much warp but little weft.

There is too little interlock among data concerning fields and levels of education, supporting funds, national objectives of work, and other factors. Even where data appear to be interrelatable, difficulties are encountered due to differing methodologies, categories, definitions, coverage, and time periods. This is the result of insufficiently coordinated collection and analysis by numerous different organizations, each of which maintains its own basic source data and publishes its own summaries and analyses.

There are numerous continuing informational projects, and also many of the *ad hoc* or crash type for special purposes, but no real integrated program that permits interrelating all the important manpower-related factors.

Unbalanced and Inadequate Coverage

There has been and still is wide variation in the amounts of effort expended and in the extent of information collected concern-

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[1] See Appendix A (available from the author).
[2] See Appendix B (available from the author).

ing the several components of the nation's scientific and technical manpower. Considerable detailed data are available concerning earned doctorate degree holders, including 100 per cent listing and collection of basic personal information. Much is known concerning scientists, particularly physical and life scientists. Far less is known in detail concerning engineers, yet engineers are more than twice as numerous as scientists and represent a much higher proportion than that of national resources in terms of funds, supporting personnel, facilities, and materials.

Very little has been expended on enumerating supporting personnel, and even less on studying their education, work-experience, age, and other characteristics. Yet the characteristics and ratios of different types of supporting personnel engaged in different functions constitute valuable comparative management information.

Many data have been collected concerning scientists and engineers engaged in research and development work, and concerning research and development funds and organizations. Yet only about one third of all scientists and engineers are primarily engaged in research and development work. About 60 per cent of scientists and engineers are engaged in production, operations, management, and other non-research and development, non-teaching work. This large group requires more study.

Insufficient Longitudinal Study of Complex Entities

Data concerning individual scientists and engineers are now collected from them periodically, each time covering key aspects of individual backgrounds and current employment. Longitudinal studies of occupational development and mobility of individuals or groups are difficult to make with this successive-collection technique, but would be relatively easy using a cumulative-collection technique in which the data are maintained and made accessible in terms of each individual (see "Lowest Adequate Information Sources" described on page 108).

Not enough coordinated longitudinal data are now collected with respect to major technical projects, such as the Apollo manned lunar-landing project and the development of the Titan-II ballistic missile. Longitudinal studies of such projects, showing through the entire work cycle of the project, the interrelationships of numbers and kinds of manpower, funds, materials, and other factors, could produce highly useful management and resource-allocating information.

Inadequate Funding and Administrative Support

It has been estimated that in 1962 the federal government spent about five to ten million dollars on collection, analysis, and publication of manpower and related information concerning scientists and engineers. This includes work done by the National Science Foundation, those whom its funds support, the Bureau of the Census, the Bureau of Labor Statistics, the U.S. Office of Education, the National Institutes of Health, and others.

But this informational expenditure was only 0.05 to 0.1 per cent of the $10 billion federal expenditure for research and development in 1962 or $1 for information concerning all scientists and engineers to guide $1,000 to $2,000 of research and development work. This ratio would be even lower if the large federal expenditures for non-research and development work were added to the $10 billion expended for research and development.

Insufficient funding is a major cause of informational inadequacies, although the low administrative level and status of informational systems and insufficient top-level Executive and Congressional support contribute.

Some Specific Examples of Inaccuracies and Gaps in Information

The differences mentioned, particularly the differing concepts and bases for enumeration, make it difficult to establish even the most elementary basic data. For example, federal publications by different agencies for the year 1960 show differences of 100 per cent in the total number of employed scientists, and of over 200 per cent for specific categories of scientists such as physicists and mathematicians. These differences persist even when the comparison is made for a presumably unitary category such as manufacturing. Published totals of employed engineers also differ, though not so greatly, but are highly suspect due to evidence showing many cases of gross over-reporting by inclusion of technicians and draftsmen titled "Engineers."

As one example of a major agency's problems with inadequate data, during 1962 and 1963 NASA was under heavy attack with respect to the numbers and proportions of scientists and engineers required for its growing program. Claims were made that the NASA space program would require as much as 25 per cent of the nation's scientific and engineering manpower. But no one had adequate data until NASA itself made a special study, including a survey of major prime contractors, distinguishing among appropriations, obligations, and expenditures for six major categories of work. This study demonstrated that even during the peak of the 1960-1970 decade less than six per cent of national requirements would be due to NASA. This and many other studies made by NASA itself have been vitally necessary to enable NASA to defend its program before that major resource-allocator, the Congress.

Progress with respect to Scientific and Technical Manpower Information

Nevertheless, a great deal of progress has been made in the collection, analysis, evaluation, and publication of information concerning scientific and engineering manpower and related factors. Only a few examples can be cited here.

The National Science Foundation has been issuing many studies of the distribution of scientists and engineers and of funds for research and development. The National Register of Scientific and Technical Personnel has accelerated and intensified its studies of the characteristics of scientists, and is considerably expanding its registration of engineers from about three per cent to about 10 per cent. NSF has also been enlarging its role of coordinating and supporting the studies of manpower and related information conducted by federal and other agencies.

The Bureau of the Census has intensified its studies of scientists and engineers throughout the economy, including depth studies of representative samples of these professionals. In addition it is just completing a study of industry for NSF, which for the first time provides direct information relating research and development manpower and funds supplied by the Department of Defense, NASA, and other federal agencies.

The Bureau of Labor Statistics has continued and intensified its detailed studies of scientists, engineers, and supporting manpower. It has developed and applied new techniques for projecting supply of and demand for scientists and engineers covering the decade 1960 to 1970. In addition it is conducting, also for NSF, a study supplementing the Census study of Defense, NASA, and other federal research and development work in industry, but in greater detail concerning scientists, engineers, and other types of personnel.

The Civil Service Commission, in cooperation with NSF, has continued its studies of federal scientists and engineers, and maintains rosters of upper-level federal scientists, engineers, and executives. It also has developed an automated data-processing system covering 10 per cent of all federal employees, but this is position-oriented rather than person-oriented and does not include educational data.

The U.S. Office of Education continues to issue its valuable detailed reports of college and university graduations, and also makes periodic projections of numbers of future college graduates.

The National Academy of Sciences—National Research Council maintains data for 100 per cent of earned research doctorate degrees granted by United States universities in all fields since 1920, including questionnaire information from each doctorate-level graduate since 1957. These data are being enriched by a special study of selected cohorts with respect to occupational mobility, supporting funds, and other variables, supported by the National Institutes of Health.

Space does not permit an exhaustive listing of recent, ongoing, and planned studies of manpower-related information, but progress on many fronts is clearly evident. In particular, see NSF's recent report of progress on the Hauser Panel recommendations, "Status of the Program for National Information on Scientific and Technical Personnel."

Informational Poverty amidst Informational Wealth

Yet a problem seems to exist with respect to information about scientific and technical manpower and related factors, in spite of the wealth of information that has been and is being collected, and in spite of the large number of organizations engaged in collection, analysis, and publication. Why are frustrations encountered at many decision-making levels with respect to manpower-related information? Why do the compilers, evaluaters, publishers, and coordinators of manpower-related information themselves seem to be aware of deficiencies and anxious for improvements? The inherent complexities of technical manpower-related information provide much of the explanation.

SOME INHERENT INFORMATIONAL COMPLEXITIES

In our increasingly technical society, scientists and engineers probably constitute the nation's most varied and complex group of individuals with respect to multiplicity of fields and levels of education, sequence and range of work experience, training and retraining, special skills, and other characteristics. Individual mobility among fields of work, functions performed, types of employers, objectives of work, and geographical location are progressively increasing this variety and complexity.

Fields of Work versus Fields of Education

There is a rapid proliferation in the number and variety of fields of work in which scientists and engineers engage, particularly in the frontier technologies. A few examples of new work-oriented fields are orbit and trajectory studies, spacecraft propulsion and power, and liquid lasers. Others less new are friction and lubrication, energy conversion, antibiotics, and frozen food processing.

These work-oriented specialties do not correspond to the traditional academically oriented disciplines such as physics, chemistry, and mechanical engineering. They are not even interdisciplinary like biochemistry, but multidisciplinary. In fact, they often cannot be allocated as between science and engineering, since they partake of both. This is shown by the wide variety of academic fields of degrees, both in science and engineering, held by individuals within such work-oriented fields.*

The accelerating emergence of numerous such work-oriented fields requires new classifications and categories, while producing obsolescence of older categories.

Functional Activities

Complexities also seem to be increasing with respect to functional activities such as research, development, and production, involving overlap and merging of such functions, different interpretations, changing meanings, and cyclic involvement.

An individual scientist may participate over a period of time in the entire cycle of a project, moving progressively through the stages of basic research, applied research, development, prototype fabrication, testing, production, operation, data collection—then back to basic research.

Functional complications are also reflected in the work of organizations. Universities engage not only in basic research and teaching, but also in applied research and development, and even in the letting and monitoring of large research and development contracts and subcontracts. Prime contractors for federal work have tier upon tier of sub- and sub-sub-contractors, and even perform the function of coordination among other prime contractors. Government laboratories engage in the full gamut of functions.

Patterns of Deployment

Further informational difficulties are added by the complex and changing patterns of deployment of scientists and engineers among federal, industrial, university, non-profit, and other employers, and self-employment. Many combine multiple em-

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* The distributions of fields of highest academic degrees held by individuals in two work-oriented specialties in NASA are listed below:

	Aero-Space Technology *Control and Guidance Systems*
39	Aeronautical Engineering
1	Chemistry
49	Electrical Engineering
1	Civil Engineering
3	Electronic Engineering
18	Mathematics
25	Mechanical Engineering
1	Nuclear Engineering
36	Physics
1	Educational Administration
1	Marine Engineering
175	Total

	Aero-Space Technology *Flight Mechanics*
78	Aeronautical Engineering
3	Astronomy
2	Chemical Engineering
1	Chemistry
2	Civil Engineering
11	Electrical Engineering
5	Engineering Physics
25	Mathematics or Applied Mathematics
41	Mechanical Engineering
1	Nuclear Engineering
46	Physics
1	Mining Engineering
236	Total

In Appendix C, Section J, are given additional explanations, usefulness in recruitment and training, and usefulness in vocational guidance. (Available from the author.)

ployments such as teaching, research, writing, and consulting for different employers or clients.

Supporting Funds

The federal government, state and local governments, industry, foundations, and other sources provide supporting funds in varying proportions and with shifting emphases. In certain cases of rapidly rising or falling funds, it is necessary to distinguish clearly among appropriations, obligations, and expenditures with respect to different types of work performed.

Supporting Personnel

Personnel working in support of scientists and engineers include not only technicians but also administrative professionals, clerical workers, technical editors, technical librarians and documentalists, modelmakers and other skilled craftsmen, shop and production workers, and others. The patterns and ratios of such supporting personnel differ widely for different types of technical work and among different organizations.

End Objectives

It is important but often difficult to determine the end objective of technical work, even in such broad terms as defense, nonmilitary space exploration, improvement of industrial products and processes, health, increase and rationalization of basic knowledge, and the like.

Interrelationships and Dynamics

Perhaps the crowning complexities involve the charting of interrelationships and dynamics. Interrelationships among paired or multiple factors are often as important as the separate data. Equally or more important are changes, trends, and flows as contrasted with static data.

Operational Problems

The preceding complexities are concerned with the inherent nature of information concerning scientists and engineers, their work, and the organizations which employ them, provide the resources which support their work, and educate them.

In addition, there are operational problems of many kinds. Failures to respond not only reduce coverage but also introduce unknown biases as between respondents and non-respondents. Definitions and categories are variously interpreted and misinterpreted. Elimination of informational chaff and processing of informational wheat require technical judgment and consumption of time.

Substantial improvements in the existing manpower-related information systems are likely to be neither easy nor fast, due to these operational reasons as well as the inherent complexities of the information itself.

SOME PROPOSED PRINCIPLES AND ACTIONS FOR AN IMPROVED PROGRAM

It was emphasized earlier that an information system should primarily contribute to improved decision-making—not be an end in itself. Three types of decision-makers were identified—resource-allocators, performing organizations, and resource producers. These groups cover a wide range of types of decisions to be made, and thus an equally wide range of required information. But there appear to be common aspects across this range which are useful guides for systems-design purposes.

Interrelationships among Factors

Most decision-makers seem to need data organized to show interrelationships among different factors such as numbers of scientists and engineers, levels and fields of academic degrees, work specialties, work functions, age, sex, and the like. Relations among factors such as supporting funds, numbers and types of supporting personnel, end-objectives of the work, organizations and facilities for technical activities, and characteristics and output of systems for education, training, and retraining are also important. The interrelationships of such factors are often expressed usefully as ratios or percentages.

One example of the usefulness of interrelated factors to resource-allocators is the distribution of percentages of scientists and engineers working toward major end-objectives such as national defense, nonmilitary space, health, and so on. Ratios of dollars to scientist-or-engineer are useful to resource-allocators for estimating and planning purposes, and also to performing organizations for comparative purposes, particularly when derived for different work functions and fields. The proportions of scientists and engineers with different academic degrees entering specific work specialties constitute useful information for management in performing organizations, for educational institutions, and for vocational-guidance counselors.[3]

For maximum flexibility and rapidity in making such inter-factor and multiple-factor analyses, and for other reasons as well, it is proposed that manpower-related information be collected from the Lowest Adequate Information Sources, in terms of the Lowest Adequate Information Units, and maintained in this same basic form; and that modern computer technology be utilized for the storage, retrieval, analysis, and printout of such data.

"Lowest Adequate Information Units" means the finest feasible granularity of information for the purposes to be served. One example is data identified specifically for Tiros-I rather than for weather-observation satellites, or Titan-II rather than ballistic missiles. Another example is identification of work as being in flight-vehicle acoustics rather than broadly in aerospace engineering or physics.

"Lowest Adequate Information Sources" means the source closest to the entity about which information is desired. For example, most information about individuals should be collected from the individuals themselves and not from their employers or other sources; most information about installations should be collected from the installations themselves and not from their company or federal headquarters, and similarly for other types of information. This is not to suggest that the information must come directly from an employee and not through his employer, or directly from an installation and not through its headquarters. But it does mean that the information, whatever channels it may follow, should be accessible in its original detailed form.

It is proposed not only that basic data be collected according to this principle, using compatible categories and methodologies, but also that the several collecting organizations make the basic data accessible for cross-factor analyses where appropriate. Some additional reasons for proposing this basic approach are listed in the footnote below.*

Future-Oriented Approach

Another common element across the range of decision-makers is that decisions are basically future-oriented. Major decisions involving or affecting scientific and engineering manpower which have been taken with explicit detailed foreknowledge of probable requirements, resources, and side-effects, both favorable and unfavorable, seem to have been all too rare. Such forecasting of the impact of major decisions has had to be crude and elementary due partly to the inadequacies of available information, partly to the difficulties of interlocking manpower data with other factors such as funds, partly to primitive methodologies, and partly to slowness in collection and processing of data.

It is proposed that improved information systems should place stress on trend analysis, on the interrelating of manpower data with other factors, and on developing rapid modern computer-based procedures. The system should have as a major objective the development of a special service to major decision-makers, not now available. This would consist of introducing into the assumptions of "continued normal growth and change," based on trend analysis, sets of new assumptions concerning such contemplated actions as increases or cutbacks in major ongoing federal programs or projects, imposition of major new programs or projects, increases or decreases in fellowship support in various fields, salary changes, development of major university

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[3] For additional explanations and examples see Appendix C (available from the author).

* Listed below are five reasons for the use of "Lowest Adequate Information Units and Sources" as a basic methodological approach:

1 Information not obtained directly from the operational source has less reliability due to increase in errors and decrease in completeness.

2 Each echelon of tabular summation of informational units conceals valuable information, and also makes back-checking for accuracy more difficult.

3 Maintenance in terms of most basal units or elements allows multiple categorizations for differing purposes, the inductive development of categories, the re-analysis of historical data into new categories which may be required by the changing structure of scientific technology, and the weighing of different variables for such purposes as measures of quality.

4 Informational storage which maintains the individuality of informational sources and units provides maximum flexibility of analyses, making possible valuable analyses such as longitudinal studies of the mobility of scientists and engineers among fields, functions, and types of employers; longitudinal studies of manpower and other requirements for various types of projects; and multiple-factor analyses of many types.

5 Maintenance of integrally connected sources and units makes possible the progressive addition of new information, thereby avoiding the necessity for repeated requests for information which, if collected and maintained in accordance with this principle, would be already stored and available for both checking and future use. Thus updating can replace resurveying, with substantial savings of time and effort by both respondents and collecting organizations.

The operational meaning, implications, and varied usefulness of this approach are further detailed in Appendix C (available from the author).

or other facilities, and the like. They would be introduced in the form of perturbations imposed on "normal" projections to reveal the probable manpower and related impact of potential actions. These projections would then be compared with anticipated manpower and related resources.

Service would have to be rapid and flexible enough to guide actual decisions. Computer programming to deal with partial and imprecise data is said to be feasible, and also the presentation of ranges of probable error in estimates and projections.

Contrasting and Mixed Strategies of Data Collection

One extreme type of strategy for the collection of manpower-related information is to collect the data when and as needed, by special *ad hoc* surveys. This has several disadvantages, including the time lag, which is often extensive, between need for and availability of the information. At the other extreme is the strategy of collecting, on a continuing basis, all the types of information considered potentially useful, as completely and comprehensively as possible. This has the obvious disadvantage of excessive cost, as well as resistance by respondents.

It is proposed that neither of these extremes be adopted or even approached, but rather that a mixed strategy be used that is best designed to meet the needs of decision-makers.

