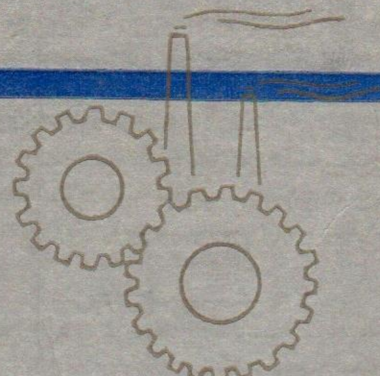
JOURNAL OF NPC

PRODUCTIVITY

True Yoga is efficiency in action



NATIONAL PRODUCTIVITY COUNCIL OF INDIA

Vol. IV No. 2

April—June '63

NATIONAL PRODUCTIVITY COUNCIL

The National Productivity Council is an autonomous organisation registered as a Society. Representatives of Government, employers, workers and various other interests participate in its working. Established in 1958, the Council conducts its activities in collaboration with institutions and organisations interested in the Productivity drive. 45 Local Productivity Councils have been established practically all over the country and work as the spearhead of the productivity movement.

The purpose of NPC is to stimulate productivity consciousness in the country and to provide services with a view to maximising the utilisation of available resources of men, machines, materials and power; to wage war against waste; to help secure for the people of the country a better and higher standard of living. To this end, NPC collects and disseminates information about techniques and procedures of productivity. In collaboration with Local Productivity Councils and various institutions and organisations it organises and conducts training programmes for various levels of management in the subjects of productivity. It has also organised an Advisory Service for industries to facilitate the introduction of productivity techniques.

NPC publications include pamphlets, leaflets and Reports of Productivity Teams. NPC utilises audio-visual media of films, radio and exhibitions for propagating the concept and techniques of productivity. Through these media NPC seeks to carry the message of productivity and to create the appropriate climate for increasing national productivity. This Journal is an effort in the same direction.

The Journal bears a nominal price of Rs. 3.00 per issue and is available at all NPC offices. Annual subscription (Rs. 12.00 to be sent by cheque in favour of National Productivity Council, New Delhi) is inclusive of postage. Subscription for three years, however, can be paid at the concessional rate of Rs. 32.00.

Opinions expressed in signed articles are those of the authors and do not necessarily reflect the views of NPC.

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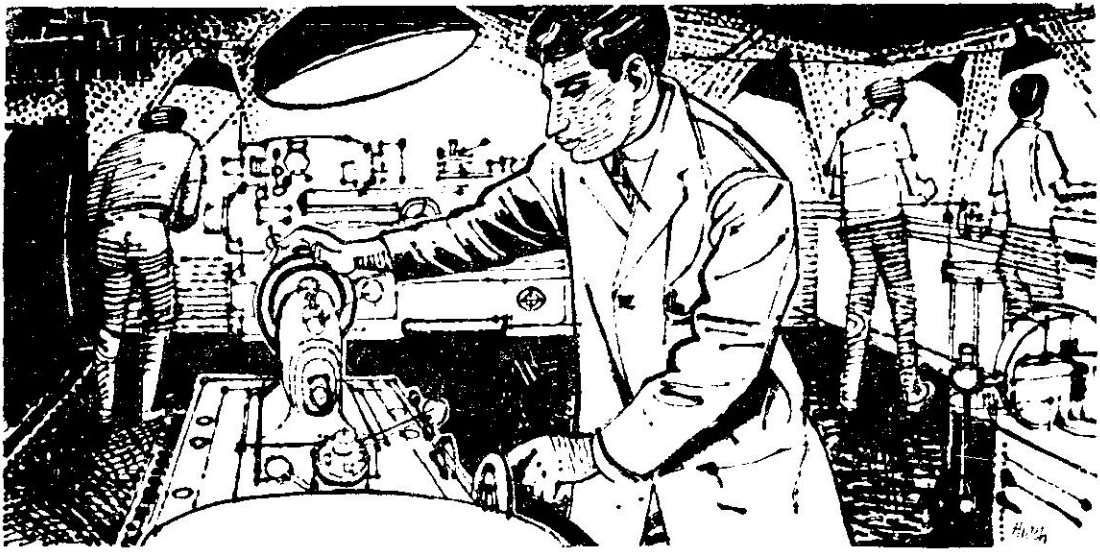
The Mother of Three Jawans Knows No Fear

Three Jawans of like ideals: Jawan on the front, Jawan in the factory and Jawan in the field. Born to enjoy the liberty of a free country, they are now face to face with the duty of protecting liberty. Together a hard-hitting force: protection combined with production: a force no power on earth can conquer.

Bata



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NPC QUARTERLY JOURNAL

PRODUCTIVITY

A few recent Opinions

"...a quite outstanding publication"
—Aberdeen Productivity Committee

"It is a very well brought out Journal...."
—HC Sarin (ICS) Additional Secretary, Ministry of Defence

"...contains very useful data...highly appreciated by staff and students alike".
—Gandhi Smarak Nidhi, Varanasi

"...very interesting. Some of the articles are really of commendable value."
—Subratesh Ghosh, Calcutta University.

"...Excellent is the only common word that comes to my mind...."
—Editor, Trade Digest

The Question-Answer Service

We have introduced **NPC Question-Answer Service** to let the reader ask us questions to which we in the NPC would try to find answers. This is really *a sort of a feeler to find out what the readers actually want.* We now feel encouraged to make a request for specific directions in which the readers of this Journal would like us to move.

NPC Values Readers' Opinion About This Journal

"The readers make the Journal what it is. They are invited to comment unreservedly on the pattern of the Journal and we shall make it what they want it to be, because Productivity means essentially nothing but the sovereignty of the Consumer...." (Extract from the leading article, NPC PRODUCTIVITY Journal Vol. III No. 5 & 6, page 793).

It is essential to get the reaction of the persons, who read the NPC PRODUCTIVITY Journal. Hence this request to answer the following questions:

I How do you like this Journal? What is your over-all impression ?

II Which do you consider the best items, so far published ?

III Which are the items, which, in your opinion, need not be included ?

IV Any suggestions for improving the quality of this Journal ?

Sri HVR Iengar, the New Chairman of NPC

Born 1902, Sri Iengar was selected for the ICS in 1926; has held several distinguished positions in the service of the State, culminating in the Governorship of the Reserve Bank (1957-62); has done pioneering work in Productivity, Planning, the Framing of the Constitution; has been intimately associated with the official work of the Prime Minister etc.

WHY PRODUCTIVITY IS LOW !

"....a very serious inhibiting factor is the jungle of red-tape in which we have got enmeshed. This has steadily become worse and worse.... decisions take an unconscionably long time to take; that even when they are taken, they are subject to further processing....as a general rule, coordination is inadequate. Occasionally also, there are complaints of arrogance and rudeness. No one asks for obsequiousness...."

from Sri HVR Iengar's article in the Commerce Annual Number

Governing Body of NPC

with the New Chairman Sri HVR Iengar and the Founder-Chairman Dr PS Lokanathan

national productivity council journal

PRODUCTIVITY volume 4 number 2

Editor's Notes

Fundamentals

OR in Defence

Mathematics in OR

special issue on operations research

April—June '63

editor DH BUTANI

THE GENERAL SECTION

NPC Quarterly Journal of Productivity

National Productivity Council
156 Golf Links
New Delhi

Dear Subscriber

Under your kind patronage, this Journal has grown both in size and maturity. Besides covering a large variety of subjects of 'productivity' interest, we have published Special Issues from time to time, on Incentives, Personnel Management, Measurement of Productivity, Work Study, Quality Control, Materials Handling, Small Industry, Defence & Productivity and Cost & Budgetary Control. The special issues were designed to provide material of permanent value on selected subjects, in self-contained numbers of the Journal. At the instance of several subscribers, we have lately brought out composite issues, containing general and special sections.

While we are happy to have been able to enhance the appeal of the Journal, we find ourselves faced with rising costs of production. This has presented a choice between increasing the subscription rates and economising on the production cost of the Journal through appropriate adjustments in its size, coverage or periodicity. True to the tenets of productivity, we are most reluctant to increase the subscription or curtail its size or coverage which might detract from its quality of which you have been so indulgently appreciative.

Taking all factors into account and also the needs of the present situation which calls for economy in the consumption of paper, we propose to issue the Journal as a quarterly publication, commencing from Vol. IV No. 1 which is already in your hands. Each issue will, however, continue to offer a special section and a general section. The present subscription rates will remain unchanged.

I am sure, this will receive from you the same appreciative understanding which I have had the privilege to enjoy.

With best wishes and kind regards

Yours sincerely

D H Butani

Editor of Publications

15 April 1963

Top left:

President NPC, Sri NITYANAND Kanungo with Sri Babubhai Chinai

Top right:

Dr Lokanathan with Sri MR Masani and Sri HD Shourie

Left bottom:

Sri Jatin Chakravorty, Sri AR Bhatt with Mr Kennedy of the George Fry Team and Kumari Ena Chaudhury

Operations Research

EMERGING FROM WORLD WAR II AS A *mystique*, the manner and the rate at which Operations Research has been applied to practically the whole range of industry, large segments of commerce, transport, service facilities, even the dark recesses of administration : all this indicates how productivity has got on into the current of social change, for Operations Research, despite its mystical aura, its mathematical mask, its intimacy with military logistics, is nothing else, in reality, but an *integrated* application of productivity techniques.

The Blackett Circus

That is exactly how it was born out of the imperative necessities of the War. The organisers of World War II—Franklin D Roosevelt, Churchill, Eisenhower–soon found out that *war had really ceased to be a mere soldier's business*: it meant an intimately coordinated working of men from several disciplines: Atomic Physics, Chemistry, Biology, Aeronautics, Industrial Management, to mention only a few. Scientists from different disciplines were organised into O.R. Teams, which were addressed initially to optimising the use of resources[1]. Prof. Blackett[2], the distinguished British scientist, called upon to help by the Allied Command, brought in a number of scientists, popularly called THE BLACKETT CIRCUS: a title significant in its implication regarding the methodology of *O.R. Fundamentally, it is the application of the scientific method through an Inter-Disciplinary Approach.*

War & post-War

When the War was over, men in industry, who had been intimately associated with Defence Mobilisation and who had seen or at least heard of O.R. Teams attacking problems such as Target Systems, Effectiveness of Bombing Operations, War Time Inventories, Communication in Warfare, Utilisation of Training Aircraft, Reconnaissance, Convoy Routing: these men in industry began to feel that if the battles of large scale war could be successfully won through O.R., it would be an excellent technique for large scale business, befuddled by the mass of data and the near-impossibility of coordinating by traditional methods, the different technologies with the findings of market specialists, the economists, the sociologists, the human relations experts and many others, who were swarming into industry without the managerial personnel knowing, not only how to storm their brains, but to make them work together for maximising the total gains from the point of view of the concern, as also of the

[1]See NPC PRODUCTIVITY Journal, Vol. III, No. 5 & 6, page 1007: article on Operations Research by Ackoff & Arnoff.

