1968

Industrial Mathematicians

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INDUSTRIAL MATHEMATICIANS

HONORS SPECIAL STUDIES H291

Spring 1968

by

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What is an industrial, or professional, mathematician? What does he do? Generally, there are two kinds: workers in pure mathematics and workers in applied math.

The pure mathematician likes to play with mathematical laws and principles just to see what will happen. They have mathematical curiosity; they are not especially interested in whether anyone ever finds any use for the result or not. They have the fun of working their problems, and that is the only reward they ask. There is a large group of men and women getting paid good salaries for having such fun; they are the pure mathematicians. For the most part, they are on the college and university campuses. Some, however, are employed by business and industrial firms. Out of the play of these pure mathematicians has come some of the most important theories and formulas in modern science. Even if industry or government isn't able to tempt him with a permanent job, he is likely to serve as a consultant time and again on very practical projects.

The second group of professional workers in mathematics are interested in what is known as applied mathematics.

They work at many problems in business, industry, government, insurance, sociology, psychology, and the sciences. In brief, the practical mathematician helps workers in other fields. In fact, he often operates under the name of physicist, chemist, economist, and so on.[1]

The 1950's and 60's have seen a startling increase in the importance of math in society and in the need for trained mathematicians at all levels. The recent phenomenal rise in the field of automation and computing has been a significant factor in this greatly increased need for mathematicians.

An effective mathematician in any type of employment should be a well-rounded person. He should have not only the technical background of calculus and differential equations taken by most scientists and engineers, and the more advanced mathematical training required for a major in mathematics, but he should have taken a selection of courses from some of the areas in which mathematics is applied---such as physics, chemistry, engineering, biology, psychology, statistics, and economics. A student who plans to continue beyond the bachelor's degree in mathematics should also acquire a reading knowledge of at least one and preferably two of the foreign languages in which much of the current

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[1] Guidance Pamphlet in Mathematics, A Report of the National Council of Teachers of Mathematics (New York: The Mathematics Teacher, 1947), p. 10.

literature in mathematics is written, namely, German, Russian, and French. All students should, of course, acquire fluency in the written and oral expressions of ideas in English.[2]

Statisticians

Mathematical statistics deals with the mathematical examination and study of various kinds of statistical problems which arise in scientific research, in social and economic investigations, in business and industry, and in government work. Statisticians who deal with those problems are of two main classes: mathematical statisticians and applied statisticians. A mathematical statistician deals with the general mathematical theory of the combination of observations, testing hypotheses, and estimating unknown quantities with an accuracy specified in terms of probability. He designs efficient experiments for obtaining such tests and estimates, and also works out methodological procedures for applying the theory. The applied statistician, on the other hand, usually concerns himself with the application of known statistical methods to problems arising in one or more fields such as agriculture, biology, economics, psychology, sociology, or industrial quality control.

The training of mathematical statisticians involves a considerable amount of advanced mathematics. The requirements

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[2]K. J. Arnold, et al., Professional Opportunities in Mathematics, Sixth edition, A Report prepared by the Mathematical Association of America (Buffalo: State University of New York Press, 1964), pp. 4-6.

in mathematics include real and complex variables, linear and quadratic forms and matrix algebra, linear programming, measure and integration theories. These mathematical subjects are essential for a full understanding of probability theory, which is the foundation for advanced mathematical statistics. An increasing number of universities are giving adequate graduate training in mathematicsito prepare for advanced courses. The student who hopes to become a mathematical statistician should be sure to take in his early undergraduate program a strong group of mathematics courses including calculus.

The training of the applied statistician is based not only on mathematics through first year calculus, but on various courses in applied statistics together with substantial training in the fields to which he expects to apply his statistics. Courses in applied statistics beyond the usual introductory courses in statistics include analysis of variance, design of experiments, quality control and engineering statistics, biometry, survey sampling and its applications, economic statistics, and psychometrics.