With respect to *types* of information, regular periodic collection should be limited to those key data already known or determined by survey to be of standard usefulness to a range of decision-makers, or of particular usefulness to those of major importance. A tentative listing is given in the footnote below.* Then data of occasional or newly recognized usefulness should be collected as needed by means of special surveys. It is to be expected that the types of data collected regularly would change over time with changing informational needs.

With respect to *coverage*, it is proposed that an appropriate combination of completeness and sampling be used. It appears essential that census-type complete coverage be achieved periodically for key data in order to provide totals, and also in order to provide the structure and context for proper sampling studies. For maximum usefulness, such censuses should be conducted and the data maintained in terms of lowest adequate information sources and units, and likewise the sampling studies. Sampling studies for more detailed standard information should be regular but at shorter intervals, to provide data on trends. For many types of data, the samples should be as identical or overlapping as possible from period to period in order to provide source-continuity for longitudinal studies, such as of the mobility and development of scientists and engineers and the cycles of projects.

With specific reference to detailed data concerning individual scientists and engineers, several alternative approaches are possible, requiring careful comparative cost-benefit studies. Perhaps a combined or mixed approach would prove best. One alternative would be to expand the present National Register of Scientific and Technical Personnel to a reasonably feasible maximum level, of perhaps 90 per cent coverage, and make special studies of non-registrants to determine any biases and provide corrective factors. This could be done by a combined drive through professional societies and employers, with strong publicity concerning the national need and benefits, with feedback of information and special services to respondents, and with cumulative rather than repetitive collection of the information to minimize effort by the individual. Another alternative would be collection of data primarily through employers of scientists and engineers, using social security numbers rather than names. This could involve repetitive rather than cumulative collection of data; however, with computer storage and retrieval, it would be feasible to collect only current data concerning an individual and collate it for longitudinal studies. This approach could start with the large federal employers of tech-

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* There appear to be about seven groups of manpower-related information which are known to have standard usefulness, when interlocked to provide cross-factor and multiple-factor analyses, for a wide range of types of decision-makers. Some of these can be collected infrequently, some by sampling studies.

1 Professional and personal characteristics of scientists and engineers including fields and levels of degrees, specialized training and experience, date of birth, and sex.
2 Deployment in terms of work-oriented specialties and functions.
3 End-objectives or missions of the work, such as national defense, space, health, industrial processes and products, and the like, including specific projects.
4 Sources and amounts of supporting funds.
5 Deployment and characteristics of technical organizations and facilities.
6 Numbers and types of supporting personnel.
7 Distribution, characteristics, and output of the systems for education, training, and retraining.

nical manpower and the large federal procurement agencies (Defense, NASA, AEC, NIH, NSF) with respect to their contractors and grantees. Employers could either retain the individual data and make specified analyses, or have a data-processing agency use the basic data for nationwide analyses and for special analyses, as a service to the responding employers. Still another alternative would be to have virtually complete registration, possibly mandatory, with respect to minimal data, including identification, and then use stratified sampling for detailed information from selected groups of individuals. A fourth alternative, to be used in conjunction with others, would be detailed studies of complete teams of individuals engaged in selected projects or organizations.

Relationship to Technical Document Information Systems

The information systems currently being developed for the storage and retrieval of technical documents involve methods of classifying subject matter, analytical techniques, and computer programs which closely parallel many of the methods required for manpower-information systems. Mutual interest and joint efforts should be developed, particularly at that interface between documentary and manpower-information systems which is concerned with ongoing scientific and engineering projects. On the one hand, such projects can be expected to produce technological documents, and, on the other hand, to constitute the active present work of scientists and engineers.

Three-Prong Proposal for Action

This paper recommends that three different lines of action be taken, with the objective of improving the existing manpower-related information systems.

First, it is proposed that a detailed analysis be made of the existing information systems, which would penetrate much more deeply than is possible in the present report. Emphasis should be on the systems and their interrelationships; on excessive time delays between as-of dates of information and dates of availability or publication; on duplicative and repetitive requests for information to be supplied by organizations and individuals; on gaps in coverage; and in general on processes rather than on products.

Second, it is proposed that a research program be undertaken concerning informational needs and uses. This should cover the decision-making requirements of major decision-makers; mathematical models for providing estimates from incomplete or inadequate data; techniques for projecting both requirements and supply; methods for estimating probable errors of statistically derived totals, trends, projections, and degrees of interrelationship; pattern-analysis techniques concerning utilization of resources on key projects in a variety of defense, space, health, and other fields, including technical manpower, funds, materials, supporting personnel, facilities, and other resources; approaches for analyzing and projecting differential flow from academic fields of training into actual work specialties and functional fields; means for studying the structure and dynamics of successful technical teams; and research in a wide variety of other methodological and data-utilization areas.

The objectives of such research should be to determine what information parameters and techniques are most illuminating, useful, and even essential for decision-making; which types of information must be collected from total populations of individuals and organizations and which may be collected from samples; how frequently the various types of information should be collected; the most efficient means for interlocking and interrelating information; the time requirement for completion of various types of information studies; and related information problems. In the present report, it has been possible to cover such essential matters in only a preliminary and tentative way. The selected proposals given herein should be validated, extended, refined, and made more specific.

Third, it is proposed that a single systems-integrating office for manpower-related information be designated or established. Logically such an office should take the actions specified in the two prior proposals, although there is much to be said for carrying out the first two proposals to provide the basis for establishing the single office.

This proposal for a single systems-integrating office is intended to suggest a means of departing from the present extreme of relatively uncoordinated multiple compilation of information. It also purposely avoids the other extreme of centralized collection, analysis, and dissemination of information by a single federal agency. It envisions continuation of decentralized information collection by many federal organizations, in fact adding to the usual list the major federal employers of scientists and engineers, contracting agencies, and education-supporting agencies, augmented by the capability to be derived from multiple access, consistency of coverage, and other use-oriented features.

The first function of this systems-integrating office should be research on needs for and uses of information. The second should be closer coordination of categories, definitions, time periods, and methodologies of the many information-compiling agencies. The third should be reduction of the present duplicative and repetitive requests for information from individuals and organizations. The fourth should be improvement of interlocks among disparate data. A fifth should be the making of cross-factor analyses not otherwise feasible, which would require access to basic data collected by various agencies in terms of Lowest Adequate Information Units and Sources (see page 108). And the sixth function should be providing to major decision-makers special projections of the probable manpower and related impacts of alternative contemplated actions (see page 109).

No proposal as to the organizational location of this systems-integrating office for manpower-related information is now suggested; but it should be given sufficient status and high-level support to function as intended.

CONCLUSION

This nation has developed its information systems for economic, financial, and other matters to a high level of sophistication. The time is now ripe to give serious attention to developing more adequate, timely, and decision-oriented information concerning one of the nation's most valuable resources—its scientists and engineers—and their work, objectives, supporting personnel, and other factors closely related to their utilization and development.

The organization and operation of such an improved information system should be considered as a normal and necessary aspect of science and technology, required by phenomenal growth in size, complexity, and importance to the nation. It should be given adequate funds, status, and administrative support—and it should not be considered as temporary or be treated by emergency or piecemeal methods.

SYSTEMS-ACQUISITION AND THE UTILIZATION OF SCIENTIFIC AND ENGINEERING MANPOWER (REQUIREMENTS AND PROGRAM-DETERMINATION, CONTRACTS AND GRANTS)

Paul W. Cherington

INTRODUCTION

The purpose of this paper is to highlight the impact of government policies and actions on scientific and engineering manpower utilization in weapon and space systems acquisition. In the sense used in this paper, "acquisition" denotes the fixing of operational and qualitative requirements (specifications), program determination and definition, and the awarding and administration of contracts and grants. Included are activities in applied research, test and development, production, installation and checkout, and support.

There can be little argument that government policies and actions in systems-acquisition are major determinants of the utilization of scientific and engineering manpower. This is true with respect to a majority of all personnel engaged in research and development activities and also to a considerable number of scientific and engineering personnel engaged in production, installation, and support activities. It is true with respect to government scientific and engineering personnel and to those engaged in a broad spectrum of industry, nonprofit companies, and universities that are working on government-funded projects. The very magnitude of government expenditures makes such an impact inescapable.

This paper is primarily devoted to scientific and engineering personnel who are directly or indirectly supported by government research and development funds. It should be pointed out that this concentration tends to ignore the utilization of a numerically large group of scientists and engineers who are at work on government-funded production, installation, and support activities. These individuals may be less skilled and less imaginative than those engaged in research and development, and certainly are less glamorous. By the same token, there appears to be less known about this group, in terms of numbers, qualifications, utilization, or potential adaptability. There is at least a possibility, furthermore, that a substantial proportion of the work now performed by scientific and engineering personnel in these areas could be done by technicians or administrative specialists having only limited or *ad hoc* technical training. The limited attention given to these scientific and engineering personnel does not imply that they are unimportant, but merely that this paper has a restricted focus.

Focusing attention here on scientists and engineers engaged in research and development supported by DOD-NASA funds means that we are dealing with some 275,000 individuals, out of a total scientific and engineering population of

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1,400,000, within which the total research and development population is perhaps 450,000. Thus we are dealing here with a significant fraction of the total scientific and engineering population and a clear majority of all scientists and engineers engaged in research and development. It is, furthermore, a group whose utilization is peculiarly susceptible to changes in government policy and action. There are plentiful data that further divide this group by age, skill, location, and other pertinent factors. But information on perhaps the most significant subdivision is not available. The evidence of industry executives with whom members of the Committee met informally is to the effect that there are at least three or four subspecies that become important in any consideration of scientific and engineering personnel utilization in research and development. These are 1) the talented innovators, 2) the expert technical managers or administrators, and 3) the rank and file. There was some testimony to the effect that this third category should be divided into those who were particularly competent in "backing up" the innovators and those who were only useful for routine work. The consensus was that there was no shortage of routine scientific and engineering personnel, and that there had always been and probably always would be a shortage of innovators, managers, and top-quality "back-up" personnel. Thus, in considering the impact of government systems-acquisition on the utilization of scientific and engineering personnel, it is important to bear particularly in mind its impact on these scarce (and valuable) members of the research and development population. Wastage of the routine members of the population may be fiscally reprehensible, but the wastage of high-quality talent may have a much higher cost in terms of lost opportunities.

Although in fact not clearly separable, it will perhaps be useful as a device of presentation to separate the impact of government policies and action on scientific and engineering personnel working in research and development into two areas —the first dealing with *what* the government buys, the second with *how* it buys it. The first deals with requirements-determination and program-definition; the second corresponds generally with contracts and grants.

REQUIREMENTS-DETERMINATION AND PROGRAM-DEFINITION

The tasks on which the bulk of scientific and engineering personnel work in the research and development area are determined in the first instance by military or space-system requirements.* Establishment of these can run all the way from a decision that a new rifle is needed (M-14 over M-1) to a decision that an urgent national program in intercontinental ballistic missiles or a moonshot is required (the von Neuman Committee in 1953-4; the accelerated Apollo decision in 1962). For small step-by-step improvements, the impact on scientific and engineering personnel is likely to be small. With respect to rifles, it is doubtful that there are more than 100-200 scientists and engineers engaged in the research and development of any particular rifle, although the inclusion of extensive field tests might increase this number. For the ballistic-missile programs of the three services, the corresponding numbers may have been upward of 75,000 in the peak year. The peak scientific and engineering manpower loading for the development of a new, small missile is estimated at about 2,200 at the prime alone, with perhaps an equal or greater number of sub-contractors, system-integrators, and government personnel.

Regardless of whether these scientists and engineers are efficiently or inefficiently utilized on the job, the laying down of a requirement, especially in new broad areas or for large new systems, establishes a sizable commitment of scientists and engineers. Yet a fair proportion of the weapons for which a requirement is determined and which enter research and development never enter production and hence never become part of the national arsenal.** (The situation in the space field is much less clear since many of the programs are by their nature experimental.) For support of this statement consider the following analysis of

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* Throughout this paper the term "requirements-determination" is used in a general sense to indicate the entire process from concept to program-definition.

** We shall ignore in this paper the question of whether and to what extent the systems that are produced make a contribution to our military posture.

"New Programs" (as against "Evolutionary Programs") in Peck and Scherer:[4]

	Total	Produced	Not Produced
Heavy Bombers	19	9	10
Jet Fighters	14	5	9
Air Defense Missiles	16	4	12
Ballistic Missiles	7	6	1

Comparable numbers on electronic systems (such as the Air Force "L" Systems) are not available. It is believed that they would correspond closely to the ballistic-missile data, although frequently their "production" is sharply curtailed—e.g., as in the Ballistic Missile Early Warning System (BMEWS) and the military satellite programs.

It would be easy to jump to the conclusion that we permit too many systems to enter research and development, and that the systems that have been developed but do not enter production essentially represent a wastage of dollars and scientific and engineering personnel. Such a conclusion would, however, be erroneous, and indeed would run counter to the very nature of research and development work, which is experimental and uncertain.* A research and development program that always resulted in a producible system either would be a very timid one or would involve decisions to produce a considerable volume of expensive, unreliable, or unusable hardware. Some volume of drop-out at the research and development stage is to be expected. The real question is: How can the research and development program be determined and managed so as to minimize the costs of drop-outs while, at the same time, assuring a flow of weapons that are at the forefront of technology?

Substantial progress has been made in the last two years by the services, prompted largely by the Office of the Secretary of Defense, in improving requirements-determination and in handling the resulting research and development programs. This progress has been replicated at NASA. The main ingredients of this improvement have been:

1 Greater use of improved cost-estimating techniques and data to get better probable total-system cost estimates.

2 Greater use of cost-effectiveness studies to determine whether a new system is worth its probable cost.

3 Greater use of feasibility studies to assure that a proposed system and its main components are really within the state of the art.

4 Insistence on fairly major advances in effectiveness (at least 20-25 per cent) before research and development funds will be released for a new system.

5 Somewhat more attention and funds devoted to components or subsystem development, or to applied engineering (but certainly not to the extent urged by the enthusiasts of this approach).

6 Identification and closer monitorship over the more important and larger research and development programs by both the Office of the Secretary of Defense and top service officials.

7 A start toward the resolution of some of the more glaring and expensive inter-service rivalry areas.

8 Insistence by the Director, Defense Research and Engineering, on detailed program-definition before the release of massive development funds and the admission of the system to formal status as part of a five-year program package.

9 A willingness and an ability to terminate or cut back to the status of an applied research and engineering project those major hardware-development programs that seem to hold little promise or which run into unforeseen technical problems.

10 Greater control by the Director, Defense Research and Engineering, over development projects as they move forward, primarily through reviews and approvals prior to the release of additional development funds.

But despite the steps which have been, are being, and are likely to be taken to improve the process of requirements-determination and resultant research and development programs, the area still appears to be somewhat spongy. The result is that a considerable number of scientific and engineering personnel in research and development are probably absorbed in pro-

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[4] Peck, Merton J. and Scherer, Frederic M., THE WEAPONS ACQUISITION PROCESS, Harvard University Press, 1962, p. 358.

* It can be argued that we have often learned more from projects that failed to emerge from research and development than from those which were produced. While this may be true in some instances, it does not alter the need for production items.

grams of relatively insignificant additional value to the national arsenal, or, one suspects, to the national space effort. At the same time, the area is one in which it is difficult to make useful recommendations beyond the simple admonition, "Do better." For the fact is that requirements-determination is a field of extraordinary difficulty, involving the artful blending of technology, economics, and military operations. Few individuals possess the requisite skills in all three areas.

The requirements-determination area is difficult not only in and of itself but also because it is intimately linked, on the one hand, with the roles and missions (and hence survival) of the individual services and components of those services and, on the other hand, with future contracts for business firms (and hence their survival). Determination of requirements is a process conducted with the accompaniment of a "Greek chorus" of scientists, engineers, controllers, economists, retired military officers, and contractors who, while sometimes in error, are rarely in doubt as to the pressing need (or lack of need) for this or that type of weapon or space system. For example, within one service there are factions supporting tactical bombers against the detractors of tactical bombers, supporters of drones versus supporters of airplanes, and of nuclear frigates against attack submarines. The inter-service rivalries are too well known to require elaboration. Factionalists within government find vigorous allies in industry, universities, and non-profit organizations who have a vested financial or intellectual interest in one concept or another. About all that can be said is: it might have been worse.

Part and parcel of the requirements-determination problem is the risk that, if too many restrictions are placed on the process, we will cease to get any new weapon system at all. If the present system has at times been wasteful, it has, nevertheless, yielded a formidable arsenal. The present Department of Defense administration has already been charged with being excessively restrictive in its handling of the evolution of requirements through the program stage, although one suspects that many of the criticisms represent primarily the expression of parochial interests. Nevertheless, the risks of excessive restrictionism are grave.

The Office of Secretary of Defense drive to improve requirements-determination and project-definition has thus far been approached primarily as a budgetary matter. In fact, it should make a substantial contribution toward the better utilization of scientific and engineering personnel. Wherever gross dollars and gross numbers of scientists and engineers are closely correlated, over-all savings or better utilization of dollars can be expected to result in savings or better utilization of over-all manpower.