[2]He was recently here at the invitation of the Government of India in connection with the work of the National Physical Laboratory.

community. It was realised that as between the ends of large scale war and large scale business—viz., the optimisation of the desired output from given resources—there were no essential differences; hence large corporations like the RAND, intimately associated with the US Air Force, began undertaking, on a fairly extensive scale, not only practical but fundamental research in O.R. We have drawn heavily upon their published resources, as also on the massive literature published by the various international and national societies of Operations Research that have come into existence in the post-war period.

The Emergency

Quite a large volume of literature on O.R. is still concerned with war experience and war problems: A study of combat stress in Korea[3]; A Monte-Carlo Model for Military Analysis[4]; Some Military Applications of the Theory of Games[5]; A Missile Allocation Problem[6]; A Lancaster Model of Guerrilla Warfare[7]: to cite only a few of the recent researches in the application of O.R. to military problems. Because of the Emergency, we have drawn extensively upon this extremely rich material, supplemented by the good work that has been done in the Research & Development Division of the Ministry of Defence, the Defence Science Laboratory etc.

The Infinite Range

Though still dominated by Defence—for the world is full of war—O.R. now extends over the whole range of what are popularly classed as economic activities, as may be seen from a sampling of a recent periodical on O.R.: Operations Analysis of Locating High-Speed Runaway Exits, The Dynamics of Brand Loyalty, Alternative Bilateral Monopoly Models, Queueing for Gaps in High Flow Traffic Streams, A Generalised Network Approach to the Planning & Scheduling of a Research Programme, Strategy of Data Selection for Adaptive Automation, Least-Cost Allocation of Reliability Investment, A Decision Problem with a Deadline, Optimum Preventive Maintenance Policies, A Dual Labelling Method for the Hitchcock Problem, O.R. in Health Services; Relation between the Travelling-Salesman and the Longest Path Problems; PERT as an Analytical Aid for Programme Planning; Optimal Capacity Scheduling: these again are only a few examples of the almost infinite range of the present applications of O.R.

O.R. in India

The Digest of this literature, in connection with the processing of this Special Issue, has been really a sort of liberal education for us in the National Productivity Council. It will be recalled that NPC organised a special session on O.R., as an integral part of our Productivity Personnel Conference, to which a reference has been made by a writer in this Journal. However, when this Special Issue was planned last year, it was considered to be difficult to muster up sufficient material from within the country for effective presentation of the work

[3]Bio-Social Research in O.R. Stanley W Davis. [4]Richard E Zimmerman. [5]Second International Conference on O.R. [6]Harry J Piccariello (Journal of the O.R. Society of America, Nov.-Dec.'62). [7]S J Deitchman.

being done in India in the field of O.R. The response has been encouraging: in fact, it is worthwhile recording the excellent and widespread work being done through O.R. methodology, not only in Defence and the Railways and private establishments like the Burmah Shell but also the various Institutes of Technology, the Central Food Technological Research Institute, the Fuel Research Institute, the Institute of Science, Bangalore, the Council of Scientific & Industrial Research, the Ahmedabad Textile Industrial Research Association, the Departments of Mathematics and of Business Management at the various universities in India: these again are only a few of the institutions and establishments, which are resorting to O.R. techniques, not only *as a short-term strategy for trouble-shooting but also for long-range programming.*

Planning & O.R.

It is probably not sufficiently known that the Draft Framework for the Second Plan was evolved by O.R. techniques. In the Approach of Operational Research to Planning in India, Prof. Mahalanobis, who has been intimately associated with the subject, has remarked: "I have been all the time using the approach of operational research with a view to getting some broad idea of the strategy of planning. In 1953 an Operational Research Unit (ORU) was established in the Indian Statistical Institute which made it possible to start some preliminary studies on planning. I may explain why I have been using the phrase 'operational research' in relation to planning in India. Our aim is to solve the problem of poverty, that is, *to find a feasible method of bringing about a continuing economic development of the country.* It would be necessary to use much scientific and technical knowledge and also to organise continuing research at various levels for this purpose. But research is not our primary objective...... The distinction is important. In my view our studies have the primary aim of solving a particular problem (and not of doing any theoretical research for its own sake). This is why I have used the phrase 'operational research' in the present connexion. We are speaking of India and suggesting methods which we think are practicable under Indian conditions. I have tried to set up a conceptual framework which would be of help for practical purposes; and I have used certain statistical methods to solve our problem. I have used them as *a scaffolding to be dismantled* as soon as their purpose has been served. There is, of course, much need of theoretical thinking and researches; but so far we have been primarily concerned with practical issues, that is, with operational (as distinguished from theoretical) research......"

Mathematical Scaffolding

Prof. Mahalanobis's remarks throw a significant light on the mathematical framework within which the language of O.R. is usually expressed: the mathematical models are only a scaffolding to be dismantled as soon as their purpose is served. The fact of the matter is that the digesting and presentation (for effective decision-making) of the enormous and complex information needed for the efficient conduct of large scale business, operating within a mobile and tremendous framework of money and markets and policies, require urgently the 'simplification' techniques of mathematics, aided by statistical sampling and designing, electronic computors, digitors and the like. The new methods in mathematical programming—Linear, non-Linear, Quadratic Programming—are only a means to an end—an essential means for summarising of complex data[8]—but still a means to an end: the end being the making of the best choice—the most productive or optimum choice—among the various alternative dispositions of resources.

The Scientific Method

This 'optimisation of resources'—which is the essence of productivity and the core of O.R.—is the ancient economic problem of the choice between alternatives.[9] It is the approach of O.R. that is original and significant. To quote LeRoy A Brothers (whose article on Operations Analysis in the US Air Force, appears in this issue of the Journal): "Operations are considered as an entity. The subject matter studied is not the equipment used, nor the morale of the participants, nor the physical properties of the output; it is the combination of these in total, as an economic process. And operations so conceived are subject to analysis by the mental processes and the methodologies which we have come to associate with the research work of the physicist, the chemist, and the biologist—what has come to be called the scientific method."

The Strategy of Productivity

The fact of the matter is that modern industry is in continuous need of a strategy on account of two concentric complexities: an inner complex system, called a factory or a firm, operating within a complex environment of government policies, markets, technologies. The factory or the firm, appearing to the external world as a single unified system, is in itself a complex world of money, men, materials and machines; and the techniques of Operations Research such as Linear Programming constitute a strategy by which managements steer their way to a rational, optimum, productive use of resources. As elaborated by the Earl of Halsbury in the thesis with which this Journal begins—from Plato to the Linear Programme—*the techniques of Operations Research can be applied to "society as a whole and ask how its performance can be optimised."* This, of course, is LOOKING TOO FAR AHEAD. At present, it would pay dividends if we were to adopt Operations Research as The Strategy of Productivity.

[8] "....the sophisticated mathematical ability required for the solution of complex problems involving many variables....." Florence N Trefethen: History of Operations Research.

[9] "......much of standard economic analysis is linear programming": Foreword to Linear Programming & Economic Analysis (RAND series). Those interested may also read Prof. Baumol's Economic Theory & Operations Analysis.

"Too many try to communicate with words alone......"

From Plato to the Linear Programme†

The Earl of Halsbury*

The USA and the UK have been aptly described as two great nations divided by a common language. It is indeed true that we do not always use words in the same sense and I shall therefore be at pains to ensure that no misunderstanding arises therefrom. Operational research (as I understand it) is concerned with optimizing the performance of a system regarded as given for the purposes of the problem.

HISTORICALLY, the first problem to receive the name of Operations Research was concerned with how to set the time fuse of a bomb to be dropped from an aircraft onto a submarine. It was solved by my friend and colleague Professor Blackett‡, who showed that the fuse should be set to explode on impact and not, as the Royal Navy and Air Force believed it should be set, to explode after a delay period. The bomb, the aircraft, and the submarine were regarded as standards; the setting of the fuse was the only recognized variable.

There is however another sense in which the word is used; namely, to denote analysis of an operation required to be performed in order to design equipment or procedure that will meet a user specification. It is not always clear in which of these two senses the words "operations research" are used and there is a connection between them that can be seen in the following way.

If, instead of regarding the aircraft as given, we allow it to range over all the air force, we enlarge the field of inquiry by the inclusion of an extra element of variability. For lack of a better word I call this an adjunction. I select this word in particular by analogy with the extension of the field of rational numbers to the field of an algebraic number by "adjunction" thereto of some algebraic mark such as $\sqrt{2}$.

If then to the resources of an air force we adjoin the resources of the aeronautical industry, our problem becomes a wider one—that represented by the alternative definition of the words "operational research"; namely, how to design and produce the best aircraft for dropping bombs on submarines.

I shall be concerned in this paper with a still wider field of operational research, a field standing in relation to any single operational study that might be proposed, somewhat as the complex number field stands to any finite number ring. This problem arises when *we consider society as a whole and ask how its performance can be optimized.* The field of inquiry cannot be extended by any process of adjunction; it is already as wide as it can be and embraces all there is.

Having dealt in this way with definitions I want to plunge backwards into history for a few minutes by inviting you to think of the

*The Right Honourable, The Earl of Halsbury, is Managing Director of the National Research Development Corporation, London.

†*Journal of the Operations Research Society of America*, Vol. 3, No. 3 pp. 239-54.

‡Professor Blackett's is probably the earliest name associated with the literature of operational research. His two papers, "Scientists at the Operational Level" (1941) and "A Note on Certain Aspects of the Methodology of Operational Research" (1943) have been published as addenda to his article, "Operational Research," in *The Advancement of Science*, Vol. 5, No. 17 (April 1948).

religious wars of the seventeenth century. That century was an age of fierce intolerance and of astonishing preoccupation with the minutiae of formalized creeds, beliefs, and practices that arouse today only the coolest of interest, if any at all. The intolerances played a critical role in the early history of European and British settlements in the New World. The issues on which intolerance was displayed now find us somewhat baffled. Not only in the United States but elsewhere, Catholic and Episcopalian, Baptist and Presbyterian, Quaker and Freethinker, have come to live over the greater part of the world in a harmonious social intercourse that no difference of creed is any longer capable of disrupting. You have only to read in history of the fierce passions aroused three hundred years ago by controversies over the permissibility of surplices or the idolatrous status of lecterns, together with the neurotic anxiety state into which the sound of a church bell had the power to throw George Fox, to ponder forthwith on why we have changed. Why have these grounds for intolerance ceased to matter though their substance has remained unchanged ? It is not as if the participants have merged their differences. The differences remain; they have merely ceased to appear as important as they once did. Why?

