Operations Research AND *Systems Engineering*

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edited by **CHARLES D. FLAGLE**
WILLIAM H. HUGGINS
ROBERT H. ROY

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FOREWORD

While there has been no editorial attempt to do so, the pages of this book trace the history of the growing involvement of a university in the day-to-day affairs of government and industry. The chapters of the book are a set of lectures delivered by the authors in The Johns Hopkins University's annual two-week course for management, a course that bears the same title as the book. The lectures assembled for the course at the time that these particular lectures were given came from many academic departments of The Johns Hopkins University and from its affiliated research branches, the Applied Physics Laboratory and the Operations Research Office.

Many and diverse disciplines are represented—physics, economics, statistics, psychology, several branches of engineering, and mathematics. Despite this range of backgrounds, the authors share a common interest that unites them to each other perhaps more than to some colleagues in their own disciplines. This binding interest is the concern for the operation of total systems—human organizations, man-machine systems such as factories or military units, or complex physical systems.

Common terms have developed and these appear intermingled with older, specialized terminologies. We are interested in the "objectives" of an organization, their "feasibility" within the "constraints" of limited resources, and "measures of effectiveness" with which objectives are achieved. The comparison of alternative strategies and tactics for achieving feasible objectives leads hopefully to the choice of an "optimum alternative," which choice is in itself a "decision process."

The initial chapters are devoted to the philosophical and historical aspects of systems engineering and operations research. These are followed by chapters on specific methodologies that have developed or have been adapted for the field. A set of case histories concludes the

volume. The editors have footnoted cross references to relate the methodologies to one another and to identify their role in the case studies. This in itself has been a considerable task since the application of mathematical analysis in operations research is often less direct than in conventional engineering. The models and formulae lend insight into system behavior and the functional relationship between behavior and the factors that affect it; but rather rarely do they yield precise numerical predictions like those that tell the design engineer the deflection of a beam or the pressure on an airfoil.

The reader who survives the early chapters must sense the authors' concern for the effects of rapid growth, in our times, of knowledge of the physical world. In our social, political, and commercial organizations the expanding application of new knowledge promotes rapid obsolescence—not only in physical equipment but in the adequacy and capability of humans. In the case of physical equipment little can be done other than to replace it under the economic pressure of obsolescence. We humans, on the other hand, can forestall our own obsolescence by continuous new learning. Each author offers here a central interest of his professional life, presenting it in brief form for a reader who is assumed to be mature and interested, but not a specialist in the field. It is for those to whom this is new knowledge that the editors have taken it upon themselves to bring this material together and publish it.

The editors are grateful to the authors for their continuing co-operation and to The Johns Hopkins Press for its support in assembling this volume. Illustrations of consistently high quality and imagination have been prepared by Mr. John Spurbeck, Director of the Illustration Division of the University, and his assistants.

Baltimore, Maryland
January, 1960

Charles D. Flagle
William H. Huggins
Robert H. Roy

AUTHORS

ALPHONSE CHAPANIS, Ph. D., is Professor of Psychology and Industrial Engineering, The Johns Hopkins University. Dr. Chapanis was elected President of the Society of Experimental Psychologists for 1959-1960.

NASLI H. CHOKSY, Ph. D., is Assistant Professor of Electrical Engineering, The Johns Hopkins University.

WILLIAM G. COCHRAN, M. A., is Professor of Statistics, Harvard University. Mr. Cochran was formerly Professor of Biostatistics, The Johns Hopkins University School of Hygiene and Public Health. He has served as President of the Institute of Mathematical Statistics, the American Statistical Association, and the Biometric Society.

WALTER E. CUSHEN, Ph. D., is Group Chairman at the Operations Research Office, The Johns Hopkins University.

SIDNEY DAVIDSON, Ph. D., is Professor of Accounting in the School of Business, University of Chicago. Dr. Davidson was formerly Professor of Accounting, The Johns Hopkins University.

ACHESON J. DUNCAN, Ph. D., is Associate Professor of Statistics, The Johns Hopkins University.

CHARLES D. FLAGLE, Dr. Engr., is Associate Professor of Industrial Engineering, The Johns Hopkins University, and Director of Operations Research, The Johns Hopkins Hospital.