It is not clear, however, whether parallel improvements will be made in the utilization of top-quality scientific and engineering manpower. While dollars are wholly interchangeable, the same is not true of individual scientific and engineering personnel in research and development. As already pointed out, of the 275,000 individuals involved, some are unusually talented, most have special skills in particular areas, and others are crucial to particular organizations. This is true of innovators, managers, and capable "backers-up." While it may be easy to move a million dollars from Program A to Program B, the movement of the top-quality manpower associated with a fraction of these dollars may have more serious repercussions. Program A may require nuclear physicists, while Program B requires electronics engineers. Program A may be a project in a particular lab with an outstanding manager, while B is in another lab with weak management. For example, even though the original technical staff in the Navy's Special Project Office numbered only about 100 military and civilian personnel, their recruitment occasioned considerable anguish in other parts of the Navy. In one instance, it is claimed that transfer of one individual to the Special Project Office wrecked the capability of an entire laboratory division; in several instances (propulsion for example), the few individuals transferred represented a significant fraction of the Navy's outstanding personnel in a particular area. This is not a criticism of the Polaris program decision, but emphasizes the qualitative dimension of the scientific and engineering personnel problem.

Comparatively little is known about the numbers, qualifications, utilization, or identification of this high-quality scientific and engineering manpower. We might describe this "high-quality" scientific and engineering manpower as the scientific and engineering "core" of any successful research and development project. It seems clear that considerable further work needs to be done on defining what we mean by this "core," on developing means for identifying it and determining its role in the evolution of a new system.

The importance of "core" groups in the development process was clearly apparent in the case studies of Titan II and the Navy Tactical Data System (pages 121-34 of this report). But these studies provide a bare start on getting answers to such questions as: For a system of a particular type, what type of "core" group is really necessary to get the program started and keep it moving? Is it possible to predict the degree of success that a "core" group with certain characteristics is likely to have? How long will the "core" group have to be held together or what changes in it will have to be made? It is suggested that questions of this type can be just as significant as either the over-all scientific and engineering manpower or over-all fiscal impact of a proposed new program. Just as there have been numerous instances in the past where the Department of Defense and other agencies have been overprogrammed relative to available funds, there is a strong suspicion that the sum of their requirements has sometimes exceeded the supply of really competent scientific and engineering "core" personnel and may have completely drained the reservoir of total scientific and engineering manpower in particular specialties. This question appears to deserve attention both in the determination of requirements and the translation of requirements into programs, and especially as to ways and means of increasing the availability of capable "core" groups.

Executives of both systems firms and research and development firms with whom members of the Committee talked were virtually unanimous in expressing the view that the heart of the process of requirements- and program-determination was a constant flow of new ideas from contractors to government. As will be discussed in the following section, some of them were concerned that the flow would result in a competitive flood of unmanageable proportions. But almost all would prefer to handle this problem, rather than see steps taken to foreclose their access to government decision-makers in requirements and programs. Several complained of the growing rigidity of the process under the current administration, but most agreed that the steps being taken were in the right direction. Others stated that current problems arose, in part, out of the fact that many past programs, despite their impressive achievements, had been "easy" programs, and that current requirements (such as Anti-Submarine Warfare and Anti-Intercontinental Ballistic Missile System) were far more challenging, calling for the application of broader and deeper systems analysis in order to isolate key problems and identify areas requiring new inventions. All stressed the rapidly changing nature of the weapons and space industry—technically and administratively—and the risks of writing tomorrow's prescriptions on the basis of yesterday's diagnosis.

CONTRACTS AND GRANTS

The means by which the Department of Defense secures the research and development it wants done is an elaborate structure of contracts, grants, and administrative controls. There is considerable evidence that this structure has a bearing on the utilization of scientific and engineering manpower second only in importance to requirements- and program-determination.

At several stages in the life cycle of a requirement from initial concept to approved and funded program, the government is almost certain to place reliance on a contractor or grantee. The main types of tasks are: applied engineering on components, system feasibility studies, program definition studies, and systems research and development. Whereas a few years ago such research and development tasks were simply a bothersome but necessary preliminary to a large production contract, system research and development contracts (and their precursors) now are of a size to be an end in themselves for most contractors. This is especially true since long production runs have come to be a comparative rarity.

Most contracts for this type of task are non-competitive in the legal sense, in that they do not involve formal advertised bidding. But the *de facto* competition for most of them is bitter, for the very good reason that the winner of a major system research and development contract can look forward to four to eight years of large blocks of business. This intense competition sets the pattern for the employment of a substantial number of scientific and engineering personnel in research and development. The pattern falls into two time periods—pre-contract and post-contract.

In the pre-contract period, anywhere from two to 100 contractors may have an interest in a new system research and development program at any one time. At one bidders' conference over 100 firms appeared. The more usual number is between 15 and 30. The amount of scientific and engineering effort devoted by any one firm at this stage is small, amounting perhaps to five man-years. However, even here the multiplier effect builds up the total effort quickly. If each of 50 firms devotes this level of effort to an annual average of ten programs apiece, we get quickly to 2,500 man-years. Out of this preliminary skirmish two to five firms may get feasibility-study contracts. The scientific and engineering input increases at this stage to perhaps 100-200 man-years. At the program-definition level (if still competitive) the number jumps again to perhaps 300-500 man-years. The winner of a good-sized contract is committed to some 5,000-15,000 scientific and engineering man-years over the three-to-four year life of the research and development contract, the numbers depending upon the nature and size of the program.

Thus pre-contract competition absorbs a considerable number of scientific and engineering personnel. No data exist as to the total expenditure, in part because it is often difficult to separate pre-contract work from the company's independent research and development. Of the total population of 275,000, perhaps five per cent are utilized in these tasks. The percentage may be higher. It is claimed further that this input represents unusually high-quality personnel, although whether it is high in sales appeal or in technical imagination and skill is not really known. Nor do we know what this considerable effort brings to the government in the way of new and imaginative approaches and other relevant benefits. More needs to be known about both areas.

Pre-contract competition appears to have intensified in recent years because of the diversification of existing weapons companies and the entry into the business of companies that previously sold primarily to the private sector. The rapid advance in technology and uncertainty as to where it may develop next have meant that firms increasingly have felt forced to build up capability in a broad spectrum of fields. Further, there appears to be a good deal of "unconscious parallel action" among firms. For example, the rise of missiles led to the development of some capability in inertial-guidance systems among 25 to 30 firms, although the existing and foreseeable demand would probably not adequately support more than ten. Each of the 25 firms, however, feels that it must remain in the business, and competes vigorously for new programs. The exact cost of this over-capability in either dollars or manpower is not known but is undoubtedly substantial.

Representatives of firms doing substantial government work, with whom members of the Committee talked, all testified to the increased level of competition, but virtually all were highly mistrustful of any arbitrary restrictions on the *right* to compete freely and openly. They recognized and deplored such practices as "buying in," but they preferred to meet this problem rather than have the government issue a dictum to the effect that only "X" number of companies would be allowed in, say, the guidance field. They hoped (but without much conviction) that the government would gradually develop a greater ability to screen out unqualified bidders quickly.

It might be supposed that the fierceness of pre-contract competition might have a secondary effect. A defense or space contractor knows that there is nothing more damaging to the tone of a proposal than an admission that, upon award, he would have to conduct an extensive recruiting campaign for scientists and engineers. Thus each contractor is impelled to show that the great bulk of the required personnel for the development phase is already "on board." If true, they can only be employed in two ways—on programs that are phasing out, or as "fat" on continuing programs. Again, there are few good data on the point. The industry executives with whom members of the Committee talked indicated that if the practice of "stock-piling" had ever existed, it was a comparative rarity today except for small groups of key personnel. To the extent that the Titan II and NTDS cases yielded probative data on this point, there were few if any signs of "stock-piling." Indeed, some small amount of "stock-piling" of key personnel may be in the interest of the government as well as the contractor as a reserve against future projects. Recognizing the difficulties of exploring this area, there is a clear need for the further collection of data.

It can be argued that the forces of competition will force down the level of any reservoir of employed but under-utilized scientists and engineers to the vanishing point. But, at least in theory, this argument may not hold. One answer is the type of contractual document used, usually some form of cost-type contract, with or without incentive provisions. Seldom are contractors initially screened out on the basis of their original cost estimates. Selections are made on the basis of a technical and management appraisal, and cost targets are then negotiated out. The more that can be built into the contract at this point the better for the contractor. Not only will a higher target tend to increase the absolute amount of his fee but more important, it will give him much greater flexibility in deploying any scientific and engineering manpower "float" that he may have. Cost-type contracts with post-selection cost-target negotiations theoretically remove the contractor from price competition. Since scientific and engineering manpower is equated with costs, the contractor is at least partially shielded from the direct forces of competition in the area of manpower loading. The contractor's incentive is thus toward the highest cost and manpower target he can negotiate, for the flexibility that this will give him later on may essentially determine his survival (e.g., ability to win new contracts). Industry personnel indicated to members of the Committee that, however valid this argument was in theory, it had little basis in practice. Increasingly, government negotiators are coming to the bargaining table with comparative manpower data, carefully analyzed against the tasks to be performed. In addition, it must be stated that some target prices are arbitrarily negotiated downward from contractors' estimates, so that there is an inevitable overshooting of the original target. In short, the forces of competition, tighter negotiations, and subsequent controls are making the "stock-piling" of scientific and engineering manpower more and more difficult.

Another aspect of the contract process which involves the utilization of scientists and engineers has to do with over-engineering and engineering changes and their control. Over-engineering results from specifications that are more demanding than necessary—closer tolerances, special metals, cleaner, and so forth. Obviously such specifications tend to call out a greater design effort. Because such specifications tend to be more expensive and hence earn a higher fee, and also, because industry is often judged on quality rather than cost, there have in the past been real incentives to over-engineer. In consequence, a certain amount of scientific and engineering manpower has been absorbed in over-engineering. It remains to be seen whether competition and increased attention to value analysis have curbed this tendency.

As most major systems move forward through development and production, there are substantial changes. These range all the way from relatively minor changes in component design to major changes in system configuration. Under cost-type contracts, the cost of changes is almost always allowable and often is the basis for an additional fee. Changes can, and do, absorb substantial scientific and engineering effort. A current Office of the Secretary of Defense study has as its objective the development of new and improved techniques for controlling changes, since there is at least a suspicion that, in the past, contractors have proposed changes either to cover up previous mistakes or for the purpose of "gold-plating" their product. Better control over changes should tend to conserve scientific and engineering manpower.

Whether or not the stock-piling of scientists and engineers is a thing of the past, the fact remains that the fluctuations in the flow of contract funds to individual companies causes variable demand for company scientific and engineering personnel. Would it be possible either to correct the situation or to devise means of utilizing these personnel more effectively while they are under-utilized on contract work? Some companies utilize such personnel on independent research and development; others use them to work on proposals. Still others try to maintain a stable work force through the extensive use of overtime. But these palliatives do not offset major fluctuations in the demand for scientists and engineers. These fluctuations could, of course, be eliminated or damped down by a smooth flow of new contracts to each firm. Given the nature of the weapons and space business, no such ideal solution is likely to come to pass. It could be greatly reduced by continuing "level-of-effort" contracts to the major firms in the industry. For example, Company X could be funded at a $300 million annual level over a five-year period with the understanding that, if its performance were good, its funding in any one year would be increased by, say, 10-20 per cent, and if poor, reduced by a like amount. This solution also appears to be somewhat detached from political and technical reality. It flies in the face of a policy of free and open competition for each contract, a policy that enjoys both governmental and industrial support. Beyond this, however, it might be possible to develop incentives that would make it attractive for firms with under-utilized personnel to use the waiting period for retraining and upgrading of skills. For at least a limited number of engineers and scientists, a six-month educational "leave with pay" might well benefit their employer, and ultimately the government. The possibility of some type of cost-shared program along this line deserves further study.

Various steps have been taken by the government in an attempt to curb or correct those wastages and abuses (in money) that stem from the contractual process. The steps are essentially of two types—incentive contracts and controls. The effectiveness of incentive contracts in producing substantial under-runs of the cost target is yet to be proven. Given the economics of the industry and the real interests of the government (usually more oriented to technical and schedule performance), the incentive to under-run cost targets appears weak, although there may be a considerable incentive not to overrun. So far as scientific and engineering manpower is concerned, incentive contracts tend to move the game from contract administration to contract negotiation, where the target is set.

The area of controls may prove more effective in the manpower area. Increasingly, contractors are being required through Pert-Cost or other systems to "shred out" the various parts of the research and development task (including manpower and dollar estimates) in advance of cost-target negotiations. Later performance can then be measured against these estimates, not in gross but in detail. This at once removes considerable flexibility from the contractor in terms of his ability to move manpower, either within a program or from program to program. It should be pointed out that the maintenance and monitorship of these control systems requires a substantial amount of both contractor and government manpower, and that some portion of this manpower probably must be scientific and engineering personnel. Nevertheless, continued experimentation, testing, and experience with a variety of control systems are probably inevitable and justified.

A final aspect of contracts and grants deserves mention, as it affects the utilization of scientific and engineering manpower. The machinery and structure that has gradually grown up around the administration of contracts and grants is of bewildering complexity. Granted that the process of systems-acquisition is complicated; granted that the expenditure of public funds must be surrounded with safeguards and controls; and granted that some contractors have failed to act responsibly in discharging their contractual obligations; still the administrative apparatus appears needlessly top-heavy in terms of reports, manuals, meetings, briefings, reviews, "fire drills," and the like. Just how much scientific and engineering manpower is devoted to these administrative tasks (in both government and contractor organizations) is not known, but the informal evidence is that it is considerable. Further data would have to be collected in order to quantify the amount of scientific and engineering effort, and considerable analysis would have to be applied to determine what portion of this effort was sheer waste and what was replaceable by non-scientific-and-engineering manpower. Data should be collected that would throw light on the cost of these administrative tasks in the scientific and engineering manpower area.

What has been said concerning contracts in the foregoing paragraphs applies, in part, to government grants. To be sure, the process of source-selection is not conducted within a competitive framework, but there is nonetheless a considerable measure of competition. The controls are not as numerous or as rigorous, but they exist all the same, as any university contracts officer will testify. But, in fact, comparatively little is known about the specific impact of the contractual process on scientific and engineering personnel working under government grants.

CASE STUDIES OF TITAN II AND NTDS

Paul W. Cherington

INTRODUCTION

As part of its study, the Committee on Utilization of Scientific and Engineering Manpower (USEM) authorized the preparation of two case studies involving the utilization of scientific and engineering manpower on two major military systems, the Titan II and Naval Tactical Data System (NTDS). These studies, prepared by Mr. James McGuire and Mr. Rudolf Graf of United Research, Inc., contain considerable proprietary and other privileged information and cannot be given unrestricted distribution. Futhermore, each is 100 or more pages in length, making reproduction in this volume impractical. The purpose of this paper is to summarize the two case studies, and to present what appear to be their principal findings.

At the outset, it should be pointed out that it would be highly imprudent to generalize on the utilization of scientific and engineering manpower engaged in military systems development on the basis of two cases. Even if it were to be assumed that the Titan II and NTDS systems were fully representative of all large missile and electronic systems, generalization from so small a sample would be hazardous. In authorizing the case studies, the USEM Committee was fully aware of this limitation but, nevertheless, believed that it would be useful to have concrete evidence of scientific and engineering manpower utilization in two actual situations even though the evidence thus adduced could not be generalized.

The specific questions in which USEM was interested and to which the cases and this summary report are directed are:

1 In the development of the systems, could "key people" in government and contractor organizations be readily identified? What was their role (technical and administrative) in the development of the system?

2 What was the background, education, and tenure of the "key people"? Did continuity of their assignment appear to affect the system development?

3 How was the technical management of the system organized and did this appear to affect the speed and effectiveness of the development?

4 How much scientific and engineering effort was devoted to the pre-contract phase?

5 What was the pattern of the build-up and stand-down of scientific and engineering personnel on the project? Does it appear to have been effective in terms of utilization?

6 Is there evidence of "stock-piling" of scientific and engineering manpower on the project, or "borrowing" from it?

7 Is there evidence of a significant amount of scientific and engineering effort devoted to "brochuremanship"?

As will be discussed below, few categorical answers to these questions can be made on the basis of the case studies. In some instances, firm answers would have required extensive personal interviews with individuals now widely scattered, or collection and analysis of data well beyond what the scope of the effort permitted. Thus the studies must be regarded as a preliminary or pilot effort, rather than the source of hard, quantitative data.

The Titan II and NTDS systems were selected for several reasons. In the first place, it was desired to include a large missile system and a large electronic system as being reasonably representative of the types of large military systems which came into being in recent years. Both were recent systems; both had completed their development phase and had become operational. Both systems were regarded as successful. Undoubtedly, there are things to be learned from an examination of "horribles," and if it had been feasible to collect a larger number of cases, some "unsuccessful" systems would certainly have been included. A final reason for the selection of Titan II and NTDS was the fact that each had its origins in or was closely associated with the scientific community—Titan II in the OSD Ballistic Missile Committee and NTDS in Project Lamplight.

Although these two systems appear to be suitable candidates for study, it should be pointed out that, in at least two respects, they are perhaps unrepresentative. In the first place, neither was the subject of a substantial source-selection effort. In the second place, both were managed through relatively strong "vertical" project offices. This type of management structure was typical of Air Force ballistic missiles, but the centralized NTDS project office within BuShips was in some respects unique at the time, insofar as the Navy was concerned.

Brief note should be made of how these cases were prepared. Permission to undertake the studies was requested by the Committee from the Secretaries of the Air Force and Navy respectively, for Titan II and NTDS. Both Secretaries graciously granted permission and made arrangements to facilitate necessary contacts, clearance, and the gathering of data. Throughout the course of the studies, excellent cooperation was given to the research effort at all levels of government and in each of several contractor establishments. For this cooperation, essential to the timely completion of the task, the Committee is extremely grateful.

Each of the researchers spent considerable time in familiarizing himself with the system assigned to him and with the general structure for systems development and for in-house scientific and engineering personnel management in his respective service. Extensive interviews were conducted, first in Washington and then in the field at government or contractor facilities. In addition, a very considerable amount of statistical data was gathered during these field trips or requested from appropriate sources. These interviews and field data formed the basis for analysis of the various issues set forth below and, of course, for the complete case write-ups.

