ENGINEERING

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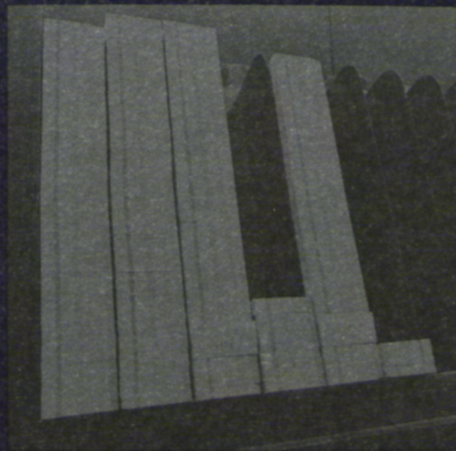

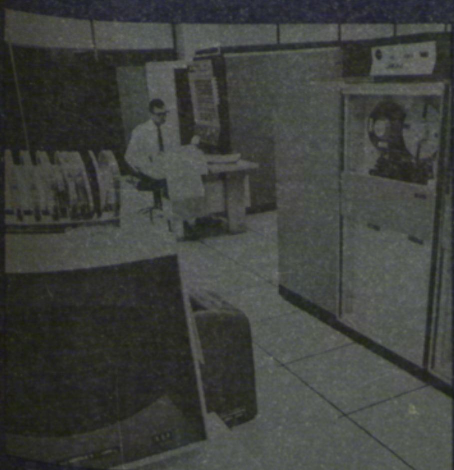

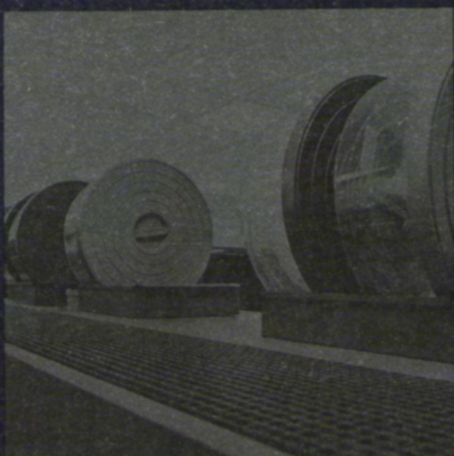

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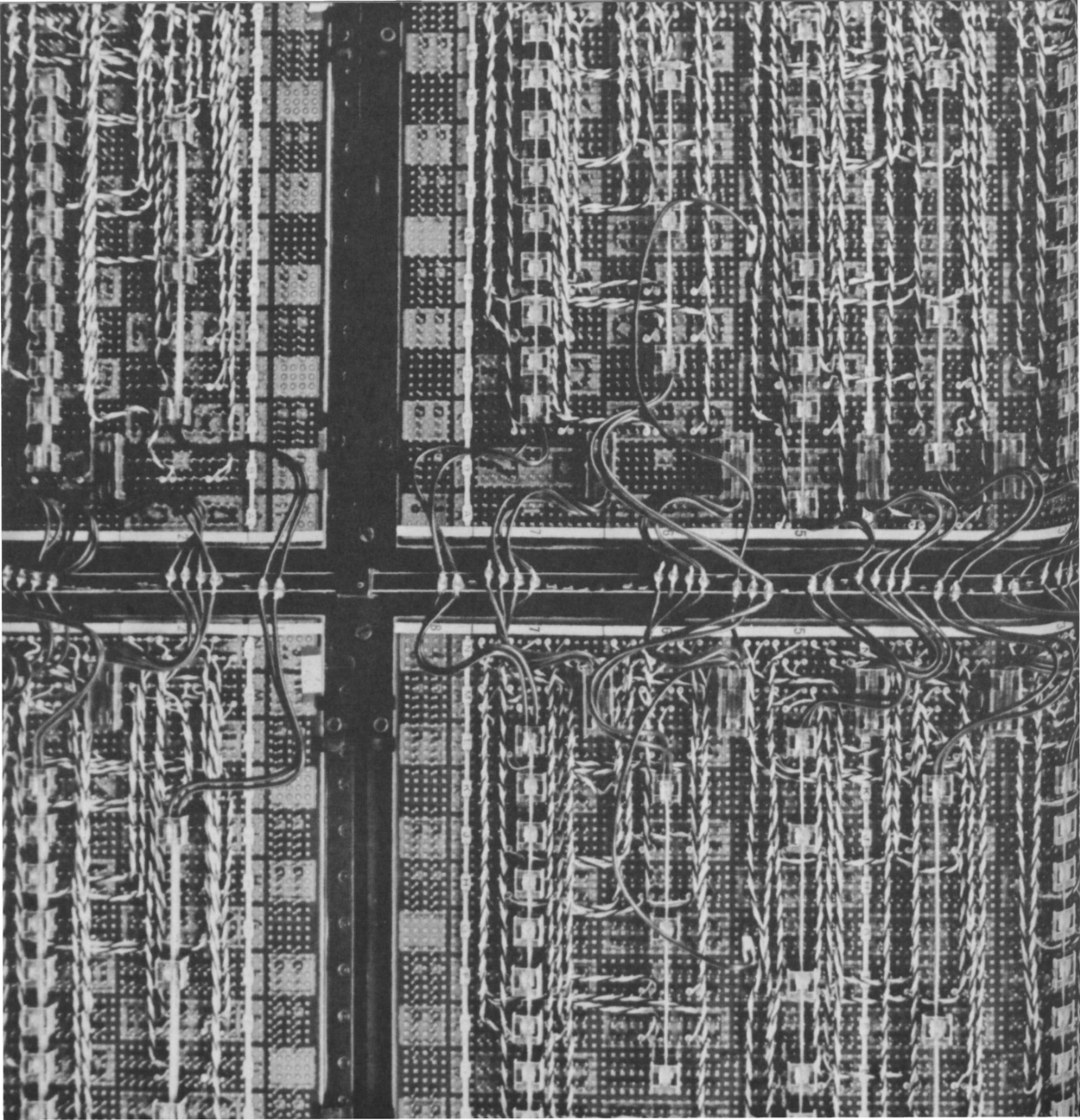
THE QUIET REVOLUTION



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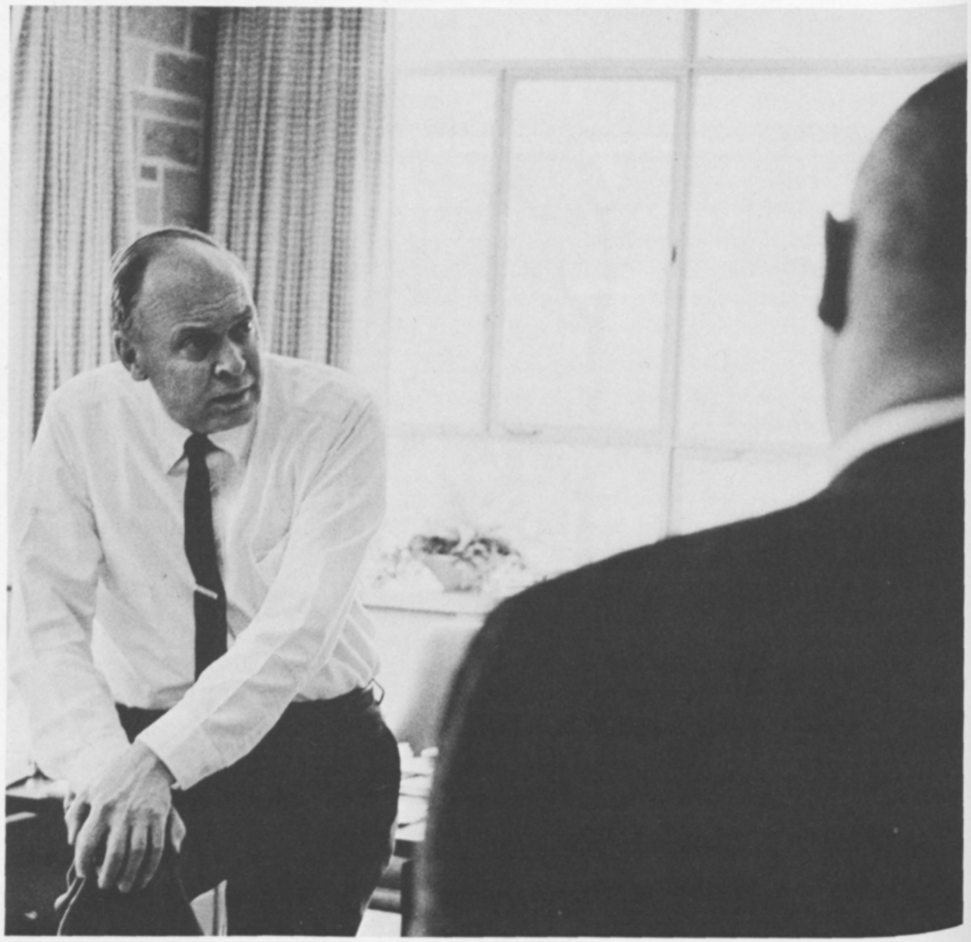
The quiet revolution wrought by the computer in industrial engineering education is evidenced by the stacks of cards, magnetic storage tapes, and central processing unit depicted on the cover and opposite.

THE QUIET REVOLUTION

From "Scientific Management" to "Operations Research"

By Andrew Schultz, Jr.

During the latter part of the nineteenth century, Frederick W. Taylor, a young mechanical engineer, began specifying in some detail the most effective way of performing a job. As a young workman, he realized that many of his fellow workers produced but a fraction of the work they were capable of turning out, but the bosses evidently did not know what a proper day's work should be. His systematic way of analyzing the work function as well as the conditions for worker motivation rapidly became known around the world as the beginnings of "scientific management," the first effort to apply logical methods to the problems of production and management.



In 1903, he presented a paper, "Shop Management," at the annual meeting of the American Society of Mechanical Engineers. Dexter S. Kimball, a future dean of engineering at Cornell and at that time works manager of Stanley Electric Manufacturing Company, a predecessor of General Electric Company, was in his audience. Of Taylor's work he said, "The more I studied this philosophy, the clearer it became to me that it contained certain principles that were a necessary part of the training of engineering students, particularly as a large number eventually become administrative officers in industry."

A year later when Kimball joined the Sibley School of Mechanical Engineering faculty at Cornell, he decided to offer an elective course in shop management to seniors, suggesting the title, "economics of production." He wrote that the dean of the Sibley School, Albert W. Smith, "thought that was a little high-brow so we settled on 'works administration' as more likely to get by the Committee on Course." The course was offered in 1904–05.

Later on, courses in elementary economics and accounting were added to the Cornell mechanical engineering curriculum, and in 1916 a senior option in industrial engineering was established.

FORMATION OF A NEW DEPARTMENT

In 1930 a new department of administrative engineering was created at Cornell under the leadership of Professor John R. Bangs, Jr. The program of this department was far reaching and pioneering in many of its aspects. In the first place, Professor Bangs, supported by Dean Kimball, considered that the substance of the program transcended the subject matter of many fields of engineering. The program had an operational emphasis, in the case of Mechanical and of Electrical Engineering, directed to manufacturing and in the case of Civil Engineering, directed to the construction industry. But the philosophy included a consideration of all aspects of a problem; it was truly an "engineering systems approach." Emphasis was on quantification and analysis. Some of the first courses in statistics, cost analysis, personnel, and industrial marketing were introduced in this program at Cornell. As can be seen in Table 1, it was highly successful within Mechanical Engineering, due probably to Professor Bangs' personality and the able assistance provided by Professors Harry Loberg, George Hanselman, Clyde Millard, Myron Lee, and S. S. Garrett. These men developed

Table 1. EARLY UNDERGRADUATE ENROLLMENT IN ADMINISTRATIVE ENGINEERING*

	1932	1933	1934	1935	1936	1937
Civil Engineering	—	—	—	9	5	26
Electrical Engineering	31	40	64	59	46	50
Mechanical Engineering	95	164	174	194	201	207
Total with Administrative Majors	126	204	238	262	252	283
Percent of Total Undergraduate Enrollment in the College	13.9	25.3	29.3	33.2	31.4	28.1

* Until 1946 the curriculum in administrative engineering cut across the traditional branches of engineering activity. A student in civil, electrical, or mechanical engineering could choose to major in administrative engineering applied to his field.

"The proliferation of OR techniques and theories... has considerably changed the mission of the industrial engineer."

entirely new courses in applied statistics, manufacturing engineering, applied economics, and industrial marketing and accounting.

Nevertheless, judging by today's standards, the analytical content of the administrative engineering curriculum left something to be desired. Many of the courses were oriented to specific problem areas; the methodologies studied in the classroom and the techniques taught in the laboratories were very practical and largely empirically derived. Methods of analysis depended frequently on graphical techniques, modeling methods were crude, and only the simplest forms of experimentation were possible. Sophisticated mathematical and computing methods had not yet been developed, and further refinement and application of the scientific approach to these problems was therefore extremely difficult.