*The content of a human social or historical situation is always richer than verbal analysis can display**. Reality is like a tangled skein of threads. With infinite patience the analyst dissects one thread out of the bundle and is delighted to observe a causal nexus between its parts. We thus reach truth but never The Truth. The reality invariably bristles with more detail than can be apprehended as a whole.

A reason (not *the* reason, accordingly) for the transition from the intolerance of the seventeenth to the tolerance of the eighteenth, nineteenth, and twentieth centuries was the light shed upon the controversies by the cooling and healing torch of rational science. When Locke and Hume were pinpointing the shaky foundations of all those philosophical beliefs that the controversialists held in common, it was difficult to become excited about the marginalia that divided them. While the heavens were opening their immediate beauty to all men under the stage management of Galileo and Newton it was difficult to become excited about the length of a surplice or the shape of a lectern.

The issues about which men were at one time prepared to cut one another's throats to the greater glory of heaven, ceased to be a cause for bloodshed and intolerance and were transformed into differences of opinion that were at most discussed in the schools and finally congealed into social habits to which it was ill-mannered to refer openly at a dinner party. In the final result, reformation and counter-reformation ceased to be political conspiracies and their adherents became sects prepared to agree to differ.

Though the world was the gainer thereby, man's prejudiced nature merely found other outlets for his aggression. Passing forward instead of backward three hundred years in time to the present day, we find the world once more bitterly divided on matters of creed and belief. Once more men are prepared to torture and murder in the name of what their misgotten prejudices conceive to be truth, and in the light of past experience it seems natural to inquire whether the issues that now divide rich and poor, nationalist and imperialist, coloured man and European, communist and bourgeois, will seem as fiery three hundred years from now as they do today. Should that be the case, will the cooling and healing light of science and rational inquiry be seen to have played its part in the process and do we have it in our power as scientists, not to take part in the controversies, but to shed light upon them so that men may see themselves more objectively, more clearly, and with less passion; can we make a positive and conscious rather than an unconscious contribution to the ending of the long tale of man's inhumanity to man ?

During the last three hundred years those who practice what we call democracy have

*Italics ours throughout.

learned many lessons from experience. Finding that power in the hands of an absolute monarch supported by a corrupt court was insufferable, we had to learn that an absolute government sustained by the sovereign authority of a corrupt parliament was no less objectionable. When the bribery and corruption that resulted from the breakdown of the traditional system of farming offices was placed under control and an honest and incorruptible civil service was brought into being as a worldwide standard of efficient administration, we learned to our dismay that the problem had but shifted elsewhere and that a sovereign nation whipped up to a fever of spurious nationalism by a corrupt press was just as much of a public menace as any that had preceded it. We live in the midst of these troubles today and, as is common, the issues have crystallized into two broad patterns resulting historically from the age-old problem of the rich and the poor, the haves and the have-nots, whether we conceive them in terms of the underprivileged individual or the technically and socially backward nations of the Orient and the African continent.

In the controversy between rich and poor that is at the heart of all the issues that vex us, there lies a danger that society may again be rent by one of those destructive wars from the most recent of which we are just emerging, and all those who, like myself, hope to see peaceful reasonableness established as the permanent and normal relationship between man and man are more than justified in dreading its outbreak. A contributory cause to such an outbreak could be a corroding lack of self-confidence among the guardians of civilization's heritage turning upon the question of whether their own house is truly in order. It is this factor that has given rise to that most dreaded of phenomena, *the fifth columnist in our midst, the overtly trusted individual who is nonetheless at heart in sympathy with the other side.* What generates him we do not entirely know, but so long as our own society is susceptible of honest criticism, the factors that render it vulnerable must play at least some role in doing so. In seeking to put our own house firmly in order we shall therefore be making a contribution to our strength and, as scientists, our contributions to doing so must surely rest upon analysis rather than partisanship.

I am myself forcibly impressed by the contribution that the techniques of the simulator and the analogue computer have made to thought in the field of economics. *What a mess economics was when I was a much younger man than I am today! Quot homines, tot sententiae*, seemed to have been the prevailing state of affairs since time immemorial. There was, it was true, *a mathematician called Keynes who claimed to understand the instability of the trade cycle, but how could one expect bankers to read mathematics?*

History has strange revenges and produces equally strange re-evaluations and assessments. I often speculate in this context whether FD Roosevelt's stature in history will loom great, not as the man who was four times President of the United States, nor as the President who saw the United States out of the great slump of 1929-31, into World War II, and nearly out the other side, but as the man who first gave the Keynesian theory of economic control an opportunity to be tried out and be discussed at the highest level by practical men, who were forced to cope with and understand it by having to live with it.

While these things transpired in the social world of events, electrical engineers were quietly experimenting with feedback amplifiers and designing methods of controlling them based upon and understanding of the conditions for their stability; out of this understanding grew a nomenclature and out of the nomenclature a means of non-mathematical presentation of the phenomena involved.

I do not know who the genius was that first perceived the trade cycle as no more than the consequences of a feedback loop, and applied electrical engineering terminology to economics as it had previously been applied to acoustics.

What is certain is that we have in England at the National Physical Laboratory a simulator that will demonstrate Keynesian theory to the non-mathematician. The spectator can raise the bank rate on one dial setting and watch the consequences thereof upon unemployment represented by a calibrated volt- or ammeter at another point of the instrument. He can couple two of these simulated systems together in an importer-exporter relationship and watch the effect of a tariff barrier upon their reciprocal trading. Having thrown the pair into oscillation by some such device he can play with the controls in an endeavour to restore stability and, on failing to achieve it, can be shown by the demonstrator how to do so.

Controversial economics are not possible under these circumstances; one cannot be partisan with respect to the reading of an instrument. One cannot exaggerate the importance of a factor, admittedly real, when the system obstinately proves itself to be parameter-insensitive in the face of that factor.

The consequence of this approach is that the temperature of discussion on all such matters is reduced to a level somewhat below fever heat. When the tumult and the shouting subside one is left with a solid, comforting, but rather simple core of truth. Control of the trade cycle is more sensitive to early and accurate measurement of stock and work in progress than to any other factor. If information on that one point were available with a three-monthly instead of a six-monthly time lag, the feedback systems need never become unstable, and local fluctuations could be readily damped out by the control mechanism. "What a simple answer to what a lot of fuss," one feels inclined to comment! Yes, but with how much labour was that simple solution won!

May it not be that there are other matters upon which science may shed light of an equally important character? I propose to discuss one such matter here; namely, economic and social justice, or the distribution of the wealth of society conceived as a problem in linear programming. It is evidently very relevant to the historical and political considerations with which I dealt earlier.

Plato in *The Republic* likened a city ruled by justice to a man ruled by his intellect. In reaching this analogy he drew many comparisons with alternative forms of rule, showing that other factors such as passion or cupidity would render a man and a city less perfectly fit to deal with their respective environments.

This case he argued with more attention to persuasion than to the semantic and logical niceties that would appeal to a modern analyst, and *his conclusions, if taken seriously, are repellent. His city state is a totalitarian and monolithic one* governed by an aristocracy. This corresponds with the man governed by his intellect. In contrast a democratic state of affairs is argued to be the worst imaginable as it would correspond with a man ruled by his passions. In rejecting Plato's conclusions we must nevertheless recognize an acceptable feature running through his arguments. The man who is *only* hungry for wealth does not in fact attain it in stable form; the ruination of all components of his nature but one frustrates the satisfaction of the one remaining. It is equally true of the man who is governed by his appetites and passions. The man who wants *only* wealth, *only* food, *only* love, *only* health never in fact attains it with any measure of permanence. The man governed by his intellect is in some sense truly endowed with all that his intellect had acquiesced in abandoning. In this sense Plato's aristocrat has sought the Kingdom of Heaven and all the other good things have been added. *Running through 'The Republic' we therefore encounter an underlying theme based upon an optimum performance resulting from a controlled compromise.*

The economists of the last century perceived that this truth applied in some way to the distribution of wealth in society. The complexity of the subject matter bewildered them, however, and their conclusions became involved with other issues on which there was insufficient knowledge available for opinions to be adequately formulated.

One of these was represented by Malthus' views on population pressure, which were put forward as a Law of Nature but which, ecologists now tell us, must, if true, be an exception to a Law of Nature. Malthus stated that every population presses on its food supply, whereas most ecologists consider that *no population ever presses on its food supply. If man does so, as in present-day India, it is part of his martyrdom. not a consequence of any law writ large in the Book of Nature.*

Since the ecological facts are not very widely known, I think it may be permissible to describe this sort of situation in a little more detail, notwithstanding the risk of irrelevancy. In the first place anyone who visits a Nature Reserve is struck by the Balance of Nature. In the Great Parks in Africa, for instance, the grass is as lush as the aridity permits, the antelopes are fat and lions are sleek. The populations in fact are *not* pressing on their food supply. Something else is holding them in check. What could be the basis for this extra factor ? Some recent experiments give a clue as to the direction in which it should be looked for. The overcrowding of field mice increases their frequency of encounter exactly as an increase in the density of a gas produces an increase in the number of molecular collisions per second. On the occasion of an encounter between males a process of aggressive display takes place which is Nature's substitute for an actual combat for possession of the female. With a rise in the frequency of encounter there is a rise in the frequency of aggressive display among males and at a critical point this appears to react on the nervous system, possibly through the medium of the pituitary, with the result that the production of an essential sex hormone is inhibited and the males become sterile. The population therefore falls sharply in the next generation.

This is so unlike the Malthusian description of population pressure that it seems worth recording. What appears to be the case is that Nature has introduced a safety mechanism to ensure that the population shall *not* press on its food supply. There are, of course, exceptions to this, particularly in the case of animals that hunt in packs. The hungry wolf pack will kill out a whole district and then starve. This, however, seems to be the case of a natural mechanism going astray rather than the operation of a natural law. The Malthusian law is, therefore, not a Law of Nature but an exception thereto. It applies to *man because man uniquely among the higher animals has the power to violate instinct through the exercise of intelligence*, misdirected and misapplied. These considerations illustrate how incomplete some of the early nineteenth century approaches were to the sort of problems that they attempted to study in this field. This criticism, of course, could be made of any pioneer. Whereas, however, the general public is reasonably well aware of the progress made in physics since the nineteenth century, progress in ecology seems to have attracted less publicity with the result that opinions that are a hundred years out of date have become frozen into the general pattern of our thought.

A second issue upon which the economists of the nineteenth century became confused was *the extent to which the immense complexity of human affairs prevents their administration in detail.* They accordingly overvalued the merits of any system in which a man, by acting in his self interest, subserved the statistical interest of his neighbour. In the most liberal of modern societies, however, we have found it necessary and possible to interfere far more with human affairs in detail than the classical economists contemplated.

