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ABSTRACT

The purpose of this project was to develop a Master of Science program in Applied Mathematics designed specifically to meet the needs of students wishing to prepare for careers in business, industry, or government. The program emphasizes problem-solving, mathematical modeling, and areas of mathematics such as differential equations, computing, and probability that are most often required in the applications of mathematics to other fields. A major innovation in the curriculum is a new 1 year graduate-level course, Advanced Mathematical Modeling, which emphasizes industrial applications of mathematics and academic-industrial interaction. The latter is accomplished in two principal ways: (1) a series of lectures by applied mathematicians from industry or government and (2) student research projects proposed by local companies or government agencies. A volume of lecture notes generated during the project is being published (Pitman Publishing Limited) under the title "Case Studies in Mathematical Modeling." Appendices include requirements for the program, lectures/topics in advanced mathematical modeling, industrial projects, table of contents for Case Studies in Mathematical Modeling, and list of presentations concerning the program. (Author/JN)

FINAL REPORT

MASTER OF SCIENCE IN APPLIED MATHEMATICS

RENSSELAER POLYTECHNIC INSTITUTE

GRANT NUMBER HES 75-03520

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July 14, 1980

Introduction

In the early 1970's it became increasingly apparent that the traditional Master of Science degree program in Mathematics was not particularly well-suited for students who wished to prepare themselves for nonacademic careers below the doctoral level. As a consequence, members of the Department of Mathematical Sciences at Rensselaer Polytechnic Institute began to consider an alternative Master of Science program in Applied Mathematics, a program that would be designed specifically with the needs of this class of students in mind.

A grant from the Alternatives in Higher Education section of the National Science Foundation was of crucial assistance in the initiation of this new degree program. The grant began on June 1, 1975, and, following a one-year extension, terminated on May 31, 1980. This final report describes the activities carried out with the assistance of this grant.

Description of the program

Prior to launching the program officially in September, 1976, we spent considerable time discussing with representatives of various industries the kind of qualifications that are sought by industrial employers of applied mathematicians. There was remarkable agreement in the responses from a wide variety of companies and laboratories.

All indicated a need for

- problem solving skills
- ability to communicate effectively with non-mathematicians
- a broad base of knowledge, both in mathematics and in areas of application

Specific desired subject matter varied more, but there was a widespread expression of need for

- skill in analytical methods
- some knowledge of computing
- ability to use statistics

The degree requirements (see Appendix A) were established with a view to meeting these often expressed needs. Courses are required in such areas as computer science, numerical analysis, mathematical programming, applied probability, and analytical methods in applied mathematics. In addition, students are encouraged to take one or more courses in a field of application. The two focal points of the curriculum, however, are a new course Advanced Mathematical Modeling I, II, and the master's project that each student is required to complete.

The program has now been in operation for four full years, with an average of ten to fifteen students enrolled at any one time. To date a total of 23 students have completed degree requirements. Thirteen have accepted positions in industry with a total of seven different companies: Bell Telephone Laboratories (6), Mitre Corporation (2), Westinghouse (1), Sandia Laboratories (1), Santa Fe, Inc. (1), Sanders Associates (1). Four have elected to continue their studies toward the doctorate, one in mathematics (RPI), one in mechanics (RPI), one in meteorology (MIT), and one in international relations (Cornell). Five graduates are career officers in the U.S. Army and chose this program as preparation for a tour of duty on the instructional staff at West Point. The whereabouts of one graduate is unknown.

The Modeling Course

The required course Advanced Mathematical Modeling I, II was constructed so as to enhance a student's problem-solving and communication abilities, to promote teamwork, and to widen each student's horizons as to the range of applications of mathematics and the variety of useful mathematical methods. The course involves several short series of lectures coupled with a seminar. The lecturers and their topics vary from one year to the next, and are chosen so that in any particular year a representative sample of current applications of mathematics, as well as a broad range of mathematical methods, are discussed. In most cases the lecturers are practicing applied mathematicians from industrial or government laboratories who are invited to participate in the course. A list of lecturers and their topics for the four years 1976-80 appears in Appendix B.

An integral part of the modeling course is a seminar in which students report on the progress of their own work. During the fall semester the class is divided into groups of two or three students, and each group is assigned a problem area. They are expected to investigate the mathematical models that have been developed in this area, to analyze their degree of validity and their limitations, and to seek out refinements. Among the problem areas that have been used are population dynamics, epidemiology, species interaction, and carcinogenesis. Students in each group report orally to the class several times during the semester, and each student prepares a written report at the end of the term.

