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ABSTRACT

This report is intended to give an indication of the variety of careers available to persons with interest and preparation in the mathematical sciences. Each part focuses on a particular class of professions, with necessary training as well as the character of the work and general conditions of employment described. Parts I through V deal with five areas in which the application of mathematics plays a major role: applied mathematics and engineering, computer science, operations research, statistics, and the actuarial professions. Part VI deals with applications of mathematics to model building in other disciplines such as social sciences and biology. Parts VII and VIII are organized around the type of employer, with the first devoted to the teaching of mathematics at all levels and the second discussing the role of the mathematician in government, business, and industry. Part IX describes the value of an undergraduate degree in mathematics as preparation for a number of other professions not necessarily thought of as mathematical, such as business or law. In Part X, a list of references to publications and professional societies is given. (MNS)

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PROFESSIONAL OPPORTUNITIES IN THE MATHEMATICAL SCIENCES

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THE MATHEMATICAL ASSOCIATION OF AMERICA

Professional Opportunities in the Mathematical Sciences

Eleventh Edition

1983

THE MATHEMATICAL ASSOCIATION OF AMERICA
1529 Eighteenth Street, N.W.
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PROFESSIONAL OPPORTUNITIES IN THE MATHEMATICAL SCIENCES

A Report for Undergraduate Students of Mathematics

INTRODUCTION

This report is designed for students in secondary school or college, and their counselors or faculty advisors. It is intended to give an indication of the variety of careers available to persons with interest and preparation in the mathematical sciences. The report is written in several parts, each focusing on a particular class of professions, and describing the necessary training as well as the character of the work and general conditions of employment. As is the case with any committee report it is subject to the authors' personal biases concerning the present and future employment situation for mathematicians.

Parts I through V deal with five areas in which the application of mathematics plays a major role. Part I is devoted to the most traditional areas to which mathematics has been applied: physics and engineering. Part II describes the role of mathematics in computer science; the nature of the problems addressed, and the kinds of employment a mathematician might seek; Parts III and IV describe Operations Research and Statistics in a similar way. Part V discusses the field of Actuarial Science, a profession of long standing dealing primarily with problems related to pensions and insurance. Part VI deals with the application of mathematics to model building in other disciplines such as social sciences and biology. Parts VII and VIII are organized around the type of employer, and encompass a wide variety of mathematical specialties. Part VII is devoted to the teaching of mathematics at all levels, and Part VIII discusses the role of the mathematician in government, business, and industry. Part IX focuses upon the value of an undergraduate degree in mathematics as preparation for a number of careers not necessarily thought of as mathematical, such as business or law. Part X gives a list of references to publications and professional societies.

Changing times have dictated changes in the focus and emphasis of "Professional Opportunities in the Mathematical Sciences." The 1960's saw a remarkable increase in the recognition of the importance of mathematics in all areas of society and in the need for trained mathematicians at all levels. This trend has not been reversed, but it has been modified. Mathematical thinking and techniques of mathematical analysis are, if anything, more important than ever before in an increasing number of professional areas. While employment opportunities for teachers and researchers in pure mathematics declined in the 1970's relative to the supply, the need for well-trained people who could apply mathematical methods and ideas remained strong. The latter situation, at least, seems likely to continue. The tenth edition (1978) of this publication contained the new section "Opportunities in Interdisciplinary Areas," which is still highly relevant, and to this, the eleventh edition, we have added Part IX, "Mathematics as a Background for Other Professions."

It is important to stress the value of undergraduate training in mathematics, whether or not the student anticipates going on for a graduate degree in the mathematical sciences. As is pointed out in Part IX, a bachelor's degree in mathematics can provide entry to jobs in management, engineering and geology, and to graduate schools in business, law and Government, among others. There are also good opportunities for those seeking many of the more directly mathematical careers mentioned in this report, particularly if they have taken some courses in computer sciences and statistics. In a number of fields a master's degree represents adequate formal education. Sometimes when higher degrees are required for advancement there are opportunities to undertake further schooling while on the job. Of course, the amount of formal education necessary depends upon the job. For college and university teaching and for basic industrial research a Ph.D. is usually a requirement.

Several variables affect job opportunities for people trained in mathematics; regional differences and the relative economic position of private and public activities are among them. But in general the prospects at this time are very good for those with some flexibility. Women, Blacks, and Hispanic-Americans, who are underrepresented in the field, should be encouraged to pursue their talents and interests in mathematics. While the percentage of women in mathematical professions has grown, it is still very small. The percentage of the minority groups mentioned above is smaller still. Additional efforts are required to direct the aspirations of these groups into the mathematical sciences. Some publications intended for women are cited in Part X, the list of references.

This report is prepared by the Committee on Advisement and Personnel of the Mathematical Association of America. The members of the Committee who contributed to this edition were Bernice Auslander, University of Massachusetts/Boston (chairperson and editor); Jane Day, San Jose University; Gordon Raisbeck, Arthur D. Little, Inc.; Martha Smith and James Vick, both of the University of Texas (Austin). The Committee owes a debt of gratitude to Alfred Willcox and the staff of the Mathematical Association of America and to the following members of the mathematical community, who also made contributions to the report: Linda Kime, University of Massachusetts/Boston; John E. O'Connor, Society of Actuaries; Richard D. Truesdell, University of Massachusetts/Boston; Henry Alder, University of California, Davis.

PART I: OPPORTUNITIES IN CLASSICAL APPLIED MATHEMATICS AND ENGINEERING

The most traditional role of the mathematician in a professional setting has been in the solution of problems arising from physical phenomena. From its very inception, calculus has been applied to laws of motion and to understanding the consequences of interacting forces. While the early applied mathematicians were necessarily physicists and engineers as well, the modern setting calls for the mathematician to serve as a member of a team of specialists, each bringing a particular talent to bear on problems.

In a broad sense, the applied mathematician is instrumental in designing and analyzing models of systems and in testing and evaluating performance. It is a characteristic of this field that the technical questions readily move across once clearly distinguished boundaries. Whether in research and development or in industrial production, the applied mathematician must interact with engineers, physicists, programmers, and other specialists. The common goal is to find ways to improve quality, reduce cost, and increase productivity. The analytical skills of the mathematician are particularly valuable in consulting for technical services or trouble shooting.

Recent mathematical research in combination with increasing computer sophistication has opened fields that saw little development in the past due to their intractability to classical analytic techniques. These include the solution of problems involving enormous numbers of equations, the numerical simulation of complex systems such as power grids, and the application of control theory and other mathematical tools to the management of traffic or industrial processes.

1. Education for Applied Mathematics. Preparation for a career in applied mathematics is discussed in the report from the MAA Committee on the Undergraduate Program in Mathematics (CUPM) entitled "Recommendations for a General Mathematical Sciences Program." The need should be stressed for a thorough background in calculus, linear algebra, ordinary and partial differential equations, probability, statistics, and advanced calculus. These courses should include some extensive use of computing, or they should be supplemented by appropriate courses in computer sciences.

Supporting work should include physics and basic engineering courses. Specific professional opportunities may require additional training in chemistry, biology, or geology. It is particularly the case in some research programs that preparation at advanced degree levels in applied mathematics is necessary.

Since the applied mathematician will often work as part of a team, communication skills are essential. The educational background must develop the ability to write clearly and effectively and to present logical and persuasive oral arguments.

2. Working as an Applied Mathematician. The tasks of the applied mathematician are as diverse as the constituencies served. The broad category of engineering disciplines is a rich source of mathematical problems. In the aeronautical field a mathematician may help to develop models for atmospheric flight including the analysis of performance in search of optimal trajectories. Biomedical engineers may rely on mathematicians when designing and interpreting theoretical models of chemical and biological processes. A mechanical engineer may require a study of heat transfer by conduction, convection, and radiation resulting from a gas turbine.

Many problems involve scientific or engineering data and the use of computer techniques to answer questions arising in research, plant operations, product distribution systems, inventory controls, and business system analyses. Mathematicians seek efficient and reliable computer programs for the numerical solution of initial value problems or special function routines capable of delivering accurate answers over a wide range of parameters. While the methods most frequently applied are based in ordinary and partial differential equations, there is an increasing involvement with probability, statistics, and computing.

According to the College Placement Council; in the Spring of 1982 the average starting salary for a mathematics major with a bachelor's degree was $21,100. The corresponding average starting salary was $25,300 for holders of master's degrees.

PART II: OPPORTUNITIES IN COMPUTER SCIENCE

Until a few years after World War II, very few persons were employed as mathematicians in non-teaching positions. Now many mathematicians receiving the Ph.D. degree and the majority of those with master's or bachelor's degrees, accept jobs in industry or government. Most of these jobs have been created by the phenomenal growth in the use of computer technology. A recent U.S. Department of Labor publication (Bulletin 2075) indicates that in 1978 about 430,000 people worked as computer programmers or systems analysts. The demand for computer scientists exceeds supply, especially for individuals with work experience or higher degrees. In 1980 there were 3,597 master's and a mere 239 Ph.D.'s awarded in computer science (National Center for Education Statistics, Earned Degrees Conferred, Annual Series).

Computer science is unique in some respects. It grew out of the union of science and engineering and forms a bridge between the two. The nation's universities reflect this dual nature. Some place computer science in engineering departments and others, in science or mathematics departments. Many universities have now created separate departments of computer science.

There are many professional organizations whose members deal with the use and applications of computer science. The two major ones are the Association for Computing Machinery and the Society for Industrial and Applied Mathematics. For additional names consult the American Federation of Information Processing Societies.

We shall concentrate here on those aspects of computer science holding much in common with mathematics.