They justified the wealth of the rich, obtained through the various market mechanisms that they recognized, not because the virtues of the wealthy entitled them to spend it, but because it was *in excess* of what they could reasonably spend and therefore was capitalized and used to industrialize the nation and thereby support a growing population at a standard of living that could be supported in no way *except* by industrialization. I do not think I need to elaborate the analogy this bears to the current of thought underlying Plato's in *The Republic.*

You will appreciate then that the problem—as a problem in optimizing a performance—of distributing society's wealth among its members is not a new one. A modern treatment of the subject can therefore but repeat what has been said before except in so far as a new tool of analysis has presented itself. I believe that such a tool does in fact lie to our hand.

"*What is wrong with the rich is idleness; what is wrong with the poor is poverty,*" said George Bernard Shaw. Like many epigrammatists he combined a superficial triviality with a profound truth to get a stage effect. I have met many rich men, and few of them have been idle. I have on my travels seen many poor men and their condition is only too obvious. *Regard poverty then as inflicting some sort of damage upon the productive resources of the community* and you will be introducing the factor that the nineteenth century ignored. By damage, I do not merely mean that maldistribution of purchasing powers that destabilizes an economy. We all recognize that a high level of production of consumer goods must be accompanied by a high level of purchasing power distributed to the wage earner, who is wage earner in one trade and consumer in the next, if the goods are to be bought. That is only true, however, of a given rate of investment. Provided that profits are expended upon capital goods for the benefit of the future, a low wage policy need not entail economic instability of the kind to which I have referred.

I mean by damage something much more positive: the damage that comes from poverty *regarded as a focus of ignorance, superstition, and disease.* Four hundred millions of peasants in India are rushing headlong upon a food crisis that must sooner or later accomplish their downfall in tragic circumstances because they are below the level of education at which they are accessible to propaganda on family limitation. In the United States, techniques of automation are progressing to the point where yet one more step will soon be taken in the elimination of the manual labourer by upgrading him to a control engineer. *Poverty and automation are incompatibles*, inasmuch as ignorance is a concomitant of the former. Psychiatrists grade their psychiatrics according to whether they are accessible or inaccessible to communication. Society will increasingly grade its poor in the same way.

Thus, to the extent that education and specialization are functions of leisure and wealth, essential to high productivity, a low consumption by the poor individual is a damage inflicted upon society whose productive resources are reduced thereby. Society cannot push the investment rate up so that consumption is pressed down to the point where the standard of living of individuals and groups ceases to rise and thereby menaces their educational and cultural progress.

I will now endeavour to give these thoughts a simple mathematical form. Let us start with the fundamental equation of an economy:

$$P \qquad = C \qquad + I$$

Production = Consumption + Investment.

Production P and Consumption C are themselves sums of individual production and consumption. Symbolically,

$$\left.\begin{array}{l} P=\Sigma_k\, p_k \\ C=\Sigma_k\, c_k \end{array}\right\} \text{ summed over the } k=1,2,\ldots n, \text{ members of society.}$$

According to the view I have expressed above, the production of the k^{th} individual is a function of his personal consumption. We do not yet know what this function is going to be like, and I will discuss it later on. For the time being we write simply

$$p_k = p_k\,(c_k);\ P=\Sigma\, p_k\,(c_k).$$

Consider next a state of affairs, somewhat un-American, I admit, in which total consumption is a constant, and in which there is a real positive investment such that

$$P > C$$

If the society under consideration were technically progressive, this state of affairs would permit economic progress as well.

The problem before us then is to maximize

$$P=\Sigma p_k\ (c_k);\quad \Sigma c_k=C,\ \text{constant},$$

subject to some assumption as to the nature of the functions $p_k\ (c_k)$ in individual cases.

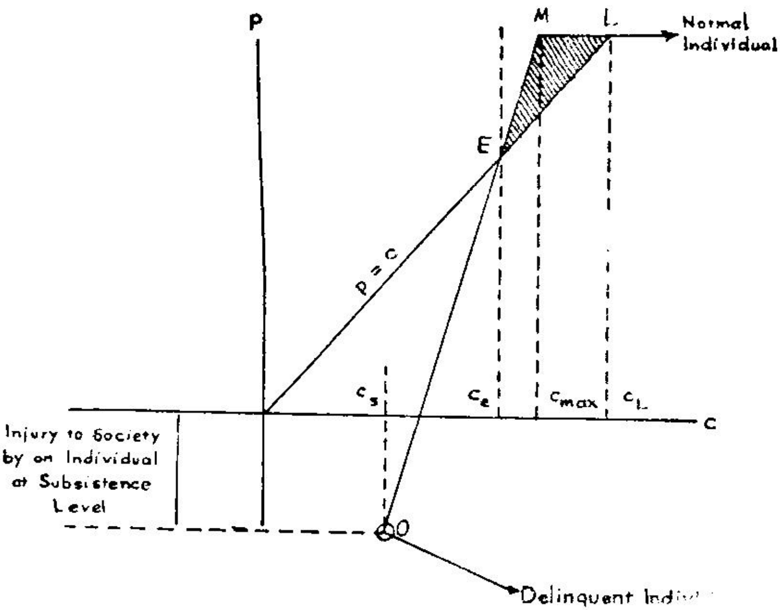
The solution at constant C will give the conditions that maximize the investment of the community, I, and therefore lead to the result we seek—the most rapid expansion of the economy. The problem as stated is a somewhat artificial one and ignores time dependence, equally with competition between consumption and investment for a given value of P. Its only value is that it serves as the simplest peg on which to hang a discussion of the function p_k.

life, but if he is a delinquent the damage he inflicts on society becomes greater as his consumption increases. At a value of $c=c_e$ the (p, c) line cuts the line $p=c$. This marks the break-even point E at which the individual is earning his keep but contributing nothing to the investment of society.

At c_{max}, the (p, c) line turns over, society obtaining no further benefit from increased consumption by the individual whose standard of cultural and educational life has grown to the point where he is getting a maximum benefit from the advantages of living in a society. A limit is reached at cL where the (p, c) line again crosses the line $p=c$ at L. At a consumption above this limit, the individual again fails to earn his keep.

The perpendicular distance from the segmental (p,c) line $OEML$ to the $p=$line falling within the shaded area gives a measure of the investment resulting from maintaining an individual at any point on the significant part of the (p, c) line EML.

The curve is characterized by four parameters or their equivalents; namely, the coordinates of the points $O(p_1, c_1)$ and $M(p_2, c_2)$.



This figure shows a somewhat simplified model of these functions; it gives an indication of how the problem might be approached.

The two axes of coordinates represent p_k and c_k, respectively. The injury caused by poverty to society is regarded as negative production and the limit of this damage is regarded as that associated with an individual at bare subsistence level c_s. Above c_s the individual's production rises, if he responds normally to the rewards of social

These will in general differ for each individual in society each of whom is characterized by personal values of p_1, c_1, p_2, c_2.

The problem then consists of placing each individual at some 'working point' on his personal curve so as to maximize the sums of personal production on the basis of a fixed total of individual consumption.

A number of solutions, some of them trivial, then arise according as to whether

$$C <=\text{or}> \Sigma_k (c_s)_k, \Sigma_k (c_e)_k, \Sigma_k (c_{max})_k \text{ or } \Sigma_k (cL)_k$$

It is clear that a problem so complex can only lead to approximate solutions. *We cannot do more than build models and test them; but they can be honest models* and the solutions to which they lead can be true solutions. We cannot convert our sums into integrals because of lack of knowledge, nor can we sum over the billions of members of society because of the impossibility of computing the answers. We could, however, break society down into a relatively small number of groups and evaluate our sums over the groups. This would, of course, limit the interest of the answer but we could test the sensitivity of the solution to the approximations made in particular cases.

Even so, the number of groups into which an honest model would require to be divided would entail the use of a digital computer in order to evaluate the solution in a particular case and the existence of different types of non-linear cutoffs would make the problem of some interest to the mathematician and the programmer.

The concept of a saint as a non-linear discontinuity may be theologically novel, but the class of such men would have to be represented by conditions in which, below subsistence level, they would starve sooner than hurt a fly, let alone their fellow men or society, while at or above subsistence level they would confer a constant benefit upon the society in which they live.

The man whose productivity ceases to rise above a certain level of consumption because his interests become engaged in other matters such as his social or cultural life, would represent another instance of a limit.

It is of interest to note that many of the classes of society into which man could be divided have been the subject of extensive social study and many statistical facts are known relating to them. In the case of a time-dependent model, each such class of individual would require to be the subject of assumptions relating his productivity at time t to his consumption up to time t and his expectation thereof from time t forwards into the future. In many cases one could use known statistical data in such a model.

Under these conditions we should also have to consider the type who will work hard for a period to accumulate a minimum sum enabling him to retire early and devote the remainder of his life to water-colour painting. This would be a further instance of a non-linearity.

There is, however, one element on which but little is known but upon which the interest of the solution and the contribution it could make to social thought would very largely turn. That is the element represented by a certain quality of individual variability that we denote by referring to anyone at one end of a certain spectrum as a *High Energy Individual* and at the other end as a *Low Energy Individual.* I believe that the psychologists' investigations are lagging rather badly in this field and I would like to draw some attention to this point because it is the one upon which the social controversies of our time so very largely turn.

I expect you think you know what I mean by a "High Energy Individual," but you would be hard put to it to give any definition of what we really do mean. *Like the elephant, a high energy individual is easy to recognize* but difficult to define.

I have in my mind a syndrome of which the component elements are an unlimited appetite for more of whatever happens to be of current personal interest; a ready overflow from one sphere of interest to another, so that any activity whose fulfilment is blocked in one channel is readily diverted into another; a firmly though sometimes transiently held sense of purpose; and a vigorous, and sometimes ruthless, effectiveness in attaining the end of that purpose. I have painted in words the portrait of my high energy individual but I have affixed no name to the portrait. Is he to be a big-shot gangster or an archbishop ? Is he to be the constructive head of a big administrative machine or the partly social, partly anti-social, millionaire whose mixed benefit and damage to society portrayed in the pages of Dreiser or Sinclair Lewis leave one baffled and unsuccessful in the search for a true appraisal or assessment ? However we define him, or however we assess him, he is the man the controversy is about.

Our linear programme will contain no constituent of social or political interest unless we somehow include him as an element in its solution.

The social critics of the late nineteenth and early twentieth century saw clearly how the low energy individual was exploited by the high. Their successors, who have watched society transformed by the post-war crop of welfare states with which Europe has been experimenting, have so far given us no equally dramatic picture of the frustration of the high energy individual by the low. Nor will they ever do so, inasmuch as *the sufferings of the poor and underprivileged have a natural human and dramatic value*, which the irritations of an executive vice-president faced with a crazy tax law have not and never can have. It is not to literature to which we can look to delineate this problem as one of interest, and yet it is of the greatest importance to any lifelike model of an economy that is constructed.