THE SYSTEMS

A brief description of each of the systems studies is given here for the benefit of those who may be unfamiliar with them.

Titan II is a two-stage intercontinental ballistic missile, a direct descendant of Titan I. One major advance in Titan II over its predecessor is the fact that Titan II's propulsion system uses a storable liquid propellant permitting long-term underground storage in a "ready" condition. Another major advance in Titan II is its airborne all-inertial guidance system, which has a high degree of accuracy. The development of Titan II is under the direction of the Air Force Systems Command's Ballistic Systems Division, with Space Technology Laboratories providing systems engineering and technical direction to the program. Martin of Denver is the integrating contractor. General Electric, Aerojet-General, and the A. C. Spark Plug Division of General Motor's head a long list of associate contractors. The case study covered only Martin and A. C. Spark Plug. The Titan II program had its origin in the fall of 1958 in the form of a memorandum from Space Technology Laboratories, outlining an advanced Titan missile. This proposal was made possible by advanced development work performed by the Government and its contractors over the preceding 18 months, especially by Aerojet-General on storable, non-cryogenic hypergolic fuels; by the M.I.T. Instrumentation Laboratory on inertial guidance components; and by the Martin Company on materials compatibility and launch techniques.

For the most part, in fiscal year 1959 through much of fiscal year 1961, the financial and manpower data on Titan II were consolidated with Titan I accounts, making a break-out virtually impossible. Even thereafter there are shared costs for the two systems. Thus many of the manpower data that subsequently appear have of necessity been estimated.

The Naval Tactical Data System is a complex command and control system which acquires, computes, and displays a variety of tactical data for shipboard use. Its four basic elements are data-conversion equipment, computing equipment, communications equipment, and displays. The unique features of NTDS lie primarily in the computer and display areas (Remington Rand-Univac and Hughes), in the speed of operation permitted and the flexibility which permits the system to be used aboard a variety of ship types and under a variety of tactical situations.

The development period of NTDS runs from mid-1955 through 1961, at which time it was installed aboard three naval ships for service test. The origin of NTDS can be traced specifically to Project Lamplight, conducted at M.I.T.'s Lincoln Laboratories in 1954 to examine various problems involved in the defense of North America. One of the Lamplight reports (February-March 1955) recommended a fleet data system, using digital equipment. The implementation of this recommendation was made the responsibility of BuShips, and Commander McNally, who had been an ONR representative on Project Lamplight, was transferred to BuShips in late 1954 to help write the technical specifications for NTDS. Commander E. C. Svendsen was at the time in charge of the Special Applications Branch in the Electronics Division of BuShips. This office had responsibility for computer work in the Bureau and Commander Svendsen was to play a key role throughout the development of NTDS.

NTDS was developed by the Navy without a prime or integrating contractor, largely through the device of keeping a small but strong project group within BuShips and utilizing extensively the services of the Naval Electronics Laboratory in San Diego, as lead laboratory. Remington Rand-Univac (St. Paul) was responsible for the computer development, and the system design, and, as such, functioned as the lead contractor. Hughes Aircraft was responsible for the display system, and Collins Radio for certain communications gear. But system management and integration remained an in-house responsibility. Due to time limitations, only Remington Rand-Univac and Hughes were studied.

With this brief introduction to the two systems that were studied, it is appropriate to turn attention to the questions and issues previously noted, which were of concern to the Committee throughout its deliberations, and to see how the findings from the two cases bear on these issues.

NAVAL TACTICAL DATA SYSTEM

1 *The Identification and Role of Key Personnel*

In the NTDS development, major roles were played by a relatively small number of key personnel in government or contractor organizations. Virtually all these individuals had some type of technical background or training, even though their duties on the project might be essentially administrative. These key individuals were identified during the case collection by asking each person interviewed for the names of other key people on the project. There was in general a strong similarity between the lists thus developed.

The key government personnel associated with NTDS were located in BuShips, the Naval Electronics Laboratory (NEL), and the Office of the Chief of Naval Operations. The program was run by BuShips. Seventeen Engineering Duty Officers were assigned to the BuShips NTDS project office at some time during its life, but only six were assigned at any one time, and usually only four. Eight of these 17 officers, together with two civilians, were identified as having played a major role in the management or technical advancement of the NTDS development, and four officers were identified as having been the "hard core" of the management team. Cdr. E. C. Svendsen (later Captain) was the project manager throughout much of the development period, both in fact and by virtue of being head of the NTDS project office. After a tour of duty at NEL, he is now in charge of the *Seahawk* program. Not only did Captain Svendsen develop the initial NTDS specifications with Cdr. McNally and play a major role in the selection of Remington Rand-Univac as the computer developer; he appears to have been the main driving force behind the program throughout its development. He and two other members of the "hard core" officers in BuShips received the Legion of Merit for their work on NTDS.

Within the office of the Chief of Naval Operations, there was a small (five-man) NTDS office that coordinated the NTDS system development with the operating arm of the Navy, thus helping to keep the system "sold." Another major part of the government's team for the NTDS development was at NEL. It was selected over several other Navy laboratories to provide technical support to the BuShips NTDS project office. In addition it performed the system definition, testing, and initial training phases, and participated in contractor monitoring. Seventeen key people, two officers and the rest civilians, were identified as having played a major role in the NTDS development program at NEL (not including the training effort). Of this number, five were regarded as the "hard core" of the effort, including C. S. Manning, the NEL-NTDS project head. These 17 key personnel may be compared with the 5,100 man-months engineering effort devoted by NEL to various NTDS tasks from January 1957 to July 1961. The program ranged from approximately 60 engineers and scientists in 1957 to 130 in 1959. At its peak this manpower represented 30 per cent of the total NEL scientific and engineering strength.

A similarly small group of key personnel appears to have been mainly responsible for the development of the NTDS computer at Remington Rand-Univac at St. Paul (RR-U). Twelve individuals who were directly assigned to the project were identified as having made significant contributions of a technical or administrative nature. In addition, the work of four RR-U scientists not associated with NTDS was regarded as helpful. As discussed more fully below, there was a substantial turnover of scientific and engineering personnel at RR-U during the development phase. Thus, S. R. Cray was NTDS project supervisor from its start in 1955 until he left RR-U in mid-1957. A successor as project supervisor, J. E. Thornton, left RR-U in 1958. These personnel shifts may have expanded somewhat the list of key individuals. The role played by these individuals was a mixture of technical contributions—design, re-design, etc.—and administrative tasks. Thus, for example, two of the key personnel were responsible for the conduct in the fall of 1959 of a study to determine the feasibility of re-designing the circuitry of the computer, and subsequently persuaded the Navy of the desirability of this course of action. In particular, references to key personnel frequently mentioned their forceful leadership or skillful coordinating roles. The twelve key personnel may be compared with the total of some 790 professional man-years devoted to NTDS by RR-U St. Paul in the seven years, 1955-1961. The peak year (1961) saw an average of 260 scientific and engineering personnel assigned to the project, 14 per cent of the total professional strength at RR-U, St. Paul.

Six individuals at Hughes-Fullerton were identified as having been the hard core in the development of the NTDS display equipment. B. Diener, the NTDS project manager from its start in 1956 until he left the company in August 1959, is reported to be a strong administrator and also to have made several technical contributions, although he is not an engineering graduate. His successor was brought into the NTDS project from a Hughes radar project and had had no previous experience with NTDS. The Hughes development effort was funded under three contracts, the first of which was for experimental equipment. Peak scientific and engineering manning under this contract included 42 members of the technical staff. A subsequent contract covering the development and production of test hardware involved 110 members of the technical staff, 100 technical support personnel and 700 production personnel.

It is apparent that, within each of the four organizations which were predominantly responsible for the scientific and engineering work on NTDS, it is possible to identify a small group of individuals who played a key role. Almost without exception these individuals had technical training, experience, or both. The project managers, in addition, were vigorous managers and demonstrated a high level of drive and leadership. The importance of these key individuals to the success of the project is clear.

2 *Background, Education, and Tenure*

Of the key personnel on the program in BuShips and at NEL, at least some biographical data were collected on 24. For example, of the eight key BuShips officers, three had attended the M.I.T. program for ED officers and two had attended the Navy Post Graduate School at Monterrey before being assigned to the program. Two others were assigned to this school following their NTDS tour. Of 14 key civilians at NEL, four had no degrees (although most had taken some college-level work). Six held B.A. degrees in electrical engineering—from Oregon State, Colorado, University of Southern California, LaVerne, California Institute of Technology, and the University of California. Two had B.S. degrees and two had Ph.D.'s (mathematics and psychology) from Iowa State and California. Of these 14 individuals, data on their employment at NEL is available for 12. Seven entered NEL in 1946 or before, and five in 1951.

Biographical data are available for eight of the 12 key individuals at RR-U. Of the eight, two had no degrees, five had bachelor degrees in electrical engineering (3), in chemical engineering or mathematics from Minnesota (3), Columbia and Brooklyn Polytechnic Institute. One had the degree of MSEE (Minnesota). One of the bachelor degree holders secured his Ph.D. during the life of the NTDS project.

No comparable data were secured for the Hughes personnel.

Although no age data were collected, a rough estimate of age of key personnel can be obtained from the date of degree. On this basis, the average age of the eight RR-U key personnel for whom biographical information is available is between 32 and 33 in 1958 (half way through the project), with a range of 27 to 37. In marked contrast are the estimated ages in 1958 of nine key NEL personnel for whom date of birth could be estimated. The average was between 41 and 42 and the range from 33 to 53.

It is sometimes assumed that short tours, and transfers at less than optimum points in the life cycle of a project, handicap a program headed by a military officer. Of the key BuShips personnel, several were assigned to NTDS for only short periods of time. On the other hand, Cdr. (Capt.) Svendsen stayed with the project as project manager from mid-1955 until late 1961, an unusually long tour of duty. Three other key officers were assigned to the project for five years or more. The holding together of this management team may well have been an important factor in the success of NTDS.

Although specific data on the question were not gathered, the tenure of the key NEL personnel on NTDS appears to have spanned the life of the project, except for some losses to industry after 1959. In marked contrast is the situation at RR-U. Here, as previously noted, there was a continuing turnover of personnel. In large part, this turnover came about because of the fact that, in mid-1957, certain top RR-U people split off to form Control Data Corporation. This cadre did not initially include any NTDS key personnel, although it did include the General Manager and the Manager of Military Systems, but they were shortly joined by S. R. Cray, the NTDS project manager. The departure of Cray, and subsequently of several other key NTDS personnel, seriously alarmed the Navy. On the other hand, the work proceeded successfully, and it is even suggested that, if Cray had remained as project manager, the successful computer re-design in 1959 would not have been undertaken. The relatively minor impact on the project of these departures is also explained by some as reflecting the fact that Cray and others had essentially finished their major work on NTDS.

The tenure of key NTDS personnel at Hughes seems to have been more stable than at RR-U, despite the fact that B. Diener left the project and the company about half way through the development task.

The scientific and engineering manning of the NTDS project does not appear to have been carried out at the expense of other programs, either through wholesale raiding or through the transfer to NTDS of a number of persons with skills in critically short supply. Within BuShips, the number of NTDS officers and other personnel was sufficiently small so that it is unlikely that the project had an adverse effect on other programs. This is not to say that individuals such as Cdr. (Capt.) Svendsen would not have been highly useful if available for assignment to a functional group.

No precise measure of the impact of NTDS manning on other projects at NEL is available, but no evidence was heard that the impact was adverse.

The manning of the NTDS project at RR-U was accomplished in part through the transfer of a limited number of selected personnel from Project Athena, an Air Force guidance project for Titan I. Athena was a considerably larger project than NTDS, and there is no evidence that these transfers to NTDS adversely affected it.

3 *Project-Management Organization*

There can be no doubt that the NTDS program was directed and run by a relatively small project office within BuShips. The project manager was given control over various technical personnel in the Bureau and, through a "two-hat" arrangement, was given control over the research, development, test and evaluation funds for NTDS. This authority, together with the personality and tenure of the project manager, assured the project of tight and aggressive direction throughout the critical development and test period. In addition, the centrality of direction meant that there was a single focal point from which to handle the difficult problem of "selling" the NTDS system "upstream" in the Navy through the NTDS office in CNO, and especially to line personnel.

Major technical decisions were made by the BuShips NTDS office. NEL served more as technical monitor, evaluator, or coordinator than as a technical directing group. It is not possible to measure the impact of this form of organization on the utilization of scientific and engineering manpower. But the impetus which the NTDS office gave to the program, the direct lines of communication set up with contractors, and the relative rapidity with which program decisions could be made may have resulted in considerable scientific and engineering manpower savings.

The organizational structure for NTDS at NEL appears to have been less vertical, the bulk of the work remaining in the functional groups. For example, the NTDS project director, Manning, remained in charge of the Systems Division. He had no line authority over certain of the NEL groups involved in NTDS.

Although there was a project structure at RR-U, the project directors appear to have been more in the nature of coordinators than line managers. At Hughes, the vertical project structure was considerably stronger.

4 *Pre-Contract Scientific and Engineering Effort*

One of the topics of particular interest to the Committee is the amount of scientific and engineering effort devoted to winning new contracts. Unfortunately the NTDS program did not involve much pre-contract effort for either RR-U or Hughes, although in both instances their extensive experience on similar types of work was brought to bear.

There was no real source-selection competition for the computer contracts. The general feeling in BuShips appears to have been that only Bell Telephone Laboratories had the capability to undertake the design, development, and management of the entire NTDS program. Since BTL was heavily engaged on other government programs, it was decided to retain systems management within the Navy and to contract out the computer, display equipment, and the communications link. RR-U had, of course, extensive computer experience, and this was thoroughly familiar to Capt. Svendsen, as a result of a survey trip he had taken to RR-U and others in 1955. To all intents and purposes RR-U was a sole source contractor. It began its work on NTDS under a new task order under an existing Navy applied research contract.

The display equipment was put out on a Request for Proposal (RFP) to a considerable number of potential bidders in early 1956. Hughes had heard that the Request for Proposal would be issued but took no steps with regard to it prior to its arrival. Upon analysis the NTDS Request for Proposal proved to be closely related to an Army display system (MSG-4) for Nike and Hawk, on which Hughes was working. Over a three-week period a very complete proposal was prepared by four members of the Hughes Data Processing Laboratory who had worked on the MSG-4 system. This was the winning proposal out of ten received. Its depth of treatment outweighed some reluctance on the part of the Navy to make the award to Hughes, which was not known as a Navy contractor and which was felt to be somewhat high in cost by the Bureau.

5 *Pattern of Build-up and Stand-down of Scientific and Engineering Personnel*

Central to the interests of USEM is the question of whether scientific and engineering manpower on a particular project is fully and effectively utilized. Admittedly, valid measures of effective utilization are difficult to obtain and it cannot be said that either the NTDS or the Titan II cases provide adequate data for such measurements. This is true for several reasons. In the first instance, there are no generally accepted standards for reasonable manning levels for particular tasks. In part this is true because the development tasks themselves are hard to define and their difficulty may change over time. For example, the development of a highly reliable digital computer for NTDS would probably be considerably easier in 1964 than it was in the middle or late 1950's. Thus, in considering the scientific and engineering manpower loading at RR-U, for example, both the tasks and the dates must be borne in mind.

A second difficulty lies in the fact that utilization is in part a subjective rather than an objective concept. Some scientific and engineering personnel could, or feel they could, do much more than they are called upon to do, or vice versa. It is probably not feasible to determine, after the fact, whether a given group of scientific and engineering personnel was effectively utilized on a particular task.

A third problem has to do with the data on scientific and engineering manpower. These are maintained and reported in various ways and under various definitions. For example, in the case of NTDS, RR-U maintained month-to-month data by sub-task under its various contracts for development work. But comparable detail for manufacturing did not appear to be available. The Hughes data were considerably more summary in form.

Despite these difficulties, some impression of the utilization of scientific and engineering personnel may be gathered from the general pattern under which personnel was built up and stood down on various parts of the project. If the build-up is erratic with numerous ups and downs in manning, it may indicate that the manning of the project was being handled so as to absorb people released from other projects or that people are being borrowed to use on other projects. It may also mean that numerous unexpected problems have been encountered, calling for surges of people to solve the problems. A long stand-down period may mean that people are kept on a project well after their work is done.

Ideally the manning of a particular system should be compared with all other projects being handled by the facility or company. In the case of NTDS the collection of such data was beyond the time and resources available. In consequence, detailed data were gathered only on the various tasks of NTDS. These data can then be compared with certain significant milestones. Detailed charts are shown in the case itself. We will only summarize here what appear to be the implications of these charts. In considering these data, the following major milestones should be borne in mind.

1 December 1955—First NTDS tasks to NEL

2 May-June 1956—Contracts to RR-U and Hughes

3 February 1958—Delivery of research and development equipment to NEL begins and continues for 18 months

4 April 1959—Nov. 1961—Testing of experimental NTDS at NEL Applied System Development and Evaluation Center (ASDEC)

5 September 1961—Service test equipment installed aboard the test vessels

6 October 1961—Apr. 1962—OPTEVFOR service tests

In connection with these dates note should be taken of the fact that two types of hardware were developed, programmed and delivered to the Navy—the research and development test equipment and the service test equipment. The service test computer effort at RR-U was begun in late 1959 and extended into 1962 under a separate contract (Nobsr 75750). The comparable effort of Hughes was begun in 1959 and was virtually completed by the end of 1961.