STEP FUNCTION CHANGES

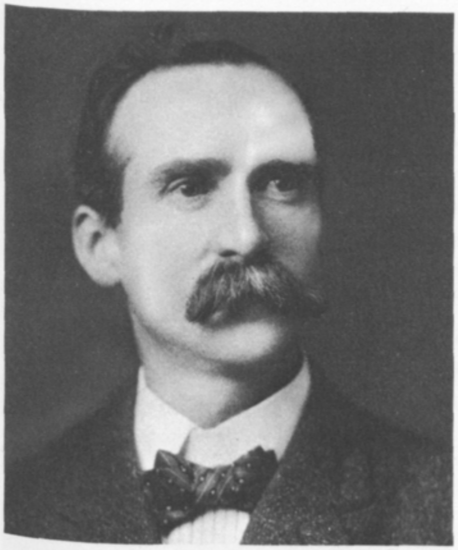
During World War II and the balance of the '40s, developments of crucial importance to this field occurred. A more fundamental approach to the engineering process evolved; engineers began to use the scientific method to extend their capabilities. And operations research emerged as a general rather than a specific concept.

The methods used by the industrial engineer, involving statistical analysis and what are now called network representations and various graphical and qualitative means of analyzing very complex systems, were found extremely useful in planning military operations. Under the pressure of war time many highly trained civilians in the mathematical area (including physicists, physical chemists, and biologists) as well as military personnel contributed to the development of new techniques and devices. They often worked in teams with sociologists and economists to determine the psychological impact of military strategies on enemy and allies alike. Their approach to the complex problems they faced became known as operations research. After the war many organizations were founded upon the concept of the OR approach, organizations such as the Rand Corporation, the Naval Operations Evaluation Group, and the Army's Operations Research Office. At this time too the digital computer was developed. It introduced quantitative dimensions to problems that were formerly solved intuitively or only approximately.

At Cornell, Columbia, Stanford, Berkeley, and many other institutions new courses in applied mathematics and computing were offered. These courses usually stemmed from an industrial engineering department or its analog. As the mathematics developed and as the automatic digital computer became generally available, it became possible for the industrial engineer to move from the rather empirical and limited foundation to which he was previously restricted to a much broader concept of operating systems founded upon the science of operations.

PROFESSIONAL SOCIETY DEVELOPMENTS

In the early 1950s the Operations Research Society of America was organized, and in October 1955 a group which included the Society's Education



Top: Dexter S. Kimball when he became a member of the Cornell faculty in 1904. From 1920 until his retirement in 1936 he was dean of engineering at Cornell.

Bottom: A former professor of administrative engineering, John R. Bangs, Jr. was responsible for the education of industrial engineers at Cornell during the depression years.

Committee met at Cornell for a two-day session aimed at defining the educational problems in this field. Their consensus was that preparation for productive careers in "operations research" required extensive graduate study. In 1956 the Long Range Planning Committee of the American Institute of Industrial Engineers met at Cornell and defined their concept of industrial engineering. The definition, which was adopted by the Institute, describes industrial engineering as that field "concerned with the design, improvement, and installation of integrated systems of men, materials, and equipment. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems."

At about the same time, a half century after the pioneering contributions of Frederick Taylor, a group of individuals with broader interests than are implied by the terms "industrial engineering" and "operations research" got together and founded the Institute for Management Science.

THE QUIET REVOLUTION

The proliferation of OR techniques and theories during the last two decades has considerably changed the mission of the industrial engineer. Today he is able to be concerned equally effectively with flow through a factory, through a tunnel, through a port, or through a communications network.

To give the reader an idea of the kinds of applications an industrial engineer might make of OR theory, I would like to consider queuing theory for a moment. Situations which may be explained by queuing theory are:

- airplanes waiting to land or take off;
- maintenance men and machines needing service;
- telephone callers and trunk lines;
- customers and bank tellers, check-out clerks, or postal clerks; and
- jobs in a shop and machines.

These "waiting line" situations can be

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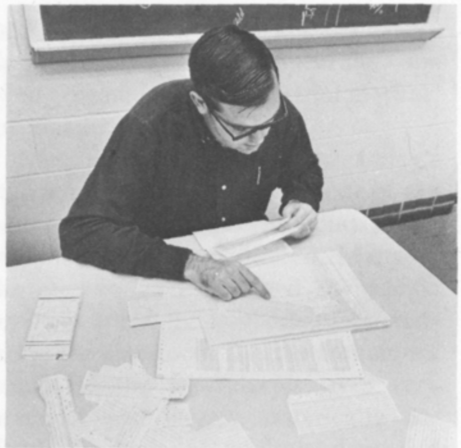

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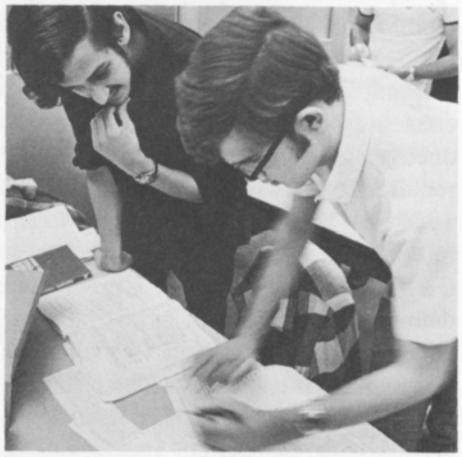

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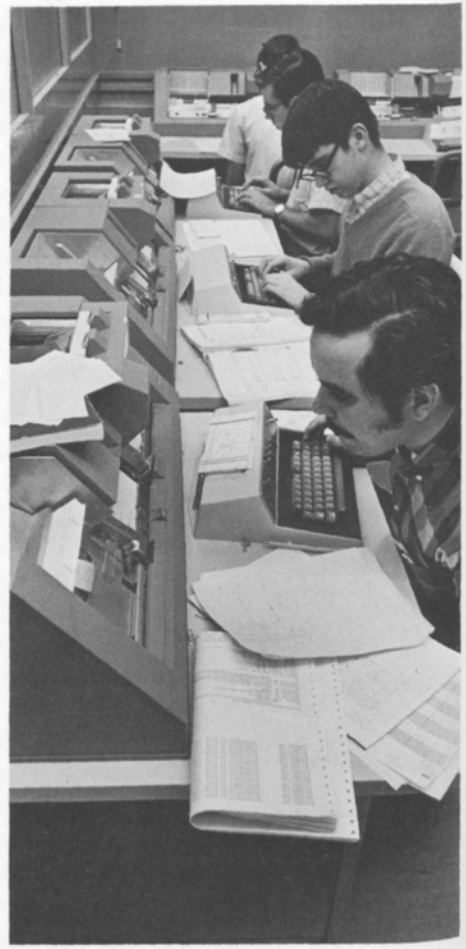


The computing facility at Cornell is kept busy by engineering students, many from industrial engineering and operations research, who are shown here preparing their program source decks (3) and debugging their programs by checking cards against printout and coding sheets (1 and 2).

modeled mathematically and the models manipulated to determine or predict the effect of change in the situation, of substituting a new design for an old one.

Only the simplest types of queuing situations, however, are easily analyzed mathematically. The more complex ones often require assumptions that may oversimplify the situation or mathematical operations which are extremely difficult or impossible to carry out. The automatic digital computer of modern capacity may be programmed to simulate such situations with accuracy and has the added advantage that experiments so performed can be reintroduced with different design parameters.

Modern computer technology allows companies and governments, indeed all large organizations, to reappraise and redesign their management information and communications systems so they may operate more quickly and efficiently. As a result, individuals with backgrounds in OR and management science are presently consulting with city and state governments, hospitals, insurance companies, banks, distribution enterprises, and many other organizations with which yesterday's industrial engineer had little concern. Many of these individuals perform their jobs under the title of engineer, but many carry the title "operations analyst" or "operations researcher." At the same time, many of the activities formerly performed by the "industrial engineer," such as time study, rate setting, work simplification, and work-place design, are currently being performed by technicians.

CORNELL'S EDUCATIONAL PROGRAM IN IE AND OR

Today the College of Engineering instructs undergraduates in the methodology necessary to the modern industrial engineer through the School of Industrial Engineering and Operations Research. It instructs graduates interested in OR methodology through the Department of Operations Research. At this point it may be helpful to describe the missions of the School of Industrial Engineering and the Department of Operations Research. The school in the College's organizational structure is responsible for the design and execution of the undergraduate program and the supervision of the professional Master's degree program. In other words, the School of Industrial Engineering and Operations Research is expected to define the educational means of preparing students for careers in industrial engineering. A department is oriented to the development of particular, more fundamental subject matter and is intent on producing teachers and researchers as well as engineering practitioners. Faculty are hired into depart-

CORNELL INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH HIGHLIGHTS

1904 Dexter S. Kimball teaches an elective course, "works administration," to seniors in mechanical engineering. This was the first known collegiate course to familiarize engineering students with the economic basis of contemporary production practices.

1915 An "Industrial Engineering Option" is offered to seniors within the Sibley School of Mechanical Engineering. This option was available until 1955, when it was dropped by the Sibley School.

1931 The Schools of Mechanical and Electrical Engineering introduce a new curriculum leading to the Bachelor of Science in Administrative Engineering degree. (Civil Engineering developed a similar curriculum in 1935.) With one more year of study the student of this curriculum could obtain the traditional engineering degree in his field; 60% of the curriculum was in technical subjects and 40% in economic and "liberalizing" subjects.

1933 The first known Doctor of Philosophy degree in industrial engineering in the United States is awarded to Ralph M. Barnes. His thesis, "Practical and Theoretical Aspects of Micromotion Study," later became the text *Motion and Time Study* (John Wiley, New York, 1937).

1958 The first Cornell doctorate in operations research is awarded to Richard W. Conway. His thesis was "An Experimental Investigation of Scheduling for Single-Stage Production."

1962 An undergraduate curriculum leading to the degree Bachelor of Industrial Engineering is authorized by the College of Engineering faculty. This curriculum was no longer under the jurisdiction of the Schools of Mechanical, Electrical, and Civil Engineering.

The Graduate Field of Industrial Engineering and Operations Research is approved by the General Committee of the Graduate School at Cornell.

1967 The current structure of the College in these areas is authorized. Candidates for the M.S. and Ph.D. degrees in operations research study in the Graduate Department of Operations Research. Candidates for the B.S. and professional M.Eng. degrees in industrial engineering study in the School of Industrial Engineering and Operations Research.

Andrew Schultz, Jr.

ments; they are invited to participate in school affairs. This structure allows for substantial changes in curriculum without major disruption of faculty. If, for example, more instruction in computer science is deemed desirable for undergraduate students of industrial engineering, the school director can seek the teaching services of the Department of Computer Science at Cornell.

Presently, 180 students are pursuing either the Bachelor's or the professional Master's degree in IE and OR. The number of undergraduates choosing this field as their major has doubled in the last five years, in which there has been negligible change in College-wide undergraduate enrollment. In the same period, in which overall Ph.D. enrollment in engineering at Cornell doubled, the M.S.–Ph.D. enrollment in the Department of Operations Research tripled.

THE DIFFICULT EDUCATIONAL PROBLEMS

There are two major problems that arise in attempting to provide a sound

FIVE YEAR ENROLLMENT COMPARISONS

	Fall 1964	Fall 1969
School of Industrial Engineering and Operations Research		
Juniors	52	81
Seniors	22	76
M. Eng. candidates		21
Department of Operations Research		
M.S. candidates	25	8
Ph.D. candidates	12	39
Total Enrollment in These Areas	111	225
Total Enrollment in the College of Engineering	2448	2742
Total Ph.D. Enrollment in the College	229	443

"I believe the systems analysis approach developed in this country during the past twenty years offers good prospects for successfully dealing with [the complex problems of our democratic society]."

education in industrial engineering and operations research. One of these relates to the amount of engineering sciences that should be required of students. The IE student must not only be able to understand operations but also be able to create more effective systems. Traditionally, he was educated first in the principles of physical engineering and then in applied techniques largely focused on manufacturing. Only recently has he been concerned with systems in which manufacturing operations are not central. As new mathematics and associated applied techniques proliferate, however, there is less time in the curriculum for engineering technologies which rapidly obsolesce. The contemporary concern with the less specialized engineering sciences and the political, socio-economic aspects of "systems problems" raises the question of educational trade-offs.

Another very serious problem is the design or laboratory aspect of educational programs in this field. Although all of society may be said to provide a laboratory for the IE/OR student, it is often impossible to manipulate the variables and observe the results in real life situations of interest to this student. As a result, the full benefit of the experimental technique cannot easily be obtained except through computer simulation.

At Cornell, we have attempted to meet these problems head-on by instituting a flexible undergraduate curriculum and requiring of Master of Engineering degree candidates a design project derived from a "real world" situation and often pursued off campus in the realistic environment.

WHAT LIES AHEAD?

Successful solutions to the complex problems of our democratic society (conservation, environmental control of pollution, highway and urban traffic, housing, education) almost always require major political decisions and even political restructuring. Frequently, therefore, the technological need is difficult to define immediately and difficult to meet. I believe the systems analysis approach developed in this country dur-

ing the past twenty years offers good prospects for successfully dealing with these problems. The methods of the new breed of industrial engineer and of operations researchers are critical in this approach. It demands a high level of education, a very sophisticated analytical ability, and in the case of social problems, a deep and penetrating sensitivity to them.

Andrew Schultz, Jr., dean of the College of Engineering at Cornell since 1963, can write about the development of modern industrial engineering and operations research education with authority. He has been associated with this field at Cornell since 1946 and has contributed substantially to its growth. A graduate of Phillips Academy in Andover, Massachusetts, he earned his Bachelor's and Doctor of Philosophy degrees from Cornell in 1936 and 1941.