The demand for statistically trained persons in business, industry, government and other nonacademic fields has been great. There are more women with statistical training employed in business and government than in college and university teaching, and there are substantial numbers employed in industry as well. The nonacademic fields which account for most of the recent growth of interest in statistical methods are (1) industrial statistical quality control, (2) design of experiments in industrial research and development, (3) reliability analysis, (4) information theory and communications, (5) research in the biological sciences, (6) collection and analysis of government statistics, (7) market research and commercial sample surveys, and (8) psychological testing. There are also fields in which there is an increased need for statisticians, such as finance and taxes, labor and employment, prices, production, and national income analysis.

Of all these fields, industrial quality control has grown fastest. Statistical quality control methods were initiated about 45 years ago by Bell Telephone engineers for the purpose of maintaining uniform quality of the thousands of kinds of pieces of telephone equipment required by the telephone system of the country. These statistical methods were introduced widely and rapidly into many mass production industries during the war. At the present time they are being employed in chemical and other industries. The training requirements for personnel to meet the needs of statistical quality control work consist of one or two courses in engineering statistics in addition to the usual chemical, electrical, and mechanical engineering curricula.

People who specialized in statistics at the bachelor's or doctor's level are being employed in industry in increasing numbers. Research and development organizations commonly provide statisticians to consult with other scientists on the design of experiments and analysis of data. The need for reliability of complex items, such as missile systems, has created a demand for both theoretical and applied statistical work. An increasing number of problems in the field of applied probability are to be found in industry. Many of these involve the analysis of continuous observations, such as the flight of an aircraft or seismic fluctuations, and involve highly sophisticated statistical techniques in the relatively new field of stochastic processes. Others involve the theory of efficient transmission of information, including the reception of information from satellites.

Interest in statistical methods in biological sciences has also grown rapidly in recent years. Statistical analysis is being more and more widely applied in agricultural experimentation, biological assay, public health studies, and medical research. The training required for this work is at the graduate level in one of the biological sciences, with a minor in statistical methods.

In the field of government there has been a considerable increase of statistical activity in such fields as sampling surveys in census work, economics, social security, and labor statistics. Sampling methods are becoming more and more widely used as an effective and economical way for obtaining information needed in government work. Experts in sampling methods require graduate training in mathematical statistics.

Statistical methods have long been used in business operations. One of the most important recent developments has been the application of sampling survey methods to business problems as a means of gathering many kinds of social and economic information for commercial purposes. Manufacturers and market research firms spend large sums of money every year to determine consumers' buying habits, brand preferences and opinions, for use in making business decisions. Magazine and newspaper research organizations, radio and television broadcasters and advertising agencies make studies of reading and listening habits for use in guiding editorial and advertising policy. Sampling methods are playing a fundamental role in obtaining this kind of information. Statisticians with training in economics and the social sciences and in the applications of sampling theory are being sought for this kind of work. Information retrieval is a field of growing interest to business and government as well as to the academic community.

Psychological testing is another rapidly growing field strongly dependent on statistical methods. This field is concerned with the development of tests for the selection of personnel for various purposes. Tests are becoming widely used not only in the selection of candidates for schools of all kinds, but also for the selection of personnel for many kinds of positions in the trades and professions. The modern theory of test construction is broadly based on statistical methods. The training required is graduate-level training in psychology and statistics.

Many medical schools and most medical research organizations employ statisticians. Medical research is highly empirical, involving trials on animals and people with new drugs and new techniques of treatment. The design and analysis of such experiments is an important new field.[3]

Mathematicians in Industry

There has been a striking increase in the number of mathematicians employed in industry in the last decade, and there has been a great expansion in the number of areas in industrial research and development in which mathematicians have made important contributions. Industry must attempt to solve its mathematical problems whether or not adequately trained mathematicians are available. In the electronic computer field alone, estimates of impending demand for mathematicians range from thirty thousand to seventy thousand, of whom at least half should have training beyond the bachelor's degree, and a significant number should hold the Ph. D. Even if the supply of mathematically trained persons for computer work is augmented by substantial numbers of trained women, it is unlikely to reach even the lower figure for several years. The number of large computing machines in use was about ten thousand in 1963 and is increasing rapidly. Hundreds

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[3] Ibid, pp. 11-14.

of the faster machines require the services of ten or many more mathematicians each to analyze the problems they are to solve, and to prepare their programs of instructions.