1. Mathematics and Computer Science. Classical and modern mathematics can and do interact with computational mathematics in a variety of ways. Computational mathematics often makes extensive use of linear algebra. One important and widely used way is in the solution of systems of equations, usually linear systems. While many elementary college (or high school) courses teach that the inverse of a matrix of order n, if it exists, can be used to solve a linear system, this is not a good way to accomplish a solution with a computer. This method would generally involve n^3 operations for a system of n equations in n unknowns. For a system of equations involving a thousand equations and a thousand unknowns, this would represent roughly one billion multiplications or simliar operations. Methods have been developed using matrix algebra and other techniques from linear algebra that reduce this number to n^2 steps or fewer. This cuts the corresponding number of required operations to something less than one million. Not only does this require far less in the way of computer resources, but these methods also tend to reduce the round-off error inherent in all digital computer operations.

A great deal of time and effort is involved in finding methods of solution for systems of ordinary or partial differential equations. While many courses in differential equations are concerned with the existence of a solution, the computer scientist must be able to compute the solution. Frequently the methods will be iterative in nature. Thus two questions arise: Does the technique converge? How good an approximation does one desire? Computing time and accuracy are paramount in the consideration of techniques.

There is tremendous interest in understanding the logic of computation, both the logic of the program and the hardware. Currently there is some experimentation in "parallel" computers designed to do a number of simultaneous operations. The question of which computational algorithms are best adapted for this type of approach represents an area of active research.

In the organization of large data bases and in the problem of sorting such data bases, the use of graph theory is proving to be of inestimable value. Graph theory also finds its applications in the design of compilers and interpreters. Such applications are needed in the matter of information retrieval for users such as the Internal Revenue Service, the Bureau of Census, and other agencies of the Federal government, as well as for large corporations.

Numerical analysis is a major consideration in solving problems with computers. In fact, several of the previously mentioned topics are part of numerical analysis. (While consideration needs to be given to the existence of solutions or the likelihood that a given problem may in fact have a solution, there are computational complexities such as round-off errors, divergence, or instability of a proposed numerical method that are of equal importance.) Other mathematics-oriented computer areas are: mathematical programming, simulation, artificial intelligence, and computational complexity.

2. Working as a Computer Scientist. A mathematician with a bachelor's degree hired in computer-related work will invariably start as a computer programmer. The largest employers are manufacturing firms, banks, insurance companies, data processing service organizations, and government agencies. It is recommended that undergraduate mathematics majors include in their preparation at least three or four computer science courses.

At the master's level more opportunities are opened. There are three basic areas where jobs are available. (1) Teaching is open at high school and junior college levels for someone who can teach computer science and the mathematics associated with computer science. (2) The majority of governmental and industrial laboratories use computers: a large number of them have their own computers. New and more efficient methods for solving problems are in demand, and many places want to have their own in-house computer expert, someone who knows computers, people, and problems, and can use this knowledge to obtain results. (3) Perhaps the biggest employers in computer science are the "software" firms—companies whose business is to write programs for computer users. A major problem is to define and write programs that are easily modified and transported from machine to machine. This involves developing programs that are modular, self-documenting, and generally well-structured. This is a very profitable business in today's market and promises to continue to be. Advancements in computer hardware are appearing on the market at very frequent intervals and new computational methods are required to take advantage of the new capabilities. As a result, new programs and sometimes whole new ideas must be generated on short notice.

Some computer manufacturing companies employ doctoral level mathematicians. Several of the finest mathematical research laboratories in the country are at the major computer companies. These companies have formal courses, post-doctoral fellows, and in many ways conduct research as though they were universities. Mathematicians as well as computer scientists working at these laboratories are among the world leaders in the fields mentioned earlier. Likewise, some of the government laboratories have a major role in the production and coordination of computer mathematics. Similar positions are to be found in some of the many consulting firms dealing with operations research and the use of the computer.

The demand for Ph.D.'s in computer science is exceptionally high, as there are very few of them. Presumably, the lure of high-paying jobs for students with master's degrees has resulted in only 15% of these students electing to continue for the Ph.D. The annual production of computer science Ph.D.'s has remained roughly constant (at approximately 220) for the last eight years. Of those who do get the Ph.D., the majority are eventually attracted by the higher pay and better working conditions of industry (see N.S.F. Program Report Vol. 5, No. 6, Oct., 1981).

The demand for people with training in computer science, especially those with experience, exceeds supply. Salary figures vary, but entry level salaries of $20,000 for holders of bachelor's degrees, $26,000 for holders of master's degrees, and $32,000 for holders of Ph.D. degrees in computer science are common (see AFIPS publication **A Look Into Computer Careers**.

References for career information are included in the listing in Part X.

PART III: OPPORTUNITIES IN OPERATIONS RESEARCH

Authors and practitioners generally agree about what operations research is, but differ in emphasis and detail and use different words to express it. One lengthy description that has passed the test of time was first published in 1946 by Phillip Morse and George Kimball in a classified report of the Navy Operations Evaluation Group entitled "Methods of Operations Research" and repeated in the updated revisions that were published as unclassified books and were in print for at least two decades. Here it is:

> "Operations research is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control.
>
> "...*operations research is a scientific method*. It is an organized activity with more or less definite methodology of attacking new problems and finding definite solutions...the term *scientific method* implies more than sporadic application and occasional use of a certain methodology; it implies recognized and organized activity amenable to application to a variety of problems...
>
> "...operations research is of service to *executive departments*...[It is, therefore,] an applied science utilizing all known scientific techniques as tools in solving a specific problem...As we shall see, operations research uses mathematics, but it is not a branch of mathematics...Just as civil engineering uses the results of science in order to build a bridge, so operations research utilizes these various techniques as tools to help the executive. It is likely, however, that operations research should not be classed as a branch of engineering...The engineer is the consultant to the builder, the producer of equipment, whereas the operations research worker is the consultant to the user of equipment.
>
> "The next important word in the definition is *quantitative*...Certain aspects of practically every operation can be measured and compared quantitatively with similar aspects of other operations. It is these aspects which can be studied scientifically.
>
> "The task of the operations research worker is to present the quantitative aspect in intelligible form to point out, if possible, some of the non-quantitative aspects that may need consideration by the executive before he reaches his decisions. But the operations research worker does not and should not make the decision."

Operations Research as we know it today is primarily an out-growth of military research in World War II, aimed at questions such as "How should patrol aircraft be deployed to maximize the expected number of enemy submarines detected in a limited number of hours of search?" and "How should a limited inventory of spare parts be distributed among units in the field, advance depots and distribution warehouses to minimize equipment down-time due to parts shortages?"

At the end of the war, operations researchers moved into industry, where it was rapidly realized that similar questions were in need of answers. They readily transferred their experience to the elucidation of a host of problems in resource allocation, production scheduling, goods and materiel distribution. Here they joined with practitioners of management science, which has a history dating back to the turn of the century, to apply the same quantitative techniques to problems in budgeting, planning, marketing, decision-making, and other aspects of management that previously were treated as arts or "soft" sciences.

A few practitioners returned to the universities to lay the foundations for educational programs in operations research. Today there are over 100 degree-granting programs that can be called operations research. They bear a variety of names and their place in academic organizations is not the same everywhere. Some have developed in schools of science and engineering by the extension of systems analysis methods to interdisciplinary operating systems. Some have developed through application of quantitative methods to business administration, political science, and economics. Others have developed in close alliance with computer centers, reflecting the importance of general purpose computers, computer modeling, and techniques such as linear programming, differential games, Monte Carlo simulation, and Markov processes to the effective application of operations research to real problems.

The major professional societies in the United States are the Operations Research Society of America (ORSA), founded in 1952, and the Institute of Management Sciences (TIMS), founded in 1954. Together they have more than 11,000 members.

1. Mathematics in Operations Research. Although operations research has many aspects, we will concentrate on the mathematical aspects. A great deal of operations research deals with determining the optimum way to do things based on some mathematical model of a situation. Often this model is a statistical model. The major mathematical tools entering into O.R. are advanced calculus, linear algebra, differential and difference equations, probability, statistics, and computer programming. A sample problem might be the optimum operation of toll booths on a bridge or turnpike. The problem is to achieve the best balance between having idle attendants during slack hours and too much delay during rush-hour. One would have to determine the statistics of the traffic flow, construct a mathematical model of the queuing system, determine the expected number of idle attendants and the expected delay as a function of the number of attendants. The resultant expression is then analyzed to determine the optimum performance, given any other restraints imposed.

The above is a rather prosaic, but not atypical, sort of problem faced every day in the O.R. field. Some of the problems are elementary in their mathematical content (but not necessarily in their formulation from the real world), but many are mathematically formidable. One such problem, which is still unsolved, is phrased as the traveling salesman problem. A salesman has a customer in each of certain cities. Find the shortest tour enabling him to visit all his customers. This problem has been worked out for specific cases, but a general solution is not known. This can be translated into a problem in graph theory—how to characterize the shortest path joining a certain number of nodes. A second fascinating mathematical problem is that of maximizing (or minimizing) some function, given inequality constraints (e.g., everything must be positive, the sum of the variables is bounded above by a fixed bound, or the variables must all be integers). Linear and integer programming are among the techniques utilized in solving this type of problem. A third question is that of finding a solution for five simultaneous equations in ten unknowns. Clearly a unique solution does not exist—what is the best "solution" and in what sense can it be uniquely defined? This becomes even more of a problem when one is faced with five hundred equations in a thousand unknowns. Such problems arise when one is not conversant with the real laws governing the underlying system involved.