During World War II, Dean Schultz attained the rank of Lieutenant Colonel in the United States Army and was chief of section in the Industrial Service, Ammunition Division, Office of the Chief of Ordnance. He returned to Cornell in 1946 as assistant professor and in 1951 became head of the Department of Industrial Engineering and Administration, a position he held for twelve years.

During one of his sabbatics, Dean Schultz was vice president and director of research for the Logistics Management Institute in Washington, D.C. He spent two previous sabbatics as an operations analyst for the Operations Research Office of the Johns Hopkins University and as a full time consultant to the Engineering Advisory Committee of Western Electric Company's Engineering Research Center at Princeton, New Jersey.

He is a fellow of the American Institute of Industrial Engineers and the American Association for the Advancement of Science and a member of the Commission on Education of the National Academy of Engineering, the American Society for Engineering Education, the Institute of Management Science, and the Operations Research Society of America. He was an associate editor of the Journal of Operations Research *from 1960 to 1969. He is also a member of Tau Beta Pi, Pi Tau Sigma, and Sigma Xi.*

At present he serves on the boards of S. I. Handling Systems, Incorporated; the Logistics Management Institute; the Lexington Growth Fund; and the Engineers Council for Professional Development.

Above: Upson Hall, the gift of a distinguished Cornell engineering alumnus, Maxwell M. Upson, houses the facilities for the Sibley School of Mechanical Engineering, the School of Industrial Engineering and Operations Research, and the Department of Computer Science.

KALEIDOSCOPE

Cornell's OR Faculty

By Donald F. Berth and Vicki Groninger

In the sense that operations research techniques and methodology are applicable to the full spectrum of engineering activity, OR may be thought of as the "hub of the engineering wheel." What began in World War II as an approach to ensure the success of military operations has now burgeoned into a full-scale discipline involving university study and having ramifications for all of society. To find out what a modern OR department is like we interviewed many of the Cornell faculty working in this area.

The faculty in operations research at Cornell are drawn from many different academic backgrounds. They are statisticians, probabilists, engineers, mathematicians, and information processing experts. Some have had extensive industrial and administrative experience and others have worked exclusively on research for private institutions before joining the faculty at Cornell. All now divide their time between teaching and research. In several cases they have joint appointments with other departments at Cornell. Environmental Systems Engineering, a department associated with the School of Civil Engineering, is a natural one to be paired with Operations Research. Two of the nineteen professors in the OR department presently share appointments with this department, and Professor Sidney Saltzman, a member of the industrial engineering and operations research faculty for several years, has recently joined the faculty of the Department of City and Regional Planning. Two other professors have joint appointments with the Department of Computer Science. Professor Jack C. Kiefer of the Department of Mathematics is a member of the Graduate Field of Operations Research as is Professor Walter R. Lynn, Director of the Center for Environmental Quality Management. In addition, the OR faculty work closely with the Graduate School of Business and Public Administration at Cornell, providing them instruction for much of their quantitative requirements (courses in probability, statistics, computing, and programming). And there is a growing need for cooperation between OR and economics, particularly as that discipline becomes more analytical.

"Each of these major areas with which OR shares an interface offers us an opportunity to enhance the applicability of our techniques and to become better acquainted with several of the difficult systems problems facing professionals," explained Professor Bechhofer, chairman of the OR department. He sees the joint appointment as a means for giving an OR department that critical mix of theoreticians, practitioners, and communicators essential for its well-being.

What does OR methodology consist of? To create mathematical models that may be applied to real systems (such as a traffic flow network), such theories as queuing, inventory, reliability, replacement, and scheduling are important. Mathematical programming (linear, probabilistic, integer) and dynamic programming are also used extensively. Game theory, graph theory, and combinatorics are some other major techniques in the field. Any student majoring in OR must use linear and matrix algebra, probability, statistics, and computational science in the development of these techniques. As most members of the department were quick to point out, however, OR is not simply a "bag of ready-made techniques." Several of the faculty are concerned solely with the development of concepts and new techniques. They leave the application of their findings to other workers.

The main work of the faculty in the department presently falls under the general heads of applied probability and statistics, mathematical programming, game theory, and information processing.

THE STATISTICIANS

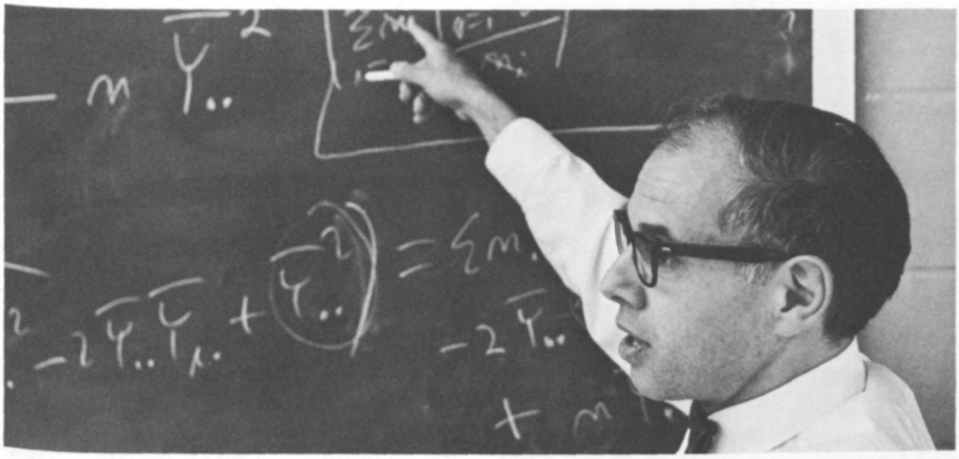
The two senior statisticians on the faculty—Professors Bechhofer and Weiss—have a combined period of twenty-eight years of teaching at Cornell. Two other faculty members, Professors Mark Brown and Howard Taylor, have Ph.D. degrees in mathematical statistics but currently devote their primary research efforts to problems in applied probability.

Both Bechhofer and Weiss were drawn to Cornell partly because of the quality of the faculty in the Department of Mathematics. Both hold the Ph.D. degree from Columbia University in mathematical statistics. As chairman of the OR department, Bechhofer has many responsibilities—faculty recruiting, exploring various avenues for support, research proposal writing—in addition to his own program of teaching and research. He serves as the senior scientist on a research project involving queues at traffic lights, intersection traffic problems, and traffic flows for the federal Bureau of Public Roads ("Analytical Methodology and Optimal Control in Urban Traffic Networks"). He is coauthor (with Professors Jack Kiefer of Cornell and Milton Sobel of the University of Minnesota) of a research monograph entitled *Sequential Identification and Ranking Procedures* (University of Chicago Press, Chicago, 1969).

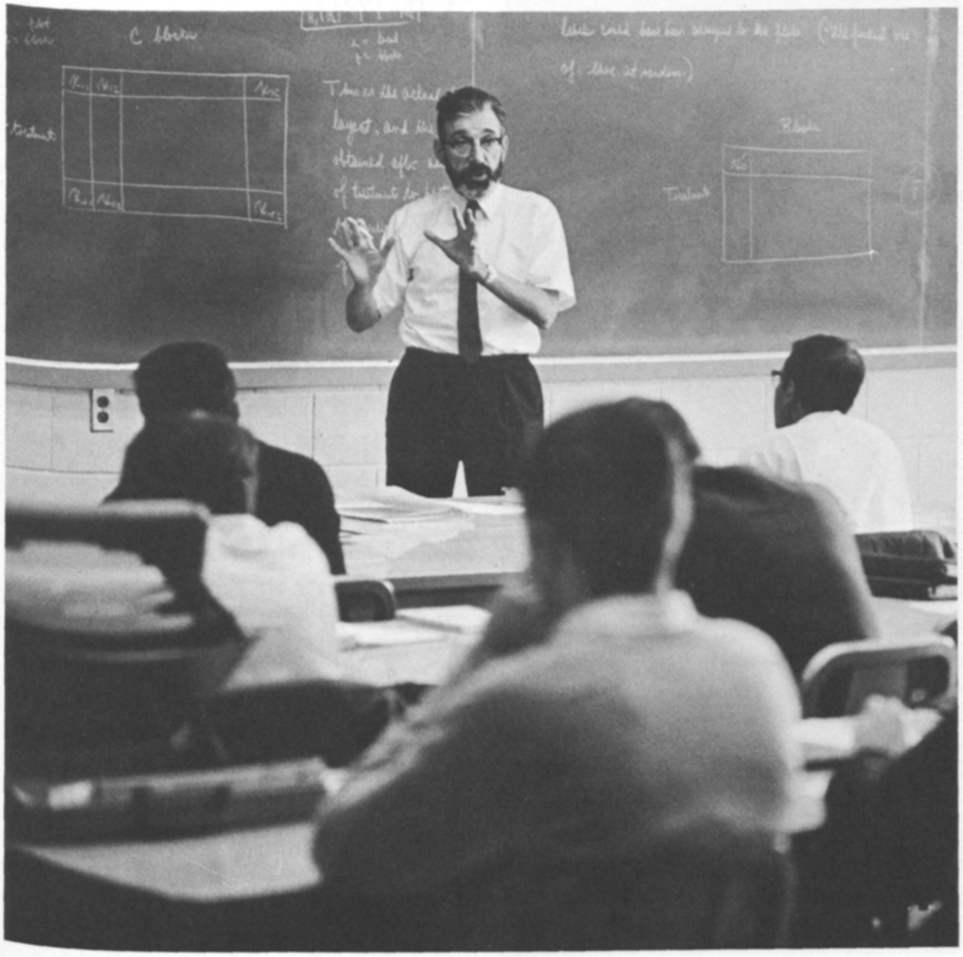
Lionel I. Weiss reflects that kinetic quality that goes with those who really enjoy classroom teaching. Author of a text, *Statistical Decision Theory* (McGraw-Hill, New York, 1961), he has been coauthor with Professor Jacob Wolfowitz of the Department of Mathematics of several recent papers in this area. In commenting on the changes in OR activity at Cornell during his tenure, Weiss claims that "things have gotten more theoretical, and the theory has become more elegant." He feels that today's undergraduates in industrial engineering tend to work harder than their counterparts of a decade ago, are more outspoken, yet want the faculty to bring subject material "down to earth."

A member of the OR faculty whose interest centers principally on applications of statistics is Henry P. Goode.

Lionel I. Weiss



Robert E. Bechhofer



Henry P. Goode

Recent Sponsored Research by the OR Faculty

Analytical methodology and optimal control in urban traffic networks
Sponsored by the Bureau of Public Roads, Federal Highway Administration

Applied stochastic processes and statistical inference
Sponsored by the National Science Foundation

Development of a core-resident, error-correcting, compile-and-go system for PL/1
Sponsored by industry

Development of Cornell University programming languages
Sponsored by the National Science Foundation

Development of a simplified, high-performance file maintenance and inquiry system
Sponsored by industry

Multiple-decision selection and ranking procedures
Sponsored by the United States Army Research Office at Durham

Stability and combinatorial structure of n-person cooperative games
Sponsored by the National Science Foundation

Statistical research with engineering applications
Sponsored by the United States Office of Naval Research

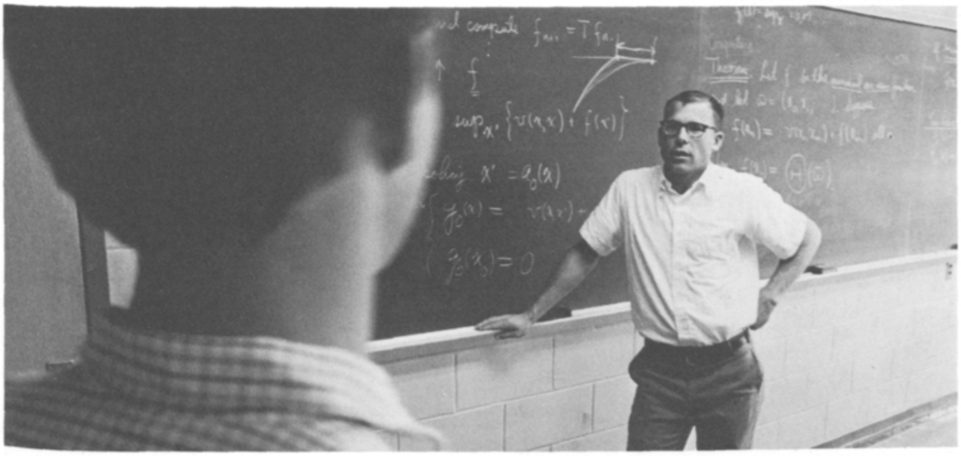
He brings to his teaching many years of industrial experience, first at the Western Electric Company and later at the American Can Company, as well as a varied background in industrial consulting. Professor Goode complements the more theoretical statisticians by his abilities to bring to the classroom real industrial problems with statistics elements. He has authored over two dozen articles on the subject of sampling procedures and is coauthor with A. H. Bowker of a text, *Sampling Inspection by Variables* (McGraw-Hill, New York, 1952).

Goode's interest has been focused recently on the problems of today's hospital—"one really fertile area which may well be amenable to many of our modern OR techniques." He has been working with the Central New York Hospital Association, a consortium of about 45 hospitals, to assist their industrial engineers in making more efficient use of medical resources and thus improving the quality of hospital services and holding down costs.