RALPH E. GIBSON, Ph. D., is Director of the Applied Physics Laboratory, The Johns Hopkins University. Dr. Gibson was given the Navy Distinguished Public Service Award by the Secretary of the Navy in January, 1958 for his "outstanding contributions to the Department of the Navy in the fields of scientific research and development."

WILLIS C. GORE, Dr. Engr., is Associate Professor of Electrical Engineering, The Johns Hopkins University.

MARVIN A. GRIFFIN, M. S. E., is Instructor in Industrial Engineering, The Johns Hopkins University.

WILLIAM H. HUGGINS, Sc. D., is Professor of Electrical Engineering, The Johns Hopkins University. In 1954 Dr. Huggins was awarded the Air Force Decoration for Exceptional Civilian Service.

ELLIS A. JOHNSON, D. Sc., is Director of the Operations Research Office, The Johns Hopkins University. The Distinguished Civilian Service Medal was awarded to Dr. Johnson in 1958 by the Department of Defense.

RICHARD B. KERSHNER, Ph. D., is a member of the Principal Professional Staff of the Applied Physics Laboratory, The Johns Hopkins University. Dr. Kershner received the Distinguished Public Service Award from the United States Navy for his work in development of the Terrier missile.

ALEXANDER KOSSIAKOFF, Ph. D., is Assistant Director for Technical Operations of the Applied Physics Laboratory, The Johns Hopkins University. Dr. Kossiakoff holds the Presidential Certificate of Merit and the Navy Distinguished Public Service Award.

P. STEWART MACAULAY, A. B., is Executive Vice-President, The Johns Hopkins University and Chairman of the Board of Trustees, Associated Universities, Inc.

VINCENT V. MC RAE, Ph. D., is a Staff Member of the Operations Research Office, The Johns Hopkins University. In 1957 Dr. McRae served on the Technical Staff of the Gaither Committee.

ELIEZER NADDOR, Ph. D., is Associate Professor of Industrial Engineering, The Johns Hopkins University. Dr. Naddor was Director of the Intensive Courses in Operations Research and Systems Engineering from which the papers in this volume have been drawn.

THORNTON L. PAGE, Ph. D., is Professor of Astronomy, Wesleyan University. Dr. Page was formerly Deputy Director of the Operations Research Office, The Johns Hopkins University.

ROBERT H. ROY, B. E., is Professor of Industrial Engineering and Dean of the School of Engineering, The Johns Hopkins University.

RICHARD E. ZIMMERMAN, M. S., is Group Chairman at the Operations Research Office, The Johns Hopkins University. Mr. Zimmerman was awarded the Lanchester Prize in 1957.

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One

*Introduction—**THE MARKET PLACE***

AND THE IVORY TOWER

P. STEWART MACAULAY

Before launching upon my subject I should, perhaps, attempt to qualify as an expert. My claim is based on some dozen years of active association with the market place, and an even greater span of years in the ivory tower atmosphere of a university. I have always asserted that this duality of experience gives me special competence to understand where, when, and under what circumstances the twain shall meet.

This claim, however, probably will be challenged on both sides. I must confess that my non-academic experience has been in newspaper work and that it has been limited to the areas of writing and editing. Anyone who knows anything about a newspaper will recognize at once that, to the business office, and especially to the composing room, writers and editors are not regarded as real people living in a real world. Conversely, in my academic career I have been concerned with such sordid matters as budgets and the economics of plant operation. Obviously, therefore, I am not fully accepted by the denizens of the academic ivory tower.

This, it seems, leaves me somewhere in the middle, and perhaps that is a good vantage point from which to launch a few observations on the relationships which exist, or should exist, between the world of affairs and the "out-of-this-world" environment commonly attributed to colleges and universities.

Let me say at the outset that historically the separation between town and gown has never been complete. Many of America's ivory towers were actually created by hard-bitten business men and industrialists. Our great privately established universities reek of oil, of steel, of railroads and tobacco—yes, even of good corn whiskey.