We have tried to suggest above a few of the mathematical questions arising in the practice of operations research—by no means exhausting such topics. Courses particularly relevant to this field include calculus, probability, statistics, linear algebra, number theory, abstract algebra, and graph theory. These are common courses in mathematics departments. Other particularly relevant courses, which may be given outside the mathematics department, are linear programming, control theory, integer programming, dynamic programming, game theory, and queuing theory, as well as computer programming and simulation.

2. **Working as an Operations Researcher.** An individual with a bachelor's degree in mathematics and some applied minor can possibly obtain direct employment in operations research, although this opportunity decreases as the number of schools offering a B.S. in O.R. increases. One generally works on a team, simulating some industrial or government process with a mathematical model. The mathematicians are expected to know how to solve the models developed, and to be able to recognize when the mathematics is so badly posed as to be unsolvable.

Most employers will be more confident in an operations researcher who has earned at least a master's degree. A good working knowledge of economics, finance, and organization theory is also valuable. With such training one can begin to lead projects such as those sketched above. Most O.R. groups, whether departments in an organization or independent companies, tend to get involved in a wide number of problems in the optimum allocation of resources, and one begins to recognize that the underlying procedures are the same. Often, the only difference between problems is that they are phrased in different languages. One must develop a speaking acquaintance with several fields, for the O.R. person is very much in the role of a consultant. In fact, there are an estimated 10,000 companies and self-employed individuals devoted primarily to consulting in operations research. Most of the people active in operations research today have academic degrees in statistics, mathematics, economics, or some branch of engineering or science, but a growing proportion are joining the profession with advanced degrees in operations research. Compensation is competitive with engineering and science, and the demand is considerable.

PART IV: OPPORTUNITIES IN STATISTICS

Statistics has been described as the science concerned with making sense out of numbers. Since numerical information plays an important role in our daily lives, all of us can profit from some knowledge of statistics. But complex problems call for the services of professional statisticians. Statisticians teach in colleges and universities, provide information for national, state, and local government, and work for business and industry. Often the work of a statistician overlaps with that of a mathematician. The student interested in statistics as a career is therefore well advised to pay attention to the other sections in this pamphlet, particularly Parts III and VIII on opportunities in operations research and the mathematician in industry and government. The pamphlet **Careers in Statistics** listed among the references is recommended reading for anybody interested in statistics as a career.

The primary professional organization of statisticians is the American Statistical Association. To paraphrase a statement in the Society's official journal, the membership of ASA is not confined to professional statisticians but includes economists, engineers, mathematicians, biologists, actuaries, sociologists, psychologists, as well as business executives, research directors, government officials and others who are seriously interested in the application of statistical data. Founded in 1839, the ASA is the second oldest professional organization in the United States. In 1939, it had about 2,500 members. By 1981 its membership had grown to about 15,000 reflecting the tremendous expansion of the uses of statistics.

Two more specialized organizations are the Institute of Mathematical Statistics founded in 1935 and the Biometric Society founded in 1947. The IMS is an international society of persons interested in probability and in mathematical aspects of statistics. The Biometric Society is an international society of persons interested in the quantification of the biological sciences.

Other associations of interest to statisticians are the American Association for Opinion Research, American Society for Quality Control, Econometric Society, Operations Research Society, and the Psychometric Society.

1. **Education for Statistics.** In recent years more and more colleges and universities have begun to offer undergraduate majors in statistics, though more often than not students will take statistics as a minor along with programs in mathematics and/or computer science, the biological or social sciences, or business. Job opportunities, both in the private and public sector, are good for the students with undergraduate training in statistics, particularly if the student also has computer programming experience.

Most professional statisticians have graduate training in statistics and probability. Students embarking on a graduate education in statistics should have good undergraduate preparation in mathematics. If the student selects a graduate program in statistics and probability that emphasizes theory, considerably more advanced work in mathematics is required. The November issue of the **American**

Statistician, a publication of the American Statistical Association, provides up-to-date information on over two hundred degree programs in statistics and biostatistics at U.S. and Canadian universities.

2. Working as a Statistician. Statisticians give advice on the statistical design of experiments, conduct surveys, analyze data with the help of existing statistical techniques, or devise new methods of analysis. They make ever increasing use of computers, often writing their own programs or modifying existing programs. Statisticians rarely work by themselves. They collaborate with specialists in fields such as agriculture, the biological and health sciences, economics, psychology, sociology, as well as business and industry. New fields for statistical applications arise continually. Two of the newest areas are law and public policy.

The diversity of statistical applications can be seen from the book **Statistics: A Guide to the Unknown**, in which well-known statisticians describe their contributions to the solution of problems of man in the biological world, the political world, the social world, and the physical world.

One of the chief employers of statisticians is the Federal Government. Statisticians are found in the National Bureau of Standards, the Bureau of the Census, the Bureau of Labor Statistics, the Department of Agriculture, the Department of Defense, the National Institute of Health, and the Environmental Protection Agency.

At universities we find statisticians in departments of mathematics and/or statistics or bio-statistics. But it is also quite common to find faculty members with strong involvement in statistics in departments such as biology, business, economics, health sciences, psychology, and many more. In recent years, even fields like english and history have developed strong quantitative interests. An important aspect of the work of statisticians in academic institutions is to provide advice on statistical matters to researchers throughout the institution. Graduate students in statistics are advised to become involved in statistical consulting at the earliest opportunity.

The role of the statistician in industry is discussed in some detail in Part VIII. Both industry and government often rely on private consultants for statistical advice and services.

Part VIII of this pamphlet discusses salaries of mathematicians in business, industry, and government. This information applies equally to statisticians. Currently (1982), in an academic career a young Ph.D. can expect to start at approximately \$19,000 for the academic year. Full professors earn between \$25,000 and \$80,000 for the academic year, with the possibility of additional income for summer research or private consulting. There are private consultants who earn \$100,000 per year or more.

PART V: OPPORTUNITIES IN THE ACTUARIAL PROFESSION

The actuarial field is one of the older areas for mathematical applications, extending back at least 200 years or more. Two of the earliest developments were in regard to mortality or life tables and to compound calculations. These were combined in the eighteenth and nineteenth centuries to provide the scientific basis for individual life insurance and life annuity contracts. In this century, individual insurance contracts have been refined greatly, and there has been a tremendous growth in group plans providing life, health, disability and pension benefits, and a parallel development of Social Security. Another part of actuarial science is concerned with the evaluation of non-life insurance risks such as those covered by automobile or fire insurance. The extent and complexity of these varied insurance plans, and the maturing of pension and Social Security systems, have created strong demand for competent actuaries.

What is an actuary is a question that most people are unable to answer with much confidence. A concise definition has been offered recently by Society of Actuaries Past President John Bragg in his paper "The Future of the Actuarial Profession as Viewed in A.D. 1974" (Transactions of the Society of Actuaries, 1974), namely: *Actuary:* A professional who is expert at the design, financing, and operation of insurance plans of all kinds, and of annuity and welfare plans. Defining an actuary as a professional implies three things: appropriate education, experience, and adherence to a code of ethics. Because actuaries affect the financial security of many people, they must bring intelligence and integrity to their work.

1. Education and Examinations. An actuary should have good mathematical aptitude and a thorough background in calculus, linear algebra, probability, statistics, computer science, and data processing. Courses in accounting, economics, English, finance, marketing, and liberal arts are also important to provide a broad foundation for approaching the many problems an actuary has to face.

The Society of Actuaries provides a series of ten examinations in the fields of life and health insurance and pension funding. Passing the first five of these qualifies a candidate to be an Associate of the Society of Actuaries (A.S.A.) and completion of the final five leads to designation as a Fellow of the Society of Actuaries (F.S.A.). In the non-life insurance field, the Casualty Actuarial Society offers examinations leading to Associateship (A.C.A.S.) and Fellowship (F.C.A.S.) in that organization. The first four examinations are jointly administered by the two organizations. A booklet describing the Preliminary Actuarial Examinations (Parts 1 and 2), and outlining the later examinations may be obtained from the Society of Actuaries, 208 LaSalle Street, Chicago, Illinois 60604, or from the Casualty Actuarial Society, 250 West 34th Street, New York, NY 10119. There may be considerable revision of the associateship syllabus over the next decade. Basic concepts will endure but their development may proceed on somewhat modified lines under the influence of advances in mathematical, statistical, and computer science areas. It behooves the prospective actuary to get a good grounding in all three of these areas. The student should also take the preliminary actuarial examinations and perhaps further examinations while he or she is still in college.

An "enrolled actuary" designation, granted by the Federal government, is required to certify reports to the government concerning pension plans. The "enrolled actuary" designation is earned by passing two examinations (jointly given by the Society of Actuaries, the Joint Board for the Enrollment of Actuaries, and other actuarial organizations) and meeting certain experience requirements.

A number of colleges and universities in the United States and Canada offer courses at the undergraduate or graduate level leading to degrees in actuarial science. A list of such institutions can be obtained by writing to the Society of Actuaries. Their courses are mainly at the associateship level but some give background for the fellowship examinations and for professional development, in addition to getting the students started through the early examinations.

A number of women have distinguished themselves in actuarial careers, and minority students are being assisted towards qualification. A special scholarship fund for minority and women students is available through the Society of Actuaries to help finance the graduate education of such students.

2. Working as an Actuary. About sixty percent of actively employed actuaries work for insurance companies. The following comments are abstracted from the booklet **The Actuarial Profession** but have been generalized to include non-life insurance.

The business of insurance involves the assumption of risks and the payment of claims. The actuary is responsible for seeing that the risk is properly defined and evaluated, that a fair price is charged for assuming the risk, and proper provision is made to pay all claims and expenses as they occur. Insurance company actuaries engage in a variety of other important activities ranging from research to management functions. For example, an actuary may study the claims experience, in particular, the mortality and survival experience of insured persons. Most actuaries become involved with development of new applications for electronic computers in their company's operations. Or they may apply mathematical models or techniques of operations research to insurance company problems and may engage in corporate planning.