Personally I would like to drop the conception of a high energy individual altogether in favour of something quantitative. I suspect that the component of performance that we describe as "high energy" could be dealt with on quantitative lines by comparing the performance of one individual with another before and after administering benzedrine to the one, and a barbiturate to the other. A man's B or "benzobarb index" would be the amount of benzedrine or barbiturate necessary to raise or depress his performance to that of a standard individual. The necessity for barbiturate would be expressed by a positive B, that for benzedrine by a negative B. When the experimental basis for the indices had been established one would be in a position to obtain frequency curves taken over the population. This may strike you as somewhat science fictional, but it is at least in keeping with the spirit of experimental psychology following a tradition established by the various IQ's and Spearman factors that have gradually replaced our more commonsensical notions of "intelligence" and "talent". I offer it as a humble suggestion to the psychologists.

There is a body in England called the National Institute of Industrial Psychology of which I am Chairman. This gives me a ringside seat, as it were, in the councils of those who are planning work for the future. I am struck, not only in the Institute of which I am Chairman but in other and similar institutes, by a tendency to shy away from problems that seem to plunge too deep and by way of compensation to concentrate investigational resources on inquiries that can with reasonable certainty be guaranteed to produce a correlation coefficient between something and something else. These deeper aspects of the subject need "getting up from down under" and being enlivened with a more controversial note.

Anyone concerned with the planning of science is aware of this tendency. *In one sense I am against the planning of science*, inasmuch as its most spectacular successes have been achieved by the freely operating human spirit. But when science leaves the universities and enters industry or government service, some provision has to be made for a plan. One invariably finds that inquiry tends to concentrate itself into a number of blind alleys in which subjects that retain an intellectual interest for the inquirer are explored in ever minuter detail after they have reached the diminishing returns portion of the effort-reward graph. If one accepts Freud's view that *the mind has an intrinsic resistance to self-exploration*, it would be understandable that with each tendency reinforcing the other, experimental psychology will be very prone to the type of marginal concentration that I have depicted.

I am therefore interested in bringing some pressure to bear upon the psychologists and social scientists to persuade them to look at the horizon where *automatic computing machines are standing waiting for what I might call the social parameters to be punched on their input tapes*. At present the psychologists, sociologists, and economists are unware of the facilities awaiting them. If anyone were to write down a few linear programmes on the lines that I have sketched herein, he would very soon become aware of the difficulty of entering real figures into the equations. Bringing some pressure to bear on our sociological colleagues will, I am sure, be beneficial.

To summarize what I have tried to explain: A facility presented by the modern type of digital computing machine is that, errors and omissions excepted, it can repeat the same operation over and over again, varying the parameters and testing for sensitivity thereto. *Analysis of social factors by reasonably open-minded people who approach their problems in a spirit of intelligent agnosticism discloses a multiplicity of causally operating phenomena that most investigators would agree exist, at least.* Controversy arises when we try to assess their relative importance. Is the factor on which Professor Z is working going to affect the result by an order of magnitude or as a small perturbation? We have little means of ascertaining, and experimental calculations in terms of a model have hitherto been so laborious that no one would have dreamed of attempting them. The ability of automatic computing machines to tackle work of this character somewhat changes that situation. We have it in our power to build arithmetical models of our marketing and distributing systems and to test their properties under a wide variety of assumptions. Provided we are content that our model of society is broken down into no more than, say, 400 groups, the machines to which I have been referring will cope satisfactorily with *the problems involved in optimizing some feature of the whole*, such as productivity, about which we care to make one assumption per group, relating (say) production to consumption. I see no reason why the greater part of these 400 groups should not be one-man groups consisting of individuals, leaving the mass of society to be represented by a few groups: an under-privileged group at subsistence level, together with groups of unskilled workers, semi-skilled workers, managers, and professional classes. One could then examine in detail the perturbation caused by an injection of some 390 individuals with exceptional characteristics and power for good and evil under different conditions and assumptions—the mathematical equivalent of a sociological novel.

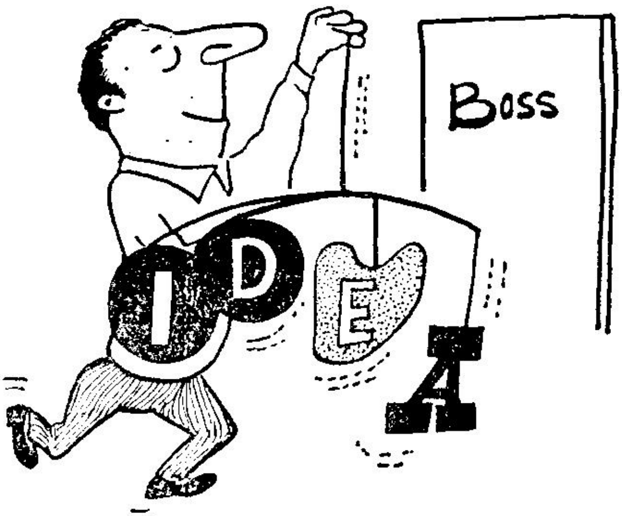
What is it that one hopes to see emerge from such studies? For my own part, a reduction in the temperature of debate is what I hope to see. Let it be granted that society has its Goulds and its Vanderbilts, its Al Capones and its Henry Fords, and that both types may be blended in the controversial figure of a Rockefeller with his monopoly practices on the one hand and his charitable benefactions on the other. Can one control the Jay Goulds and the Al Capones without at the same time frustrating the Vanderbilts and the Fords? *If we break up the Rockefeller monopolies, who provides the Rockefeller endowments?* How much real power have we to benefit society by putting its high energy individuals under control?

When I look back on the history of England and the United States over the quarter of a century represented by my adult lifetime, I perceive on my side of the Atlantic a growing reconciliation with socialist ideals and practices, accompanied by a cognate recognition of their limitations. On the American side I find an ever more passionate adherence to the doctrine of free enterprise while the volume of paper controls and red tape in which the Americans are entangled grows to dimensions just as preposterous as it threatens to do in England. We seem to have evolved on surprisingly similar lines in spite of inspiration by very dissimilar doctrines. What are we both really playing at? This is the point at which, under our present dispensation, reason politely yawns and hands the tiller to passion. What we need is knowledge. Just as electrical engineering techniques have shed light on the theory of economic stability and Von Neumann's theory of games is shedding light on the true nature of a market, so I believe that linear programming can shed light on what we can hope to achieve by different methods of distributing wealth among competing groups in the community.

The Colombo Plan is a rather simple example of a two-component system. The wealth of America, Britain, Canada, and some other countries is being shared with the backward nations of the East. This gesture arises partly from altruism and partly from self-interest inasmuch as it is hoped to arrest the spread of communist doctrines thereby. Owing to the immense number of Oriental people involved, any literal sharing out of wealth would so reduce the standard of living in the United States that its power to assist would be permanently crippled. Common sense suggests that there must be a limit to what can be done if altruism and self-interest are not to defeat their own purposes.

That the conclusions of a mathematical analysis should reinforce common sense will no doubt be welcome to taxpayers !

The need for shedding light upon our distribution of wealth becomes ever more clear as collective bargaining on conscious lines replaces controls by the impersonal market rate of the last century. A socialist or semi-socialist order such as prevails over much of Western Europe runs into inescapable difficulties when fixing rates between different skills. Every year in England about five billion dollars worth of increased wealth becomes available for wage increases or increased capital formation. Who is to get it ? The unions cannot agree among themselves. There is no market mechanism with its imperfect but impersonal control; the market mechanism having been abolished, no principle has emerged to replace it. Equalitarianism is in practice rejected, and so negotiations flounder along from year to year while proponents of this pay rise or that pay rise argue endlessly about the consequences of moves in a game that they only dimly understand. Notwithstanding the differences in our philosophies I do not believe that the situation in the United States is notably different from that in England ! What we need is light, the light that only a rational approach can shed. The instrument of illumination is, however, in our hands, though the parameters must be supplied by others. If this analysis results in but one operational analyst and one social scientist getting together and making a beginning, it will not have been written in vain.



This Foggy Area

Russell L Ackoff*

Operations researchers are no different than their consumers in one important regard: they do not like to have their own decision-processes subjected to scientific study. They resent the intrusion of others into *this foggy area*, and they are disinclined to illuminate the subject with self-consciousness. Yet operations researchers should be the first to recognize the value of a critical examination of decision procedures, others or their own. It is apparent that scientists have no more justification in their plea, 'Leave my unconscious alone', than does anyone else. *Can it be that this disinclination to self-examination is based on the fear of uncovering hitherto unknown inefficiencies?* If so, there is certainly nothing for the operations researcher to be ashamed of, particularly since he, unlike his consumers, can take credit for his own improvement.

MUCH of the recent probings into the methods of science have been done by philosophers, most of whom have been so detached from actual research that their results have been held in disrepute by scientists. On the other hand, most of that small number of scientists who have probed this domain have been amateurs who have proceeded in blissful ignorance of the important philosophical analyses of enquiry which were conducted in the past. Contemporary scientists are continuously rediscovering the ideas of Plato, Aristotle, Descartes, Spinoza, Leibniz, Locke, Berkeley, Hume, Kant, Mill and the other great methodological analysts of the past.

It has only been in this century that the possibility of studying scientific research scientifically has been seriously entertained. Operations researchers, it seems to me, are uniquely equipped to contribute to such studies. There are two reasons for this:

First, the major problem in the development of an adequate methodology for science has derived from the lack of objective and quantitative criteria for evaluating alternative research procedures. As a consequence, convenience and associated rationalizations rather than rationality have pervaded. For example, given a sample of data drawn from a population from which an estimate of a population's parameter is to be derived, what estimation procedure should be used? The most commonly used criteria are 'least squares' and 'maximum likelihood'. Consider only the former for illustrative purposes. It was developed because of its mathematical simplicity. It assumes, however, that the costs of error are independent of their sign and that they are a quadratic function of error-magnitude.

In OR, perhaps for the first time, we can expose the falsity of these assumptions and measure the costs of making them. We can do this because the models used in OR can also be used to derive cost-of-error functions for each parameter in a model. This opens up the possibility of developing estimation procedures which minimize some function of the cost of errors due to estimation.

The general situation, of which the estimation problem is only an instance, is that models of a consumer's decisions can be used as a basis for generating models of

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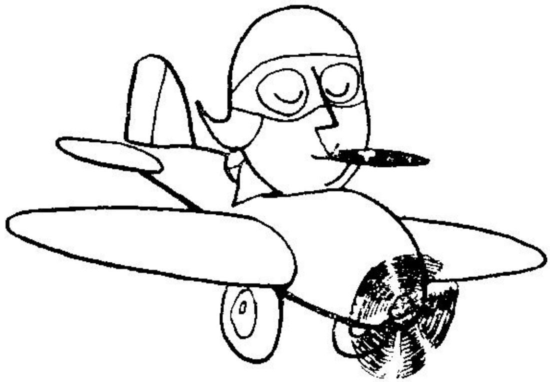
the research decisions which are involved in solving the consumer's problem. Put another way, operations researchers have the skill and information necessary in many cases for constructing models of research operations and for optimizing them or approximating such optima.