Whereas mathematicians in industry in the decade following World War II were largely concerned with problems involving the use of advanced calculus, differential equations, mechanics and statistics, it would now be fair to say that important applications to industrial problems are furnished by virtually all well-developed mathematical disciplines, including function theory, functional analysis, both partial and ordinary differential equations, geometry((including non-Euclidean), and probability. Numerical analysis and logical design have come to receive prime emphasis with the enormous expansion in computer work, and industrial mathematicians have done a major portion of the advanced mathematical research in these areas. Thus the increase in numbers of mathematicians needed by industry has been compounded by an increase in the variety and depth of training required by modern technology. Training beyond the bachelor's degree level is becoming essential in many areas. Collateral training in allied disciplines such as engineering, physics, applied mechanics, or economics is highly desirable for the industrial mathematician, since he must understand a problem in its own setting before he can design a mathematical model of it.

One who is considering a career in industrial mathematics should be warned that there may be a considerable difference in particular of views between the practice of mathematics in industry and in the universities. The primary concern of the former is the actual solution of problems, whereas the academic mathematician may be concerned with questions of existence and uniqueness of solutions without having to actually exhibit such solutions. The academic mathematician may be concerned with the logical organization of a discipline, without regard to its possible applications, while the industrial mathematician seeks to find the mathematics which may be useful in solving particular classes of problems and often in extending "pure mathematics" to fit situations of interest. The difference is perhaps a matter of taste, since each endeavor has produced mathematics of the highest caliber and each demands commensurate abilities. However, an individual mathematician may well be suited to one kind of activity and not to the other.[4]

In discussing the activities of industrial mathematicians it is convenient to separate levels of training or equivalent experience. The duties of mathematicians may differ considerably between those holding the Ph. D. degree and those holding lower degrees. There may also be considerable variance from industry to industry in conditions under which mathematicians at all levels are employed. Some industries, following the lead of the Bell Telephone Laboratories, have segregated mathematicians into special groups. Others may assign mathematicians to groups consisting principally of engineers or scientists. There is an increasing tendency to attack problems with research teams consisting of members from various

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[4] _Ibid._, p. 15.

disciplines---engineers, physicists, mathematicians, members of management, etc. There are instances where mathematicians have even headed such teams.

Service as a consultant is the primary function of a mathematician in industry. In this capacity he cooperates with engineers, physicists, other technical personnel, or management, and must be able to discuss problems in their language. A typical problem involves the mathematician in three major phases: (1) the formulation of the problem, (2) its solution, and (3) the testing of the agreement between the solution and the experimental evidence.

> "First, the mathematician constructs one or more mathematical models that simulate the problem under study and embody its essential features, and yet are amenable to analysis and solution. In dealing with problems that are too complex for complete analysis even with the aid of large computers, the construction of appropriate models is a function requiring the highest order of creative imagination, and is often the most rewarding activity of the industrial mathematician. The successful model maker must have a sympathetic understanding of areas such as fluid dynamics, solid mechanics, structural design, or electromagnetic theory, in which his problems arise. He must also be able to communicate effectively with the persons responsible for the problem, both to be able to understand more than superficially the essential features of the problem, and to interpret the results of his work. The second phase, the solution of the problem, may at times require only routine application of well-known results, but it may also tax the highest mathematical abilities, and may sometimes require the development of new, nonstandard methods. A good approximation to an exact solution may suffice, but finding even this may require great ingenuity. The third phase, that of testing the solution against experiment, also requires good mathematical work in the design of a meaningful experiment and the interpretation of the data obtained