Consulting actuaries, who now include more than one third of all active actuaries in America, offer professional advice to corporations, insurance companies, state and local governments, labor unions, joint labor-management trustees, Federal government agencies, and attorneys. As indicated in the booklet, **The Actuarial Profession**, the consulting actuary often deals with top financial and administrative officers of client organizations who present a variety of challenging assignments such as: designing a pension plan for an employee group and advising on a sound program for financing the benefits; participating in a collective bargaining session on pension proposals; developing a new computer system for an insurance or pension organization; testifying in court regarding the assessment of damages in an accident.

Through the old age, survivors, disability, and medical benefits provided by Social Security, and through the supervision of insurance and pension funds by governmental agencies, there is a growing number of opportunities for actuaries in public service. Important general responsibilities of actuaries in government are to advise on legislation and to act on regulatory matters. Specifically, an actuary may be called upon to testify before a Congressional committee on insurance matters; to establish actuarial guidelines for tax deductibility of pension costs; to assist in census or demographic studies; to examine an insurance company or an employee benefit plan to determine if it complies with regulations.

Some actuaries are also employed by large corporations or labor unions with major responsibilities related to employee or member benefit plans. Other actuaries are employed in organizations offering computer or financial products and services. A number of actuaries have found opportunities in universities for actuarial teaching, research, and public service.

Although some indications are emerging that the supply of actuarial students has been catching up with the perennial demand, there will remain for the foreseeable future a strong need for competent actuaries. An uncertain economy is posing many new problems for the actuarial profession, and the current active demand for qualified actuaries should continue strongly.

In 1982, the median starting salary for students with no examination or only the first part passed was approximately $18,000, and for students with 4 or 5 examinations passed the median starting salary was about $22,000. Actuaries can advance rapidly with experience and examination qualifications to salary levels which are three or more times the starting levels. A substantial number of actuaries go on to senior management positions in their organizations.

PART VI: PROFESSIONAL OPPORTUNITIES IN INTERDISCIPLINARY AREAS

Mathematics has always been used as a tool for organizing and understanding the physical sciences. The solution of mathematical problems arising out of these fields is the work of the classical applied mathematician, described in Part I of this pamphlet. This section is concerned with a much newer and less well-known class of professions involving the application of mathematics to other disciplines. The twentieth century has seen a remarkable increase in the use of mathematics in biology, medicine, management, linguistics, and the social sciences—particularly economics and psychology. This has resulted in the emergence of new interdisciplinary professions in which mathematics plays a central role.

Initially the area of mathematics which was of primary importance outside the physical sciences was classical statistics, used in the collection and analysis of data. More recently there has been a growing interest in the exploration of other areas of mathematics for the construction of non-statistical models. These endeavors coexist and sometimes overlap, but are considered to be different aspects of their respective disciplines. The professional nomenclature reflects this difference. Economists who specialize in the application of statistics to their field are called econometricians; biologists, biometricians; psychologists, psychometricians, and so on. Economists who are primarily interested in non-statistical modeling are called mathematical economists. Similarly there are mathematical biologists, mathematical psychologists, and so on (in management the field is called operations research, not elaborated here, but described in Part III of this pamphlet). The growing importance of these professions provides an opportunity to combine mathematical training with a serious interest in another discipline.

1. Mathematics in Interdisciplinary Areas. The role of statistics in applications of mathematics to the social sciences, biology and medicine is extremely influential, especially, as has been noted above, in a major category of interdisciplinary research.

The mathematics used in non-statistical modeling varies with the kind of problem under consideration. The construction of a mathematical model entails the formulation of laws or axioms which describe in mathematical terms the (necessarily idealized) underlying structure of a system. Examples of systems range from free competitive economics to neural networks. Since we are discussing such a variety of fields and diversity of approaches within each field it is hardly possible to enumerate all the branches of mathematics used. Furthermore it must be remembered that many of these efforts are still young; the number of mathematical tools drawn upon and their level of sophistication are continually increasing. We offer below a sampling of the kinds of problems treated and the kinds of mathematics used.

Mathematical economics is the oldest, and probably the best developed of these interdisciplinary pursuits. The first Nobel Prize in Economics went to a principal founder of the field. One topic which has been the subject of research in this area is the existence of equilibrium in a competitive economy. The problem simply stated is this: given a free market in which prices respond to the law of supply and demand and a set of assumptions about the behavior of consumers and producers, will prices eventually regulate themselves to values at which supply and demand exactly balance? Other topics which occur concern individual behavior, stability of equilibria, oligopolic systems and the economics of the welfare state. Linear algebra and real analysis are heavily used, as well as differential and difference equations, topology, set theory, logic, and combinatorial mathematics.

Recently some sociologists have adopted some of the techniques of mathematical economics to study social relationships.

One of the earliest uses of mathematics in biology was in the study of population growth. If we assume that the growth of a population of organisms is not affected by pressure of resources, then we arrive quickly at the conclusion that the number of organisms existing after a given period of time is a constant multiple of an exponential function of the time period elapsed. However, as we take into account additional factors such as availability of resources, the model becomes more complicated and the mathematics more sophisticated. Other areas in biology and medicine which are studied by means of mathematical models are immunology, epidemiology, ion transfer across membranes, and cell differentiation. Neurophysiology is closely associated with psychology in the study of models of perception and learning. Frequently used mathematical tools are ordinary and partial differential equations, control theory, optimization theory, stochastic processes, and computer science, as well as some topology.

In psychology, one finds mathematical modeling closely associated with experimentation. For example, consider the "simple learning" model. A subject is placed in a repetitive choice situation in which different responses carry different rewards. As the reward pattern reveals itself to the subject, the subject's responses slowly change. The problem is to explain the laws governing the evaluation of the choice pattern within the framework of the experiment. More complex learning situations are studied, as well as problems in stimulus response, reaction time, preference behavior, and social interaction. Computer modeling is used to simulate the organization of the nervous system. Another kind of problem which arises in mathematical psychology occurs in the theory of measurement and scaling. The categories of mathematics which have been heavily used are probability and stochastic processes, computer science, combinatorial mathematics, set theory, and some analysis.

Mathematical linguistics has become a major force in the study of linguistics, the science of languages. It has some relationship with mathematical psychology since it is concerned with the range of humanly possible linguistic structures rather than with the particular qualities of any given language. This area makes use primarily of set theory, logic, algebra, automata theory, and computer mathematics.

The above descriptions of mathematical problems arising in other fields are by no means exhaustive. The student interested in doing mathematical research in biology or the social sciences is on an intellectual frontier where the possibilities are manifold.

2. Education for Interdisciplinary Research. There is no well-defined educational path for students wishing to enter these interdisciplinary areas. A sampling of those now engaged in each of the various fields would show considerable diversity in patterns of formal education, although it can be safely said that there is little opportunity without a doctoral degree. A strong undergraduate education with a double major would be the ideal start. Short of that ambitious program a major in mathematics with considerable course work in the other field would be a good beginning. It does appear to be important that the mathematical training be started early, and preferably that it include some work in statistics and computer science. There is no prescription for graduate study. This depends very much on finding an individual or group working in the area one would like to pursue. Mathematical biologists and psychologists may be found in some departments of biology and psychology, respectively, but often are based in departments of mathematics or applied mathematics. A student who is interested in entering one of these interdisciplinary fields, or any of the others involving social sciences would do well to engage in some preliminary research to locate an appropriate graduate department. (A partial list of professional organizations is included among the references at the end of this pamphlet.)

3. Employment in Interdisciplinary Areas. Most of the people now working in the interdisciplinary fields described above hold academic posts. Others are employed in research organizations sponsored by government, industry, or foundations. Still others are in hospitals and in consulting firms. Since these fields are increasing in importance one can expect the employment picture to be favorable. It is, however, vulnerable to the pressures affecting the general academic market and government supported research, and growth is more likely to occur in the areas of consulting and industrial research.

PART VII: TEACHING MATHEMATICS

There is a serious, nationwide shortage of mathematics teachers in 1982, especially at the secondary school level. The need for new teachers is expected to continue through the 1980's.

According to a 1980 survey conducted by the State Department of Public Instruction in Iowa, a shortage or critical shortage of mathematics teachers was identified in 35 states. By 1981, 43 states had such shortages. A separate survey by the Association for School, College and University Staffing (ASCUS) confirms these figures and reports that no region of the country, except Alaska, has an adequate supply of qualified mathematics teachers. A research memorandum of the National Education Association detailing teacher supply and demand in public schools during the 1980-81 school year stated that mathematics was the only subject in which every region of the country reported shortages. Still other independent surveys confirm these findings.

This need for mathematics teachers has developed because the demand for mathematics and computing courses has increased sharply during the past decade, while the number of new mathematics teachers decreased during the same time period.

Among the reasons for the increased demand for mathematics in secondary schools are desires for minimum competence, increased number of girls taking higher mathematics, growing enrollments in computer science, and higher admissions requirements in mathematics at universities and colleges.

Yet, while the demand has been increasing, the supply has been diminishing. This was partly due to the fact that in the 1970's the employment situation for mathematics teachers, especially at the secondary level, was not good. Shrinking school populations and concurrent economizing by cities and towns in most parts of the country lowered the demand for teachers during that period and jeopardized the security of those who did hold positions. At the same time a burgeoning computer industry was able to absorb many young people with mathematical training. In consequence, the number of students in teacher certification programs decreased sharply over the last decade.