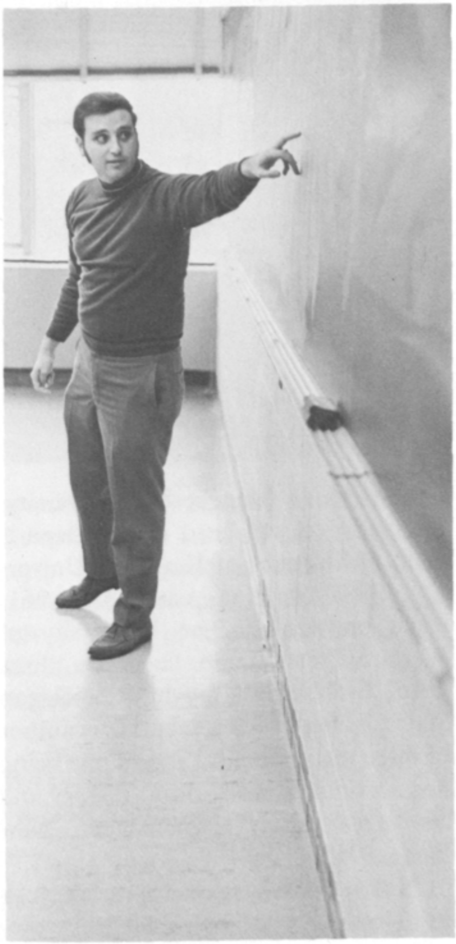
THE PROBABILISTS

Six of the OR faculty—Professors Brown, Emmons, Neuts, Prabhu, Stidham, and Taylor—have concentrated their interests in the area of applied probability. As a group, their average age is about 34 years. Four of the six hold doctorates from Stanford University, one holds a doctorate from Johns Hopkins University, and one holds the Master of Science degree from Manchester University, England. Taylor holds a Bachelor's degree in mechanical engineering from Cornell; the other five have undergraduate backgrounds in mathematics.

Howard M. Taylor 3rd



Mark Brown

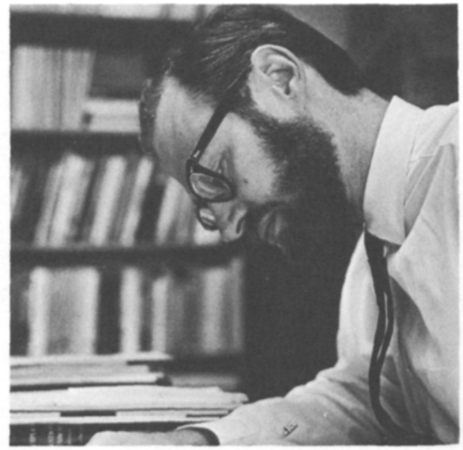


Howard M. Taylor 3rd is now in his fifth year of teaching at Cornell. He shares an appointment with the Department of Environmental Systems Engineering and finds "the best probabilists in the country at Cornell." Much of Taylor's work involves relating theory to a wide variety of "real world" applications. He has done research on epidemic control with the Veterinary College at Cornell, developing a model for control of bovine virus diarrhea, and presently is cooperating in an interdisciplinary study involving parasitology. In this work, a lamb-parasite system was simulated on the computer to study effects of interactions between parasite and host. In addition, Professor Taylor has studied random fluctuations in the stock market and supervised research applying the idea of reapportionment to school zones. The latter problem involved the reordering of school districts to minimize segregation. A graduate student under Taylor's direction developed techniques for avoiding the splitting of neighborhoods and for creating new schools. The results of her work were reported by Professor Taylor at a recent conference, "Computer Applications to Desegregation," held in Tallahassee, Florida.

While an undergraduate in mathematics at Harvard College, Shaler Stidham, Jr., who also holds a joint appointment with Environmental Systems Engineering, held a National Merit Scholarship and the Harvard National Scholarship. Before joining the Cornell faculty, he worked at the Stanford Research Institute as an operations analyst for their Logistics Systems Research Group. His Ph.D. degree is in operations research. Mark Brown, in his second year of teaching, holds his undergraduate degree from the City College of New York. He held a New York State Regents Advanced Graduate Teaching Fellowship while at Stanford University, where he earned M.S. and Ph.D. degrees in statistics. The summer before coming to Cornell he worked as a mathematician at the United States Naval Radiological Defense Laboratory in San Francisco.

Hamilton Emmons, a Harvard undergraduate, holds Master's degrees in applied mathematics from the Univer-

Hamilton Emmons



Shaler Stidham, Jr.

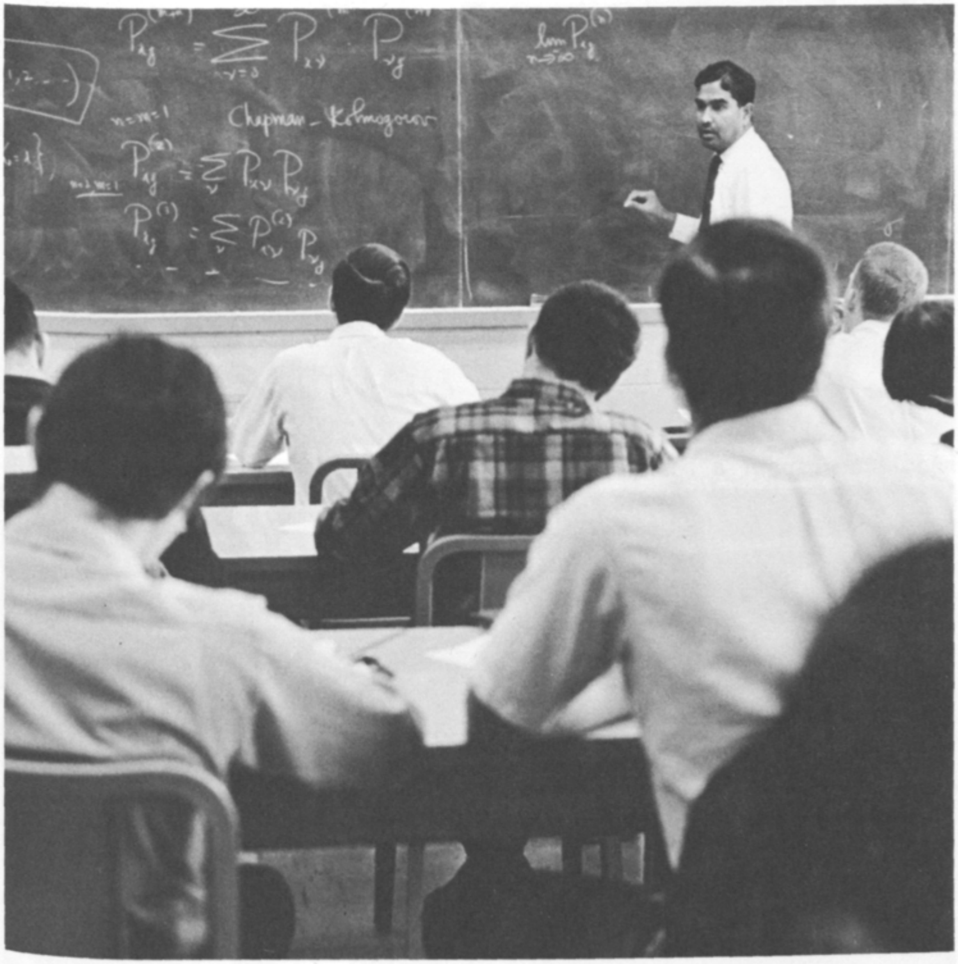
sity of Minnesota and in electrical engineering from New York University in addition to the Ph.D. degree in operations research from Johns Hopkins University. He was a member of the technical staff at Bell Telephone Laboratories during six years of his graduate study and did research for his doctorate in the Division of Nuclear Medicine at Hopkins, studying optimal selection and use of radioactive pharmaceuticals.

Marcel F. Neuts, who will join the faculty in July 1970, earned the License in Mathematics from the University of Louvain in his native Belgium. He has been a member of the Purdue University faculty since 1962 and was visiting professor of operations research at Cornell in 1968–69. His interests lie in stochastic models in queuing theory, traffic theory, and biology. Neuts is currently an associate editor of the *Journal of Operations Research.*

Narahari U. Prabhu's biography reads like a romantic travelogue. Holder of a Bachelor of Arts degree with honors from the University of Madras, India, he earned Master's degrees in statistics at the University of Bombay, India and at Manchester University, England. He was head of the Department of Statistics at Karnatak University, India for nine years until 1961, when he went to the University of Western Australia to teach for three years. Prabhu then taught at Michigan State University for a year. He is author of three texts, the most recent one being *Stochastic Processes: Basic Theory and Its Applications* (Macmillan, New York, 1965).

Professor Prabhu describes his work as follows. "I work on problems involving waiting lines, water reservoir systems, and traffic flows." In the area of traffic congestion he says, "Progress so far in the understanding and solution of these problems has been relatively slow. The reason for this is that it is only during the last fifteen years or so that [this area] has become the subject of intensive research using sophisticated mathematical and computer techniques. The results obtained by this research have provided the necessary background for fruitful collaboration between the academic researcher and the

Narahari U. Prabhu



traffic engineer." Professor Prabhu thinks that OR will deal with a wider scope of problems in the future—problems drawn from the areas of health, hydrology, and urban and educational systems. He also thinks the present emphasis on theory in OR is a trend for the future. "There is a tendency in some quarters to think that the concepts and techniques required to solve [problems of this nature] are all readily available, waiting to be used by an OR faculty. If this were true, then the OR faculty would be reduced to a bunch of problem-solvers. My research experience indicates that the currently available concepts and techniques are very often inadequate even to formulate (let alone solve) some of these problems, and therefore new concepts have to be generated."

MATHEMATICAL PROGRAMMING

Those involved with mathematical programming on the Cornell OR faculty are Mark J. Eisner, George L. Nemhauser, Stella Dafermos, William F. Lucas, and Howard Taylor. Mathematical programming is a class of optimization techniques in which a routine search is made for a set of mathematical variables that optimize a certain function (objective function) subject to some mathematically stated constraints.

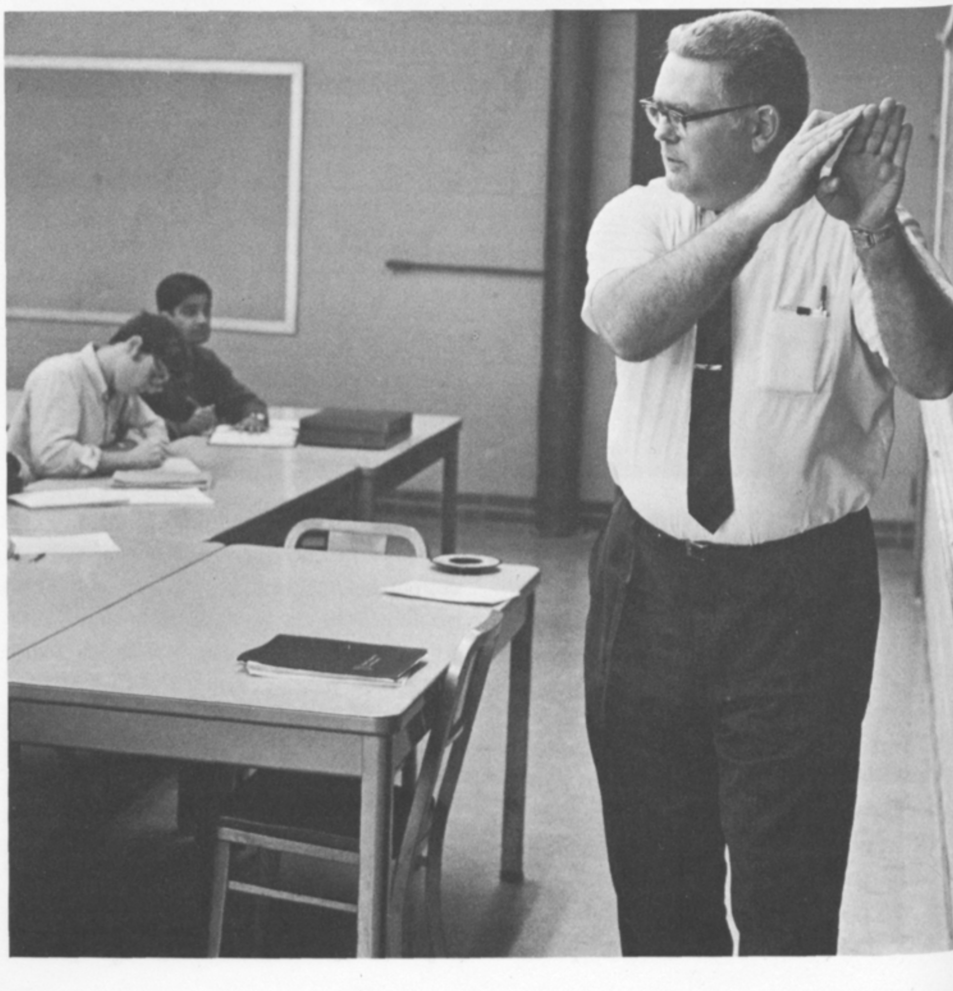
Professor Eisner, who earned his Bachelor of Arts degree at Harvard College in 1960, is in his second year of teaching at Cornell. He received the Ph.D. degree in operations research at Cornell this fall and for five years before coming to Cornell was an operations analyst with the Research Analysis Corporation in McLean, Virginia.