> from the experiment. Here statistical training is often advantageous.[5]

Almost all major industries now have research laboratories, in which mathematicians frequently play an important role in activities such as the development of new products, the attainment of technical competence in new areas, and the improvement of techniques for production. A few industries maintain laboratories for basic scientific research, in which mathematicians are free to devote a significant portion of their time to research of their own choice, even though this may not be their principal assignment. Mathematicians chosen for such research appointments are usually selected on the basis of their interest in applications of mathematics to special fields, such as mechanics, electromagnetic theory, elasticity and plasticity, or numerical analysis.

Statisticians are employed in large numbers by industry in all phases of statistical work. The mathematical statistician may act as an adviser in areas such as economics and business administration, in which statistical work is primaily nonmathematical. An area of major emphasis at present is reliability theory, in which mathematicians are developing theories to insure that design of products, replacement policies, and proper use and maintenance of equipment will provide maximum reliable operation of complex systems.

Operations research is another area of important mathematical investigation in which mathematical analysis of operations,

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[5] *Ibid.*, p. 16.

methods and products, provides a basis for sound management decisions. For example, what kind of schedules, routes and pl planes are best in operating a commercial airline, or how many persons are needed to most efficiently maintain a tool crib, or what new markets should be sought? Sophisticated mathematical techniques have been developed in this area, including the useoof linear and nonlinear programming, dynamic programming, graph theory, and queueing theory.

The area of computing will continue to absorb large numbers of competent mathematicians for programming, numerical analysis, and logical design. Emphasis will certainly be placed on advanced training for a large percentage of these people. Imaginative and efficient programmers are needed to prepare operating instructions for machines that are required to solve non-routine technical problems of increasing complexity; Procedures that can shorten the time required for computation on an expensive modern electronic computer, improve its accuracy, or guard against breakdowns in the computing process, can be very significant. Numerical analysts, most of them holding the Ph. D. degree, will be in great demand to analyze problems from the point of view of finding the best numerical procedures for insuring both stability of the procedure and convergence to the actual solution of the problem. The logical design of new computers will also require the services of large numbers of highly trained mathematicians. Effectiveness [illegible] programmer presupposes an appreciation of the nature of the problems requiring solution.

Since many persons trained exclusively in mathematics have an inadequate background in allied disciplines, there is an increasing trend to employ as programmers persons who have had training in engineering or related fields.

The teaching of courses within industries is an activity of mathematicians that is just bedoming extensively appreciated. Such courses are needed both to acuqaint the engineering personnel with new developments, and to retrain and upgrade the various technical staffs.

Industrial mathematicians not only submit reports of their work for internal consumption within their company, but many are active in publishing these or other articles in mathematical or technical journals. Journal contributions of industrial mathematicians are now quite comparable to those of academic mathematicians, and a significant proportion of recently published mathematical books have authors who are employed in industry. Industrial mathematicians form a large proportion of the membership in the various mathematical societies, and make noteworthy contributions in research papers, lectures and addresses presented at professional meetings.[6]

In the past, mathematicians in industry with training at the bachelor's level have dealt largely with routine computations, the simpler problems in programming for digital computers, data processing, and similar tasks to assist senior

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[6] Ibid., pp. 18-19.

personnel. However, it is perhaps fair to say that present trends do not present an optimistic outlook for employment of persons who have earned only a bachelor's degree in mathematics and do not also have strong supporting courses in engineering, physics, or economics. Majoring in one of these fields with a strong minor in mathematics is better training for the computing field than majoring in mathematics with out supporting courses in these fields. Colleges and universities are offering programs of interdisciplinary training to alleviate the shortage of bachelors who combine the requisite mathematical knowledge with broad backgrounds in allied fields; but such programs are few and as yet experimental.