Naval Electronics Laboratory (NEL)

Detailed month-to-month data for scientific and engineering manpower by task were not available. The year-to-year figures were as follows:

	Approximate Number of NEL S&E Personnel on NTDS	Percentage of NEL Total S&E
1957	60	14
1958	110	26
1959	130	30
1960	110	24
1961	60	17

No real conclusions can be gathered from the neat symmetry of this build-up and stand-down.

Remington Rand-Univac

The data for scientific and engineering manpower at RR-U are divided between development personnel at St. Paul and those at San Diego engaged in the installation and test of equipment.

The following figures show the total force of engineers working on the development of NTDS, compared to total professional personnel of RR-U St. Paul (including San Diego):

	St. Paul Engineers on NTDS	Percentage of All St. Paul Engineers
1955	15*	6
1956	35	8
1957	60	7
1958	80	8
1959	140	16
1960	200	13
1961	260	14

* Precontract

These figures show a steady over-all build-up in professional personnel, although the monthly data show a topping out in late 1961. By tasks the build-up looks quite different. For example, the pattern of build-up and stand-down for major segments of the development and service test efforts may be broken into the following segments: (1) system design, programming and test of the research and development and service test computer system; (2) hardware development of the six research and development computers; (3) hardware development of the service test computers; (4) miscellaneous tasks. The bulk of the scientific and engineering personnel were assigned to the first of these segments which in fact can be further broken down into numerous subtasks, some performed at St. Paul and some at San Diego. By dates personnel assigned to these tasks were as follows:

	Approximate Numbers Assigned to System Design and Programming		
	Total	St. Paul	San Diego
Mid-1958	55	55	
Mid-1959	80	75	5
Mid-1960	100	65	35
Mid-1961	150	55	95
End-1961	130	38	92

Thus, while St. Paul was going through a gradual stand-down from 1960 onward, San Diego was building up rapidly. While a few personnel were transferred, most of the San Diego contingent appears to have been new hires.

The build-up and stand-down on the service test computer development was much more abrupt. From late 1959 until June 1960, the engineering group built gradually to about 25. By December 1960 the peak was reached at 68. Thereafter there was a sharp decline to 29 in June 1961.

The over-all impression of scientific and engineering manning at RR-U is that it was reasonably orderly with no major perturbations. A complete answer, however, would call for a much more complete and detailed analysis. One area that would require considerable probing is the relationship between scientific and engineering manpower engaged in development and those engaged in manufacturing, and the degree of transferability between the two functions. All the foregoing numbers refer to those engaged in development only.

Hughes

The build-up and stand-down data collected at Hughes is in considerably more general form. There are no major perturbations in the pattern, but the data are not sufficiently detailed to arrive at any positive conclusions.

6 *Stock-piling and Borrowing*

An examination of the data at RR-U and Hughes do not show any indications either of major stock-piling or borrowing of personnel on or from the NTDS program. As already recited, much more complete data would have to be gathered and analyzed before a positive assertion could be made to the effect that there was no stock-piling or borrowing.

7 *Brochuremanship*

There is no indication at either RR-U or Hughes that an excessive amount of time was devoted to brochuremanship or other type of sales or "overhead activity" by key personnel or large numbers of personnel. Perhaps this was a reflection of the fact that RR-U was virtually a sole-source contractor and that Hughes was able to prepare its proposal with a minimum of effort.

OTHER POINTS OF INTEREST TO USEM

Of considerable interest to USEM is the break-off from RR-U of the Control Data Corporation. Interviews with a number of individuals indicate that, in part, the impetus for this break-off was a feeling on the part of RR-U St. Paul personnel that they were isolated from the top management of the company in New York, and that the top management had little knowledge of or appreciation for the capabilities and work of the St. Paul group. (The hard core of the St. Paul group had come to Remington Rand with the acquisition of Engineering Research Associates in the early 1950's. Remington Rand and Sperry Gyroscope merged in 1955, two years before the break-off.) In part, the St. Paul group was in competition for management support and attention with RR-U Philadelphia and, to some extent, with RR-U South Norwalk. The St. Paul management in the mid-1950's apparently was uncertain as to their status within the company.

TITAN II

1 *The Identification and Role of Key Personnel*

As was true in the case of NTDS, the Titan II development was driven forward by a relatively small number of key individuals in the Air Force Ballistic Systems Division (BSD); Space Technology Laboratories (STL); and the contractors, which for purposes of this case study are confined to the Martin-Marietta Co., the integrating contractor, and to General Motors' AC Spark Plug Division.

Within the System Project Office at BSD, 16 officers were identified as key personnel who made major contributions to Titan II. This compares to total SPO officer scientific and engineering strength, as of the spring of 1963, of 64. An additional five officers in the functional staff at BSD were similarly identified.

At STL, the systems engineering and technical direction contractor, 15 key individuals were identified, 10 in the Titan program office and five in the functional staff. Total Titan I and II scientific and engineering manpower loading at STL averaged about 250 until mid-1962, when it declined to about 200. The data do not permit a more detailed analysis.

Eight members of the Titan II Program Office at Martin were identified as key, while 11 members of the functional staff were so listed. This compares to a peak number of Martin/Denver scientific and engineering personnel manning of Titan II of over 1,200 plus additional Martin/Baltimore scientific and engineering personnel. The corresponding numbers at A.C. were five, and three. The total scientific and engineering personnel assigned by A.C. to the Titan II program fluctuated between 300 and 550 until the beginning of 1963 when it dipped below 300. In addition the close working relations between A.C. and M.I.T. on the concept and development of the inertial guidance system resulted in the addition of six members of the M.I.T. staff to the list of key individuals on the guidance system.

Within BSD, STL, and Martin, the bulk of these key individuals had had a prior connection with Titan I before joining the Titan II program. The two programs were often jointly managed and used personnel almost interchangeably. For example, the first BSD Systems Project Director (SPD) for Titan I, Colonel Blasingame, later General Manager of A.C. Milwaukee, had initiated several of the studies which led ultimately to Titan II. Col. Wetzel was the SPD for both Titan I and II, from the latter's inception in 1959 until his reassignment in April 1961. His successor, Col. (now General) McCoy, managed both programs until his re-assignment in August 1963. His successor, Col. Griffin, now manages both programs. A similar dual responsibility has also prevailed at STL. At Martin, Titan II did not really become a project, in the sense of having a considerable staff and full systems-engineering responsibility of its own, until August 1962. Thus many of the Martin personnel worked on both Titan I and II. At A.C., the company, while believing in the economy of functional organizations, nevertheless recognizes that funding is obtained on a project or program basis, and in consequence organizes its engineering-design groups on a project basis. The head of this group, called a Project Engineering Director, is provided with key design, test, and performance evaluation personnel. He reports to a program director who has responsibility not only for the immediate program but also for follow-on work in the same general area. The Program Director reports to the Director of Engineering and through him to the Manager of A.C.'s Milwaukee operations. The Program Director's staff in the fall of 1963 numbered some 375 people in total, although by no means were all of these scientific and engineering personnel. It is thus apparent that while Titan II absorbed far more scientific and engineering manpower than did NTDS, the number of individuals who could be identified as having made major contributions to the program was still relatively small.

2 *Background, Education, and Tenure*

Again, as in the case of NTDS, the overwhelming preponderance of the key personnel in each of the four organizations studied were technically trained and had considerable technical experience.

All but two of the 21 key officers identified at BSD had bachelor degrees in engineering or science. Eight had master's degrees in these fields, three had M.B.A.'s, and one a Doctor of Science degree. The educational background of the STL key personnel is even more impressive. Of the 15 key individuals identified all had bachelor's degrees in science or engineering and nine had Ph.D.'s in the same fields. An additional man had an M.S. and four more had taken graduate work in scientific or engineering fields.

In contrast, of the 18 key individuals at Martin, although all but one had bachelor degrees, only three had advanced degrees. All the eight key individuals at A.C. held bachelor's degrees in science or engineering; one had an M.S. and two held doctorates. Four more had done some graduate work but held no advanced degrees. (The A.C. group includes Dr. [formerly Col.] Blasingame, who is also listed among the key individuals at BSD.) Of the six M.I.T. Instrumentation Laboratory personnel, three held doctor's degrees, one a masters, one a bachelor's degree, and one held no degree, although he had attended college.

Exclusive of the M.I.T. personnel, the 61 key individuals held a total of 55 B.S. and three B.A. degrees, 13 in electrical engineering, 12 in mechanical engineering, 11 aeronautical, six in physics, four in mathematics, and the rest scattered or unspecified. Of the 58 bachelor degrees held, no more than three came from one university. Michigan and Texas A&M had three graduates; Penn State, M.I.T., Wisconsin, UCLA, Colorado, Carnegie Tech, Georgia Tech, NYU, California, and West Point each had two, while 31 institutions, some of them obscure, had one graduate each. The 12 doctoral degrees were more concentrated; three each were from M.I.T., Michigan, and UCLA.

It is interesting to note that the ages of the key individuals on the government team (BSD and STL) are somewhat closer to those of the industrial team (Martin and A.C.) than was the case in NTDS. Based on data on year of B.S. degree, the average age of the BSD key individuals was 39-40 years in 1960; for STL, 38-39 years; for Martin, 37-38 years; and for A.C. 36-37. Nevertheless, weapons development is clearly not an old man's game. Out of 60 individuals for whom ages can be computed, only one was 50 or more in 1960 and out of 25 at Martin and A.C., only four were 40 or more.

The tenure of these key individuals on the Titan II program appears to have been relatively long, although the comparatively short development span of the project perhaps makes this inevitable. There are severe difficulties in counting tenure on this project, since at BSD, STL and Martin, Titan I and II personnel were somewhat scrambled. Further, although Titan II reached project status in 1959 and went operational in 1963, a good deal of work on its major components was carried out in prior years. At BSD, key personnel had some association with the project for an average of 56 months, several of them for the entire span of the project. The first project officer held office for 36 months, the second for 28, while the incumbent has been associated with the program for 60 months. At STL the average tenure is 32 months, at Martin 27 months, and at A.C. 35 months. At Martin there has been only one program director, but two technical directors. Perhaps the M.I.T. key personnel have had the longest association with the project since four of the six have been associated with the program in some form from its inception to the present time.

It is interesting to note the previous jobs of scientific and engineering personnel in both government and industry teams as a measure of whether their experience on the

Titan II project appeared to be a logical step along a useful career progression. The previous assignments of the BSD personnel seem to lead logically to their Titan II assignment. For the most part they had held previous assignments in a SPO, in a research and development position, or had attended graduate school. The subsequent assignments of those no longer with the project seem equally apropos, except for those who retired. Much the same thing can be said of the STL, Martin, and A.C. personnel.

3 *Project-Management Organization*

Despite the fact that Titan I and II programs were sometimes combined for management purposes, the project has, nevertheless, been characterized at both the government and industry levels with a relatively high degree of centralized control and vertical project organization. To what extent the success of the program can be traced to this organizational pattern or to what extent it had an impact on the number and utilization of the scientific and engineering manpower devoted to the program cannot be determined with any degree of precision. But the fact that the project became operational in a very short period, and with relatively small excess costs over targets, is almost certainly a partial reflection of this organizational pattern. A vertical project structure was, of course, the standard pattern under which BSD ran its major missile projects. The combined Titan I and II office varied from about 70 to about 140 personnel during the development of Titan II.

But while BSD believes in a strong project office, with clear-cut responsibility and control residing in the Systems Project Director, it has strong functional groups in such areas as propulsion, communications and electronics, and guidance. The SPO draws heavily and frequently upon this scientific and engineering talent. A rough estimate of the ratio of scientific and engineering man-hours spent on Titan II by project versus functional area personnel is 40-60. This number varies considerably with the stage of development, and the project ratio is probably considerably higher at BSD than at most other AFSC Divisions. In short, while BSD is project-oriented, this implies neither a downgrading of the functional staff nor a duplication of scientific and engineering manpower.

At STL, there is a comparable arrangement and a comparable ratio of project to functional scientific and engineering input.

The early organization at Martin consisted essentially of a project-coordinating office superimposed on a functional organization. The Titan II Technical Director within the Engineering Division had a small staff, limited authority within the Division, and no authority to direct and control the funds or personnel of other Divisions. This office as strengthened in August 1962 when the Technical Director was given system-engineering responsibility, and its strength has gradually increased to between 60 and 65 personnel, of whom 40 are systems engineers. This added responsibility was urged on Martin by both BSD and STL. The current manning of the project office is about 10 per cent of the total scientific and engineering manpower on Titan II. It may be noted that the Martin Titan III office is still bigger (150-180) and has considerably more authority and responsibility.

The project-management structure at A.C. has already been briefly described. Despite the claims of the company that a vertical project-management structure is costly, the A.C. Titan II program office has relatively more people in it than any of the other offices thus far described, including about 75 per cent of the A.C. scientific and engineering personnel working on the project. Although the Titan II Program Director reports to the Division Manager through the Director of Engineering, he seems to have no difficulty in getting full cooperation from the Divisions of the company.

Unique features of the A.C. structure have been its close working relationship with M.I.T. on Titan II, its various experiments to work out the difficult transitions between advanced design, design engineering, and production, and the assignment to the Project Director of responsibility for developing and securing down-the-road projects. The first item is discussed in the next section on pre-contract scientific and engineering efforts. The problems of transitioning from laboratory to production line, although not necessarily confined to Titan II, may be described as follows: In 1959, A.C. research and development work was divorced from production and located primarily in the Boston and Los Angeles laboratories, where there were large numbers of available research and development personnel. It first tried to have its laboratories produce a complete design of the equipment, through drawings—a package that was then handed to production. This pattern was less than satisfactory. It then experimented with a system under which a small group of Milwaukee development and production engineers were remoted to the research and development laboratories to follow development and to bring back a producible package. This system worked fairly well, but the Milwaukee engineer cadre found it highly unattractive. Current thinking is to remote a still smaller group of Milwaukee engineers at a laboratory, but to draw the design back to Milwaukee sooner and "finish it" for production there.

Reference has previously been made to the fact that A.C. Program Directors have the responsibility of developing and securing follow-on business in their general areas. While A.C. feels that the better scientific and engineering personnel are not unduly concerned with security, but rather with the interest of their tasks, nevertheless the rapid pace of most modern systems makes follow-on business essential if the project office nucleus of scientific and engineering personnel is to be held together. The addition of new business responsibility to the Program Director's current responsibilities makes him the focal point for both the current and the prospective activities of his team. To what extent it distracts his attention from current problems is not known.

4 *Pre-Contract Scientific and Engineering Effort*

As previously stated, the early stages of Titan II consisted of a series of applied research projects. These efforts began in mid-1957, whereas the STL memo proposing a Titan II did not come until November 1958, and OSD program approval not until late 1959. But, well before OSD program approval, extensive efforts at source selection had been undertaken by BSD-STL, system definition had been completed by STL, and some design work undertaken with help from personnel working on the Titan I contract.

As early as March 1959, meetings at STL and Martin/Denver had refined the systems configuration. During the winter and spring of 1959, some doubts were voiced by the government team as to whether Martin should be given program-integration responsibility. There were, at the time, some problems connected with the Titan I test program, and there had been some unhappiness with the Martin/Denver management. But by mid-summer these doubts had been resolved, and it had been determined to retain Martin. The decision apparently rested on the Martin experience on Titan I and the substantial scientific and engineering groups that would be useful on Titan II. Additional reasons were that the two high-risk subsystems had been assigned to others; there seemed to be relatively few technical unknowns; and Martin/Baltimore was available for technical and management back-up.

Firm data on the amount of scientific and engineering manpower devoted by Martin to Titan II during 1959 (essentially the pre-contract period) are not available. It is estimated that 10-12 scientific and engineering personnel worked on the configuration definition through March 1959, and that the team built up during the balance of the year, so that, at year-end, there were approximately 50 scientific and engineering personnel aboard. A rough estimate is that the pre-contract effort absorbed 30-35 man-years of effort. This probably does not include a considerable amount of time spent on the program by top Martin management.

The situation at A.C. with respect to pre-contract effort was quite different. A.C. was selected to produce the Titan II inertial-guidance system, not because the Air Force believed that it had outstanding research and development capabilities, but because A.C. seemed to be the most likely candidate to translate the inertial-guidance concepts and designs developed by Dr. Draper at the M.I.T. Instrumentation Laboratory into operational hardware. A.C. had extensive experience in the production of bomb-sights, bomb-nav computers, and in the mid-1950's had produced the guidance system for the Thor. In the early 1950's, it had developed a close working relationship with the M.I.T. Instrumentation Laboratory in connection with this program. But, through 1956, A.C.'s emphasis had been on production, not research and development. Late in 1958, the company began a concerted drive to develop its research and development capability, in large measure using company funds. In early 1959, it hired Dr. Shea from Bell Telephone Laboratories to organize an advanced research and development group. Dr. Shea was the team leader of the group that developed the winning proposal for the Titan II guidance system. Throughout late 1958 and most of 1959, there was close coordination between M.I.T. and A.C. At that time, the Air Force had decided to bring the Draper inertial-guidance system out of the laboratory. In April 1959, A.C. received a contract for a guidance system to be used as a back-up for Titan I. This system was transitioned to Titan II following OSD approval of the Titan II program in November 1959. The Air Force had issued RFP's for this system to three bidders, including A.C. But the real source selection was that of the M.I.T. guidance system. Once that decision had been made, the selection of a contractor depended in part on which one could work best with the Instrumentation Laboratory and who was available. A.C. scored high on both counts, and had the additional advantage of having recently strengthened its research and development capability.