During the second semester of each of the last three years we have arranged for the student groups in the modeling course to work on projects proposed by local industries or government agencies. These projects have been extremely valuable for the students in several ways: they see a problem that someone in industry is interested in solving; they get acquainted with a few scientists and engineers who are doing research and development work; they hear a little bit about the constraints under which such work is done; and they see the inside of a modern research facility. All of this helps them to know what to expect when they leave school and accept a position in industry.

On the other hand, the industry receives the benefits of having a group of bright and enthusiastic students work on one of their problems at minimal cost to the company. In some cases the projects have led to quite worthwhile results from the point of view of the proposer. Even in instances where this did not materialize, and it is the nature of research not to be successful in all cases, the individuals involved from the industrial side have often found it to be a personally stimulating experience.

The output of a project is an oral or written report to the sponsor that is as formal as the sponsor desires. For example, in the project (spring 1979) with Mechanical Technology, Inc., the output was simply a working computer code for the computation of the pressure distribution in a two-layered elastic medium under given boundary conditions. In contrast, the project (spring 1979) with the New York State Department of Environmental Conservation resulted in an extensive written report analyzing the available data, proposing a rather complex mathematical model, and predicting via computer simulations the consequences of various sets of hypothetical conditions.

A complete list of projects and sponsors is given in Appendix C.

In addition to its purely technical aspects the course is important in several other ways as well. The frequent oral reports provide an opportunity for each student to sharpen his or her skills in effective oral communication. The written reports that are required each semester provide a similar opportunity to develop skill in technical writing. Feedback occurs through questions and comments from classmates in the audience and through consultation with the instructor. The individual master's project (described in the next section) gives a further chance for practice in written and oral communication.

The experience in working as a member of a team on a problem of joint interest is also extremely valuable. This is new to many students, whose previous education has been largely based on individual rather than co-operative effort. Finally, there is the effect of the course as a confidence-builder. This is particularly true of the industrially sponsored projects, which at first sight seem to most students to be utterly beyond their abilities to deal with effectively. The fact that in most cases they have been able to make some worthwhile progress in a reasonably short time has resulted in an easily visible, although not measurable, increase in self-confidence for the majority of students. We believe that these nonmathematical benefits are of comparable importance to the technical information that is acquired during the course.

The Master's Project

The project provides an opportunity for each student to organize and execute a substantial piece of independent work under the general supervision of a faculty adviser. It allows the student to follow a line of investigation that he or she finds interesting and challenging. Some projects have had a strong modeling component, others have involved the analysis of existing models; some have been largely analytical, while others have involved extensive computation; some have been closely tied to a specific real-world problem, while others have dealt more with mathematical methods. A written project report is required in all cases, and an oral presentation is arranged whenever it is possible. Appendix D contains a list of master's projects completed to date.

Advisory Committee

To assist in formulating plans for the program an Advisory Committee was appointed, consisting of the following distinguished applied mathematicians:

Jagdish Chandra (U.S. Army Research Office)

Hirsh Cohen (IBM)

Burton Colvin (National Bureau of Standards)

James McKenna (Bell Telephone Laboratories)

Melvin Scott (Sandia Laboratories)

There was an all-day meeting of the Advisory Committee in New York on November 7, 1975. Other meetings were held in conjunction with national meetings of the Society for Industrial and Applied Mathematics. In addition, members of the Advisory Committee were frequently consulted by telephone. Their advice was particularly helpful in choosing guest lecturers for the modeling course.

CASE STUDIES IN MATHEMATICAL MODELING

Since the course Advanced Mathematical Modeling was a substantial departure from existing courses, both at Rensselaer and elsewhere, there was a lack of suitable text materials. As a result, all lecturers were urged to prepare lecture notes for distribution to the students concurrently or shortly after their lectures. A substantial body of notes was accumulated in this way.

Several of the most appropriate sets of lecture notes were selected for publication in a volume entitled CASE STUDIES IN MATHEMATICAL MODELING. Following an extended period of investigation and negotiation, a contract was signed with Pitman Publishing, Ltd., of London for the publication of this book. It is now in press and will be published during the latter part of 1980. We hope in this way to provide text materials for others who may wish to institute similar courses.

The Table of Contents of CASE STUDIES IN MATHEMATICAL MODELING appears in Appendix E.

National Impact

The impact of this program nationally has been felt in several ways. In the first place, the announcement of the NSF grant and the launching of the program in 1975 resulted in a large number of inquiries from across the country. Information was provided to all who requested it, and this resulted in widespread acquaintance with our program. Particularly close ties have developed with faculty members at Clemson, Washington State, and Claremont.