Industrial mathematicians with the master's degree also will usually work under the supervision of senior mathematicians. They should have some solid training in engineering, physics, economics, or allied fields. Much of the programming for computing machines, and a considerable amount of numerical analysis may be done by people at this level. They may be responsible for such activities as the collection and processing of data, computations on large electronic computers, preparation of graphs, solution of equations, and evaluation of integrals. This work may be challenging and not purely routine; it may contribute significantly to the education of the individual and prepare him to assume larger responsibilities, comparable to those assigned to the mathematician who has earned the doctorate.[7]

What kind of mathematics do industrial mathematicians use? It would be a mistake to say that they use only advanced mathematics. It is true, that in assisting engineers in solving their problems, mathematicians are most likely to use advanced mathematics since the more elementary problems would be solved without their assistance. But in research such simple processes as algebra, trigonometry and the elements of calculus are the most common and the most productive. They frequently lead to results of the greatest practical importance. The single sideband system of carrier transmission, for example, was a mathematical invention. It virtually doubled the number of long distance calls that could be handled simultaneously over a given line. Yet the only mathematics involved in its development was a single trigonometric equation, the formula for the sine of the sum of two angles. Next in the order of importance are linear differential equations with constant coefficients which are used extensively in studying vibrations of linear mechanical, acoustical, and electrical systems consisting of "lumped" elements. Among the less frequently used subjects are calculus of variations and integral equations. These are the basic types of applied mathematics common to all fields of application. In addition there are types with a special physical flavor: Mechanics, dynamics, elasticity, potential theory, fluid flow, and electrodynamics.

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[7] Ibid., p. 19.

An applicant for a job is not expected to be conversant with specific fields of activity in industrial laboratories, but he is expected to be equipped for attacking these problems effectively. Here, imagination, originality, and ability to make simplifying assumptions without sacrficing the practical value of the results count more than specialized training.

The communication field is the one in which mathematical methods of research have been most widely used. The problems are varied in character: electrical, acoustical and mechanical. Mathematical activity is most intense in designing wave filters and equalizers, in studying transmission by wire and radio, in providing a rational basis for the design of instruments such as transmitters and receivers, vacuum tubes, television scanning devices, etc. Most activites consist in solving specific problems. In addition there are long range activites in developing more effective methods of handling various classes of problems. Mathematics is invading general thinking about communication; a basic theory of information and its transmission is being developed. Most recently the design of control systems has become an important area of research.[8]

Mathematicians in Government

The overall role of the Federal Government in support of activities requiring the services of individuals with

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[8]*Ibid*.

mathematical skills and knowledge is shown by the amount of money the government contributes. $4.4 billions were spent in 1963 for research activities in the physical sciences, space sciences, and operations research in which mathematics and mathematicians were integrated into team efforts. One and one-half billions of the $4.4 billions were for basic research activities. Projects clearly identified as mathematics research were supported by obligations totaling $67 millions, of which $34.9 millions were for basic research.[9]

While the amounts listed are for all support by the Federal Government, most of the money was disbursed through grants and contracts to nongovernmental agencies. Of the monies listed, 75% was disbursed to private industry, 14% to support governmental establishments, 9% went to colleges and universities, and 2% went to nonprofit organizations.[10]

By Federal agency, the money was obligated as follows: 58% by the Department of Defense; 22% by the National Aeronautics and Space Administration; 9% by the Atomic Energy Commission, and 6% by the Department of Health, Education, and Welfare, The remaining 5% was from all other Federal agencies. Obviously employment of mathematicians for work performed for the Federal Government is expressed through a number of channels.[11]

If a young man or woman enters government service (or the service of a university working on a government contract)

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[9] Ibid., p. 21. [10] Ibid., [11] Ibid.

as a mathematician or statistician immediately after graduation from college, this job will almost surely have some computational aspect. Finding numerical solutions of differential equations, or some very similar problem, is likely to be assigned to him. In general it is expected that the beginning mathematician will perform miscellaneous duties which are specifically assigned and which involve a variety of standard mathematical techniques. Assignments typically are confined to a few relative processes and require a minimum of mathematical judgment, although they require sound collegiate training in mathematics. The usual courses through differential equations and some work in mathematical statistics are desirable.