Professor Nemhauser has been associate professor of operations research at Johns Hopkins University and will join the faculty at Cornell this summer upon completion of an NSF Science Faculty Fellowship at the Center for Operations Research and Econometrics (CORE) in Haverlee, Belgium. He received his Bachelor's and Master's degrees in chemical engineering and earned the Ph.D. degree in operations research at Northwestern University. The author of

Mark J. Eisner

Stella C. Dafermos

William F. Lucas



Louis J. Billera

a very well received book, *Introduction to Dynamic Programming* (John Wiley, New York, 1966), he is interested in both the theory and applications of operations research. One of his recent research projects was sponsored by the National Municipal League and had to do with developing algorithms for computer redistricting of political subdivisions.

Stella Dafermos is interested in an area related to mathematical programming, network theory, with particular reference to traffic flow problems. She is in her second year as a member of the OR department at Cornell, having recently obtained her doctorate in operations research at Johns Hopkins University. Her Ph.D. dissertation on "Traffic Assignment and Resource Allocation in Networks" has proved an excellent starting point for her current research in urban traffic networks.

GAME THEORY

Professor William Lucas and Louis J. Billera are the resident game theorists on the OR faculty.

Game theory, according to Lucas, "involves mathematical methods to study conflict and cooperation. It provides a guide for rational behavior in these situations." The subject became popular in 1944 with the publication of a book by von Neumann and Morgenstern. At first used primarily to analyze military strategic problems, game theory is applicable to a range of activities stretching from arms control and limitations to urban problems, such as pollution, political science, and economics. By helping people see the outcomes or "payoffs" of certain actions, game theory provides an advance means of judging alternatives. By its use, for example, the voting power of individuals in relation to one another can be measured. "Before we throw out the Electoral College," Lucas pointed out, "we should realize that many of the alternatives have the same inequities."

Professor Lucas joined the faculty at Cornell this fall after several years of research activity at the Rand Corporation in Santa Monica, California. While there he solved a fundamental open question in game theory which had withstood the efforts of the best research workers since it was first posed by von Neumann in the mid 40s. Lucas earned his Ph.D. degree at the University of Michigan and returned to an academic community because he found "research by itself not as rewarding for me as a balance among research, advising, and teaching. Teaching allows me to mix with people from other disciplines and with young people." He stressed the fact that "the important contributions of multi-person game theory are conceptual . . . concerned with how coalitions form and break," and admitted that "the deepest research I do won't be immediately applicable."

Twenty-six year old Louis J. Billera received his Ph.D. degree in mathematics from the City University of New York in 1968. His doctoral dissertation dealt with bargaining sets for n-person cooperative games. He had an NSF Postdoctoral Fellowship to study game theory at The Hebrew University of Jerusalem in 1969 but decided to quit Israel hurriedly after several months when "the atmosphere there became too hot."

INFORMATION PROCESSING

Information processing deals with the analysis and design of systems which record, transmit, store, and process information. Also included under this heading are such underlying theoretical topics as information theory and computing language structure. The integration of equipment rather than the design of machines is stressed.

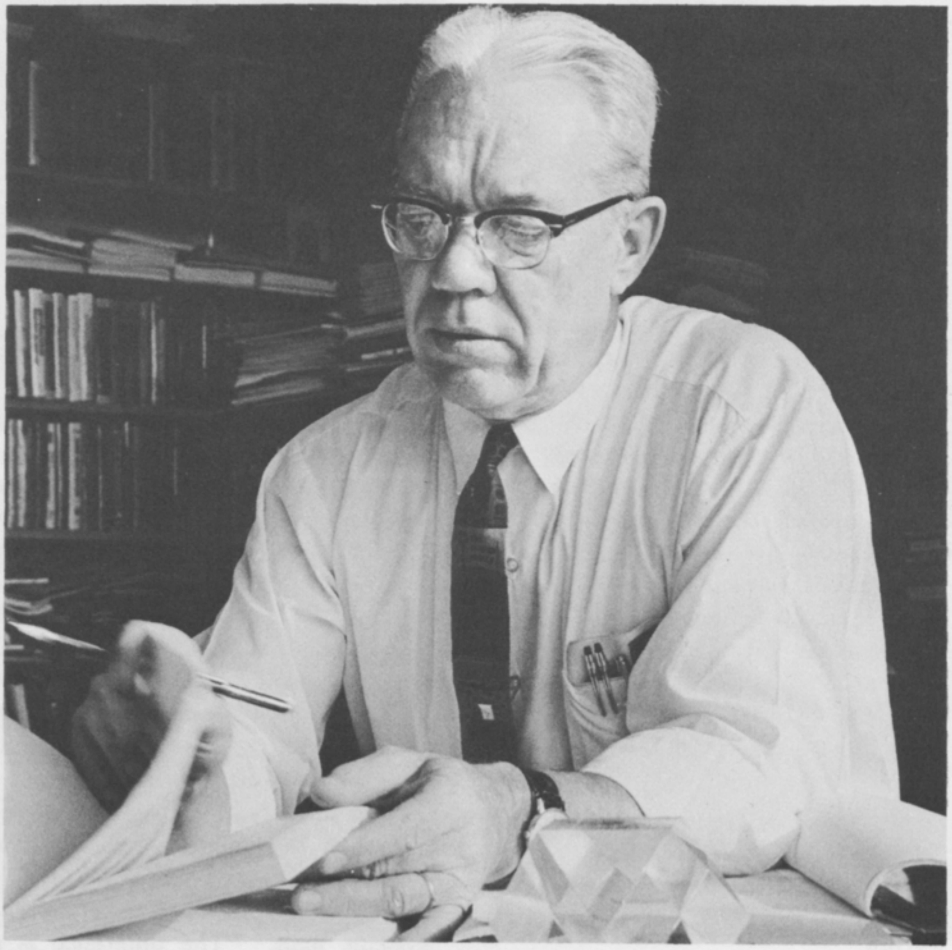
Here, two of the College's brightest graduates, Richard W. Conway and William L. Maxwell, have been important anchor men for the impressive growth in this area in recent years. Both earned their Bachelor's degrees in mechanical engineering and their Ph.D. degrees in operations research at Cornell. Howard L. Morgan, who studied physics as an undergraduate at City College of New York and received his Ph.D. degree in OR at Cornell at the age of 23, joined them in 1968.

Cornell's computing languages, CORC, followed by CUPL (Cornell University Programming Language), were developed by Conway and Maxwell in collaboration with Professor Robert J. Walker of the Department of Mathematics. These developments drew attention to the need for establishing a faculty in the computer sciences, and a department was established in 1965. All three men—Conway, Maxwell, and Morgan—are members of the Graduate Field of Computer Science, and Conway and Morgan hold joint appointments with that department.

William Maxwell bridged the gap for us between the kinds of applications an industrial engineer might make of OR techniques and the applications of the "systems man." "The difference is a

William L. Maxwell

Byron W. Saunders



physical one between handling the actual operation of specific manufacturing machines and handling decks of cards on a computer. Arranging time on machines is the same essential operation as arranging time on a computer." With Conway he is a principal in a firm they established to market their software products. Presently, they are supervising research on the development of a full capability language which should be useful to scientists and commercial data processors alike.

Richard Conway explained his work as primarily in the areas of data processing and scheduling. He and Maxwell coauthored a book on the subject of scheduling (*Theory of Scheduling,* Addison-Wesley, Reading, Ma., 1967) and he has worked for the Rand Corporation, as has Maxwell, on scheduling problems. His interest in dealing with real problems is illustrated by his service as director of the Cornell Office of Computing Services during 1966–68 and his reflections on the make-up of OR departments: "It is the continuing task of OR departments to keep theory and practice related, to make sure that practitioners know about the best work being done and that theoreticians get problems from practitioners." He was awarded the first Ph.D. degree in operations research that Cornell presented, just ten years ago.

STRIKING THE BALANCE

It is especially important, as we have seen, that faculty and students develop sensitivity to those areas in society to which their skills and expertise can be honed. The tendency is ever-present in an OR department to develop in the

Howard L. Morgan

Robert N. Allen

Walter R. Lynn

direction of theory alone. But, as Professor Bechhofer indicated, many of today's graduate students are asking that their research work be relevant to society as well as acceptable theoretically.

To aid the future practitioners, Professor Byron W. Saunders, director of the School of Industrial Engineering and Operations Research, with which the graduate Department of Operations Research is associated, coordinates projects which are required for the Master of Engineering degree. Twenty-one candidates are currently enrolled in this one-year program, which is integrated with the last two years of the student's undergraduate work. In the program, students work usually in teams on projects obtained from the industrial, educational, and business world. Part of the task each student faces is to properly define a problem. As Saunders explained, "One company had what they thought was a problem in materials handling. It didn't take long for the students to realize that what they really had was a scheduling problem."

Professor Saunders has taught in the area of industrial engineering since he joined the faculty at Cornell in 1947. The major topics considered in the industrial engineering curriculum involve mathematics, computer science, costs, and economic analysis. Another member of the industrial engineering and operations research faculty who figures prominently in showing students the practical applications of their classroom experience is Robert N. Allen. He directs Cornell's Engineering Cooperative Program, 17 of whose 125 enrollees are industrial engineering students.

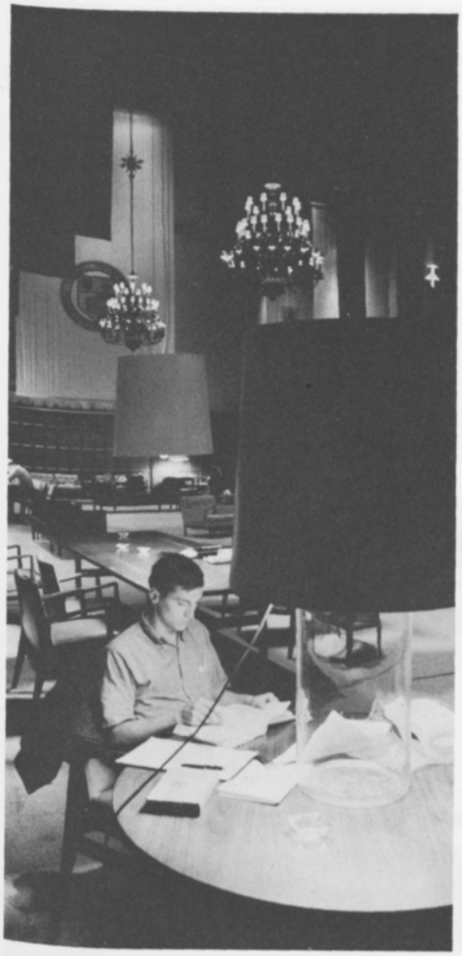
Today's industrial engineer must be equipped with the modern analytical techniques associated with rational decision making and the establishment of valid design criteria. He may be employed as a systems specialist in commerce, banking, distribution, merchandising, hospital management, or any one of a number of other fields of activity in our society.

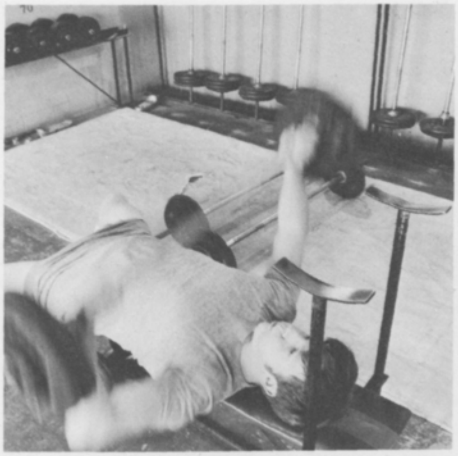
To educate him to fill this role, today's industrial engineering and operations research faculties must prepare theoreticians as well as practitioners. Unless we have people with the capacity to look into tomorrow's problems, the contributions of today will be of limited value.