As a result of their involvement in this program, Professors William Boyce and Donald Drew have been invited to speak at several regional, national, or international conferences. A complete list is given in Appendix F. Their remarks at the Fourth International Congress on Mathematical Education will also appear in the proceedings of the conference.

The book of lecture notes CASE STUDIES OF MATHEMATICAL MODELING arising from the program will be marketed on a world wide basis.

It seems clear that the latter part of the 1970's was marked by a relative increase in interest in applied mathematics, and many colleges and universities created programs of one kind or another in this field. With one of the earliest and strongest programs in applied mathematics, Rensselaer has helped to strengthen this movement and in some cases to influence its progress.

Evaluation

The most convincing evidence of the success of the program is that its graduates are in demand by employers. With the exception of one graduate whose whereabouts are unknown (and who may well have secured satisfactory employment), each graduate who entered the employment market found professional employment at competitive compensation. Most had a choice of positions, and the limiting factor governing the number of offers appeared to be the time and energy that the candidate devoted to his or her job search.

We have advertised the program extensively each year of its existence, and there is beginning to be evidence that students are attracted specifically to it. Several students are planning to enroll in the fall of 1980 without full financial aid, evidently feeling that it is a worthwhile investment in their own professional development.

Our own appraisal of the program is that it has definitely been successful. We believe that students completing the program are well-trained for employment in industrial or government laboratories, better trained than those students who have completed a more traditional Master of Science program in mathematics. We have begun to cultivate closer ties with industrial users of applied mathematics and applied mathematicians, although this is something that will never be completed.

We are in the process of developing corporate support for those aspects of the program largely supported by the NSF grant, and we are hopeful that a reasonable measure of success will result from these efforts. Initial contacts have been made with Bell Laboratories, General Electric, IBM, and Mechanical Technology, Inc.

In any event, the program is now firmly established and will be continued indefinitely as a permanent part of Rensselaer's offerings. Thus the main goals set forth in the initial proposal to the NSF have been reached.

APPENDIX A

REQUIREMENTS FOR THE M.S. IN APPLIED MATHEMATICS

Rensselaer Polytechnic Institute

Department of Mathematical Sciences

This program provides an alternative to the traditional M.S. in Mathematics for those students who wish to prepare themselves for employment in business, industry, or government. It stresses the construction, analysis, and evaluation of mathematical models of real-world problems, and those areas of mathematics that are most widely useful in solving them.

1. Each student must follow a program of study in accord with the general rules of the Graduate School governing graduate work.

2. Following an approved plan of study, each student must complete at least 30 semester credits of study with an average grade of at least B. These 30 credits must include the following:

   (a) at least 18 credits at the graduate (600) level;

   (b) the course 65.651-652 Advanced Mathematical Modeling I, II, or its equivalent;

   (c) 6 credits in each of two of the following areas:

       numerical analysis/computer science;

       mathematical programming/applied probability;

       analytical methods in applied mathematics;

   (d) an individual project.

Note: Courses not specified above can be chosen from among the many available at Rensselaer. Among the possibilities are:

courses in all three of the areas listed in 2(c);

courses in a field of application;

courses in advanced mathematics.

Note: The project provides an opportunity for each student to organize and execute a substantial piece of independent work. In general, the project should be concerned with some aspect of a real-world problem; it might focus on the development of appropriate mathematical models, or on their analysis, or it might involve some combination of modeling, problem-solving, and critical dvaluation. While the project should demand original and independent work of the student, it need not result in a significant original contribution to the field, as for a doctoral dissertation. Both a written and an oral presentation of the project will normally be required.

APPENDIX B

LECTURERS AND TOPICS
ADVANCED MATHEMATICAL MODELING

Fall 1976

Donald A. Drew (RPI), Models of Traffic Flow

Alan G. Konheim (IBM), Queueing Theory with Applications to Data Communication

Bernard O. Koopman (Arthur D. Little, Inc.), Hydroacoustic Wave Propagation

Spring 1977

Judith F. Gilsinn, Douglas R. Shier, Christoph Witzgall (National Bureau of Standards), Shortest Paths in Networks

Donald A. Drew (RPI), Two-phase Flows in Nuclear Reactors

Douglas H. Shaffer (Westinghouse), Probability Models for Dielectric Breakdown in a Coaxial Geometry

Lynn O. Wilson (Bell Telephone Laboratories), Semiconductor Crystal Growth

Fall 1977

Lee A. Segel (Weizmann Institute and RPI), Why Don't Weeds Develop Resistance to Herbicides?

and

A Mathematical Representation for a Desalinization Process

Donald A. Drew, (RPI), Models of Traffic Flow

Paul B. Bailey (Sandia Laboratories), The Calculus of Variations and the Sturm-Liouville Eigenvalue Problem as Encountered Outside the University

Stephen S. Wolff (Aberdeen Proving Ground), Simple Stochastic Models for Estimation and Prediction

Spring 1978

Moayyed A. Hussain (Watervliet Arsenal), Models in Fracture Mechanics

Donald A. Drew (RPI), Two-phase Flows in Nuclear Reactors

APPENDIX B (cont.)