Secondly, because the operations researcher knows or estimates the objectives involved in a problem, he can estimate the costs associated with various research procedures in terms of their consequences on the decisions being researched and, hence, on the ultimate performance of the system involved. The ability to do this may well equip the operations researcher to determine what procedures should be used in so-called 'pure' research, where the uses of the findings and their consequences are not known. That is, he may be able to determine how the pure researcher should 'hedge' against the possible uses to which his results may be put.

Many operations researchers tend to be more interested in the techniques than in methods; that is, in how to solve the consumer's problems rather than in how to solve his own research problems. This emphasis is not difficult to understand. But more attention to methodological problems than has been given to date is required if OR is to develop as rapidly as possible, and certainly if it is to become a unique scientific activity. Scientific disciplines are distinguished by both the aspects of phenomena which their practitioners study (their subject matter) and the methodology which equips them to study this subject matter more effectively than anyone else can.

The effectiveness of operations research can be permitted to increase by reliance on luck, intuition, and the unconscious abilities of its practitioners, or it can be based on the self-conscious direction of their efforts and abilities to the development of better ways to study the operations of systems. I, for one, prefer the latter approach and so, apparently, do my colleagues.



Executive in Wonderland!

Science & Operations Research

J Sayer Minas*

The theoretical-practical distinction is an old and pervasive one. Its history is traced briefly in this paper, with particular attention given to its effect on the development of the sciences. It is shown how the practical disciplines came to be regarded as lying outside the domain of science altogether. The recent development of operations research (as well as the other action or policy sciences) seems to represent a break with this tradition. Alternative ways of interpreting this development are discussed in the context of the main contemporary philosophic schools and their respective views of the practical disciplines. Some of the implications of these schools for science generally and for operations research specifically are brought out. In particular, the question of the status of policy recommendations or value statements is discussed from the point of view of *logical positivism, intuitionism, and experimentalism.*

ARISTOTLE, who is responsible for the majority of our common sense distinctions, distinguished among three kinds of activity: (1) theoretical (2) productive and (3) practical. He characterized each of these by certain aims and by certain disciplines that pursued these aims. The aim of the theoretical disciplines (e.g., physics and chemistry) he said to be knowledge, of the productive disciplines (e.g., politics, economics, and ethics) prudential behaviour. Aristotle thought of all three types of disciplines as science. Since the Renaissance, however, the theoretical and productive disciplines have come to be regarded as pure and applied science, while the practical ones are thought of as arts or skills rather than as science.

It is not difficult to understand how this dichotomy between arts and sciences developed historically. During the Renaissance, political, religious, and social pressures made it safe for the scientist to investigate only those phenomena that were not directly connected with commonly accepted beliefs. In a culture which threatened the lives of believers in even the heliocentric theory it is not surprising that there was little systematic scientific study of politics and ethics.

Scientists and philosophers were not content merely to accept the social pressures that forced the exclusion of consideration of values from science; they felt compelled to justify the separation of values from science. Kant accomplished this in the middle of the eighteenth century. He explicitly separated the pure and the practical in his *Critiques of Pure and Practical Reason* on the basis of what he claimed to be an inherent difference between their respective subject matter, method and faculty of the mind.

Since then, the traditional sciences have developed under increased social support; between them and the practical disciplines there has appeared a widening and deepening chasm into which mankind may ultimately fall and vanish. Today economics, so-called 'political science', and ethics are primarily harboured in schools of administration and humanity. Seldom is work in these areas rewarded with a degree in science.

As a result of these social pressures, what science did in effect was to restrict itself to questions whose answers either had no perceptible application or were to be applied

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in a way that was clearly not the responsibility of the scientist. The scientist could not be held accountable for the use to which his results were put. Practical or policy problems, on the other hand, were those for which the solver could be held responsible for the use made of his solution.

Into this atmosphere of a legally separated household, operations research (and the other action, or policy sciences) appeared, apparently daring to combine in successful wedlock the disparate practical and pure-applied disciplines. Furthermore, its practitioners openly accept responsibility for the solutions they provide. This development is much more revolutionary than many realize; its significance is not yet completely appreciated.

There are several ways of rationalizing this violation of scientific tradition. First, it may be argued that the apparent break with tradition is only illusory and that in fact the only responsibility the policy scientist is assuming is substantially the same as scientists have traditionally assumed. Second, it may be argued that in operations research extra-scientific considerations are involved, as they have always been, but that they now play a more important role in science's activity. Finally, it may be argued that ultimately policy questions are as amenable to scientific study as are theoretical ones, and that, furthermore, consideration of these questions is essential to the development of pure and applied science.

These three reactions to the involvement of operations research are projections of the three dominant philosophical positions of our day. The relevance of these philosophies to the role and status of policy sciences is most clearly revealed in their positions regarding the nature of questions of value. The relationship between questions of value and policy decisions is apparent; there are no alternative ways of using a policy, and hence he who recommends it is responsible for its effect on the values of those who are involved. It is thus worth examining what each of these philosophies has to say about the methodology of answering questions of value.

The first of these positions we wish to consider is logical positivism, which in one or another of its forms is probably the most widely held philosophic view of science. Among its more prominent proponents are R Carnap, AJ Ayer, and CL Stevenson; it derives from the eighteenth century Scottish philosopher David Hume, stepping along its way to borrow heavily from Bertrand Russell and Ludwig Wittgenstein. According to the positivists, in order for a sentence to be meaningful (i.e., to be either true or false) it must either be a statement of logic or mathematics or else confirmable or disconfirmable on the basis of immediate, sensory experience. The formal sciences are devoted to the analysis of the first class of sentences; the second class constitutes the subject matter of the natural sciences. The propositions of the physical sciences, in this view, are to be analysed into their elementary components; each of these components represents a single elementary, or atomic, experience, and can thus be verified or falsified by an appeal to immediate experience, and can thus be verified. A great deal of analysis has been devoted to the reduction of complex sentences to their elementary forms; similarly, much effort has been devoted to the attempt to identify the set of similarly atomic experiences that is required by the theory. Both of these activities have led to grave difficulties; it is doubtful that a general reduction scheme can be found. Likewise, the existence of atomic experiences appears to be an untenable psychological hypothesis.

For our purposes, however, the important aspect of positivism is treatment of recommendations. A recommendation may be cast in the form of an imperative, 'You ought to do *x*.' The analysis positivists give to imperatives is two-fold. In the first case, 'You ought to do *x*' is taken to involve an implicit reference to some state of affairs, *A*. Then the original sentence may be taken to be equivalent to the hypothetical 'If you want *A*, then you ought to do *x*', which will be true or false depending on whether or not x is efficient for A. Assuming that you do want A and that x is efficient for A, then the imperative 'You ought to do x' is true. Because of these two assumptions, this analysis is called the hypothetical one. Now, clearly, this hypothetical use of recommendations is a common one, but just as clearly there is another one as well. With respect to this non-hypothetical use (i.e. the categorical use) of imperatives, 'You ought to do x' means either 'x is efficient for A and A is actually good (for you)' or 'doing x is inherently obligatory (for you)'. For the positivist, in neither of these cases is the sentence either true or false. For me to say 'A is actually good (for you)' is for me to say 'I approve of A (for you); do so likewise.' And for me to say 'doing x is inherently obligatory (for you)' is for me to say 'I approve of (your) doing x; do so likewise'. What distinguishes categorical from hypothetical recommendation, on the positivistic view, then, is that the former are essentially exhortative. Since exhortations are neither true nor false (i.e., are meaningless), they may not be investigated in any scientific manner.

The implications for operations research are obvious. The evaluation of decision-making must always be hypothetical. The operations research scientist merely comes up with recommendations that if so-and-so is done, such-and-such will result; he may not enquire into whether such-and-such is actually valuable or good. Answering this question lies outside the scope of the research. Presumably, it is up to the sponsor to tell us what he wants; we must take his estimate of what is good. It is possible to maintain consistently this position, and it is actually held, at least verbally, by many research workers. On the other hand, there is some question as to whether it is consistent with the practice of operations research and whether the highly restricted character of operations research that results from it is desirable.

First, in many cases sponsors of operations research projects are able to state their objectives only in rather vague generalities if at all. As Hitch has pointed out, "Appropriate and operationally meaningful objectives for OR must in general be developed as a *product* of the OR analysis; while they must be consistent with 'higher level' objectives, they cannot be simply deduced from them. If we begin with tentative objectives, feedbacks from the analysis are likely to require their modification or replacement". Frequently, in attempting to analyse loose statements of objectives we are forced to consider the kind of complex technical issues with which the sponsor may be so unfamiliar as to be unable to respond effectively. For example, while the objective may be loosely stated as 'to maximize profit', it is often necessary to distinguish among: 'to maximize expected profit', 'to minimize the probability of profit below a certain level', 'to minimize the variance of average profit from period to period', etc., etc. Thus it appears that the research worker is, in many cases, unable to avoid having a hand in formulating the objectives. The extent to which his role in formulating them, can, or should remain at the purely descriptive level is a complex issue which cannot be decided here. It is clear, however, that at present the research activity does have an effect on sponsor's objectives and that the research worker who chooses to disregard this effect is in a real sense conducting research irresponsibly.

Second, the positivistic conception of operations research, as well as of science generally, is confronted with a fundamental problem in the methodology of inference. As is well known, inference-making is a risky business. For example, the criterion for selecting a procedure for estimating a parameter on the basis of a sample makes certain assumptions regarding the cost of errors. The positivistically oriented methodologist may try to avoid making explicit such assumptions; he may tacitly assume a criterion that presupposes such costs to be symmetric and quadratically distributed. The point here is not that such assumptions are wrong, although in many cases they clearly are, but rather that they are value assumptions. Are they to be regarded as representing the system of approval of the scientist, individually or collectively ? When this question is raised, the positivist tends to hedge by asserting that estimates of parameters are also hypothetical. That is, when using a least-squares estimate, for example, the scientist must prefix his estimate of the parameter with the qualification 'if the cost of error is a quadratic function of the magnitude of the error'. Even the so-called pure scientist seeks to minimize some function of the error of his estimates. The question is: 'What function ought to be minimized ?' The answer that in the absence of any information about costs one ought to minimize the simplest function of error that does not appear to be *a priori* ridiculous is so reminiscent of the Principle of Sufficient Ignorance in the history of probability theory as to need no further comment.

On the positivistic view, then, science may not attempt to answer (categorical) value questions. It may make only hypothetical recommendations. Further, since most, if not all, of our scientific knowledge is inferential, science may make only hypothetical statements of fact. And in this case the hypothesis is a value-statement. Accordingly, even the aim of the theoretical disciplines, knowledge, may be pursued only by presupposing answers to certain questions of value, certain practical questions.