Do you think I stretch a point when I mention whiskey? I am sure you identify the others—Rockefeller's oil and Carnegie's steel helped to build large segments of our system of higher education; railroad money built Stanford University; and profits from the sale of tobacco produced Duke. But what university owes its origin to whiskey? Let me quote a passage from the biography of Johns Hopkins by his great-niece Helen Hopkins Thom: ". . . he decided to go into business for himself and, taking his three brothers, Philip, Gerard and Mahlon as salesmen, he formed the wholesale Provision House of 'Hopkins Brothers.' This house soon did a large business, especially through North Carolina and the valley of Virginia, where they had important connections. The new firm took whiskey in return for goods and sold it under the brand of 'Hopkins' Best.'

"This action on the part of Johns Hopkins offended the Society of Friends and he was temporarily turned out of Meeting. He continued to sell whiskey, nevertheless; but he went regularly to meeting, continued to contribute and was later reinstated. In his later life, however, he felt that he had been wrong in the stand he had taken; and he told his nephew Joseph Hopkins, that he wished he had never sold liquor, and that in so doing he had made the greatest mistake of his life."

Those of us who are concerned with the current finances of the institution which bears his name often wonder whether Johns Hopkins' greatest mistake was not in giving up the trade in liquor. Perhaps many of our current woes would be eased if we could still count upon the profits from "Hopkins' Best." But I have deviated from my main theme.

The men who founded these universities did not expect to collect dividends for themselves or their enterprises in terms of specific contributions by the institutions to business and industry. They felt, perhaps rather vaguely, that education was a good thing. They enjoyed the sensation of having created something of value to society in general. They expected to claim their rewards in heaven or in Gothic architecture bearing their names. The idea that a professor might emerge from the ivory tower with a practical down-to-earth idea certainly never occurred to them.

Nor did such a ghastly thought often occur to the professors. Having had a fairly comfortable ivory tower provided for them, they were content to reside therein, pursuing endlessly and in relative seclusion the conventional academic objective of learning more and more about less and less. The humanists were immersed in their books—ancient books containing the wisdom of the ages, and their own books in which this wisdom, presumably, was distilled. Scientists worked in solitary grandeur in their laboratories, creating curious odors and sounds, or perhaps contriving candid microscopic exposés of life among the amoebae. Political scientists observed the functions of government from the safety of their cloisters but seldom, if ever, ventured into the political arena themselves. Economists with jaundiced eyes surveyed the systems which they generally disapproved, emerged occasionally to bite the hand that fed them, then scuttled back to the protecting walls of tenure and academic freedom.

I have not done enough research to establish without question the *exact* moment at which the first breakthrough occurred—the first uneasy and perhaps questionable marriage between the market place and the ivory tower. It is reasonably certain, however, that this was a union between a chemist and a promoter.

Certainly chemistry was the first of the academic disciplines to produce things of value to the population at large and therefore of interest to industry and commerce. At about the turn of the century the market place began to cast sidelong glances at that part of the ivory tower which encompassed the chemistry laboratories. A few early commercially profitable products of these laboratories burgeoned into many, and an entire new and rapidly growing industry established a debt to academic education and research which it probably will never completely repay.

In this process not many academic chemists got rich. A few, however, were stubborn enough to insist on a share of the profits which their discoveries had created, and so was established the first regular exchange between the market place and the ivory tower.

Gradually the areas of exchange broadened. Engineering, of course, came into the picture quite early, for engineering training was directed specifically at the needs of industry. Engineering research was closely related to the discovery of new products and better ways of producing them.

Perhaps the most dramatic outpouring of academic personnel into the world of affairs occurred during the great depression of the early

thirties. Then the economists, the experts in government, the psychologists, and various mixed breeds from within the ivory towers descended upon Washington for the purpose of creating a brave new world. There are some who say that they did not do a very good job, that the change in environment was too much for them, that the world would have been better off if they had stayed where they were. I shall not take sides on this issue, for my purpose is not to evaluate but simply to describe—and there is no doubt that the emergence of social scientists into active relationships to government and even business and industry at that time was a major development.