No firm data are available as to the level of scientific and engineering manning involved at A.C. prior to the April 1959 award, or for that matter for the remainder of 1959. In the pre-April period, it could only have been 20-30 individuals, and perhaps fewer. By the end of 1959, the number of scientific and engineering personnel assigned to what had by then become Titan II work was approximately 300.

5 *Pattern of Build-Up and Stand-Down of Scientific and Engineering Personnel*

As in the case of NTDS, it is difficult to tell from plots of scientific and engineering personnel assigned to the Titan II project whether the numbers represent efficient or less-than-efficient utilization of such personnel. In the following table the approximate scientific and engineering manning levels for STL, Martin, and A.C. are shown at six-month intervals from January 1, 1960 to November, 1963.

	STL*	Martin—All Div.	A.C.
Jan. 1, 1960	178	100	300
July 1, 1960	225	1200	400
Jan. 1, 1961	238	2000	525
July 1, 1961	243	2500	500
Jan. 1, 1962	248	2700	500
July 1, 1962	257	3300	400
Jan. 1, 1963	235	3300	350
July 1, 1963	230	2750	300
Nov. 1, 1963	218	2600 (Sep.)	240

* Includes Titans I and II

Space Technology Laboratories

Because the Titan I and II SPO's were merged, except for a brief period, it is not possible to tell the exact numbers of STL personnel working on Titan II. The pattern, however, has remained remarkably stable, and has only recently begun to drop off. One factor that has tended to hold the numbers up is the Titan II up-date program, recently inaugurated.

Martin

The figures for Martin in the preceding table are for scientific and engineering equivalent man-months of work, rather than for personnel assigned. These numbers may be compared with the total manning of the project (scientific and engineering, and other) which reached a peak of 16,500 man-months equivalent in October 1962, and then declined to 13,000 in September 1963. The figures in the table also include scientific and engineering personnel who were not in the Denver Engineering Division, such as those working on the production aspects of the project. In contrast to the peak equivalent man-months figures in April 1962, personnel actually assigned to the project in the Denver Engineering Division, which was primarily responsible for development, peaked in August 1961 at 1,240, remained very stable until February 1962, and then began a gradual decline to approximately 600 in September 1963. The various sub-areas of these Engineering Division personnel show markedly different patterns of build-up and stand-down. For example, the electrical group rapidly built to a peak of 540 in February 1962, then declined steeply to about 95 in September 1963. The structures group peaked at 240 in February 1962, then declined slowly to about 85 in May 1963, after which it rebuilt to 115 in September 1963. The propulsion group peaked in November 62, and then declined slowly. Given the fact that Titan II was still undergoing tests while in production, it cannot be concluded that the stand-down was too slow. And a judgment as to the reasonableness of the absolute numbers of personnel would require an extremely detailed analysis of individual section tasks and manning.

A.C.

Over-all figures for scientific and engineering personnel assigned to Titan II by A.C. show a relatively flat pattern. Because of the April 1959 contract for the Titan I back-up guidance, which became the guidance for Titan II, A.C. was heavily manned at the time of OSD program approval in November 1959. Its peak manning came in mid-1961. The stand-down appears to have been gradual, but it cannot be concluded that it was unreasonably so.

6 *Stockpiling and Borrowing*

From the data collected, it is impossible to conclude that there was "stockpiling" on the Titan II program. In part, the program moved too quickly for much stockpiling to have taken place. While the stand-down of scientific and engineering personnel in certain cases appears to have been quite gradual, it must be remembered that testing was still going on throughout the period covered by the study, and that in mid-1963 the Titan II up-date program was initiated.

There clearly was some borrowing or sharing of scientific and engineering personnel, especially from or with the Titan I. But, given the stage of development of Titan I at the time that Titan II was started, it is probable that the sharing was beneficial to scientific and engineering personnel utilization.

7 *Brochuremanship*

The interviews did not indicate any excessive degree of brochuremanship on the project, perhaps largely a reflection of the source-selection process.

GOVERNMENT'S IMPACT ON CIVILIAN RESEARCH AND DEVELOPMENT MANPOWER: AN INDUSTRIAL VIEW

Augustus B. Kinzel [*]

This report summarizes the conclusions and discussions of a panel of industrialists, concerning specific aspects of the government's impact on civilian research and development manpower.

CONCLUSION ONE

The current high levels of individual and corporation taxation, government procurement policies, and restrictions on foreign investments have greater inhibiting effects on the civilian economy than does the current degree of availability of technically trained manpower.

Private enterprise and educational institutions, working under the pressures and forces of our inherently flexible economic system, can and will meet any foreseeable problem of technical manpower imbalance, provided the federal government moderates further expansion of government-sponsored research and development. Exercise of constraint by the Federal Government in its own spending can provide a total economic atmosphere in which those concerned with educational, industrial, and scientific responsibilities will be able to meet the situation. The way in which the problem is met may or may not result in optimum performance, depending on the severity of the problem. Such optimum performance relates to the degree of training and quality of the technical personnel employed.

CONCLUSION TWO

No general or acute shortage of engineers currently exists; it has generally been possible to obtain the scientific and engineering personnel needed to conduct civilian research and development, although at greatly increased dollar cost.

Difficulties are being encountered nationally in connection with research and development management personnel and in a few special fields such as mathematics. There are also local difficulties in many specialties. There is a shortage of the very best people, but this has almost always been true. The shortage of the best always becomes more apparent when total demand is close to total supply. The majority of the panel members reported that college-level recruiting results during 1963 have been more favorable than

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in recent years and, in fact, have been satisfactory. This could be of particular significance, since 1963 is the first of three years of major increase in projected scientific and technological employment by the National Aeronautics and Space Administration and its contractors.

CONCLUSION THREE

There will be an increasing need for more people with scientific and engineering training as our society becomes more technologically oriented.

Since enrollments in science and engineering have not been increasing to meet emerging requirements, the increase will have to come from larger enrollments in four- and five-year engineering schools and two- and three-year technical institutes, and from greater numbers of graduates with scientific training in chemistry, mathematics, and physics who will be willing to devote such knowledge to applied scientific and engineering pursuits. The problem will be aggravated if National Aeronautics and Space Administration and Department of Defense activities increase beyond levels now planned.

CONCLUSION FOUR

The panel feels that there is a deficiency of information concerning the precise nature of our national technical manpower resources and that the commendable efforts to provide better information should be encouraged.

The National Academy of Sciences, the National Science Foundation, the United States Department of Labor, the United States Bureau of the Census, the Scientific Manpower Commission, the Engineering Manpower Commission, and others who have already done much in this area should be encouraged to review and further improve their criteria. It is axiomatic that any engineering or scientific approach requires the best facts economically available. It is important that any statistical examination of our technical manpower resources should include an appraisal of quality. It is imperative that assumptions for numerical projections of employment and graduation trends be clearly validated with respect to research and development, and that such projections are not obfuscated by undefined use of the terms "research and development."

INDUSTRIAL PRACTICE AFFECTING THE UTILIZATION OF SCIENTIFIC AND ENGINEERING MANPOWER

Lawton M. Hartman

The aerospace and electronics industries, with which these comments are principally concerned, are characterized by (1) significant concentrations of scientific and engineering personnel, (2) substantial support for these personnel through government funding, and (3) an increasingly urgent need to respond well to shifting patterns and levels of this support. They are thus both central to the problem of utilization and atypical of industry generally. To the extent, however, that the management habits of these industries are the product of the general industrial scene in the United States, the following comments may apply to other industries as well. They should not be construed as referring to any specific corporations or reflecting the position of any government agency.

There is genuine concern throughout industrial management about the problems of effectively utilizing scientific and engineering manpower. There is also a common belief that definitive doctrine on the subject does not exist or is not comparable with that prevailing, for example, in financial or production management. After a generation of intuitive platitudes concerning leadership, supervision, and benign personnel practice, such broad areas as creativity, motivation, group dynamics, organizational behavior, and interpersonal communications remain today in the forefront of research in the social, behavioral, and management sciences. Thus these comments can represent only an attempt to discern in the elementary logic of the situation several patterns that deserve examination.

A general attitude, shared by many critics of industrial practice, appears to be that an inherent conflict exists between a corporation and the technical community, that somehow a corporation is or should be a patron of creative endeavor, and that the loyalties of technical personnel are directed largely to themselves or their profession rather than to the organization

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that supports them. It is a thesis of this paper that these three views (1) are concerned with effects rather than causes, (2) stem from a distorted picture of the corporation, the technical community, and the scientist or engineer (considered as a human being and an employee within an organization), and (3) apply equally to other types of institutions within which scientists and engineers work.

1 THE CORPORATION

Under the free enterprise economy of the United States, the primary responsibility of the corporation is to its owners. Its primary objective is survival through the optimization of profit margins and return on investment. It achieves this objective through the production and sale of goods and services within a more or less competitive market. It accomplishes this production and sale through the economic use of its resources, among which are materials, tools, and personnel. As in the case of any resource, therefore, appraisal of the utilization of scientific and engineering manpower should be made within this perspective. There are three classes of relevant questions:

(a) Selection of resources

Are the appropriate types of scientists and engineers assigned to the task? Are they over- or under-qualified? What tasks suffer from their assignment?

(b) Maintenance of resources and inventory control

Is there an appropriate cadre of scientists and engineers to undertake the task? Does the assignment contribute to their development or to their obsolescence? Is the assignment a diversion, or is it part of the normal professional activity of the individual? Are there adequate educational and professional opportunities to maintain or enhance knowledge and skills? Is the working climate conducive to the effective use of these skills? Is there excessive turnover and replacement of personnel?

(c) Utilization of output

Is there economic or market justification for the use made of resources? Is there a waste of professional effort?

As an example that is frequently cited, it cannot be assumed from the outset that "stockpiling" and "brochuremanship" are to be avoided at all costs. The former is simply an aspect of inventory control, the latter a marketing or utilization device that can be effective. Both can and should be appraised in any specific case within the context of the types of questions posed above. It is certainly true that some corporations maintain at times an inventory of scientific and engineering skills in excess of that required for current or anticipated business; it is also true that some corporations misuse these skills through excessive assignment to brochure or proposal writing or to other tasks where lesser skills may suffice. But these are only two of a long list of examples of managerial malpractice which affect the utilization of scientific and engineering manpower. They are not necessarily characteristic of industry.

2 NEED FOR A TAXONOMY OF SCIENTISTS AND ENGINEERS

A distinguished scientist recently stated that "engineers are the labor class of the future." In this remark he was referring to the continuously rising level of requisite skills to maintain the economy; as a scientist he was simultaneously recognizing a basic distinction within the skills of the class of technical personnel. Just as there is a tendency to refer to technical work as research, research and development, science, technology, engineering—terms that are used interchangeably by technical and non-technical personnel alike in budgetary and policy discussions—there is a similar tendency to lump all manner of technical skills into an ill-defined class of "scientists and engineers."

(a) A systematic review of the utilization of scientific and engineering manpower in industry necessarily implies the recognition of a broad and complex spectrum of personnel, ranging from technicians, draftsmen, and engineering assistants to senior professional scientists and engineers. This spectrum results from a wide range of parameters: education and general intellectual preparation, age and maturity, orientation toward working in project groups or on individual assignments, nature and breadth of technical or other skills, nature of output with respect to creativity or productivity, personality factors of leadership and communicational skills.

(b) Without the traditions of a taxonomy based upon individual differences rather than similarities, there has developed throughout industry a vast egalitarianism that has seriously affected utilization. New professional employees are all "engineers." Initial compensation reflects age and highest degree received, not ability or quality of education. All job descriptions look the same. Annual salary adjustments peak sharply around a common percentage. The working day is 8:30 to 5:00; deviates are "late" or "goof off." Office and laboratory design follow the convenience of the architect and the air-conditioning system. Provision of technical libraries follows the needs of the lowest common denominator. Scientists and engineers are subject to "retreading." And so on through an enormous list of detailed administrative practices that have the common effect of minimizing individual differences, stifling creativity, and erecting irrelevant gods of conformity and getting-along-with-people.

(c) Contributing to this homogenization have been the advent of the "project team" and the notion of the creativity of the group, the financial domination of massive programs under the name of research and development in which scheduled progress is monitored by a computer, and the time-honored practice of according privilege by status in the organizational hierarchy. Correspondingly, there is a frequent failure by both corporate and technical management to place a premium on quality achievement by the individual. The premium is placed on productivity—technical or verbal—and the resulting permissiveness with respect to standards of excellence becomes a central feature of poor utilization. But the detailed and objective appraisal of utilization, in terms of selection and maintenance of resources, noted in 1(a) and 1(b) above, will remain difficult without a viable classification of "scientific and engineering manpower."

3 ISOLATION FROM THE SOURCES OF MOTIVATION

Of fundamental significance to the problems of utilization are a number of apparently unrelated management and organizational practices which, taken together, serve to erect a barrier between the scientific and engineering personnel and the corporations they serve. These are characteristic of large organizations. A well-known electronics executive recently commented on the "Mach 1" type of barrier that a small firm must pass through and survive if it is to continue growing. The barrier corresponds to a sales volume of perhaps $1-5 million annually, and it is interesting to note how many small firms in the electronics industry appear to stabilize around this size. Beyond this point the firm must develop new kinds of structure, and the barrier may represent the size at which personal relationships must be supplemented by organizational relationships. It could be instructive to compare the utilization of scientists and engineers in small and large corporations. The present discussion is concerned with the latter. There are four principal aspects:

(a) *Corporate Objectives*

Apart from the central objective to maximize profits, there is frequently lacking a clear corporate position on business purpose: nature of the business, diversification policy, balance of short-term and long-term goals, growth objectives, balance of commercial versus government business, specific need for creative output, and related matters. Even where such policies exist, within the corporate executive group, there is too often a failure to communicate these objectives throughout the organization, either because of a lack of confidence in the professional personnel of the corporation or, probably more frequently, a lack of awareness that such understanding can play a central role in the motivation to creative achievement. As a substitute, there are formalized statements of corporate charter, carrying about the same conviction as the annual report, "pep talks," and periodic formal visits, quarterly or annually, to laboratories and engineering operations. For senior professional personnel, this patronizing insistence on caste distinctions (they have been referred to as the "non-competing classes" of industry) can have a deadening effect, rather than one of inspiration, and serves to emphasize differences within the organization rather than unity of purpose and common goals.

The obverse is also true, for good utilization of scientific and engineering manpower is closely interwoven with the success of that growing class of corporations that are based on technology and innovation. Where the technical input to policy formation is inadequate, goals become unrealistic, short-term objectives tend to predominate, risk-taking becomes gambling, and sound bases for growth give way to opportunism.

(b) *Corporate Planning*

For many corporations, planning and policy formation constitute staff adjuncts of the president, and thus reflect strongly the professional background of the president. As integrated functions of the business, bringing together the skills and experience of the financial, technical, marketing, manufacturing, and personnel executives—and continuing the process throughout the organization with the active participation especially of the top grade scientific and engineering personnel—for the common purpose of solving the business problems of the corporation, meeting its objectives, and setting the course for the future, it remains a new concept in many corporations. Integration and policy formation are characteristically provided by the president personally or by the general managers of decentralized divisions. Thus research and development management is frequently in the position of selling rather than participating. The corporate office publicly acclaims research and development achievement, jokingly acknowledges its lack of technical understanding, and specifically avoids involvement in the technical planning and evaluating process. Again, a degree of isolation of the scientific or engineering function can result, with the related effects of poor utilization of technical output and diminished motivation for creative effort.

(c) *Diversification by Acquisition*

Most corporations in the aerospace and electronics industries are aware of impending deceleration of government support of research and development, of actual or threatened excess capacity in the industry, of the disappointing "spillover" into the commercial economy that has occurred, and of the need to diversify for purposes of stability and even survival. They are somewhat less aware of their lack of marketing skills applicable to commercial competition. They are still less aware of the enormous technical, creative, problem-solving resources on their payrolls. Rather than attempting to build commercial marketing capability, to offer scientists and engineers broad creative outlets over a wider business base, or to build new businesses through the normal processes of risk, many companies choose to acquire another company, either to provide a diversified financial investment base or to provide a ready-made outlet for gadgets, which have come into being accidentally or as by-products of other work, and which they are unable or unwilling to exploit within the parent organizations. This becomes a third source of isolation of technical personnel—isolation from the exploitation of their own products and isolation from the technical problems and opportunities such exploitation generates.

(d) *Decentralization*

A fourth source of isolation of technical groups results from the "organization planning" process and the subdivision of the corporation into semi-autonomous businesses. This provides excellent motivation for the general manager of each business, but it simultaneously decimates the power of the technical resources available to him. The resulting barriers between technical groups, impeding the constructive interaction, communication, and cooperation between these groups, tend to impose linear rather than exponential growth curves of technical opportunity.

This organizational distribution of technical resources is opposed to the creation of centers of excellence. It leads rather to the fractionation of technical talent, loss of "critical mass" in specific technical disciplines, duplication of facilities, dilution of effort, and, in many instances, the duplication of overlapping and uncoordinated technical activity.

The same effect can be seen on a national scale as a consequence of the almost hypnotic preoccupation of many companies with the government as a sole or primary customer; many of these companies have felt impelled to achieve, or at least to claim, capability in as many technical areas as possible within the government sector. Again the result is frequently the formation of "centers of mediocrity," duplication of resources, and the dilution and impaired utilization of creative talent.

(e) *In Summary*

This phenomenon of isolation of technical groups—isolation from corporate management, isolation from other functions of the enterprise in the planning process, isolation from technical opportunities in the diversification process, and isolation from other technical groups through decentralization—may be the most important single factor adversely affecting the utilization of scientific and engineering manpower in industry. The conflict frequently cited as prevailing between the corporation and the technical man is generated by the corporation; it is not due to his advanced or specialized training, for he is first a human being as is any other employee; but he is forced to identify himself with something external to the corporation, and this function is provided by the technical community—through, for example, the professional societies, his network of acquaintances within the technical fraternity, or a university. An extreme example is provided by the sporadic appearance of the engineers' union.