Although the high school population nationwide is not yet increasing, demand for mathematics is. The necessity for preparing students for an ever more technological society and the role of mathematics as the foundation of such preparation has become apparent to all.

Students should be encouraged to think about teaching as a career if they have any inclination in that direction. It is a demanding profession, but one which offers substantial rewards. Professor Edwin Moise of Queens College of the City University of New York put it well:

> Teaching is a very ambiguous interpersonal relation. The teacher is a performer, an expositor, a taskmaster, a leader, a judge, an advisor, an authority figure, an interlocutor, and a friend. None of these roles is easy,

and many of them are mutually incongruous. . .one of the vital elements in teaching is the enlargement and refinement of the student's aesthetic perceptions; when he is 'turned on' by something that did not turn him on before, real progress has been made.

(Notices, AMS 20 (1973) 219.)

Mathematics teachers today must know more mathematics and more about related fields than was required in the past. They must have a breadth of mathematical knowledge, including, now, some knowledge of computer science, and also some understanding of how to apply mathematics to other disciplines.

There are three essentially different types of mathematics teaching: elementary and secondary school teaching, junior or community college teaching, and college or university teaching. The conditions of employment, education for employment, and the nature of the students differ drastically, so they will be discussed separately.

1. Teaching in an Elementary or Secondary School. Teachers in a public school (as opposed to a private school) generally must be accredited by the state education system. The requirements for accreditation vary from state to state. (Candidates for public school teaching should be alerted to the National Council for Accreditation of Teacher Education (NCATE) and the reciprocity agreement among many states which enables one trained in one state to teach in another and allows changes in position with reasonable smoothness.) They generally require that certain courses, usually in education, be taken prior to any permanent appointment as a teacher. Sometimes these courses can be taken at night or during the summer while teaching. Having a master's degree in mathematics, or even a Ph.D., does not by itself certify someone to teach in a public school. A person envisioning teaching at this level is well advised to check on the certification requirements early in planning a college program.

Since calculus and linear algebra are now being taught in many high schools and in practically every preparatory school, the prospective secondary school teacher must be qualified beyond this level. Geometry (Euclidean and transformation), probability, statistics, and the history of mathematics are necessary parts of a teacher's preparation. To teach effectively it is also desirable for the teacher to have taken more advanced courses in analysis and algebra in order to know how the material being taught is related to more advanced mathematics.

"Advanced calculus" is a nice integration of calculus and geometry; projective geometry gives an insight into both Euclidean geometry and algebra; and numerical analysis courses give a good mixture of algebra and calculus. Another variable course is number theory, because this is one of the few areas of mathematics where high school students can do original research. This is also an area especially suited for encouraging the really gifted student. A course in model theory, particularly models related to non-traditional areas such as business and the social sciences, would also be beneficial.

Most secondary schools and many elementary schools already have computers available for classroom use. Microcomputers are most common. Teachers should know at least one computer language well. (BASIC is still used primarily, but PASCAL and LOGO are growing more popular in education.) Many mathematical ideas and skills are stimulated by computer use. In addition to teaching students to program, teachers should use computers, as appropriate, to enhance the learning of mathematics. For example, a microcomputer with video display can be an effective demonstration aid during lectures, and an effective stand-alone instructor of new concepts or for drill. Also, computer assignments can be made which stimulate creativity and strengthen students' reasoning skills, but would be too tedious to do by hand.

The prospective secondary school teacher will do well to study all of the above subjects. Both for breadth and for "relevance," these courses will increase the prospective teacher's marketability. The prospective teacher in the private school will probably find all these courses necessary and may find a master's degree essential.

Elementary school teachers face different problems. They must teach all subjects, not just mathematics. Therefore, they usually do not major in mathematics, although such a major should be seriously considered by anyone who particularly enjoys mathematics and desires to teach at the elementary level. The mathematics courses they should take are primarily those in number systems, elementary algebra, geometry, probability and statistics, set theory, and logic. There is a great need to improve the quality of mathematics education at the elementary school level.

For more information on what secondary and elementary mathematics education should be, see **An Agenda for Action: Recommendations for School Mathematics in the 1980's**, National Council of Teachers of Mathematics, 1980.

Salaries in the public school system tend to vary widely from one geographic area to another. According to the figures from the Educational Research Service,* the nationwide average for secondary and elementary school teachers was estimated to be $19,275 for 1981-82. The 1981-82 salaries averaged 8-9% higher than those in 1980-81. Various fringe benefits are also available to most elementary and secondary school teachers.

2. Teaching in a Junior or Community College. These colleges attract students with widely varying academic needs. In the big inner-city community colleges, close to 85% of the mathematics taught is remedial (near the grade-school level). These students are frequently those who did poorly in high school, but who are re-entering school and are better motivated. The remaining 15% is freshman and sophomore mathematics of the type usually taught in a major university. For the schools in more affluent areas the percentages change, but the range of mathematics courses is not significantly different. Many junior colleges are offering

*National Survey of Salaries and Wages in Public Schools, Part 2, Educational Research Service, Inc., Washington, D.C., 1982.

extensive computer programs. Relevance to career opportunities is often the major factor in the schools' existence and choice of curriculum, particularly in the case of public community colleges.

The teaching loads are usually heavier in junior colleges than in most four-year colleges, but often lighter than in secondary schools. Most junior colleges have a great many students and quite a number take mathematics. Because of the very wide range of student abilities, many of the junior colleges have experimented, with varying degrees of success, with individualized instruction, programmed learning, and non-traditional ways of teaching. In fact, one of the fascinations of being on a junior college faculty is the opportunity to try new methods of teaching with an audience which is mature, often desperate for a working understanding of the subject, and generally well motivated.

The essential criterion for employment is a master's degree. There are some Ph.D.'s on junior and community college faculties (the 1980 American Mathematical Society Two-year College Survey indicated that among those institutions reporting, 15% of the full-time mathematics faculty members held doctorates), but as yet there is no major push to hire Ph.D.'s in mathematics. Faculty members with doctorates often become administrators because the primary function, in fact almost the sole function, of these schools is teaching, not research. With the typical range of students, the teaching is an inspiring and exciting challenge. A knowledge of applications is essential. Most students here are job-oriented, many even work part-time. These students are primarily interested in how mathematics can be used. They recognize that mathematics does have application to the careers they intend to enter and they are well motivated to learn the mathematical tools of the trade.

Many junior and community colleges are under State Education Systems, and have certification criteria similar to high schools. Others are strictly under local control. The salaries at such schools are reported in the **Two-Year College Mathematics Journal**. The 1979-80 salary survey showed the following range for the middle fifty percent of salaries reported: nondoctorate, \$15,800–\$22,000; doctorate, \$16,800–\$23,400. Since these figures are based on 9-10 months employment, one can often add up to an additional 20% for summer employment.

3. Teaching in a College or University. The Ph.D. is required, with rare exceptions, for positions in a college or university. Many positions are open throughout the U.S., mostly in four-year colleges, and most of these prefer or require mathematicians able to teach computer science courses. Since not many college level openings were available during the 1970's, the supply of Ph.D.'s diminished. Hence there is now a shortage of candidates for these. There are also some openings at universities for new Ph.D.'s with outstanding research potential.

University professors, that is, teachers in an institution offering a graduate program, are expected to specialize and to spend a major portion of their time with graduate students, doing research, and keeping abreast of the developments on the frontier of their fields. Formal classroom teaching usually occupies less time than at an undergraduate institution. These professors are expected and required to maintain a reputation beyond their school's boundaries by publishing original research, writing books, turning out outstanding research students, or contributing their expertise to national organizations. As this description suggests, the university professor has a responsibility for expanding the boundaries of knowledge.

The college professor, that is, a teacher in an undergraduate institution, will typically have twice the teaching load of the university professor. He or she may be expected to maintain a reputation beyond the school walls, but even outstanding research will not guarantee employment in the face of poor teaching performance. The college teacher should expect to have to teach mathematics courses outside his or her own specialty. (Typically one learns some of these fields "on the job" by continuing to study after starting to teach. Sometimes one is given time off to learn new ideas.) In a college the professor has students who want mathematics simply because it is a beautiful subject, but most of the students want to use mathematics or are required to take it. It is quite valuable for the prospective college teacher to learn applications, be versatile, and, most important, have a knowledge of computer science and statistics. Furthermore, a number of universities and colleges are now offering remedial courses in mathematics. Prospective teachers should recognize that courses must be taught at various levels, and hence they must be prepared to teach at developmental as well as advanced levels.

Salary figures for college and university professors are published each year, usually in November, in the **Notices of the American Mathematical Society**. The latest issue (1981) lists salaries for schools depending upon their mathematics reputation. For a "distinguished" school offering the doctorate the average beginning salary for an assistant professor was $20,100, up about $300 from the previous year. The professorial salaries averaged $40,450, although the top salary reported was $61,000. These are salaries for 9-10 months employment. One can expect to add additional income (up to 20% of the base salary) for summer employment.

For colleges and master's degree granting schools, the salary figures are slightly lower. An assistant professor with a doctorate in a four-year college was averaging $18,600, up $1,600 from last year. In an institution granting an M.S. the average assistant professor salary was $20,750, up $1,600, and the average full professor salary was $31,300, with the top salary reported as $47,600.

The major professional organizations for mathematics teachers at the college and university level are the Mathematical Association of America, the American Mathematical Society, and the Society for Industrial and Applied Mathematics. For mathematics teachers at the elementary and secondary levels the major professional organization is the National Council of Teachers of Mathematics.