As one proceeds to positions in higher grades--and one can qualify usually by a combination of experience and study--the level of work becomes more difficult and the responsibility greater. Very frequently, as in industrial laboratories, a combination of mathematical competence with background training in one or more fields of science may be needed for higher positions; a student of mathematics would be well advised to take account of this in choosing his courses in college.

The types of mathematical work carried on in government posts are extremely varied, and call on the widest background of training in mathematics. For an assignment on one of the senior levels, a Ph. D. in mathematics or mathematical statistics and a good deal of maturity in mathematics and in applying mathematics to physical or engineering problems are practically essential.

There are phases of computing appropriate to all the levels of professional activity. The need to get numerical answers to real problems which can be solved only approximately makes extensive computing necessary. Many problems have in the past been solved by very rough approximations because the amount of computing was prohibitive. Now, the newest development in large high-speed computing machines has made it possible to improve greatly the accuracy of our approximations to some of the most difficult problems. New mathematical results are needed in order that these machines may be used effectively. The government has a research program involving professional mathematicians at the highest levels who are trying to secure some results in this direction. Thus computing involves mathematical work at all professional levels.

Similarly there are applications of mathematics in preliminary studies of designs of all types of engineering equipment. These studies extend from relatively simple equipment to complicated structures like airplanes, ships, and missiles, and there is a corresponding variety in the professional level of the mathematicians working on such studies. Activity of this sort is carried on in many military development programs in an attempt to secure the best operating characteristics with the least experimental cost.

Mathematical statistics is playing an increasingly important role in government establishments in the designs and analysis of experiments, and in the acceptance of materials purchased for the government. Thus there are positions at all levels for well-trained persons in this field.

A new activity in government which has a considerable appeal to well-trained mathematicians is operations research. The primary government activities in this connection are concerned with problems of military operations, logistics, and strategy, and in the study of optimum methods for employing the complex equipment of modern warfare. The possibilities of this technique are being extended to program planning and management also, and adaptation of mathematical methods to a wide variety of such problems is under way.

Clearly there are counterparts in government of many of the activities carried on in private industry, and there is a legally protected job security comparable with the faculty tenure system of university employment. Working conditions are in most cases comparable with those in industry.[12]

This job security is called Civil Service. In 1961 there were 4671 individuals employed in Civil Service positions as mathematicians, mathematical statisticians, survey statisticians or actuaries. A survey in 1960 showed that about 14% of those employed in mathematical or statistical work in government and industry were women, and that 22% of those who were under 30 years of age were women. The employment of women by the government in positions of mathematics, statistics, and computing is apparently increasing. There is the

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[12] <u>Ibid</u>., p. 22.

added opportunity in the Federal service for employment or reemployment irrespective of age, so that qualified women will have opportunities to return to a mathematical career after marriage and child-rearing.

Except in certain beginning positions, examinations for scientific positions intthe Federal Government are "unassembled," that is, they are based on a review of the candidate's experience, education, and training. Civil Service positions are classified in a series of GS (General Service) ratings, in which professional personnel range from GS-5 to GS-18. College graduates without experience can normally qualify for GS-5 and occasionally GS-7. Those with advanced degrees or experience can enter at correspondingly higher grades. The GS grade assigned to each position in the Civil Service corresponds to the scientific level of activity expected in the position; for many positions above grade GS-13 the rating takes into account administrative or supervisory expectations along with the scientific requirements. Approximately 40% of the people employed in mathematical positions in the Federal Government have previously worked either for private industry or for universities and colleges.

Most of the mathematical positions intthe Federal government are in the Department of Defense, principally in the various research laboratories of the Army, Navy, and Air Force. About half of these positions involve applied research and development with the remainder divided between basic research, administration, and operations research. Other agencies which employ a significant number of mathematicians are the National Aeronautics and Space Administration and the National Bureau of Standards. In each of these agencies, the mathematical positions are principally concerned with basic research and applied research and development, in about equal proportions. A recent survey shows that approximately one-third of the persons in mathematical positions hold a master's degree (26%) or doctor's degree (7%).