4 THE FINANCIAL FUNCTION

An area that deserves considerably more attention than it has received, and which can fundamentally affect the utilization of many technical personnel, is the coordination of financial and technical planning. The issue is not the perennial mutual suspicion between the "long hairs" and the "bean counters," implicit in 3(b) above, although much could be done to improve this relationship to the benefit of both. It is rather the way in which a corporation funds its technical organizations and recovers the cost. It is an almost universal practice today to treat such cost as current expense and to write if off currently on sales. This is true *a fortiori* for cost-based government contracts, since only the recovery of current expense is allowed under the Armed Services Procurement Regulation and its counterparts in other agencies. The method is certainly appropriate for technical work associated with design, production, and test; it can work, however, to the disadvantage of research and development: when sales are up there can be pressure to augment the staffing of contract work; when sales are down there is pressure to write proposals and seek new business. Even more important, since cost competition does not permit wide variations in overhead rates, this method tends to force research and development into the periodicities of the business cycle, the government buying cycle, and other sources of business instability. In general, it tends to subordinate research and development to the short-term exigencies of the corporation.

A second method, commonly used for the development costs associated with identified commercial products, is adoption of cash-flow accounting, capitalizing the development costs, and amortizing over future sales. The method, although avoiding the effects of business fluctuations over the short term, may not be generally applicable to advanced technical work because of the artificialities associated with capitalizing the cost of failures, inherent in high technical risk.

A third method is to establish a corporate reserve, through a charge to current sales, thereby providing for stable support of research and advanced engineering operations. The danger is the potential isolation of the technical work from the rest of the corporation if it is separately organized, as discussed under 3(d) above. The opportunity is to relate financial planning, technical planning, and staff planning to the longer-range goals of the enterprise, and to appraise the technical work within this context.

5 CONCLUSIONS

The characteristic stability of organizations and habit patterns precludes any simple approach or early solution to the types of problems suggested here. As indicated at the outset, doctrine does not exist to provide for prescriptive remedies. There is here a clear challenge to management research, namely, to devise a way to synthesize an organizational structure that combines two successful, though opposing, traditions: (1) the decentralized, pyramidal, functionalized, procedure-controlled institution of the modern corporation, whose validity is attested by the economic strength of the United States, and (2) the unstructured, individualistic, innovative, person-oriented institution of science and technology, whose success is dependent upon the quality of the individual and his opportunities to communicate with his environment, technical or organizational.

Awareness of these problems must come first, and here there are encouraging signs. One school of business reports a "ground swell" of technical graduates seeking M.B.A. degrees. The major management-consulting firms now recognize the research and development function on their staffs, unheard of ten years ago. Similarly, management associations, journals of business management, administration, and economics, and symposia attended by corporate management are increasingly devoting time, space, and effort to these problems.

The situation has its origin in the phenomenal growth of research and development, especially during the past ten years. The problems have become most pronounced in the aerospace and electronics industries, owing to considerations of national security. It is here that the two traditions have met for the first time on something approaching equal terms. But industry generally, and with it a growing economy, will benefit from the solution.

MAN-MACHINE PARTNERSHIP IN INTELLECTUAL PURSUITS: A LOOK AHEAD

*Richard H. Bolt**

In the year 1980 and probably much sooner a study made on the utilization of manpower will differ drastically, at least in one respect, from any such study made today.

That study in the future will have to take into account, both explicitly and implicitly, an intimate partnership between man and machine in carrying out intellectual pursuits, including creative pursuits in science and engineering. New machines, with extraordinary versatility in handling information, will have made profound impacts upon man's selection of things to do, upon the ways in which he does them, and upon the means used to manage and coordinate his efforts.

The history of machines, from the wheel to the space ship, reflects man's progress in controlling nature and in supplementing and extending his own human capabilities. First he extended his physical capabilities, his muscle power, to plough his fields, to transport himself and his goods, and to industrialize his society. Then he extended his sensory powers, his vision, touch, and hearing, better to observe nature, to make measurements, and to communicate over large distances.

Today, in a third, broad stride, man is developing machines to extend his cognitive powers, his abilities to think and reason and interact meaningfully with huge amounts of information. Although this third era has only begun to show itself, already it commands our attention. Demonstrations of technical advances already made, as well as lessons from history, impel us to expect this age of machine-aided cognition to move from infancy to maturity in decades rather than centuries or millennia.

The development of hand tools spanned millennia, dating from prehistory. The harnessing of mechanical power, as in the form of steam, and the development of sensory extensions, from microscopes to radio and television, spanned the past few centuries. Invention, technology, and science build upon themselves; man's exploitation of them, consequently, progresses at ever increasing tempo.

Although Charles Babbage in 1834 described an "analytical engine" to help men do their "figuring," the technology needed to make the computer he foresaw did not appear until the 1940's. Then the digital computer came into being, owing largely to pioneering ideas put forth by John von Neumann.[1] Vannevar Bush, in "As We May

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[1] See, for example, J. von Neumann, "The General and Logical Theory of Automata," *The World of Mathematics*, Simon and Schuster, New York, pp. 2070-2098 (1956).

Think," *The Atlantic Monthly,* July, 1954, described the computing machine brought into reality and predicted for it a broader role than just helping man calculate. Fifteen years later, J. C. R. Licklider wrote his imaginative article, "Man-Computer Symbiosis," *IRE Transactions on Human Factors in Electronics,* March, 1960, which was followed quickly by scores of publications bearing directly upon machine-aided cognition.*

In this paper, then, we are dealing with a subject that has received direct, explicit investigation for only half a decade. Can progress made in so short a time warrant predictions concerning the outcome? The answer is yes, emphatically, in the opinion of persons closest to frontiers of this new field of research. This man-machine partnership, they say, will amplify enormously man's capabilities in carrying on creative pursuits, and will exert widespread impacts upon the utilization of manpower, especially of scientists and engineers.

Today, of course, we cannot spell out in detail what the impacts will be and when they will be felt. Evidence in hand suggests strongly, however, that almost no aspect of utilization will remain totally unaffected. The purpose of this paper is to sketch the evidence.

Machine-Aided Cognition

At the very outset we face a difficulty in talking about this subject: neither its name nor its scope has been defined in any generally accepted terms. Names that have been used to designate the subject, or parts of it, include: man-computer symbiosis, augmenting human intellect, on-line man-computer communication, synnoesis, computer-relater science, and other words and phrases. Without implying that our term is a preferred one, in this paper we use "machine-aided cognition," and occasionally, for brevity, "the partnership."

As some of the names cited imply, the subject of this paper relates to computers. Just how it relates deserves some comment here. Briefly, the progress made up to this time in evolving a cognitive partnership could not possibly have been made without the use of high-speed digital computers; for this purpose, computers are being used in certain ways that were not envisioned when they were designed; and in the future, the nonhuman part of the partnership may bear little resemblance to the computer we know today.

Computers were designed to calculate mathematical relations among numbers and perform logical operations using symbols. In the modern world, unless a worker is engaged in manipulation of physical materials he is engaged almost totally in manipulation of symbols. Further, computers for the most part have been used to carry out long and tedious but conceptually simple manipulations. The design of high-speed digital computers endows them with an extraordinary ability to perform mathematical and logical manipulations in amounts and at speeds that completely overshadow man's ability in these respects.

When man thinks and reasons, however, he generally uses words, sentences, and language that do not behave neatly like numbers. Further, the manipulations man performs on linguistic information usually are more subtle and complex than mathematical calculations. Here we are drawing two quite different distinctions between computation of the sort usually done on today's computers and cognition of the sort we shall be able to do in tomorrow's partnership. Today we use mostly numbers; tomorrow we shall use not only numbers but also words—verbal abstractions. Today we perform mostly simple, routine operations; tomorrow we shall perform not only simple operations but also operations that are more complex than any that today's computer systems and programs can handle.

The more important distinction, probably, is the one that concerns complexity. Advancing from numerical to linguistic communication will not be an easy step, but the reward is simply the one we gain from learning a foreign language: now we can communicate where before we could not. Once we have achieved linguistic communication with the machine, however, we then can develop an ever-expanding ability to handle complex processes of thought, and we can apply this ability to all spheres of intellectual endeavor, which, of course, involves a combination of two faculties, memory and association.

The sort of new complexity we can tackle, if we "take a machine into partnership"

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* Even Licklider's article was written within an intellectual environment made up of related concepts already put forth by several persons, including J. McCarthy, M. L. Minsky, C. N. Mooers, A. Newell, N. Wiener.

instead of simply using it from time to time as a one-shot computer, can be explained with the help of an analogy. Solving a problem is like making a journey. There are two distinctly different ways in which we can make a journey—say, from Boston to San Francisco. We can get into an automobile and set off along the highway, following at every intersection the direction-signs that were already in place before this particular journey began. This procedure, of course, depends upon the existence of an elaborate road network and system of signs which exploit and codify the experience of our predecessors, and, to that extent, the element of discovery is taken out of the journey.

At the other extreme, we may travel as the pioneers did, working our way westward toward a goal whose nature is known beforehand only in the most general terms (the Pacific Ocean). In this case, we have no set procedure or highway system: we must make our way from point to point, resetting our course whenever we crest a ridge and come in sight of the next stretch of countryside before us. In such a journey, we are continually being faced with the need to make fresh decisions as we go along, and it is—in the nature of the case—impossible to specify beforehand a detailed set of instructions that will guarantee successful and efficient completion of the journey.

There are two correspondingly different kinds of intellectual problems. There are those in which we can specify explicitly beforehand all the intellectual steps that must be taken if the problem is to be followed successfully through to its solution; and there are those in which, once again, we have to make our way from point to point, repeatedly taking new intellectual decisions in the light of things that are discovered only as we go along. Solving the first, simple, straightforward kind of problem is a standardized and routine operation. All intellectual work involving an element of discovery is of the second, more complex kind, and involves the making of decisions repeatedly and in succession, as the investigation proceeds. Each great discovery made in science, for example, may be viewed as a decision made at an important crossroad.

It is this sort of complexity with which the new generation of machine-aids to cognition is enabling us to deal. The first generation of computing machines was programmed and used largely for routine and standardized operations, comparable to a journey by highway along a route entirely predetermined. Hitherto, that is, machines have been used mainly for "batch processing," in which a completely determinate set of instructions is laid down at the beginning of computation, and there is no opportunity to vary the manner in which the machine deals with the input data in the course of its operation. Although variations are allowed for in some commercial operations, in which the program selects different branches depending upon the inputs received, even in this case all contingencies must be specified in advance.

In order to tackle the more complex kind of intellectual problem, in which we proceed from point to point, making fresh decisions as we go along, we must develop new ways of working with machines, so as to open up the possibility of repeated interactions between the machine and the user in the course of any particular operation. We must replace batch-processing with a more flexible partnership between man and machine, thereby providing for a sequence of decisions to be taken on route. We mean decisions among *unforeseen* alternatives.

The advantages of this new kind of procedure can be explained easily enough by extending our analogy. There are only two ways we can, in advance, lay down precise instructions for making the automobile journey from Boston to San Francisco: (1) by specifying explicitly, before the journey begins, which road is to be taken at every single intersection along the way, or (2) by requiring that at every intersection all the alternative routes are to be explored, one after another. We can follow the first procedure only if all the essentially creative work of exploration and mapping has been done already; the second procedure will no doubt be effective in the long-enough run, but it may be intolerably wasteful, and we shall most likely end up by surveying a great part of the United States before we actually reach the Pacific.*

Yet these are, in effect, the only alternatives batch-processing offers us. We can

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* Whether this second procedure is too wasteful depends, of course, on the speed and cost of the computer used. Also, economy can be increased by programming the machine to remember its successes and failures as it proceeds over any route it has seen before, or to recognize general features of the "map" that may have been described in the program.

either instruct the computer beforehand precisely how it is to proceed at every step (and this may involve guessing the answers to a lot of difficult questions, about which reliable information would turn up only in the course of solving the problem under investigation), or else we can set the machine to explore every single possibility as it turns up (and this, once again, is a highly wasteful procedure).

The new style of procedures for machine-aided inquiry, involving repeated interaction between the user and the machine, opens up a whole new degree of freedom in the solution of complex intellectual problems, and permits one to escape from the limitations of batch-processing. But we can gain the advantages of a "repeated interaction" only if we can resolve a major economic problem that such interaction poses.

An investigator who was in a position to monopolize a high-grade computing machine could, no doubt, break down any inquiry into a sequence of small steps, and proceed from point to point by orthodox methods—as it were, stopping his car at every intersection to consult his map afresh. But such a use of a computer would in practice be unacceptable: the machine would be effectively used for only a few milliseconds at a time, and would lie inactive after each step for minutes or even hours. An apparatus costing millions of dollars would thus be utilized for only a very small fraction of the time.

If we are to make repeated-interaction procedures economic, we must develop techniques by which *many independent users* or *teams of users* can operate in partnership with a single central machine *at one and the same time.* In a word, the price of repeated-interaction procedures is the development of a "multiple-access" computer. This is the new technical step upon which all machine-aided cognition, as contrasted with simple computing, fundamentally depends.

Progress in Machine Capabilities

The step required has been taken: during the past three years, time-sharing operation of computers has moved from concept, to laboratory demonstration, to prototype systems being used simultaneously by many users.[2]

Time-sharing in itself is not a new art: it is used extensively, for example, in telephone switching networks. What is new is the capability to provide man-machine partnership simultaneously to several users of one computer. Especially relevant is the multiple access to the computer's memory, as is reflected in the expression *memory-sharing* now coming into use. The key step has been the development of special programs that control the access to the computer.

An example of a large, multiple-access system now operating is the Project MAC system at the Massachusetts Institute of Technology. This system includes some 40 Teletypewriters (Model 35), which have access to an IBM 7094 computer in Project MAC and also to another computer of the same type located in the M.I.T. Computation Center. Placed in offices and laboratories throughout the campus, these Teletypewriters offer access to the system simply by dialing through the M.I.T. telephone exchange. Professors and students in many departments are using the system to carry on research on such diverse topics as solving mathematical equations, proving theorems, designing mechanical structures and systems, and making decisions in industrial management.

The system is connected to the TELEX network of the Western Union Company, and within months will be connected to the TWX network of the American Telephone and Telegraph Company. Access thereby offered to persons throughout the United States and in Europe enables the carrying

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[2] J. C. R. Licklider, and W. E. Clark, "On-Line Man-Computer Communication," *Proceedings Spring Joint Computer Conference*, Vol. 21, pp. 113-128, National Press, Palo Alto, California (May, 1962).

J. McCarthy, "Time-Sharing Computer Systems," *Management and the Computer of the Future*, The M.I.T. Press, Cambridge, Massachusetts, and John Wiley & Sons, Inc., New York, N. Y. (1962).

D. C. Engelbart, "Augmenting Human Intellect: A Conceptual Framework," Summary Report AFOSR-3223, Stanford Research Institute, Menlo Park, California (October, 1962).

J. McCarthy, S. Boilen, E. Fredkin, and J. C. R. Licklider, "Time-Sharing Debugging System for a Small Computer," *Proceedings of American Federation of Information Processing Societies*, 23 (1963).

G. J. Culler, and B. D. Fried, *An On-Line Computing Center for Scientific Problems*, Thompson Ramo Wooldridge, Canoga Park, California, Report MI-3U3 (1963).

H. Stommel, E. Fredkin, and M. Pivar, "Computer Compiled Oceanographic Atlas: An Experiment in the Man-Machine Interaction," *Proceedings of the National Academy of Sciences*, Vol. 50, p. 369 (August, 1963).

F. J. Corbato, et al., *The Compatible Time-Sharing System: A Programmer's Guide*, The M.I.T. Press, Cambridge, Massachusetts (1963).

out of several experiments, to provide experience in long-distance operation of time-sharing systems for machine-aided cognition. Already one scientist in Europe has used the system at M.I.T. through a trans-Atlantic telephone connection.

How many other time-sharing computers are in operation now? Perhaps five or ten, but the number is uncertain because experiments with new uses of computers are springing up faster than news about them can get around.

Most of the progress achieved thus far has come from the development of new programs for the computers. Some of the advances have appeared in the form of new devices, such as visual displays, that help give man an easier, more natural way of interacting with the computer. Not many changes specifically to aid machine-aided cognition have as yet shown up in the design and construction of the basic computer itself, although more such changes will find their way into computers in the future. Perhaps more relevant is the change in the balance among types of "hardware" used; proportionately more of it will be input-output equipment used in linking man and machine.

Advances made in computer programs, now usually called the "software," have been aimed at serving functions of several kinds. One function, mentioned earlier in this paper, is the provision of new language that enables the user to communicate more easily with the machine. Another function is the rapid switching needed to provide multiple access; any one user is hooked in for only a very short interval at a time, but the intervals recur so often that the user, in effect, has continuous access to the computer. Other programs manage the handling of data stored in the computer, call up bodies of information as needed, or assist a programmer in preparing still more programs.

Let us now look, in somewhat more detail, at a few representative systems (perhaps we should say sub-systems) that have been put together to serve man-machine cognition in certain ways. Although for the most part these systems are experimental ones, they already have led to practical results through use in activities such as planning, engineering design, research, and teaching.