The next exodus came, of course, with the threat of World War II and a general recognition for the first time that those scientists who had been most securely protected by the ivory tower had something to contribute to the national defense. Thus the physicists first, and then even the mathematicians, joined the chemists and the engineers in an all-out effort to win what was generally recognized as a scientific war.

I find up to this point that I have not mentioned another very important area of academic research and activity generally—biology. I should not wish to overlook this field, for it does enter very completely into the processes I have just attempted to describe. Early in the game, however, it was recognized that a good deal of biological research had immediate and practical implications, mainly, perhaps, in agriculture and in medicine. The tribe as a whole, therefore, never has been completely insulated from the world of affairs. Biology has not followed the gradual and evolutionary pattern which I have described with respect to other academic activities, simply because the practical potentialities of biological studies were recognized in many cases as soon as the discoveries were made. Nevertheless, a limited number of biologists found a new role in the World War II period, joining their fellow scientists in explorations of methods of attack and defense which have been described as "biological warfare."

The ultimate development of this widespread and sporadic emergence from the seclusion of academic halls to the arena in which real problems are attacked and perhaps solved was inevitable as we look backward to it. If the physicists, the chemists, the mathematicians, and the engineers could combine to build an atomic bomb, why could not the same kinds of groups, working in concert, solve other major problems, both military and civil? The concept of the multi-disciplinary approach was utilized in a number of areas during World War II,

and it was only natural that the techniques thus devised should carry over. It was equally natural that these techniques should be given a name—the name most commonly accepted is operations research.

I am not competent to give you a precise definition of operations research. Many have been brought forward and no two seem to be in agreement. There is one school, I believe, which seems to feel that practically all problems can be solved by appropriate application of the principles of physics, mathematics, and statistics. Another school, whose leader is Ellis Johnson of The Johns Hopkins Operations Research Office, believes that the solution of many problems requires also the intervention of such specialists as economists, political scientists, historians, and philosophers. Regardless of these differences, one thing emerges clearly—the ivory tower no longer is inviolable. The academician of whatever stripe, if he be so inclined, has the possibility of contributing something to the solution of real problems, and the people who have to contend with real problems are recognizing more and more the resources which lie behind these formerly impregnable walls. This dramatic development is certain to produce changes which will be felt on both sides and which will have a profound effect on both the academic community and business and industry.

The effect may be generally beneficial, but I see some dangers in it. I hope the pressure will never become so great upon the truly academic person that he will be forced by public opinion or economic necessity to participate in activities which are uncongenial to him. Even though the ivory tower as a sanctuary may be crumbling, I believe that strong measures should be taken to preserve within it at least a few cells which are still inviolate. There are in many of the conventional disciplines people of high caliber and high devotion who should be protected against all pressures designed to force them into action situations. They must be permitted to do their thinking without concern for what happens to the results of their thinking. They should be nurtured as men of ideas, not of action. And the greatest defenders of these remaining bastions of pure scholarly or scientific thought should be the businessmen and the industrialists who have most to gain ultimately through the preservation, somewhere in our social and educational system, of that kind of an intellectual environment from which the world's greatest discoveries have come, and from which they will continue to come in the future.

Two

THE DEVELOPMENT AND FUTURE OF OPERATIONS RESEARCH AND SYSTEMS ENGINEERING

ROBERT H. ROY

"When *I* use a word," Humpty Dumpty said, in a rather scornful tone, "it means just what I choose it to mean—neither more nor less."

"The question is," said Alice, "whether you *can* make words mean so many different things."

"The question is," said Humpty Dumpty, "which is to be master—that's all."

Lewis Carroll: *Through the Looking Glass*

"What's in a name? That which we call a rose
By any other name would smell as sweet."

William Shakespeare: *Romeo and Juliet*

Within the past two decades, something called "operations research" in the United States and "operational research" in Great Britain has been born, has flourished and multiplied, has attracted and continues to attract much attention, and appears to hold great promise for the future. More recently, something else called "systems engineering," or "system engineering," has had analogous birth, development, attention, and promise. This chapter deals with what these things are, how they have developed, and what may be expected of them in time to come.

That there have been such births and such developments cannot be denied. Nor can it be said that operations research and systems engi-