In contrast to positivism and its preoccupation with problems of scientific method, the second school in our survey has devoted little attention to its relationship with science, and is consequently relatively unfamiliar to most scientists. This school, which I propose to call intuitionism, is actually a cluster of viewpoints regarding the methodology of answering (categorical) questions of value. The characteristics common to these viewpoints are: (1) that (categorical) value-statements are capable of being true or false (i.e., are meaningful), and (2) that the method appropriate for dealing with such statements is essentially *a prioristic* and is thus distinct from the methods employed in the natural sciences. A new realm different from that of natural phenomena (or at least from the realm of natural phenomena as studied by science) is introduced. It is for this reason that those who like to consider themselves as 'hard-headed' and 'scientific' generally regard intuitionism as 'soft-headed' and 'metaphysical'.

Frequently, intuitionism takes a quasi-deductive form. That is, the set of value-statements is regarded as forming a kind of deductive system, the axioms of which are given to us by intuition or by revelation. Thus it is supposed to be self-evident that one ought to keep one's promises or it is supposed to be revealed to us that killing is wrong. We are familiar with also similar arguments in favour of using the maximization of expected value as a criterion or the criterion of minimax.

Other versions of intuitionism lack even this degree of systemacity; value properties in any given case are thought to be immediately perceived or recognized. For example the contemporary intuitionist GE Moore asserts that the sentence '*A* is good' is like '*B* is yellow' in that both predicates are simple and unanalyzable. But whereas the recognition of the property of yellow is associated with some sensory organ, the recognition of the property of good is extra or non-sensory. In yet other versions, common-sense replaces intuition or revelation.

The difficulties associated with such *a priori* theories are numerous and well known. To how many must a proposition be self-evident or revealed in order for it to be accepted ? When two mutually inconsistent propositions are revealed or intuited, how is consistency to be restored? etc., etc. Aside from these questions, however, a major defect of such theories, especially the deductive types, is that all too often they have nothing relevant to say. For example, even if the Decalogue be accepted on *a priori* grounds, in what way is it of any use to the decision-maker confronted with the problem of setting safety standards ? Although such theories have quite a long history, even their contemporary advocates (e.g., HA Prichard, D Ross, and AC Ewing) seem quite unperturbed about this state of affairs.

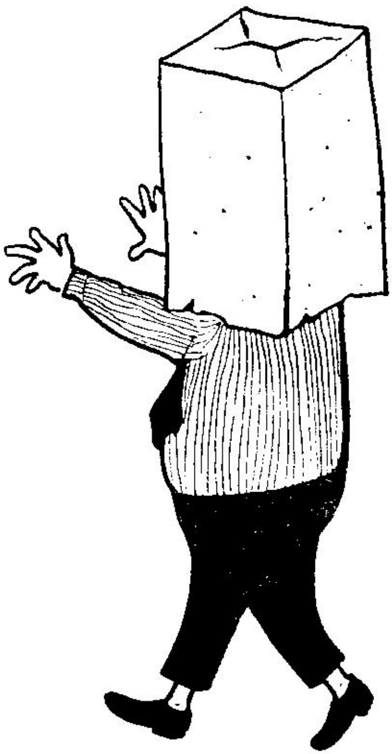
The point here is not that the method of intuition, or self-evidence, or common-sense is to be discarded. Rather it is that such methods must be integrated with the total organization of the research. The difficulty with the programme of intuitionism is that since the realm in which intuition is supposed to operate is closed off from the natural realm investigable by science, such an integration is impossible. Fundamentally, this implies that there exists a certain class of decision-processes that are inherently exempt from scientific enquiry. Thus, the concept of control in this area becomes empty.

Experimentalism, the third view in our survey, has its roots in pragmatism as developed in the works of CS Peirce, William James, and John Dewey and is developed most fully in the works of EA Singer.

One of the distinguishing features of this point of view is its rejection of the theoretical-practical distinction. It will be remembered that for both positivism and intuitionism knowledge and action are regarded as not only distinct but also as investigable by totally disparate disciplines. They differ primarily on the basis of whether the practical diciplines are to be taken as cognitive or non-cognitive. As we have seen in the critique of positivism, when pressed, this view insists that even our knowledge of the physical world must remain hypothetical. What experimentalism asserts here is that the job of detaching the antecedent (i.e., confirming the hypothesis) must be assumed by science. In order to do this job, a science of values is required. Unlike the earlier forms of pragmatism that assumed a relativistic attitude toward such a science, experimentalism insists that it is necessary to make evaluations with respect to a criterion of progress that is not completely reducible to the values of particular individuals or groups. Thus, for the experimentalistically oriented operations research worker, the categorical imperative 'You ought to do *x*' is not only meaningful but is also potentially confirmed or disconfirmed on a scientific basis.

A second important characteristic of experimentalism is its non-hierarchical ordering of the individual sciences. According to positivism, the sciences are ordered on a scale of 'fundamentalness'. The most fundamental sciences are the formal ones: logic and mathematics. Next comes physics, then chemistry, and so on up the ladder. Somewhere near the top (or perhaps a little bit off the ladder altogether) are the social sciences. The idea of this hierarchy is that each science presupposes none of the results of those above it. The contention of experimentalism is that no such hierarchy exists. It argues that even though psychology is above physics on the positivistic ladder, the methodology of physics makes psychological presuppositions, for example, in determining the magnitude of the observer error in taking readings. In fact, the experimentalist claims that all problems of science are interrelated in such a way that enquiry in any branch of science presupposes results from every other branch of science. The rationale for these claims has been developed in detail, and so will not be gone into here. It is interesting to note how this last claim is related to the concept of interdisciplinary research. A number of arguments for such research have been made. For example, one case is that an interdisciplinary team is needed to identify the special discipline into which a problem falls, but that once the identification has been made the problem can be turned over to workers in that discipline. A second case is that the application of the methods and approaches of one discipline to a problem in another is often fruitful, and thus an interdisciplinary team is a useful device for effecting such cross-pollination. Thirdly, it is often argued that problems, at least of the type encountered in operations research, do not occur within disciplines but rather across them. Thus an interdisciplinary team is essential in order to deal with such problems. Finally, the strongest case is the one that relies on the claim of the experimentalist, that in order to maximize research control all the disciplines must cooperate. This is not because of the nature of the problem at which the research is orginally aimed but rather because of the nature of the sciences themselves.

The purpose of this paper has been to raise some of the philosophic issues associated with the existence of action or policy sciences such as operations research. It was undertaken in the belief that all too often in discussions of operations research, its status, and methodology, appeals have been made to one or another philosophical view in order to justify a given point without an awareness of all the other points that would have to be accepted on that view.



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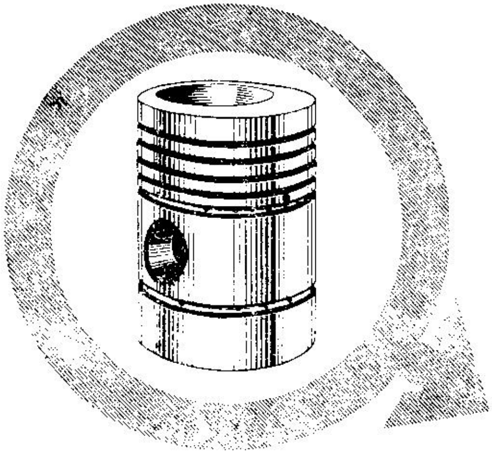

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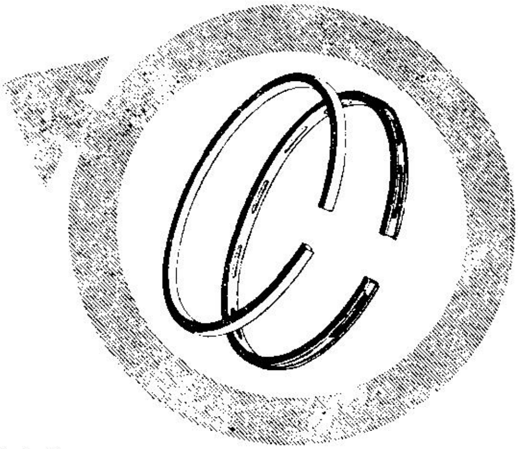

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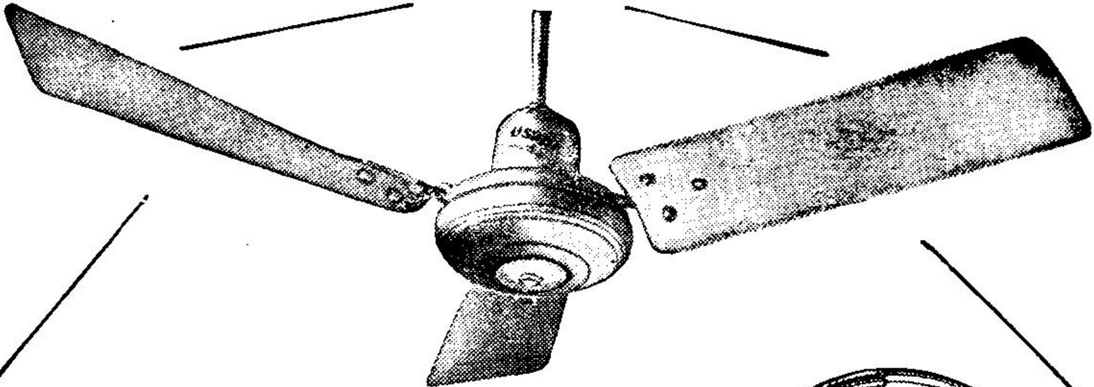

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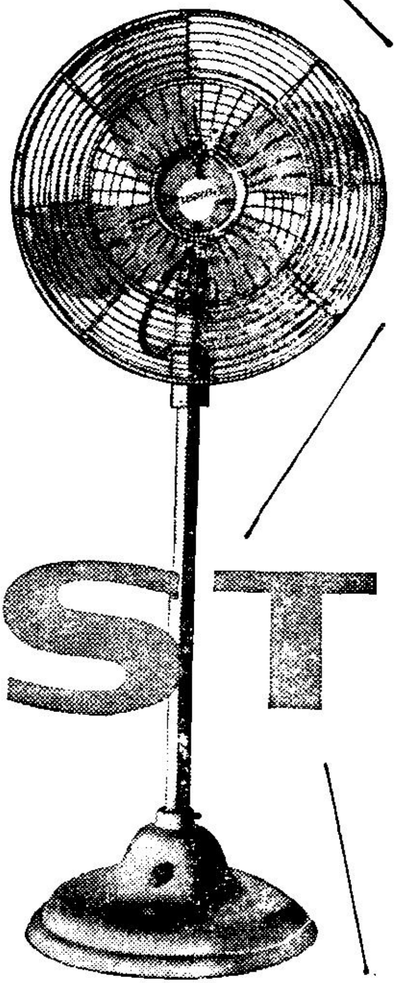

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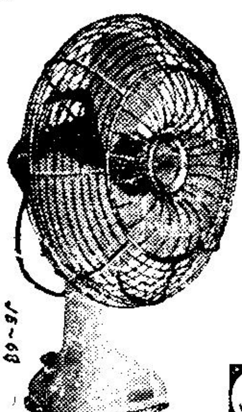

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War & Technology

Donald E Marlowe*

The interaction between war and technology would be a fascinating field for exploration by a scientifically minded historian. To the extent that we measure progress by our state of industrialisation, it seems likely that we would regard war as a period of stimulus, rather than of retrogression. Certainly many concepts which might require decades to flourish in more peaceable times are brought to an early bloom through the forced measures required for national defence. Such was the case in the fields of operations research and systems simulation. The seed was there (for example, the Theory of Games was developed as early as 1928) and certain tentative steps towards the organisation of mathematical models of complex systems had been attempted, but society itself is not sufficiently organised, nor its objectives sufficiently simple in peacetime to encourage the growth of this new art. Mankind has been formed in the habit of looking to the movements of the planets or the entrails of birds, rather than to matrix algebra, for the solution of predictive problems.