Donald F. Berth is assistant dean of the College of Engineering at Cornell. He has been editor of Engineering: Cornell Quarterly *since its introduction in the spring of 1966. In addition to his responsibility for the preparation of informational and promotional material for the College, Mr. Berth maintains an active interest in teaching. This fall he directed a freshman project group dealing with transportation problems and led one of several upperclass seminar groups in a new College-wide lecture series on "Social Implications of Technology."*

In her second year as associate editor of Engineering: Cornell Quarterly, *Vicki Groninger previously served as a manuscript editor for the Department of Nutrition and Food Science at the Massachusetts Institute of Technology. She is married to a graduate civil engineer who is currently completing work for the Doctor of Philosophy degree in environmental systems engineering at Cornell.*

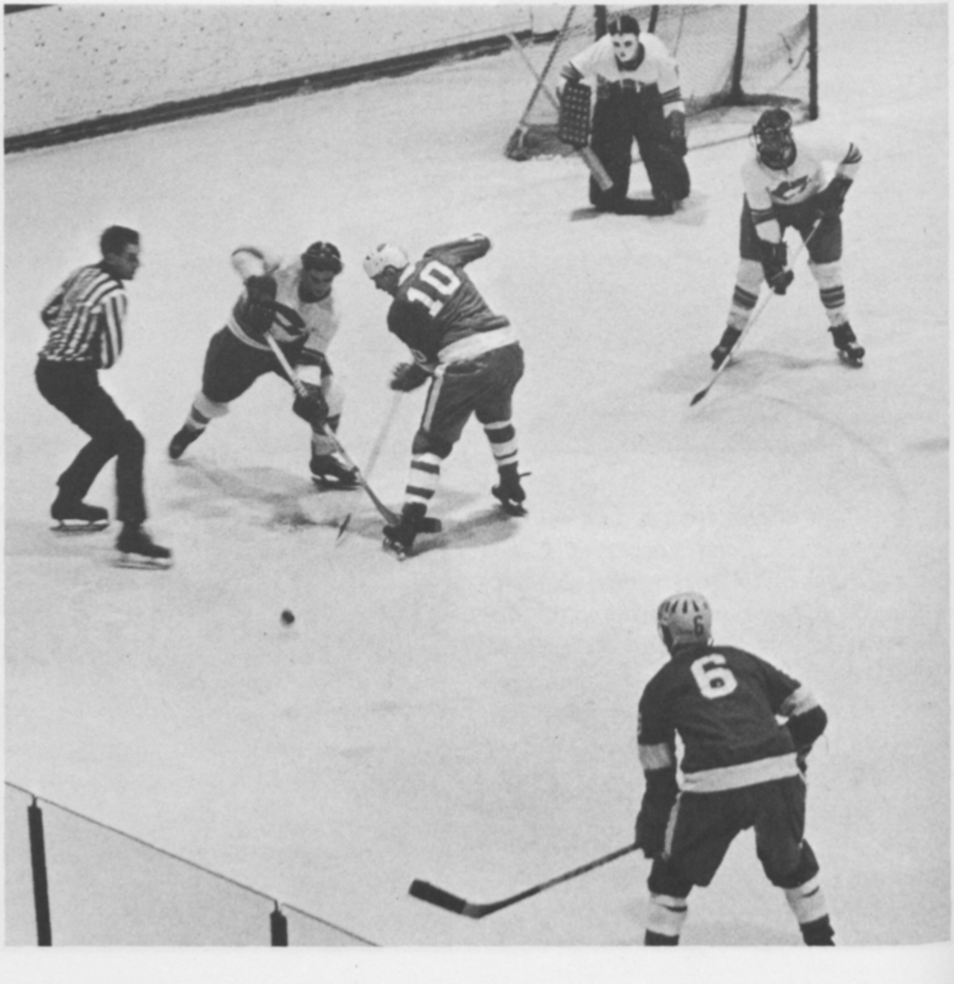
VANTAGE

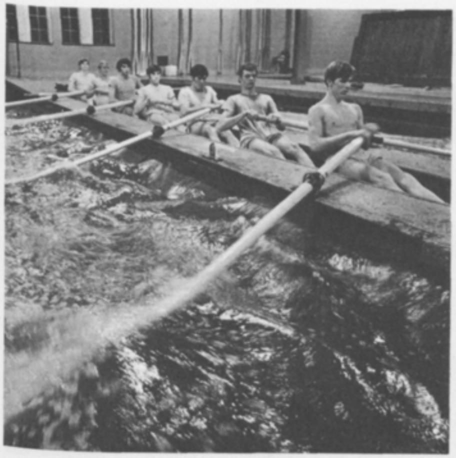


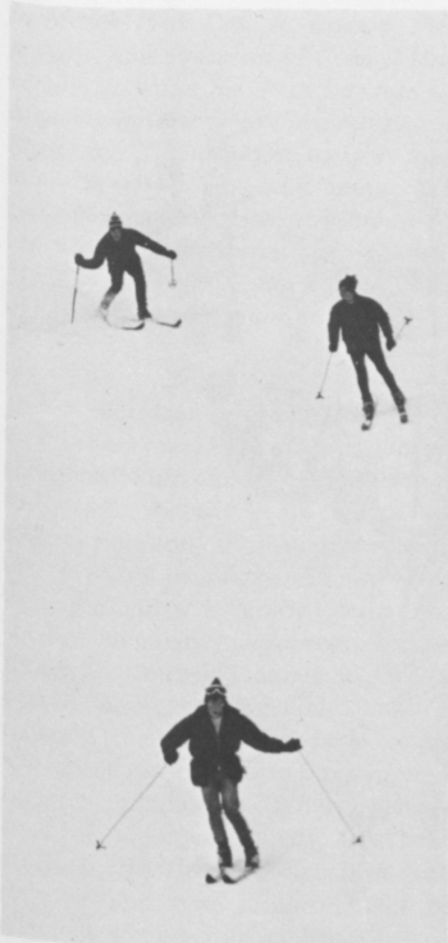


Winter stays late in Ithaca. The snowy slopes, cascades, and gorges of Cornell's campus invite brisk walks, solitary relaxation indoors, and participation in winter sports. Hockey and ski enthusiasts perhaps most appreciate the long season, for Cornell's hockey team is good and Greek Peak and Intermont offer nighttime and daytime skiing within an hour's drive of the campus. Winter holidays and intersession provide time for traveling, too, as the Glee Club did this year visiting Europe on a concert tour in January.

VANTAGE







COMMENTARY

Engineering Education: The Problem of Allocation of Resources

In March 1969 Dale R. Corson, then provost, now President of Cornell University, spoke at the Sixth Institute for Engineering Deans at their meeting in Monterey, California. Excerpts from this speech follow, including "six principles of good deansmanship in the resource allocation area" and remarks Mr. Corson made on the broader topic of engineering education.

. . . The first principle [for educational vitality and leadership] is *allocate resources differentially*. The certain road to mediocrity is to spread resources uniformly over all departments and over all programs. At any given time particular programs need, and should command, resources out of proportion to their ultimate role in the overall effort. A threshold level is required to make any new program go, whether it is a curricular program or a research program. . . . After a plateau level of vigorous activity has been reached, the level of support can stabilize and new resources can be channelled in other directions.

There are also programs where the level of achievement is so low that only the input of really major additional resources will achieve significant results. The second hardest question any dean has to answer is, "Do we close out a weak program, or don't we?" The hardest question is, "Having decided to close out a program, how do we do it?"

The second principle is *use other people's money wherever possible*. There are many sources of other people's money—some of them restricted to specific purposes, as in the case of research grants or industrial fellowship support for a particular field. Federal matching grants for facilities is another [source of funds]. Sometimes one can develop industrial sustaining grants for a particular department or a particular research activity. Sometimes gifts of equipment by industry are possible. . . .

Most important to a private institution is the gift of buildings and other major facilities. . . .

Using other people's money sometimes has disadvantages as well as advantages. Foundation grants sometimes fall in this category. Foundations naturally are interested in funding new projects which serve as demonstration projects for new ways of doing things or [in] beginning new lines of activity, and without such support it would often be impossible to undertake a new activity. The pain comes, however, when the grant runs out and when it is necessary to pick up the ongoing program on ordinary funds. The only way this can be done with any degree of grace is through constant awareness of the problem and with a carefully planned phasing in of normal support.

The use of other people's money implies an organization which can help develop such sources of funds. An organization which can produce high quality local publications is useful. These publications can be quarterlies or they can be brochures on particular programs. Continuing education programs which keep the particular institution constantly in the view of its constituency [are] a useful mechanism.

The third principle is *make the available money go as far as possible*. Matching one's own resources with

"...we are still far too much wedded to the concept of producing a professional man at the undergraduate level."

other people's money is one obvious way to do this. Another is to give each faculty member support personnel in order to extend his own effort. At Cornell we have steadily increased the number of such people over the last dozen years from about 2.8 supporting people, that is, technicians, secretaries, custodians, accountants, vice presidents, per faculty member to about 4 per faculty member at the present time. . . .

One important way to make money go farther is to eliminate the big laboratory equipment. I have in mind particularly the big heat-power laboratories, the big electrical machinery laboratories, and the chemical engineering unit operations laboratories. One gains in at least two ways with such a policy. In the first place, it is not necessary to maintain large amounts of expensive equipment—small equipment with sophisticated instrumentation can provide more effective teaching opportunities at less cost. In the second place, large amounts of space can be recovered at the same time.

The fourth principle is *be flexible.* One never knows when a special opportunity to move ahead in some particular area will arise. . . . Such situations always require the commitment of funds —a commitment which had not been planned for. Flexibility is also required to fight off raids on faculty members by other institutions.

Quick response is important and is possible only if contingency funds are available. These can be budgeted in limited amounts, but life is easier if the dean has available a dean's fund which only he can commit. Industrial grants for such purposes, gifts from alumni, [and] bequests to the college, are all sources of such money. Such flexibility is probably easier to achieve in the typical private institution than it is in the typical public one. If you must wait until the next biennial budget is approved before you can move on such opportunities the opportunities are not likely to sit still that long. In any case, some mechanism for setting aside money for purposes such as these is important.

The fifth principle is *gamble—be bold.* This is a way of saying that you should overcommit the resources available to you. If you do it wisely you won't necessarily have to leave town in a hurry because you have gambled and lost. . . .

The same gambling principle applies in other areas, as in the case of approaching people in parallel rather than in series for a position where the probability of acceptance by any one person is small.

This principle should be applied with a certain degree of restraint. It is like the three rules for courting a woman. The first rule is be bold; the second rule is be bold; the third rule is don't be *too* bold.

The sixth principle is *know your people and programs.* It is obvious that priorities can't be properly assigned or the overall objectives of the college defined unless the dean knows all the programs, both curricular and research, in some detail. There is also great advantage in dealing with granting agencies, foundations, or other sources of money if the dean can speak with assurance about the people and programs in his college or school. . . .

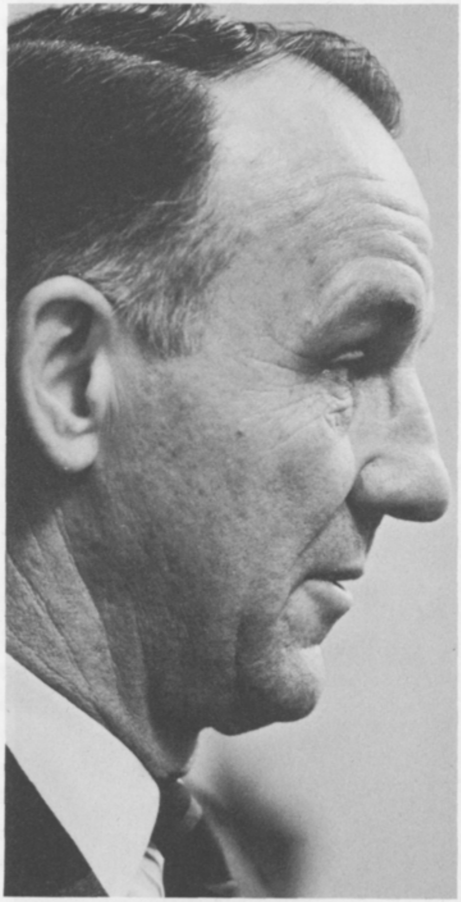
With this "how to do it in six easy

lessons" completed, let me turn to a number of problems which interest me from an overall institutional point of view. Many of these problems bear on the allocation of resources among the constituent elements of the institution. . . .

Let me say at the outset that my experience has been with a university-based engineering college and not with an institute of technology. Some of the problems are quite different in the two situations. . . .

I am going to begin with the nature of engineering education itself. I am dissatisfied with the way engineering education is generally organized now, and, while I believe the trend is in the proper direction, there is still a long way to go. In my opinion we are still far too much wedded to the concept of producing a professional man at the undergraduate level. I believe that engineering education should consist of a pre-professional undergraduate program followed by professional education at the graduate level, with the engineering practice part of the graduate program quite different from Ph.D., research-type, graduate education.

But let me go back and fill in. Rather than imply that I am dissatisfied with all engineering education, I should say I am disappointed with some of it. More specifically, while I think we may be moving in the right direction, as with the Goals Report, in the preparation of the rank and file engineer, I would have to say that for the most part we have failed in the education of that small but elite group of minds who, in the short history of engineering, have given their names to its greatest triumphs. It may



sound like a contradiction to say we have failed in education with the very people who have won success, but I think it is not. My contention is that with proper educational effort we might have turned out many more such winners and that some of those who did succeed did so despite our efforts to frustrate them.

We all have our heroes, those we regard with special esteem and affection. Two of mine are Philip Sporn and Sir Eric Ashby, the former an engineer's engineer who became preeminent in the electrical power industry, the [latter] a distinguished scientist and educator in Great Britain, now Vice Chancellor at Cambridge. Both have had dreams about educating engineers which confirm my own. . . .

The Sporn-Ashby philosophy can be summarized briefly as follows: education for leadership in the engineering profession must (1) be rooted in adequate science and mathematics, (2) embrace a knowledge and understanding of the humanities and social sciences, (3) show the development of advanced technological skills, and (4) blend all of these *from the start* so as to interact with each other. Sir Eric emphasizes the point that *all* of this education of the engineer should relate to and be focused on [the individual's] desire to be an engineer. Only so can the spark be generated which will drive the young man to his goals. [Ashby put it well in] *Technology and the Academics:* "A student who can weave his technology into the fabric of society can claim to have a liberal education; a student who cannot weave his technology into the fabric of society cannot claim even to be a good technologist."