Fall 1978

Donald A. Drew (RPI), Models of Traffic Flow

Thomas F. Balsa (General Electric), Aerodynamic Noise

Bruce A. Powell (Westinghouse), Mathematical Modeling of Elevators

Spring 1979

Christoph Witzgall, Judith F. Gilsinn, Douglas R. Shier (National Bureau of Standards), Shortest Paths in Networks

William E. Boyce (RPI), The Propagation of Nerve Impulses

Jonathan K. Millen (MITRE Corporation), Operating System Security Verification

Fall 1979

Donald A. Drew (RPI), Models of Traffic Flow

New York State Department of Transportation, Research Planning Bureau

a. David Hartgen, An Overview of the Role of Mathematics in Transportation Research

and

Forecasting Energy Demands

b. Gerald Cohen, Disaggregate Models and Individual Choice

c. Wayne Ugolik, Urban and Rural Transit Services

d. Peter Koeppel, Psychometrics and Attitude Scaling

Thomas Lorenzen (General Motors Research Laboratories), Multiple Attribute Sampling Procedures

Spring 1980

Department of Energy, Environmental Measurements Laboratory

a. Keran O'Brien, Physics of Radiation Transport

b. Gail de Planque, Environmental Monitoring Around Nuclear Facilities

c. Carl Gogolak, Micrometeorological Models

John Lew (IBM), Signature Verification Models

Bell Telephone Laboratories

a. Richard Hinderliter, Design of Telephone Networks in Small Population Areas

b. Richard McLaughlin, Planning Local Cable Networks

c. Norman Noe, Forecasting Demand for Small Populations

APPENDIX C

INDUSTRIAL PROJECTS

Spring 1978

1. Transient Response of a Solar Storage Subsystem (General Electric Company)

The problem is to determine the transient response of thermal storage of a solar power plant. More specifically, the objectives of this problem are to determine the temperature distribution within the storage tank and the outlet temperature as a function of time during charging and discharging.

2. An Axisymmetric Layered Contact Problem (Mechanical Technology, Inc.)

The problem as posed by MTI concerns the surface displacement of a paraboloid on a layered surface due to a pressure distribution. The problem is to determine the pressure in the contact zone. The result was a system of equations for the unknown pressures at nodes within the contact zone. The coefficients of the system were presented in a form suitable to program on a computer.

3. Flutter of a Turbine Blade in Supersonic Flow (General Electric Company)

Under certain extremely rare operating conditions, a blade in a compressor may experience severe and unwanted vibratory motion. This is called compressor flutter. Very sophisticated analyses and computer programs exist for the prediction of the onset of flutter; invariably these predictions are based on so-called two-dimensional analysis involving space variables (x, y) only. The purpose of this problem is to obtain the precise conditions under which the well accepted two-dimensional analysis is adequate; this is to be done by examining the solution to a simplified three-dimensional problem and by establishing criteria under which this solution weakly depends on the spanwise coordinate, z.

Spring 1979

1. Thermodynamic Analysis of Shocks (General Electric Company)

The object of the project was to produce a computer code for the computation of thermodynamic variables downstream from a shock in a fluid not obeying the ideal gas law. This required the development of an efficient numerical algorithm for solving the Rankine-Hugoniot equation, using an assumed equation of state.

APPENDIX C (cont.)

2. An Axisymmetric Layered Contact Problem (Mechanical Technology, Inc.)

A thin elastic layer resting on an infinite elastic substate is subjected to an unknown axisymmetric pressure distribution. For a given displacement pattern, the problem was to determine the pressure distribution. The procedure was based on a Hankel transform solution of the biharmonic equation, and resulted in a working computer code for the inverse transform.

3. Mathematical Models in Wildlife Management (New York State Department of Environmental Conservation)

The problem was to develop a mathematical model for the interaction of natural predators with white-tailed deer. A model was developed and simulated on the conputer. Data were taken from studies in the Adirondack Mountains, Isle Royale, and the Idaho Primitive Area. In addition to the predator-prey interaction the effects of hunting and weather were also taken into account.