PART VIII: THE MATHEMATICIAN IN GOVERNMENT, BUSINESS, AND INDUSTRY

Private industry, business, and government are major employers of mathematicians and computer specialists. A recent U.S. Department of Commerce sample survey (Facts from the 1976 National Survey of Natural and Social Scientists and Engineers, U.S. Department of Commerce, Bureau of Census, issued in February, 1977) shows that in a population of about 25,000 mathematical specialists, the proportion who were employed in 1976 in industry, Federal and public administration, and services other than education was 50%, compared to 47% employed in educational institutions; or, alternatively, the proportion who reported their primary work activity as research and development, management or administration, production and inspection, consulting report writing and statistical work, or computer applications, was 58%, compared with 37% who reported teaching as their primary activity. The proportion of computer specialists in private industry, business, and services was even higher, 78% of a population of about 51,000. Except in a few research institutes, mathematicians in government, business, and industry were hired because they can contribute to the solution of some on-going problem, and at least some of their work must show some relevance. Rarely do they work alone; usually they are part of a team. Thus a fundamental requirement is the ability to communicate about problems that are poorly formulated mathematically by people with limited mathematical training.

1. Working as a Mathematician in Government, Business, and Industry. Several of the areas in which mathematicians serve in government, business, and industry are discussed at some length elsewhere in this publication. However, since many students and teachers of mathematics have had no personal experience with the opportunities which exist outside schools, colleges and universities, a brief summary of each of the major areas is given below.

a) Computer Mathematician (Some of whom have job titles like Systems Programmer or Systems Analyst). Almost every government agency, business, and industry in the world now makes extensive use of computers, and there is a great demand for people who can communicate with a computer correctly and efficiently. There is a wealth of genuine mathematical problems in computer programming involving logic, combinatorics, number theory, and algebra. Computers are expensive to operate and there is a premium on efficient usage, and hence most companies, both users and designers of computers, are interested in the efficient working of computer operations. Most young mathematicians at the B.S. and M.S. level are, in fact, hired as computer programmers. This work can be routine and dull if one allows it to be, but it need not be. Most users of computers do not understand the non-commutativity of finite arithmetic, or the elementary logic of algorithms, or how to estimate errors accurately in approximations. They routinely use the most available computer program, regardless of its real applicability. Someone who can understand poorly worded problems and translate them into efficient algorithms becomes valuable. To understand the problems requires good will, common sense, and a great deal of persistence, as well as a sound knowledge of mathematics. Anyone who expects to work as a mathematician in government, business, or industry must have some computer experience. More information about computer science may be found in Part II.

b) Operations Researcher (Some of whom have job titles like Operations Analyst, Systems Engineer or Systems Analyst. Note that the last job title is usually ambiguous). There is a rapidly growing demand for this type of mathematician. He or she is expected to construct simple mathematical models of complex structures—social, economic and technical, civil and military, government, business, and industrial. Ideally, the models must be complex enough to approximate the real world with some predictive value, and simple enough to be exercised. As with any relatively new field, operations research can be exciting, challenging, frustrating, and disappointing. Part III of this pamphlet discusses operations research in some detail. Essentially, it is the "mathematics of the decision sciences." It involves the use of mathematics, statistics, and computer science, with an emphasis on how to quantify things so as to make decisions.

c) Statistician (This class includes many specialist job titles). This can easily overlap with the above category—a person who can utilize data, and say what data are appropriate. Data abound in government, business and industry, and those who know how to extract usable, reliable information are very useful. Statistics plays a role in operations research, but many assignments involve primarily the application of statistical methodology. Statistically sound design of experiments, together with planned analysis of data in accordance with the experimental design, can be used to great advantage in improving products and processes, and so are of great importance to a variety of firms and agencies. More information about opportunities in statistics may be found in Part IV.

d) Classical Applied Mathematician. The phrase "applied mathematician" has traditionally meant someone with a differential equations and physics orientation. This is still a fundamental field in government and industry, which often uses computers. There is still a tremendous interest in solving equations of motion and those of steady state fields. In the last two decades the computer has made formerly impractical problems routinely solvable. Some of these computer solutions are being developed very effectively by engineers, partly because mathematicians have not been interested in such work. However, the engineer is usually interested in just one type of problem and will stay with any method which will give an answer to that problem. The mathematician acts more as a consultant, being interested in several methods and trying to find which problems are best solved by each method. Part I gives more information about Classical Applied Mathematics and Engineering.

The mathematician in government or industry soon learns that colleagues are primarily interested in efficient answers, even if they are only approximate. The mathematician who learns this has taken a significant step forward.

e) Information Scientist (Many have job titles containing words like Control Systems, Communications Systems, and Signal Processing). The mathematical roots and many of the main branches are the same as those of statistics, but for historical reasons these subjects were actively developed during the 1950's and 1960's independently of the main stream of what was then called statistics. Information scientists are concerned with problems involving information-bearing characteristics of signals, patterns, and observations, and their conversion from one form to another; storage, retrieval, and transmission and reception from one place to another. If any distinction is to be made between statistics and information sciences, the former is concerned more with after-the-fact analysis of relatively slow processes, such as interpretation of national economic data, whereas the latter are more concerned with the interpretation as they occur of fast events, such as modulated radio waves.

Transforming speech into various electrical signals suitable for transmissions over telephone cables, fm or am radio broadcasts, or digital transmission by satellite relay, and reconstruction of the voice at the receiver are applications of information science. Further applications are found in every part of a telecommunications system where a message is transformed from one form to another or transmitted from one place to another. Other applications are found in information transmission, storage and retrieval systems like those used to maintain business records and accounts, automated libraries and "data banks," for example, electronic fund transfer systems, security systems, real-time inventory and reservation systems, and real-time police, credit-service, and news-service data banks. Still other applications are found in search and pattern recognition, as in analysis of geophysical records to locate petroleum deposits or the organization of displays and communications in an air traffic control system. Further applications are found in automatic control, from the simple household thermostat or more complex aircraft autopilots, to highly sophisticated control systems for automated factories and space exploration vehicles.

Mathematical ideas from analysis, statistics, algebra, and other branches are essential in the information sciences. Practical applications—conceptual design of information-using systems, design and development of equipment, and system operation—always require some knowledge and understanding of engineering, the sciences, and the particular kind of operations involved. Probably more of today's information scientists were originally trained in electrical engineering than in any other branch of engineering or science or mathematics. When looking for information scientists, most employers will seek people trained in engineering or science and overlook mathematicians. However, there are numerous examples to show that an academic background in pure or applied mathematics or statistics is a sound foundation for a government, business or industrial career in information sciences.

f) Consultant. A mathematical consultant usually has an established reputation for solving problems and carrying out research. If the client employs mathematicians, they may have formulated the scope and content of a mathematical investigation and identified the particular kind of mathematical talent and experience required to carry it forward. In such a case, the consultant reviews their work, advises them, and suggests methods of approach to be worked out in detail by the client's resident staff. In other cases, it is necessary that the consultant master the fundamentals of one or more fields of science, engineering, business or government operations or management in which complex quantitative issues susceptible to mathematical treatment can become urgent and economically important.

The consultant must recognize the client's objectives and nonmathematical constraints and produce results that do not violate them. Fees ranging from several hundred to one thousand dollars a day are common. Many consult only occasionally while pursuing full-time careers as, say, university professors; others are in private practice, like lawyers and physicians; still others are members of consulting firms, sharing a practice with other mathematicians or with a more diversified professional staff capable of undertaking total responsibility for interdisciplinary assignments; some are employed full-time by large corporations to serve as internal staff consultants.

g) Mathematician in a Non-mathematical Role. Quantitative problems that yield to rigorous logical thinking are not peculiar to mathematics, and a training in mathematics is a very good background with which to approach them. People whose academic training is in mathematics have been successful in many jobs traditionally thought of as belonging to other fields. These are too numerous to list, and include many branches of engineering, physical and social science, finance and management, law, and medicine. The incidence of mathematicians in any one field is small, but the aggregate number of mathematicians thus occupied is large enough to constitute a professional opportunity not to be overlooked.

Not too many years ago, a great many industries, businesses and government agencies hired mathematicians quite readily, and were glad to have any mathematician. In the last few years this situation has changed. A survey of industrial mathematics departments (**American Mathematical Monthly** 81 (1974)) records the opinions of industry concerning Ph.D. mathematicians and their training, but the report is relevant to all mathematicians. A typical negative comment is "...the push towards 'near-term relevance' in our research programs has made it virtually impossible for us to afford the luxury of a topologist, an algebraist..." A typical positive comment is "...the discipline and logic which they have learned through their training is a valuable part of their usefulness to the company." Government agencies often take a longer view and can afford more time to indoctrinate new employees, and their enthusiasm for mathematically-trained personnel has not fallen as fast.

2. Working Conditions and Employment Opportunities in Business and Industry. The reader is advised to read the article in the **American Mathematical Monthly** Vol 81 (1974) by R.E. Gaskell and M. Klamkin for a detailed list of comments. In general, mathematicians are considered professionals, and work in a group often as though they were consultants to that group. A nice description is contained in the reference above. "The applied part consists mainly in hearing a client's description of his situation, plowing through his jargon, overcoming his tendency to start in the middle, digging out all the constraints that he has forgotten to mention, developing a model that takes account of enough detail to be realistic (but not so much as to become mathematically unwieldy), explaining it to the client in his language to determine if it is reasonable and relevant, solving whatever problems are suggested by the model, and explaining to the client, again in his language, how he can use the solution."