. . . All of us at times, in our references to the engineering curriculum, have talked glibly about the "liberal content," "basic studies," "core" programs, "practice" courses, and so on, but always with constraints. Whatever balance is to be achieved among these areas of engineering education should be homogenized for all students, and whatever results are accomplished must be within a time span not to exceed five years (preferably four) and lead to a designated engineering degree at the finish.

"In each discipline . . . the leaders in the momentous task of getting a mad world back on the track will be those who see and understand beyond their own professional horizon."

The point I wish to make is that for the prospective great engineers of tomorrow, assuming we can somehow identify them in the making, we need unique and flexible programs which will demand all of the imagination, enterprise, enthusiasm, and expertise which . . . faculties can bring to bear on this elite group. And I don't mean just honors courses. An education will have to be provided for the engineering leaders of tomorrow . . . which will turn out men and women with social conscience and political acumen in addition to their technological skills. There must be some engineers who will see the forest as well as the trees; we shall need engineers who are truly educated persons in a broad sense, non-professional as well as professional.

. . . Speaking about engineering education [Philip Sporn once] said, "Is it not pertinent to ask, how well equipped are the products of such training to solve the engineering problems of . . . tomorrow? The answer depends, of course, on the kinds of engineers we want. If what we are looking for in engineering are people who can solve a particular problem from a specialized, rather narrow viewpoint, then the kind of curriculum we have in many of our engineering schools, and the faculties we have to implement these curricula, are all good. But, if we are looking for people who can take an integrated view of a problem and can place it in its broad social, political, and economic as well as technical context, if we want people who start out with an integrated view of the world and what engineers can do in and for it, then it seems to me that the adequacy of curriculum and faculty, in most cases, is not so good." . . .

What does it take to turn out a Sporn-type engineer? I think it will take professional graduate education on top of pre-professional undergraduate education, but we can't achieve our objectives simply by turning engineering colleges into post-baccalaureate institutions and admitting graduates of liberal arts undergraduate curricula. The pre-professional undergraduate program must be an engineering "major," providing the necessary background in the natural sciences, the social sciences, and the humanities, but at the same time building the base in technology which will provide the motivations, the appreciations, and the attitudes which characterize the true engineer. . . . Somehow the graduate effort must include internship or apprenticeship in significant engineering enterprises, whether on the campus or off.

To achieve what is needed in this type of attack on engineering education may take five years with some students, ten years with others. It will take the best efforts of the best teachers, some of whom have yet to be found. It will mean cooperation between schools and departments in our universities where perhaps suspicion and distrust have prevailed in the past. It will tax our ingenuity to enlist necessary cooperation and support from government and industry. In the end, from a variety of disparate experiments we as educators should learn a great deal, and society should benefit. Such pilot programs with the higher echelon of engineering students should also lead the way to some basic changes in the standard curricula for the rank and file engineers; and they may well involve undreamed of blendings of [academic] resources in areas remote from engineering. . . .

Let me turn now to a far simpler problem—but one which perplexes [all engineering deans]. The problem is who teaches mathematics, physics, and chemistry to the engineers and what subject matter should be embraced in the science courses. . . .

The number of graduate students in physics, for example, is tied to the number of students and number of courses taught to engineers, since the graduate students are necessary as teaching assistants. The number of faculty in the physics department is tied both to the number of undergraduates taught and to the number of graduate students in the department. The engineers want to eliminate some of the physics taught by the physicists and substitute courses taught by [engineering faculty]. If there is a shift in this direction, can funds now going to physics be shifted—with consequent reduction in the number of graduate students and faculty members in physics—to engineering so that the engineers can staff themselves properly to teach the added engineering courses? The answer to this is "no," or at least "only with difficulty." . . .

If the answer is "no" in cutting back physics, can the engineers take on the new responsibility without adding staff? Again the answer is probably "no," although [all] engineering [faculties] now include individuals with Ph.D.s in physics who are completely qualified to teach the relevant physics whether it is general 20th century physics or quantum electronics.

Does it make sense pedagogically to make such a shift? The engineers want more time to build the rather specialized physics needed for various modern engineering fields. The physicists want to present a complete physics course, not a truncated one. They want to be sure to present the subject in all its generality. . . . I won't answer the question. I will only say that I believe the trend is in the direction of the engineers teaching more of the physics and mathematics for their own students as they add physicists and mathematicians to their faculties.

As I bring these remarks to an end I wish to tackle a final problem. We have been talking about "engineering education." Others talk about business or medical education, education for law or for teaching. We have become overwhelmed with the concept of professional education. Even the major efforts of the humanists sometimes seem to be [involved] in the development of those who will succeed them in the professorial ranks. Education has become distressingly fragmented.

Is it not imperative that we turn to what, in our day, must constitute the education of the whole man in and for contemporary society? And what is this contemporary society? As all of us well know it is one in large measure governed, for good or ill, by the dictates of the technology [that] we are the heirs to and which we are developing at a dizzy pace. The good and evil consequences of this development lie all around us in our crowded cities, our congested airports and airways, our despoiled rivers and lakes, and in the affluent society, which so many of our young people now question or even deny, with all its material largesse. We see men literally reaching for the stars, yet building devices which may in minutes destroy half of mankind. We see a world in great disarray, which, if man is to survive, must be set right. Those who face these problems and who, hopefully, will solve them sit in our classrooms today. What we do for them, to them, or with them will make a great deal of difference.

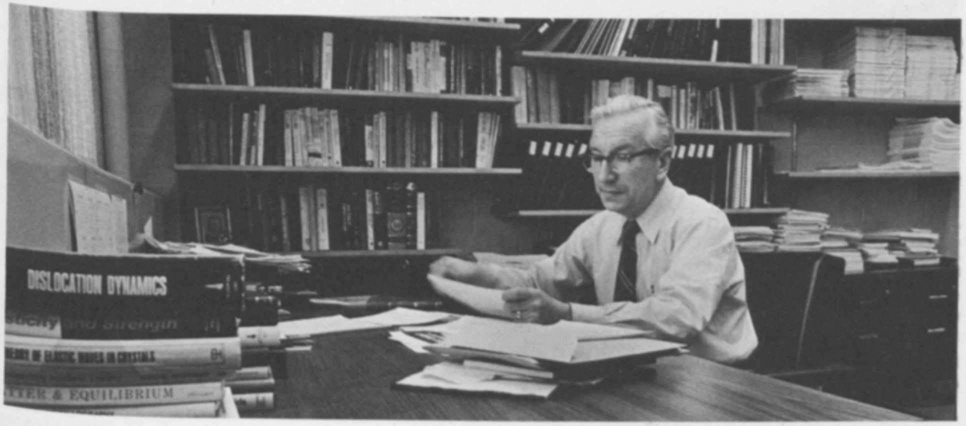
But, remember, I am not talking here only of engineers; I am talking of the students who sit in all the classrooms, in history, anthropology, English, romance literature. How much do students in these classes know about the technology which has created their world? How much can we as engineers teach them? Do we have an obligation here [that] extends beyond our own students? I think the time has come when we must break the professional educationists out of their cells and get them talking not only to each other's students but to each other. No one discipline, no one professional group, can any longer lay claim to being the world's savior. In each discipline, in each professional category, the leaders in the momentous task of getting a mad world back on the track will be those who see and understand beyond their own professional horizon.

The engineers have a key role to play in a world now dominated by their fruits; they need not only to extend their own perception into the realm of value judgments, [but to interpret] their own technological heritage to all the other professionals and non-professionals. It is a challenge which none of us in [higher education] can afford to ignore.

Dale R. Corson was dean of the College of Engineering and professor of engineering physics at Cornell from 1959 to 1963.

REGISTER

A Materials Scientist's Odyssey



Walter S. Owen

■ There is an attractive ease about Walter S. Owen that envelops his kinetic qualities. He is equally at home discussing the most abstruse research in materials science and the broadest concerns of the modern university community. Professor Owen was the Thomas R. Briggs Professor of Engineering and director of the Department of Materials Science and Engineering at Cornell from January of 1966 until January 1970, when he undertook his new appointment as dean of the Technological Institute of Northwestern University in Evanston, Illinois.

When Professor Owen came to Cornell in 1966 he took over a young department and established it as one of the few distinguished groups of materials specialists in American universities. "At Cornell the fields of mechanics, physics, and chemistry all have good rapport with the materials science department," explains Professor Owen, "and this in part accounts for the highly favorable intellectual environment for study in materials science."

A Commonwealth Fund Fellowship at the Massachusetts Institute of Technology brought Professor Owen to the United States from his native England in 1951. At M.I.T. he was associated with Morris Cohen, who, with Professor J. C. Slater, conceived of a basic engineering science, now known as materials science, that would bring together scientists and engineers working in areas as diverse as materials technology and solid state physics.

Walter Owen has been devoted to this science through teaching and research activities for more than half his lifetime. He derives his chief personal satisfactions from his teaching and his association with young people. Of the faculty and students in the Graduate Field of Materials Science and Engineering at Cornell, he commented, "We have five of the best young assistant professors to be found anywhere," and, "I have never met such outstanding students. . . . They are well motivated and enthusiastic."

In England, Professor Owen received his Bachelor of Engineering and Master of Engineering degrees from the University of Liverpool in 1940 and 1942.

Walter Owen conducts a meeting of the Department of Materials Science and Engineering faculty. From left to right around the table they are Professors Malcolm Burton, Herbert Johnson, Eraldus Scala, Owen, and Edward Kramer; Mr. William Van Duzer, administrative assistant; Professors Boris Batterman, Joseph Jeffrey, Arthur Ruoff, Paul Ho, and Deiter Ast. Missing from the picture are Professors Robert Balluffi, John Blakely, Che-Yu Li, Stephen Sass, David Seidman, and George Smith.

During World War II he worked on the development of materials for high-speed aircraft and the then new jet engines. After the war he returned to the University of Liverpool to study diffraction phenomena in graphite; he received the Doctor of Philosophy degree there in 1950. Walter Owen then came to the United States as a Commonwealth Fund Fellow and worked as a research associate in the Department of Metallurgy at M.I.T. for four years. After this short stay in the United States he returned to England with his wife, Carol, whom he met while in Cambridge. At that time she was a student at Boston University. At the University of Liverpool he became Henry Bell Wortley Professor of Metallurgy and in 1962 was made dean of the Faculty of Engineering Science.

Professor Owen has applied much of his research to the practical problems he faces as a consultant to industry. In this capacity he is now working with the Whittaker Corporation on the design of information systems for the engineering prescription of materials to fit specific applications. His recent research interests have been in martensite transformations, brittle fracture, and the development of high-strength materials. Firms and agencies for whom he has consulted in recent years include Manlabs Consulting and Research, Cambridge, Massachusetts; the English Electric Company, Leicester, England; and Fundiciones Industriales, Barcelona, Spain. Professor Owen returns to administrative work with the hope of lending his talents to the task of producing graduates who are educated persons as well as competent engineers.

Progress on the Molecular Frontier

■ "We're still fighting the fight," Walter S. Owen said, referring to the fight to establish materials science as a highly significant educational and research activity in the United States. Because the study of materials requires a team effort—the work of engineers, physicists, chemists, and metallurgists—progress can at times be very slow. All too often the centrifugal forces operating in a group are greater than the binding forces holding it together. For years, metallurgists have been concerned with metals and their alloys and have been closely associated with the industries producing these materials. Today, however, the materials-scientist engineer should also be able to design new materials, to tackle "any messy materials problem." Further, the design engineer must meet the demands made on materials by their environments.

Much of the impetus for creating the materials-scientist engineer has come from our national space and atomic energy efforts. Major grants made initially to five American universities, one of which was Cornell, by the Advanced Research Projects Agency (ARPA) of the Department of Defense, gave scientists the funds to cultivate significantly new approaches in the study of materials' properties. The traditional manner in which a material was selected for a particular application was to scan the various properties (for example, thermal conductivity, tensile strength, ductility) of well-known materials and select the best material from among the alternatives. Then, too, commented Professor Owen, "We have always tended to think in terms of what material has been associated with a particular commodity—steel with automobiles, for example." The motivation for the metallurgist has been either to improve materials already in use or to seek less costly alternatives that could do the job as well or better.

Today, however, we see the need to be able to design materials that have unique characteristics. The problem of creating new materials becomes critical when one considers the multitude of conditions and environments to which modern materials are being subjected. Greater probing of interactions at the atomic and subatomic levels, both within and on the surfaces of materials, and the study of defects and dislocations, are needed if the promise of "designed materials" is to be achieved.

SOME MATERIALS PROBLEMS

We asked Professor Owen where he thought the action was likely to be in materials science and engineering in the next decade. To this, his response was effusive. He began with the oceans. Here, all kinds of materials problems arise because of the high pressures encountered by deep submergence vessels. Not only must materials be fabricated into structures that can sustain high pressures, they must in some cases be transparent and buoyant too. In the laboratory, effects produced by pressures much greater than those experienced in the deepest ocean are being explored. At Cornell Professor Arthur L. Ruoff has completed several investigations on the behavior of materials at high hydrostatic pressures. Studies in this area involve using pressure to produce new forms of familiar elements. It has been postulated, for example, that hydrogen in metallic form would have

the properties of a superconducting material at temperatures closer to room temperature than other superconductors.