4. Experimental Designs for Analysis of Pharmacokinetic Data (Sterling-Winthrop Research Institute)

This problem concerned the statistical analysis of rate constants in a two-compartment pharmacokinetic model. The procedure involved the development of a nonlinear estimation technique appropriate for this situation. Several methods were tested and compared for effectiveness and cost.

Spring 1980

1. Calibration of Drug Doses (Sterling-Winthrop Research Institute)

The problem involved the study of various possible correlation techniques to determine the relation between a standard set of drug dosages, and some response, for example, the concentration of the drug in the patient's plasma after one hour. The procedure should be able to determine accurately an unknown dosage from a known response. Standard, inverse, and multicurve correlation techniques were investigated using a computer code.

2. Pheasant Population Models (New York State Department of Environmental Conservation)

The project involved a study of pheasant populations in two counties in western New York State. Large collections of data were compiled on pheasant populations, predator (raptor) populations, weather, hunting, etc. Weather was found to be the most important factor, but predation had some influence.

APPENDIX D (cont.)

Spring 1979

John Durgala, Baseball: an Analysis of Winning

Raymond J. Hall, Two-phase Flow: The Stability of Small Perturbations in the Basic Flow Problem

David C. Smith, Some Mathematical Models for Optimizing Running and Swimming

Carl D. Springer, Multiple Time Series Investigations into the Control of a Paper Mill

Daniel S. Stevens, Perturbed Bifurcations

Summer 1979

Richard J. Montedonico, Impact of the Electric Car upon New York State Electric Power Systems

Ursula A. Sinkewicz, A Simplified Geometrical Interpretation of Plate Subduction

Stephen E. Zebiak, An Investigation of the Steady Zonally Symmetric Motion of the Equatorial Atmosphere

Fall 1979

J. Michael Coyle, A Numerical Method for Approximating Solutions of Two Point Boundary Value Problems by Averaging and Using a Spline under Compression Basis

David W. Meek, Ideal Two-Phase Slug Flow in a Horizontal Nozzle

Spring 1980

James J. Grazioplene, Some Applications of Self-critical Estimation Procedures

John M. Greenwalt, Multiple Time Series Investigation into the Control of a Diffuser Bleach Plant

Ronald A. Hanisch, Singular Inverse Eigenvalue Problem with Applications to Vibrating Membranes and Drums

APPENDIX E

TABLE OF CONTENTS

CASE STUDIES IN MATHEMATICAL MODELING, W. E. Boyce (Editor)

To be published by Pitman Publishing Limited in the fall of 1980.

APPENDIX F

PUBLIC PRESENTATIONS CONCERNING THE PROGRAM IN APPLIED MATHEMATICS

Professor Boyce has participated in the following regional, national, and international conferences.

"Training, Teacher Qualifications, and Curricula for Applicable Mathematics", panelist, Northeast Regional Meeting, Mathematical Association of America, University of New Hampshire, June 19, 1976

"Models and Project Courses in Applied Mathematics", panelist, NSF Conference on Graduate Programs in the Applied Mathematical Sciences: Perspectives and Prospects, Clemson University, August 26-27, 1977

"The Growing Role of Applications in Mathematical Higher Education", panelist, CBMS Panel Discussion, Winter Meeting of AMS and MAA, Atlanta, Georgia, January 6, 1978

"The Mathematician Outside the University", organizer and moderator of panel discussion, Winter Meeting of AMS and MAA, Biloxi, Mississippi, January 26, 1979

"The Master of Science in Applied Mathematics at Rensselaer Polytechnic Institute", Conference on Experiential Applied Mathematics Education, Claremont Graduate School - Harvey Mudd College, May 31 - June 2, 1979

"University Programs with an Industrial Problem Focus", symposium panelist, Fourth International Congress on Mathematical Education, University of California, Berkeley, California, August 11-12. 1980

Professor Boyce also participated in two meetings of the Advisory Committee for the NSF sponsored program at Washington State University, September 26-28, 1975, and June 26-27, 1978

Professor Boyce also participated in meetings of NSF Project Directors, January 11-13, 1976, and February 7-9, 1979

APPENDIX F (cont.)

Professor Drew has participated in the following national and international conferences.

"A Master's Degree in Applied Mathematics - Who Needs It?" SIAM National Meeting, Philadelphia, PA, June 13-15, 1977

"A Report on Upper Level Mathematical Modeling Courses and Seminars"; panelist, MAA/SIAM Panel Discussion, Winter Meeting of AMS and MAA, San Antonio, Texas, January 5, 1980

"Educating Mathematicians to Work in Engineering and the Physical Sciences", Fourth International Congress on Mathematical Education, University of California, Berkeley, California, August 13, 1980