There is a general feeling now in industry that most mathematical training is too narrow. An obvious alternative to narrow specialization is to learn something about everything. For a mathematician in industry, this would be just as inadequate as narrow specialization. The most promising solution to this dilemma is training which includes specialization in one or more areas appropriate to the tasks at hand, together with some command of all branches of mathematics at an elementary level. To nonmathematician colleagues, the industrial mathematician is an emissary from the universe of mathematics, and he or she should be able to represent all of that universe. Thus, it is very useful for a mathematician looking for employment in industry to have had some courses in other fields—economics, operations research, biophysics, computers, physics, engineering, or statistics. Mathematicians will be able to learn a great deal about the nonmathematical aspects of the industry from colleagues, whereas few colleagues will be available to enrich the mathematician's own mathematical background.

In general, the employment opportunities in business and industry are greater for candidates with the B.S. or M.S. degree than for those with Ph.D. The candidate with no graduate training may have to be satisfied with a job with little technical content. Whatever the candidate's educational level, the technical competence of the individual will soon diminish in a rapidly changing technological environment, unless an effort is made to continue the education process. Many employers offer excellent educational programs for obtaining an M.S. degree (in some cases, even a Ph.D.) or for keeping up to date without seeking a degree.

Salaries paid to mathematicians in business and industry are usually comparable to salaries paid to engineers and scientists, and most published salary survey data do not separate mathematics from other disciplines. One exception is **1981 National Survey of Compensation** by Battelle Columbus Laboratories. It can be inferred from this report that the median starting salary in 1981 for a holder of a bachelor's degree in mathematics or statistics was about $21,000 per annum, for a master's degree holder about $22,000, and for a doctor's degree holder about $30,000. For those who received the first (bachelor's) degree in 1961, median salary figures are $39,000 p.a. for those with no further degree, $40,000 for those with a master's, and $43,000 for those with a doctorate. This survey is based on a statistically balanced sample of over 96,000 scientists and engineers doing research and development, of whom over 65,000 are in industry, about 3,000 are in educational institutions, and about 27,000 in other research institutions and Federal laboratories. The sample included about 4,500 whose highest degree is in mathematics.

3. Working Conditions and Employment Opportunities in Government. The Federal and state governments employ a number of mathematically trained people, generally as "applied mathematicians," at all levels of education. In the 1970 American Science Manpower report about 6% of the mathematicians surveyed worked for government, but 57% of the statisticians and 9% of the computer scientists worked for Federal and local governments full-time, and these proportions appear to be rising. The employment of mathematically trained people comes largely in serving two main functions: both the local and Federal governments devote a significant amount of their resources to the collection and analysis of data; and the Federal government has a considerable research effort of its own in several fields, notably space, defense, agriculture, and the environment.

a) The Uses of Mathematics in Government. The mathematical work is invariably computational at the beginning levels of government work and particularly so for someone at the bachelor's or master's level. Typical problems involve solving algebraic or differential equations or analyzing statistical data. These problems are not generally mathematically sophisticated, but a sound grounding in mathematics is a great asset. A combination of mathematics and statistics or mathematics and computer science is a valuable asset. In fact, knowledge of how to use high speed computers is almost essential.

With some experience the mathematician generally becomes a department-wide consultant. Many problems involving data analysis are problems trying to match data with imperfect mathematical models of physical, economic, or sociological systems. One must somehow perform the sometimes unhappy marriage between what can be observed, what can be modeled mathematically, and what can be solved mathematically in finite time and finite resources. A mathematician who can learn to understand the modeling process in some applied area becomes very valuable and experiences tremendous challenges.

A number of government agencies are highly involved in the physical sciences (e.g., the National Aeronautics and Space Administration and Department of Defense). Also, there are many engineering applications of mathematics such as the design, simulation, and occasionally construction of complicated structures. Efficient modeling of engineering problems is a task calling for the assistance of many mathematicians at all professional levels.

The Federal government is responsible for the direct support of a significant amount of fundamental research, even in mathematics. A substantial portion of this support is through research grants to mathematicians throughout the country, either at universities or in private industry. Most of the "pure" research is funded by the National Science Foundation, but other agencies, especially the Department of Defense and NASA, support considerable work with a high mathematical content. All together in the 1970's the Federal government typically granted more than $100 million per year to various institutions and individuals for work in pure and applied mathematics and allied subjects. This amount is not likely to increase, and will probably decrease if policies prevailing in 1982 are maintained. The recipients of these grants however, are not really considered as "working for the government." They are rather like consultants, hired for a short period for a certain task. The people involved in these grants are usually university professors, research associates, post-doctoral fellows, and graduate students working on their doctoral theses.

In addition to the considerable support of mathematics through these outside research grants, the Federal government has a number of excellent research laboratories of its own. These labs have their own full-time staff of professional mathematicians and do research as competently as any university. It is not feasible to list all but we do mention, in particular, the U.S. Army Mathematics Research Center in Madison, Wisconsin, the Atomic Energy Commission's Oak Ridge National Laboratory in Tennessee, and the National Bureau of Standards in Washington, D.C., which have internationally known mathematicians on their staff. A great many of the research and development labs have independent research programs, where promising ideas can be explored. These ideas are not necessarily directly applicable to the lab's immediate purpose. The work here is in many ways comparable to that in industry.

b) Working Conditions and Salaries. A major difference between employment in industry and that in government is in the employment structure. Most government employees are in the Civil Service, a nationwide employment plan with a great deal of structure to it, with the concomitant features of security and lack of flexibility. Someone with a bachelor's degree would typically find a position somewhere near the GS-5 level. (Civil Service grade level salaries are frequently revised, and current salary scales are readily available from public sources.) With a master's degree the starting level is usually GS-8 or higher, and with a Ph.D., GS-11 or higher.

A 1972 NSF publication listed 2,446 mathematicians, 2,802 statisticians, 7,332 computer specialists, and 1,807 operations research analysts in the Federal government, and 1,839 mathematicians, 1,053 statisticians, 4,206 computer specialists and 602 operations research analysts in state and local government who answered a questionnaire sent out by NSF. The 1981 U.S. Department of Energy National Survey of Compensation Paid Scientists and Engineers in Research and Development Laboratories shows 18.1% of a total population of over half a million in Federal (Civil Service) and Contract Research (industry operated on behalf of the Federal government) establishments. The percentage of mathematicians has not been calculated separately from other scientists and engineers, but there is no reason to believe the proportion would be very different.

In general the professional conditions in government service are good. Advanced schooling is encouraged, frequently at government expense. Attendance at professional meetings is encouraged, and the government sponsors or cosponsors a number of professional meetings. Exchanges of scientists between laboratories is often possible. The Federal government has mathematical labs in most every state and in many overseas locations as well. Working for the Federal government gives one access to the vast Defense Documentation Center with its wealth of information. As with most jobs, a government job can be as exciting or as tedious as the individual makes it. However, research, per se, is probably on the decline in these jobs.

PART IX: MATHEMATICS AS BACKGROUND FOR OTHER PROFESSIONS

An undergraduate degree in mathematics is excellent preparation for many careers not usually considered "mathematical." Why? The reasons stem both from the use of mathematics in other fields and from the nature of the study of mathematics. Mathematical techniques are being used to a large extent in increasingly many areas (resource exploration, data processing, corporate management, and pollution control, to name just a few). In some instances, knowledge of mathematics is more crucial than knowledge of specific subject matter. Moreover, non-technical professionals (managers, policy analysts, sales people) who work with technical personnel have an advantage if they speak the language—i.e., if they know mathematical terminology and symbols. The nature of learning mathematics enters in three ways. First, it is usually easier to learn mathematics in college and pick up specifics of subject matter later than vice versa. Second, the mathematics student typically gets more practice solving problems than does any other undergraduate major. Problem solving skills are valuable in many disciplines. Finally, mathematics is not an easy major. The student who succeeds in an undergraduate mathematics program has demonstrated both ability and the willingness to work hard. He or she is apt to learn more quickly on the job than is a graduate of a less demanding program.

1. Careers Requiring No Graduate Training

Sales and Management. These are lumped together since both primarily use the "ability to speak the language" aspect of a mathematics background. College graduates with many different majors enter these fields. If the company is technologically oriented, the math major has an advantage over the liberal arts (and often over the business) major. For a career in management, you might supplement a mathematics major with three or four business courses.

Geophysics. As resources become scarce, exploration techniques become more sophisticated and accordingly more mathematical. Math majors with a minor in geology (or vice versa) are currently in great demand by oil companies.

Engineering. When the demand for engineers exceeds the supply, mathematics majors are recruited to fill the vacancies—they already know the mathematics and are receptive to on-the-job training. Even when supply equals demand, a good math major with a few engineering courses may have an advantage over a run-of-the-mill engineering graduate.

2. Graduate and Professional School Opportunities

Many graduate and professional schools draw students from a wide variety of majors. Often a few courses outside the major are required for acceptance into these programs, so if you are interested in any of the areas discussed here, be sure to check graduate school catalogues early enough to be able to include required courses in your undergraduate schedule.

Business Administration. Mathematics is a good pre-business major for many reasons: many modern business techniques are highly mathematical; most businesses today use, produce, or sell sophisticated technology; and success in the competitive business world demands problem solving skills, hard work, and the ability to learn quickly. We quote from the article "What's needed to become a company superstar," **Business Week**, September 15, 1980: "...one combination appears to be emerging as the surest ticket to instant employment, a high salary, and a promising future. That is the combination of an undergraduate degree in engineering, math, or science, and a master's degree in business administration."

Government. Air and water pollution, resource depletion, the arms race, complex budgets—these are just a few of the concerns of government that involve use of mathematical tools. And, of course, most of what was said above about business holds equally true for government. It is thus not surprising that, for example, the John F. Kennedy School of Government at Harvard actively recruits math majors for its programs.