While future professional opportunities for mathematicians with the Federal government are difficult to predict, a recent manpower report shows that Federal employment in connection with computer usage will probably continue to grow, although at a lesser rate than during the immediate past.[13]

Actuaries

The professional activities of actuaries include almost every important field relating to the provision of insurance or annuity benefits on either an individual life or a group basis. Actuaries traditionally have been, and still are, responsible for determining the premiums which companies charge for insurance. However, there are relatively few actuaries who work exclusively in this field. Many more actuaries are currently devoting their energies to such diverse fields as supervising the accounting procedures of

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[13] *Ibid.*, pp. 23-24.

insurance companies, preparing and approving the text of new policy forms, establishing appropriate rates of agency compensation, developing new methods of office administration which will successfully exploit the advantages of the newest large-scale electronic computers, providing consulting services in connection with pension plans set up by small or large corporations, etc. The reason why the services of actuaries are needed in so many aspects of the insurance business is that in many of these areas a complete understanding and effective solution of the problems that arise require a thorough appreciation of the mathematical structure that underlies the insurance business. Thus, although it is not unusual for many actuaries to spend weeks or months without writing down an equation, proving a theorem, or engaging in other activities that may be characteristic of the professional mathematician, the unique contribution that actuaries bring to any field of the insurance business with which they are concerned is their thorough familiarity with the mathematical considerations which govern the operation of the business.[14]

Summary

Mathematics is useful in many fields other than the ones already mentioned. Thorton C. Fry, former Mathematical Research Director, Bell Telephone Laboratories, lists eight wa ways in which mathematics is useful to industry in general. First, it provides a basis for interpreting data in terms of a preconceived theory, thus making it possible to draw

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[14] Preliminary Actuarial Examinations, Thierteenth Edition (Chicago: Society of Actuaries, 1968), p. 2.

deductions from them regarding things which could not be observed conveniently, if at all. Second, when data are incompatible witht the preconceived theory, a mathematical study frequently aids in perfecting the theory itself. Third, it is frequently necessary in practice to extrapolate test data from one set of dimensions to a widely different set, and in such cases some sort of mathematical background is almost essential. Fourth, mathematics frequently aids in promoting economy either by reducing the amount of experimentation required, or by replacing it entirely. Fifth, sometimes experiments are virtually impossible and mathematics must fill the breach. Sixth, mathematics is often useful in devising so-called crucial experiments to distinguish once and for all between rival theories. Seventh, mathematics also sometimes performs a negative service, but one which is often of very great importance, in forestalling the search for the impossible. Eighth, mathematics often plays an important part in reducing complicated methods of calculation to readily available working form. [15]

To sum up the function of mathematics, and mathematicians, in the vast jungle of industry, one sentence will suffice. Mathematics is a language which simplifies the process of thinking and makes it more reliable.[16]

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[15] Guidance Pamphlet in Mathematics, op. cit., pp. 18-19.

[16] Ibid.

BIBLIOGRAPHY

Arnold, K. J., *et. al.*, *Professional Opportunities in Mathematics.* Buffalo: State University of New York Press, 1964. 4-24.

Guidance Pamphlet in Mathematics. New York: The Mathematics Teacher, 1947. 10-19.

NASA Guide to Careers in Aero-Space Technology. Washington: U. S. Government Printing Office, 1966. 37-48.

"New Jobs with a Big Future," *Changing Times*, XXI (November, 1967) 6-10.

Planning a Career in Electronics. Washington: Electronic Industries Association, 1967.

Preliminary Actuarial Examinations. Chicago: Society of Actuaries, 1968. p. 2.

Space: The New Frontier. Washington: U. S. Government Printing Office, 1967.