First we mention two systems, developed independently, that link a computer to a designer engaged in planning. *Sketchpad*, developed at M.I.T.'s Lincoln Laboratory, puts before the designer a cathode-ray screen, like the face of a television set, flanked by a set of control buttons. With a light-sensitive pointer or "light pen" in one hand, the designer sketches a diagram, which may, for example, represent a small machine part or a complete office building. With the other hand on the control panel, he gives the computer the additional information needed to interpret the meaning of the lines he is sketching. The computer can help the designer in a number of ways: it can rotate the figure, change its size, display different cross sections, or combine it with other pieces drawn previously.

In doing its work, *Sketchpad* can put individual pieces together to form an assembly; combine several such assemblies together as sub-assemblies to form a higher assembly; and so on, until the entire structure is put together. Eventually the designer completes his first rough sketch. At this point the computer, using specific dimensions and scales specified by the user, takes over and produces on the screen an accurately scaled drawing with all relevant dimensions indicated. Then the designer can continue to interact with the computer in order to modify and improve his design.

Coplanner, a somewhat different system, is being developed by my colleagues for use in architectural planning. In designing a new hospital, for example, the architect might start by giving the system some relavant statistical data concerning operations in a number of existing hospitals, such as the number of patients served per day, the number of trips that doctors make between various parts of the hospital, and the flow of visitor traffic.

On its screen, *Coplanner* can display the data in any of several forms, such as graphs, tables, or bar charts. With the use of a light pen, the designer can modify the statistical distributions to make them apply more specifically to the particular hospital under consideration, or to project future requirements. Then the designer sketches a possible plan of the hospital, and instructs the computer, using the statistical data, to evaluate the hospital layout in terms of objective design criteria, such as communications efficiency, delays in serving patients, the number of doctors and support personnel needed, and so on. Working together, *Coplanner* simulates the assumed operations in the hospital and the designer modifies the layout, back and forth, until a suitable plan emerges.

Next we cite the use of computer-based systems in engineering design. New roads being built in Sweden, Norway, Finland, and Germany have been designed by engineers interacting with programmed aids developed by AB Nordisk ADB and the Swedish Board of Roads. Aids provided include computer-made movies that let you see "from the driver's seat" what it would be like to drive along roads you have designed. Recently this movie technique has received further development at the Bell Telephone Laboratories.

Stress, a computer program for use in the analysis of structures, is being developed in the Civil Engineering Department at M.I.T. *Stress* converses with the engineer in his own language; helps him analyze a large variety of structures; and carries on a dialogue resulting in successive modifications and improvements to the original design concept.

Machine-aided cognition is starting to play a role in fundamental research. At Thompson Ramo Wooldridge (now Bunker-Ramo), Culler and Fried have developed a system to help the scientist carry out mathematical computations. Seated at a console that includes display scopes and keyboards, the user develops his mathematics on a symbolic level, using any new symbols and operations he may need in exploring the mathematical problem at hand. When he embarks, the scientist may have no clear-cut idea as to how he can solve the problem. At any point along the road, he can ask the machine to display the partial results found up to that point. Then the scientist may continue to follow the route he has chosen or he may go back and try another approach. In actual use, this system has enabled the solution of some complex, previously unsolved problems in contemporary physics.[3]

As we can see, some of these systems resemble a fast, tireless laboratory assistant with an unlimited memory. And some of the systems being conceived or demonstrated promise to bring truly revolutionary capabilities to bear upon intellectual tasks carried out by planners, managers, physicians, lawyers, educators, writers, scientists, and engineers.

Although very large (and costly) computers serve as the central processors of information for many of the systems being developed, some of the new aids to cognition, such as *Coplanner*, operate in connection with small or medium sized computers. Each size has its advantages and disadvantages, which are being studied in several different organizations using computers of different size and kind. Larger machines can more readily provide multiple access by users in large numbers, and this more widespread use can help in defraying the high costs associated with the development of the auxiliary equipment and with the complex programs needed. Smaller machines, on the other hand, can be set up more cheaply and quickly to explore new approaches in early stages of conception; and can be enlarged later. As we have already noted, the future will see the evolution of computers specially adapted, in size, speed, and all other characteristics, to the special needs of machine-aided cognition.

Future Impacts upon Utilization of Manpower

We turn now to speculations based upon the evidence sketched in preceding sections and elaborated in many publications including those cited in the references. We try to visualize ways in which machine-aided cognition in future decades may affect the utilization of manpower, particularly scientists and engineers. Any or all of the impacts suggested could occur, but we shall not try to guess which ones will prove to be the more important or when the impacts will show up. Some of the impacts will be felt as benefits; others, as difficulties to be overcome. All the impacts will compel us from time to time to reassess the patterns of utilization.

Machine-aided cognition will increase the effective *supply* of manpower in research and, at the same time, will increase the *demand* for such manpower. The research scientist or engineer working in partnership with the machine will be able to carry out a given intellectual task in less time

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[3] G. J. Culler and B. D. Fried, "Plasma Oscillations in an External Field," *Phys. Fluids*, Vol. 6., No. 8, 1963, pp. 1128-1138.

than he would take working alone. Parts of his task automated, and thus speeded, will include searching the literature for information relevant to his research problem, checking the information for reliability and consistency, combining the information with new facts that he (in partnership) has found, plotting graphs and combining graphical data from several sources, and recording all the results. Helping the man carry out these relatively routine chores will not be the most significant contributions the machine will make, but it will save him a great deal of time. The time thus saved converts into an increase in the effective supply of research manpower.

What seems quite likely, in view of the motivational nature of highly creative people, is that the man will go on and do more research, make additional discoveries, and uncover yet more problems that merit research. He will increase the *demand* for more research personnel and for more assistants to help investigators work on the new problems.

More significantly, machine-aided cognition will give men some fresh *capabilities*, beyond those they possess when working alone: notably, in the study of complex processes, involving enormous numbers of variables and interrelationships. To return to our analogy of a cross-country journey, such extremely complex processes present one with many "crossroads," points at which one must make choices among alternatives that could not be foreseen except in the vicinity of the new choice-point. In such cases, man-machine partnership, with its continuous, on-line interaction, will bring its greatest rewards, and the analytical power of this partnership will gain in strength as we discover how the responsibilities may most effectively be divided between the man and the machine.

As a result, the ways in which scientists and engineers tackle their work will be greatly changed. The relative amounts of time they spend on different tasks, the kinds of problems they attack, the patterns of machine-aided collaboration among different persons: the whole *pattern of endeavor* in science and technology will be altered by revolutionary new equipments and environments.

Here the main effect will be an indirect one: machine-aided cognition amplifies the role of automation, such as machine tools, and the automation then replaces skilled and semi-skilled labor in large numbers. For example, certain systems, such as aircraft, already are being designed in part through the use of computers and automated instruments, which are replacing rooms full of draftsmen and months of routine handwork in the shop. In many cases, too, simulation based on the use of computer-based models enables one to dispense with the making and testing of large-scale, physical models of the system. Thus the net impact upon the pattern of endeavor will be a shift away from the more routine tasks and toward the more creative ones.

As the above discussion makes clear, widespread use of machine-aided cognition may bring with it severe *dislocation* of workers, at all levels within the labor force. Such dislocation probably will be most severe during earlier stages of adoption of the new capabilities. As experience in industrial evolutions has shown, the introduction of new capabilities tends to bring with it initial dislocations in labor; but these have usually been temporary, and in time man has learned to readjust himself to the new conditions. Perhaps, as we enter the age of machine-aided cognition, we can be more far-seeing, and take steps in advance to guard against at least the graver difficulties.

These difficulties will be of two kinds. On the one hand, the new capabilities will at once create heavy demands for positions requiring aptitudes in computer science and programming, and computer maintenance, and for the training of persons to use machine-aided cognition. Almost as quickly, however, many kinds of jobs will become obsolescent, as the need for technicians and assistants in many kinds of routine work vanishes. Even at professional levels, some fields of specialties may become redundant. This could happen, for example, in those branches of engineering where machine-aided cognition will permit systems to be designed and developed with but a fraction of the number of persons needed to do this job with conventional approaches. At this early stage in the new era, we cannot see in any detail precisely what, or how severe, the dislocations will be, nor what groups will be most affected; but we can see quite clearly that all these questions demand prompt study, which will have to be carried on in close consultation with the specialists who are pushing forward the technology of machine-aided cognition.

The *management* of science and technology will also be greatly affected, if only to accommodate the impacts already discussed: those having to do with time-saving, the solution of previously unsolvable problems, the shifting patterns of work, and the dislocation of workers.

The cognitive partnership has the power to increase enormously the efficiency of management at all levels of organization. In principle, all the computer centers in the country, or for that matter throughout the world, can be linked together through telephone lines and other communication networks, and this could make accessible to each individual all the information that is stored in all the centers. In principle, also, the new data introduced into each computer by every individual worker can be made immediately available to all other users.[*] In this way, all the persons working on a given project or within a given organization could be linked together, wherever they were geographically located.

When, for instance, an engineer, working at a remote location, completed his part of a group task, the results could immediately be put into the system and become accessible to all his collaborators at headquarters, including the manager of the group. So persons responsible for administering and managing group efforts of any kind can maintain an immediate, up-to-date watch on all the progress being made on the tasks of the group. This could greatly reduce the need for written reports and meetings, both of which today absorb a sizable amount of time in group projects.

Such procedures will demand clear-cut, logical thinking on the part of users. A system can be programmed to reject information that does not achieve specified standards of precision, and this information will have to be conveyed in a clearly-defined, standardized terminology. Thus, the cognitive partnership should reduce the errors and misunderstandings that so often creep into written and spoken communication. Nor need the results fed into the common pool of data be confined to reports in conventional language; the system can process, equally well, linguistic words and phrases, numbers, mathematical formulae, graphs, rough sketches of conceptual models, and even qualitative graphical representation of abstract ideas.

These new possibilities of cooperation will be particulary important in the design and development of large-scale, complex systems—e.g., in engineering and town-planning. In such cases the manager will be put in a far better position to coordinate the efforts of the group effectively, and to report back quickly to other members whenever a result obtained on one particular element in the system is incompatible with results previously obtained on other elements. At the level of an entire firm or large organization, similarly, a cognitive system will enable top management to keep in closer touch with plans and accomplishments of all divisions within the organization. Corresponding potentials will become available to the armed forces and government at the broader national level.

These new capabilities will, of course, carry with them grave responsibilities, and the moral issues so raised may be as difficult in their own way as those highlighted by the development of nuclear weapons. By his very nature, man will continue to expand his intellectual horizons and venture into the unknown. His new power to control nature will increase his power to control and to encroach upon the privacy of his fellow man. Every such new intellectual advance will carry with it a moral responsibility to use the new powers wisely. This applies to the development of machine-aided cognition as much as to any other new development. Man cannot resolve this issue of possible abuse of his new powers simply by preventing their development; instead, he must learn to live with these powers, to use them properly and so to grow in wisdom and moral sense.

The new man-machine partnership will increase the rate at which scientific and technical information accumulates, and thereby will create added demands for *storage, dissemination, and retrieval of in-*

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[*] We use the words "in principle" for a particular reason. Matters of privacy and security classification must, of course, continue to be respected in the future, not only by human beings and organizations, but also in systems of man-machine communication. Consequently, we expect that some of the information stored in the system will be made accessible only to certain specified users. For example, one system might contain all the information that flows in a hospital. Some of that information is held in confidence by attending physicians, because it contains private information concerning patients. It is quite feasible to design a hospital information system in such a way that confidential information can be obtained only by certain specified persons, such as doctors in charge, who will have to use some sort of code, perhaps similar to the way in which a bank vault is opened.

formation. At the same time, systems for man-machine cognition will automatically—we might say necessarily—contain the seeds of solution for the problems associated with the "information explosion."

Through linkages among all the machine systems involved, all recorded information, including the contents of all libraries, will become accessible to all users, no matter where they are. The word "accessible" here refers to the full power of the system to search, check, correlate, and display all relevant information to the human user. The system would, of course, contain such aids to information retrieval as automated card catalogues, aids to bibliographic search, display and print-out capabilities, and all the other appurtenances of the automated library of the future.[4]

Two particular possibilities merit comment here. First, through the use of associative memory, the system will retrieve items of information related to a specified topic but expressed in different ways—specialized jargons—used by workers in different fields. The computer memory is organized in such a way as to associate all items that resemble each other in specified, substantive respects no matter how they are put into language. Second, the system will seek out the user instead of waiting to be consulted. If Scientist A is interested in a certain topic, the information system will recognize the relevance of a new contribution reported by Scientist B, and will relay it directly to Scientist A. Both of these new capabilities, associating similar items and initiating the dissemination of new information, will also find valuable uses outside of science—for example in business management, in which decision makers often require up-to-date information from many unrelated sources.

Improving our ability to retrieve information, in the several ways mentioned, might alone justify all the investments of men and dollars now being made or contemplated in the development of man-machine systems to aid cognitive processes. But again we must emphasize that these relatively "mechanical" gains, speeding and expanding the search for information, are not the contributions that will in the long run be most significant for man's progress. Even more significant will be the creation of entirely new capabilities to deal with complex problems and those that enlarge our conceptual outlooks.

Finally, machine-aided cognition will impose new demands on *education and training,* while at the same time offering new aids to learning and teaching. Specialists are opening up exciting new possibilities faster than they can exploit them. One consequence is an acute shortage of persons equipped to advance the science and art of men-computer partnership. An apt statement of the situation is this:

"The demand for specialists in the field of computers and information-processing will be growing very fast, particularly if convenient access to computers is to be available to a much larger community of users. Computer designers and system programmers are already very scarce, and the present output of our schools is still inadequate to meet the demands of industry, government, and educational institutions."[5]

Even after the coming decade, during which the demand for more computer specialists will be especially acute, the need to expand the supply of these specialists will continue to be felt throughout the foreseeable future simply because machine-aided cognition promises to invade almost every aspect of man's creative endeavors. Already students in all the natural sciences are beginning to find a familiarity with computer techniques as important as knowledge of mathematics and physics. The acceleration of research and innovation by machine-aided cognition will intensify the obsolescence of knowledge, and thereby will increase the need for added education and training in all fields.

Yet we can see also—at any rate in rough outline—how the new techniques may enhance the capacity of the educational system to meet new demands. Already, teaching machines and programmed instruction, developed out of research in the psychology of learning, are beginning to provide useful new aids to education and training. Viewed in retrospect from the mid-1980's, however, these aids may appear as only the primitive beginnings of a new technology to aid in learning and teaching. For, as one can now

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[4] *Toward the Library of the 21st Century.* A report prepared for the Council on Library Resources, Inc., Washington, D. C. (March, 1964).

[5] Personal communication from R. M. Fano, Massachusetts Institute of Technology.

see, the major advances will come from the use of computer-based systems in which the student and the machine interact intimately.

In one system demonstrated recently in rudimentary form, a digital computer with a typewriter output gives a student a complex problem of study; e.g., a problem of medical diagnosis, in which an advanced student in medicine will be required to face the subtle difficulties of putting together many pieces of evidence, and must work his way to a reasonable conclusion about the likely ailment. A series of questions and answers, varying according to the student's responses, then leads the student to a solution of the problem. The system and the student thus carry on, in effect, a "Socratic" dialogue.

In these many ways, then, the partnership between man and machine may well give rise to new potentials for the utilization of manpower. Adding its logical and mathematical perspicuity to the imaginative insight of the human, the machine may make possible a level of cognitive process that in the past could be achieved only through a long and grueling process of trial and error—if at all.

Here we end our speculations and our sketch of the evidence and inferences on which we base them. We have omitted many important examples of progress already made. But the examples cited suffice to carry the message of this paper: machine-aided cognition offers new capabilities for helping man carry out his creative, intellectual pursuits; and these capabilities, now seen only in rudimentary demonstrations in the laboratory, within decades will move into the work environment and there will affect, in many ways, the utilization of scientific and engineering manpower.

ADDITIONAL READING

In addition to the references cited in the text, the following ones (which do not constitute an exhaustive bibliography) may be of interest to the reader who wishes to examine this subject in more detail.

I. J. Good, "How Much Science Can You Have at Your Fingertips?" *IBM Journal of Research and Development*, Vol. 2, No. 4 (October, 1958).

C. Strachey, "Time-Sharing in Large Fast Computers," *Proceedings of the International Conference on Information Processing*, Paris, UNESCO, pp. 336-341 (1960).

A. L. Leiner, W. A. Notz, J. L. Smith, and R. B. Marimont, "Concurrently Operating Computer Systems," *Proceedings of the International Conference on Information Processing*, Paris, UNESCO, p. 353 (1960).

S. Ramo, "The Scientific Extension of the Human Intellect," *Computers and Automation*, (February, 1961).

L. Fein, "The Computer-Related Science (Synnoetics) at a University in the Year 1975," *American Scientist*, Vol. 49, pp. 149-168, (1961).

M. L. Manheim, and B. F. Alexander, "The Design of Highway Interchanges," M.I.T. publication R 62-1 (March, 1962).

F. J. Corbato, M. Merwin-Daggett, R. C. Daley, "An Experimental Time-Sharing System," *Proceedings of the Spring Joint Computer Conference*, Washington, D. C., pp. 335-344 (1962).

L. S. Christie, "Computer Programming Standards in Command and Control," System Development Corp. Report TM-688, Santa Monica, California (1962).

A. Perlis, "The Computer in the University," *Management of the Computer of the Future*, The M.I.T. Press, Cambridge, Massachusetts, and John Wiley & Sons, Inc., New York, N. Y. (1962).

C. N. Mooers, "The Reactive Typewriter," *ACM Communications*, (January, 1963).

S. J. Fenves, R. D. Logcher, S. P. Mauch, K. F. Reinschmidt, "STRESS - A User's Manual," The M.I.T. Press, Cambridge, Massachusetts (1964).