Law. The lawyer in court must use the evidence available to prove that the defendant is innocent or guilty, just as the mathematics student must prove the conclusion of a theorem from the hypotheses given. Where else in the undergraduate curriculum does one acquire as much experience in "arguing a case?" Moreover, as mathematical techniques become more prevalent in government and business, they inevitably show up in legal proceedings. The lawyer with a knowledge of statistics, computers, or other mathematical topics has an edge over her or his colleague with a pure liberal arts background. With today's flood of lawyers, this edge can be especially important.

Meteorology, Oceanography, Wildlife Management. These are just a few of the "smaller" disciplines which have become highly mathematical and usually do not offer undergraduate degrees. In some cases, a minor in another field (e.g., biology for wildlife management) is advisable as preparation for a graduate program in one of these fields. A thorough study of graduate school catalogues for the areas that interest you is therefore particularly advisable.

PART X: REFERENCES

General Career Information

1. *Careers in Mathematics*, American Mathematical Society, P.O. Box 6248, Providence, RI 02940. One copy, free.

2. *Careers in Statistics*, American Statistical Association, 806 15th St., NW, Washington, D.C. 20005.

3. *Actuary*, Careers, P.O. Box 135, Largo, FL 33540. 65¢ each.

4. *Mathematician*, Careers, P.O. Box 135, Largo, FL 33540. 95¢.

5. *Programmer*, Careers, P.O. Box 135, Largo, FL 33540. 95¢.

6. *Statistician*, Careers, P.O. Box 135, Largo, FL 33540. 65¢.

7. *Systems Analyst*, Careers, P.O. Box 135, Largo, FL 33540. 65¢.

8. *Casualty Actuary*, Casualty Actuarial Society, 250 W. 34th St., New York, NY 10119.

9. *Chronicle Occupational Briefs*. Among various briefs of interest are those relating to *Programmers, Mathematicians and Technicians, Statisticians, Statistical Clerks,* and *Actuaries*. Chronicle Guidance Publications, Inc., Moravia, NY 13118. $2 per 4-page brief. (Complete list of titles free on request.)

10. *Statistics: A Guide to the Unknown*, J.M. Tanur, Ed., 2nd Edition, Holden-Day, Inc., 4432 Telegraph Avenue, Oakland, CA 94609.

11. *Career Mathematics: Industry and the Trades*, Houghton Mifflin Co., One Beacon St., Boston, MA 02108. $6.99.

12. *Science Education for You?*, 1975, 20 pgs. National Science Teachers Association, 1742 Connecticut Ave., NW, Washington, D.C. 20009. $2. Prepaid orders over $15, waive $2 postage & handling fee.

13. *Careers in Operations Research and the Educational Programs in Operations Research/Management Science*, Operations Research Society of America, 428 East Preston St., Baltimore, MD 21202. Up to 3 copies, free.

14. *Careers in Applied Mathematics*, Society for Industrial and Applied Mathematics, 117 South 17th St., Philadelphia, PA 19103. One copy, free.

15. *Profiles in Applied Mathematics*, Society for Industrial and Applied Mathematics, 117 South 17th Street, Philadelphia, PA 19103. One copy, free.

16. *Actuarial Profession*, Society of Actuaries, 208 S. LaSalle St., Chicago, IL 60604. 25¢.

17. *From Actuarius to Actuary, the Growth of a Dynamic Profession in Canada and the United States*, Society of Actuaries, 208 S. LaSalle Street, Chicago, IL 60604. $2.

18. *Mathematics. The Student, Subject, and Careers Series*, Guidance Center, Faculty of Education, University of Toronto, 252 Bloor St. W., Ontario, M5S 2Y3 CANADA. $3.90.

19. *Occupational Information Monograph—Mathematician*, Guidance Center, Faculty of Education, University of Toronto, 252 Bloor St. W., Ontario M5S 2Y3 CANADA. $1.

20. Issues of the *Notices of the American Mathematical Society* contain the following articles which may be of interest:

"Comments on Panel Discussion: Nonacademic Employment of Ph.D.'s," 155(1974)206-211.

"Nonacademic Employment of Ph.D.'s in the Mathematical Sciences," Wendell H. Fleming, 161(1975)152-155.

"Case Studies—Some Mathematicians with Nonacademic Employment," 157(1974) 346-348; 160(1975)100-102; 162(1957)181-184; 163(1975)241-244; 165(1975)355-357; 184(1978)115-118.

"Current Trends in Graduate Education in Ph.D. Granting Mathematics Departments," Wendell H. Fleming, 168(1976)109-113.

"Comments on Panel Discussion: The Changing Role of the Master's Degree," 170(1976)206-209.

"Employers' Viewpoint on Nonacademic Employment—A Panel Discussion," 185(1978)184-188.

"Employment of Mathematical Sciences Doctorates," Wendell H. Fleming, 184(1978)99-104.

21. Issues of the *American Mathematical Monthly* contain the following articles which may be of interest:

"Computer science and its relation to mathematics," Donald E. Knuth, 81(1974) 323-343.

"The industrial mathematician views his profession—a report of the committee on corporate members," R.E. Gaskell and M.S. Klamkin, 81(1974)699-716.

"Mathematicians in operations research consulting," Daniel H. Wagner, 82(1975) 895-904.

"Mathematics and Sex," John Ernest, 83(1976)595-614.

"Mathematicians in the practice of operations research," Gordon Raisbeck, 83(1976) 681-701.

Recommended Study

See also #13.

22. *Professional Training in Mathematics with a Selected List of Available Scholarships and Stipends in Mathematics,* American Mathematical Society, P.O. Box 6248, Providence, RI 02940. $2.

23. *Recommendations for Study,* Casualty Actuarial Society, 250 W. 34th St., New York, NY 10119.

24. *Preliminary Actuarial Examinations,* Society of Actuaries, 208 S. LaSalle St., Chicago, IL 60604.

Support for Study

See also #22.

25. *Assistantships and Fellowships in the Mathematical Sciences, Notices of the American Mathematical Society,* (published every December), American Mathematical Society, P.O. Box 6248, Providence, RI 02940. $3.

Women in Mathematics and Science

26. *Women in Physics,* American Physical Society, 335 E. 45th St., New York, NY 10017. One copy, free.

27. *Careers for Women in Mathematics,* Association for Women in Mathematics, 422 Founders, Wellesley College, Wellesley, MA 02181. (Self-addressed, stamped envelope must accompany request. One copy, free; over ten copies, 10¢ each.)

28. *Science Career Exploration for Women,* 1978, 77 pgs. For science teachers, counselors, and others who work with young women. Contains activities modules designed to assist women students in exploring science related professional careers. National Science Teachers Association, 1742 Connecticut Ave., NW, Washington, D.C. 20009. $5. Prepaid orders over $15, waive $2 postage & handling fee.

29. *A Profile of the Woman Engineer,* Society of Women Engineers, 345 E. 47th St., New York, NY 10017.

Advice for the Employment Seeker

30. *Seeking Employment in the Mathematical Sciences,* American Mathematical Society, P.O. Box 6248, Providence, RI 02940. $1 for first copy; $1 for each additional 2 copies.

See also #20.

See also #21.

Other Sources

31. *Women Scientists Roster,* 1979, 143 pgs. A listing of over 1,300 women in science related fields who have volunteered to address students and other groups interested in science careers from a new perspective. National Science Teachers Association, 1742 Connecticut Ave., NW, Washington, D.C. 20009. $5. Prepaid orders over $15, waive $2 postage & handling fee.

32. *Science and Engineering Careers—A Bibliography* (1974), Scientific Manpower Commission, 1776 Massachusetts Ave., NW, Washington, D.C. 20036. $2.

33. *National Survey of Compensation for Paid Scientists and Engineers engaged in Research & Developmental Activities*—1981 edition. (#061-000-00569-2) Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. $9.

34. *Employment Outlook for Education and Related Occupations,* (BLS Bulletin 2200-9) Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. $2.25.

35. *Employment Outlook for Computer and Mathematics Related Occupations,* (BLS Bulletin 2200-4) Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. $2.25.

For further information we list the addresses of professional societies referred to in this pamphlet:

1. American Mathematical Society, P.O. Box 6248, Providence, RI 02940.
2. American Federation of Information Processing Societies, 1815 N. Lynn Street, Suite 800, Arlington, VA 22209.
3. American Physical Society, 335 E. 45th St., New York, NY 10017.
4. American Statistical Association, 806 15th St., N.W., Washington, D.C. 20005.
5. Association for Computing Machinery, 11 West 42nd St., New York, NY 10036.
6. Association for Women in Mathematics, 422 Founders, Wellesley College, Wellesley, MA 02181.
7. Biometric Society, 806 Fifteenth St., N.W., Washington, D.C. 20005.
8. Casualty Actuarial Society, 250 W. 34th St., New York, NY 10119.
9. Institute of Mathematical Statistics, 3401 Investment Boulevard, Suite #6, Hayward, CA 94545.
10. Mathematical Association of America, 1529 Eighteenth St., N.W., Washington, D.C. 20036.
11. National Council of Teachers of Mathematics, 1906 Association Drive, Reston, VA 22091.
12. National Science Teachers Association, 1742 Connecticut Ave., N.W., Washington, D.C. 20009.
13. Operations Research Society of America, 428 East Preston St., Baltimore, MD 21202.
14. Scientific Manpower Commission, 1776 Massachusetts Ave., N.W., Washington, D.C. 20036.
15. Society for Industrial and Applied Mathematics, 117 South 17th St., Philadelphia, PA 19103.
16. Society of Actuaries, 208 S. LaSalle St., Chicago, IL 60604.
17. Society of Women Engineers, 345 E. 47th St., New York, NY 10017.
18. The Institute of Management Sciences (TIMS), 146 Westminster St., Providence, RI 02903.