Biomaterials is the second area in which Professor Owen foresees some imminent breakthroughs in materials research. "Right now blood clotting occurs on polymeric materials, yet it has been found that polymers with artificially charged surfaces do not clot the blood so quickly." To discover why, one must know what chemical and biological action is occurring at the surfaces of such materials. The understanding of surfaces, known as Tribophysics, involves the study of surface wear and the description of what ions and atoms look like on the surface. The emphasis again is on the design of materials to fit applications, in this case the replacement of defective parts in the human body.

Another area capturing the attention of materials specialists is the understanding of composite materials. Here the primary problem is one of establishing failure criteria, knowing how to predict failure and anticipating the correction.

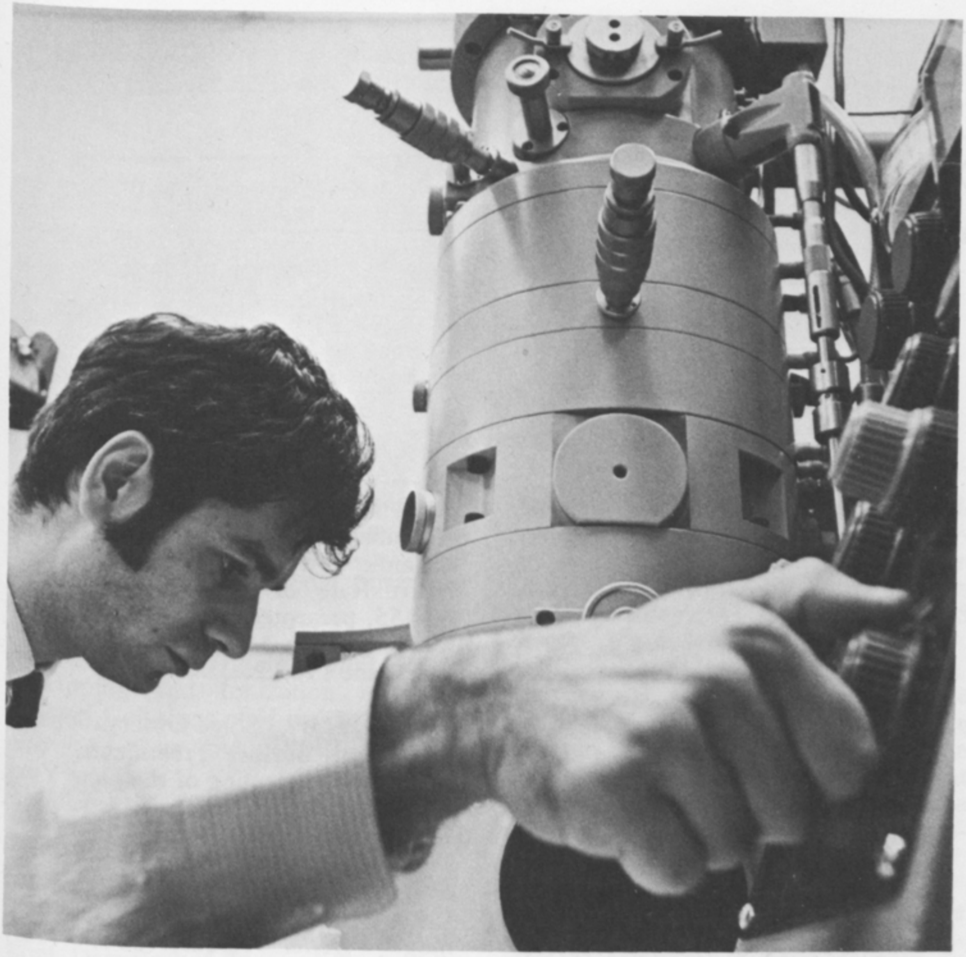
Attacking the serious problem of solid waste disposal, Professor Owen stated, "A real possibility exists for reducing the problem by developing bulk materials for construction." What is needed is a better understanding of the process by which bonding of diverse materials takes place. Much important work on the theory of aggregates in concrete is currently being done at Cornell by a group headed by Professor Floyd M. Slate of the School of Civil Engineering. "One day we may be able to combine the slag from blast furnaces with the products of waste incinerators to produce a new aggregate material for building purposes."

Many materials of the future are likely to be glassy materials, and the problem facing the materials specialist is one of describing the motion of the defects which determine the properties of glassy structures. Noncrystalline materials are being looked at as crystals with more defects than regularities.

SUPPORT OF RESEARCH ACTIVITY

Little progress in materials science is possible without the development of techniques which enable researchers to observe and test materials' phenomena. The recent developments in diffraction, ion implantation, and field ion microscopy techniques have been essential to the advancement of our knowledge of basic phenomena. Advances in our knowledge will depend to a large extent on the building of sophisticated experimental facilities. The high-voltage microscope may be considered as a case in point. "Our capabilities in this particular experimental technology are a long way behind the current capabilities in England, Germany, and Japan," mused Professor Owen. Although the 100 kilovolt microscope is a relatively common experimental tool, the cost of the 1,000 kilovolt microscope ("about a buck a volt")—whose energy resolution is necessary for exploring such phenomena as that which makes pieces of concrete stick together—has proved prohibitive for any one institution. This high energy level will damage metallic samples but should prove useful in the study of polymers and living cells.

Who will support efforts such as these



Postdoctoral researchers examine high-resolution dark field electron micrographs (opposite page), the product of the 200 kilovolt electron microscope shown opposite. This microscope was recently acquired by the Materials Science Center at Cornell.

at a level that will ensure their success? At Cornell the research expenditures of the Department of Materials Science and Engineering average about $1 million annually. At this time these dollars support over fifty graduate students, almost all of whom are at the doctoral level. Less than one-half of the dollar support currently comes from ARPA, and the rest is derived largely from the Atomic Energy Commission (AEC). The AEC support is primarily directed to the peaceful uses of atomic energy. During the current academic year Cornell's Professor Che-Yu Li is doing research at the Argonne National Laboratory on materials for the next generation of fast breeder reactors. The work of Professor Robert Balluffi, also of Cornell, on the damage of materials by radiation in atomic reactors has contributed immensely to our understanding of "vacancies" (atoms knocked out of the crystal).

Industrial involvement in support of future national activities in materials science clearly must be increased. At Cornell a study of composite materials' failure characteristics has just begun with the support of the United Aircraft Corporation. The problem of achieving a balanced overall design for good materials performance when composite materials are employed in technical systems of different materials is being looked at as well as the question of why certain composite materials (fiberglas, for example) fail differently in compression than in tension.

One suspects that it will take the enlightened imagination and tenacity of men like Walter S. Owen to ensure the output of useful knowledge in this field. The moon and stars can be seen by all of us, crystal dislocations by only a few. Yet in the long run the significance of research on the atomic and subatomic frontiers is likely to be of greater consequence than that on the larger scale.

FACULTY PUBLICATIONS

The following publications and conference papers by faculty members and graduate students of the Cornell College of Engineering were published or presented during May, June, and July 1969. The names of Cornell personnel are in italics.

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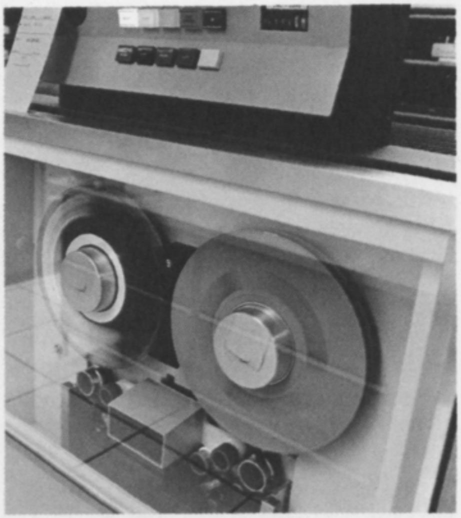
The Quiet Revolution



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The science of operations research had its beginnings in World War II. During that dark period, many individuals who were not accustomed to working outside their specialties pooled their knowledge and talents to make military strategies and systems most effective. Their experiences demonstrated the merits of the "systems" approach to large problems, and since then we have seen growing numbers of professional persons from complementary fields putting their combined expertise to work on civilian systems.

Operations research is one of the fastest growing fields in Cornell's College of Engineering. There is, of course, hardly an area of modern engineering that has not been transformed since World War II, but in no area has the transformation been more dramatic than in industrial engineering. Practically overnight, what had been a descriptive science became a quantitative one.

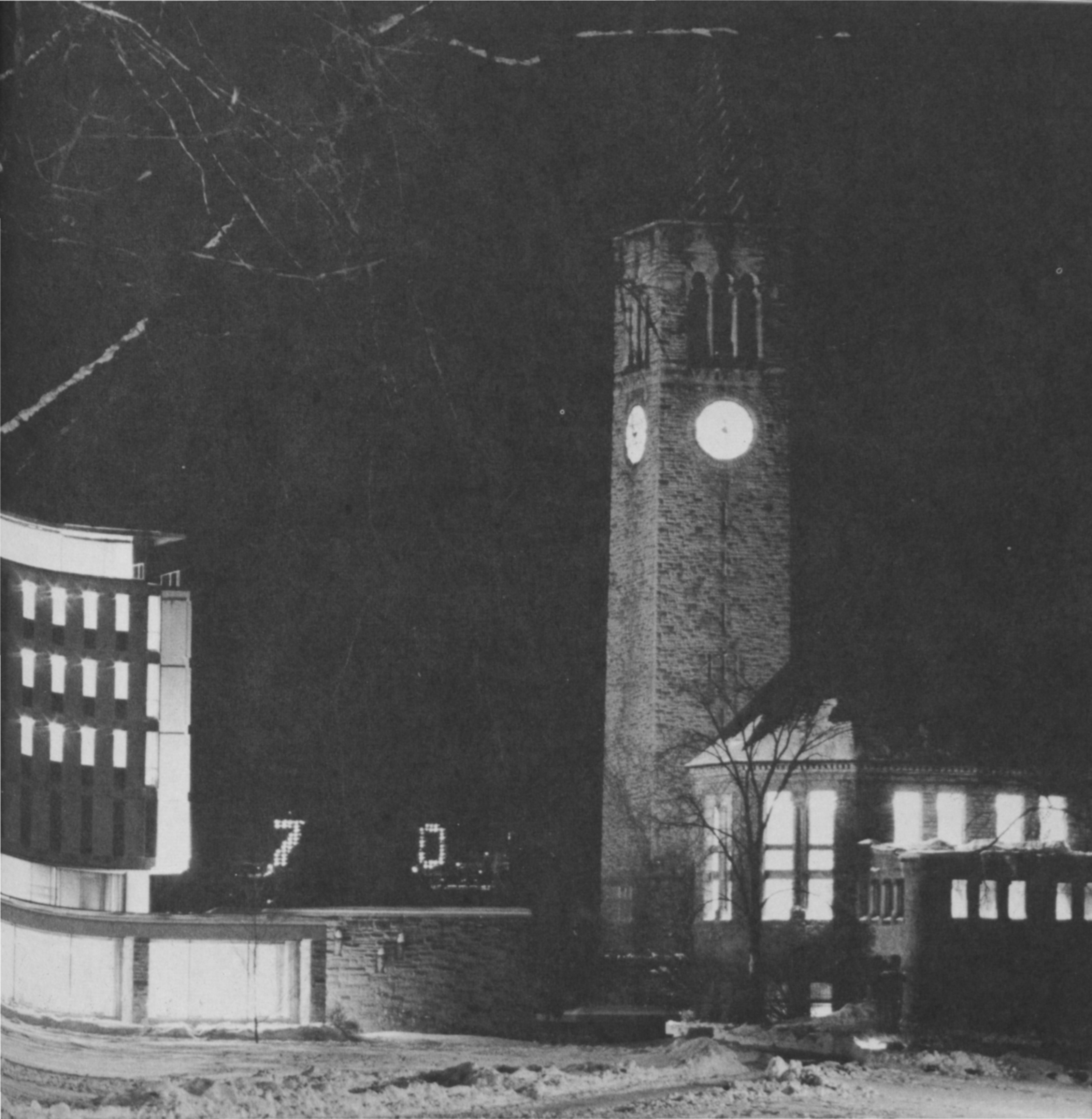
Cornell's tradition of applying quantitative skills to industrial problems, however, is not new. It goes back to Dexter S. Kimball's first course in "works administration" in 1904, some seventeen years before the various autonomous schools of engineering at Cornell were organized into the College of Engineering.

The academic interests of Deans Kimball and Schultz, whose administrative terms have covered nearly half of the years since the College was established in 1921, have been in the area of operations research.

The diversity of backgrounds, interests, and outlooks of Cornell's faculty in operations research has contributed to, as well as reflected, the "revolution," and the results are apparent in the curriculum changes and increased student interest. More than two hundred upperclass engineering students enrolled this past fall in a Monday evening lecture series "Social Implications of Technology." Probably most of them were trying to gain a better understanding of how the large-scale, socially centered problems of America can be resolved in a systematic rather than a piecemeal way. Simon Ramo in his book *Cure for Chaos* said, "The 1970s may well be cited as the decade in which a noticeable and important tilt began to take place in the balancing of technological and social advance."

We can expect that a high proportion of the solutions that are found to the complicated systems problems of our society will come from graduates in the field of industrial engineering and operations research.

THE EDITOR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