WAR time is more demanding of its soothsayers, and in all countries there soon developed a feeling that the methods which had proved successful in the post-action analysis of physical experiments could, rather straightforwardly, be applied to the predictive analysis of the performance of man-machine systems. At first this restriction was felt to be necessary, since the machine introduced many limiting parameters into the equations which were felt to contribute substantially to the accuracy of the prediction. Only with more experience was it learned that man himself, at least "*en masse*", was perhaps as limited as his machines.

Beginning with the work of Rowe, in England, and Johnson, in the United States, systems analysis and operations research were taken up by nearly all major operational commands on both sides of the conflict. Before the end of the World War II, the advantages of applying the scientific method to military operational problems were well understood. It was inevitable that men who had felt the power of these methods would seek to apply them to the problems of the post-war world. And, indeed, the time was ripe for such a move. The war had contributed to the formation of aggregations of economic might on a scale quite unforeseen in the previous quarter century. The billion dollar corporation was no longer a rarity, and governments grew in comparable manner. The optimum organisation of these vast endeavours was, and still is, a most pressing problem.

Where the intuitive genius of the super-manager sufficed for a simpler world, it now seems wise to attempt a mathematical model of these great enterprises, the analysis of which may guide the manager in his critical decisions. The development of such models is, of itself, a scientific task of the first magnitude, and has occupied some of our best minds for the last decade.

Prof. Dimitris N Chorafas's work on Operations Research for Industrial Management represents some of our most advanced thinking in the field today. The advent of the large-scale computer has made possible the development of more complicated (and thus more realistic) models, while the solutions can still be obtained on a reasonable time schedule.

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Operations Analysis in the US Air Force

Leroy A Brothers*

This is an example of operations research from the author's early World War II experience. In 1943, three operations analysts assigned to the Ninth Bomber Command in North Africa were faced with the problem that arose from the fact that German fighter pilots appeared to have no respect whatsoever for the gunners in the bombers of the Command. The author was not one of these analysts—he came into the story later.

THE B-24, then a heavy bomber, was being used in North Africa in World War II. It had .50 caliber machine guns in turrets in its nose, its tail, its waists, and in a top turret. All guns were hand-operated and aimed by eye; modern fire control mechanisms were not used in these airplanes. Aiming rules were provided so that the gunners would know where to point the guns to hit the targets. Either the gunners did not know the rules or the rules were bad.

The analysts assigned to this problem soon recognized that it was a simple matter of relative velocities: those of the bomber, the projectile, and the fighter. The problem was one of figuring out the three paths so that, at the right time, the projectile and the fighter would meet.

Examination showed that the gunnery manuals were based on good theory, but that the instructions which told the gunners how to aim their guns were too complex to expect the gunners to remember under stress of air combat. As a result, they had forgotten about the rules and had been relying on common sense. Anyone who has gone duck hunting knows that he must "lead" the duck in aiming so that the shot will hit the duck as he moves along the path of his flight. It turned out that the B-24 gunners were "leading" the fighters—and this was just exactly the wrong thing to do. Leading the fighter, as one would lead a duck, neglected the velocity of the bomber; the correct procedure was to aim apparently behind the attacking fighter. The analysts invented a catch-phrase for this: they told the gunner to "lead toward your own tail". This meant that every gunner, regardless of which gun position he was manning, should point his guns directly at the attacking fighter, then move them off toward the tail of his own airplane before firing. The analysts devised some simple aiming rules that later were given to all gunners in the form of a well illustrated manual. It was possible to illustrate only four situations; the gunners were asked to memorize these four pictures, and to interpolate for situations between the four.

It is history now that when the new rules were put into use the German fighter pilots soon learned to respect our gunners. With slight modifications the new rules were adopted for general use throughout the Air Force and by the Navy and the Marine Corps.

This happened just as I was ready to take

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off for India in late 1943 for my first assignment as an operations analyst in the Air Force. So I took along a copy of the manual, thinking that the bombers in Southeast Asia might be having the same trouble. Sure enough, they were ! I loaned my copy of the manual to the plans officer at our headquarters. He showed it to the commander of the Tenth Air Force when he came to our headquarters on a visit. Later, when I was scheduled to visit the Tenth Air Force, I went in to see the plans officer to get my little book and to find out what the general thought of it. To my surprise the reply was, "He didn't like it at all. He just doesn't believe it."

"Well, that's just fine. Now I've got a problem. I'll go down and convince him. Where is my little book ?" He didn't have it. The general had taken it with him. So I didn't even have the manual that showed what should be done. On the flight from New Delhi to Calcutta, I spent several hours trying to figure out what I should say to the general in order to convince him that the new aiming rules were right and that what his gunners were doing was wrong. Finally I figured it out and I was sure I could convince him. I would take him out on the parade ground of his headquarters (an old headquarters of the British army) and ask him to do the following:

First, stand on the ground and throw rocks at a passing jeep—he'd see he had to lead as in duck hunting.

Second, ride in a moving truck and throw rocks at a stationary object such as a post or tree trunk—he'd see he had to "lead toward his tail," the rear of the truck.

Third, ride in the moving truck (the bomber) and throw rocks at the jeep (the fighter) as it attacked the truck from a variety of directions—he'd see he had to "lead toward his own tail" every time.

This would be *operations analysis of the highest order* !

You can imagine my disappointment upon my arrival at the Tenth Air Force to learn that the general did not disagree with the new rules. On the contrary, he had reproduced the manual and distributed it to all his gunners. So my problem went out the window.

Seriously, I claim that this incident—the development of the new manual, not the evaporation of my problem—illustrates operations research at its best. For here *an operation was improved by a study that led to recommendations for change without requiring either the introduction of new equipment or the modification of existing equipment; only the method of operation was changed.*

The first Air Force operations analysts went to England in September 1942 to work with the Eighth Bomber Command, which later became the Eighth Air Force. They were greeted by the commanding general with the question, "How can I put twice as many bombs on my targets ?" It is interesting to note that the general did not ask such questions as, "How can I improve bombardier training ?" "How can I reduce combat losses ?" "How can I increase the payload my aircraft can carry ?" or any other of a large number of questions he could have asked dealing with the specifics of his mission. Instead, he took the broad view of his overall task—which was to place bombs on enemy targets—and simply asked how to achieve greater effectiveness in carrying out his mission. This was and is typical of the questions brought to operations analysts. They are often of major importance, of great magnitude and difficulty, and many times they are stated in quite vague terms, by scientific standards. Nevertheless, they offer the analysts great opportunities to make major improvements in the effectiveness of the Air Force.

The new analysts were somewhat nonplussed by the question but recognized at once that, in effect, *the general had given them the whole bomber command as their laboratory.* With practically no knowledge of military matters among them, they set to work to understand the bombardment operation as it was being carried out by the Eighth Bomber Command. This required a considerable period of time and was accomplished by studying in detail and at first hand all phases of the operation, from initial planning to the assessment of the completed mission. They learned from the commanding general himself, from his staff officers, from the commanders of the operating groups and squadrons, and from the junior officers and airmen who flew most of the missions.

It soon became apparent that there were many factors affecting the placement of bombs on targets, such as:

(1) Bombing accuracy: the accuracy of the delivery of the bombs from the aircraft to the target;

(2) Weapon selection: the choice of the bomb-fuse combination judged best for the particular target;

(3) Enemy opposition: the intensity and effectiveness of enemy opposition, including defending fighters, anti-aircraft artillery, and passive defences;

(4) Battle damage and losses: our losses and damage from enemy action;

(5) Flight procedures: those followed on the actual mission, such as whether to attack by single aircraft or by formations, what speeds and altitudes to use, etc.;

(6) Intelligence: information available from a variety of sources about enemy targets, disposition of his forces, etc.;

(7) Training methods: whether our crews were adequately trained and, if not, how to achieve adequate training.

Each of these factors clearly had an influence on the mission of the bomber command. Each of them was worthy of study and would require a major effort by the analysts. It was decided to select from among them so that the initial effort of the analysts could be placed on the one that appeared likely to be the most lucrative at the time and for the particular group of analysts available. Bombing accuracy was chosen for the initial subject of study; it was studied intensively from then until the end of the war. Later, as the operations analysis section grew, all the other factors (and many others) came under study.

The Eighth Bomber Command was bombing at that period of the war in formations of B-17's and B-24's ranging from 19 to 36 aircraft. Many such formations were used to attack a single target where such a force was judged to be required. Each formation attempted to release all of its bombs at the same time so that the bomb fall from a formation formed a pattern on the ground. Each aircraft carried a number of bombs with the result that the bomb pattern from a single formation covered an appreciable area on the ground.

The analysts' first task was to select a measure of effectiveness of the bombing. The measure of effectiveness necessarily had to be something that actually could be measured objectively and that had a real relationship to the desired effect of the attack; namely, to achieve damage to the target that would have military value. It was also important that the measure of effectiveness be easily visualized in its relationship to the purpose of the mission and that it be capable of being related to the physical factors affecting the bombing. This latter was necessary if the analysts were to be successful in recommending means of improving the bombing. After long study in which many possible measures of effectiveness were considered, it was decided to use as the measure of effectiveness the percentage of bombs falling within 1,000 feet of the assigned aiming point.

The next step was to isolate as many as possible of the factors thought to affect the percentage of bombs within 1,000 feet of the aiming point. The following is a list of such factors: (1) size and type of formation; (2) number of independent aimings per formation; (3) selection of lead bombardiers; (4) training of bombardiers; (5) selection of aiming point; (6) briefing material and procedures; (7) tactics on bomb run, including speed and altitude; (8) target identification; (9) enemy opposition, active and passive; (10) counter-measures, enemy and friendly; (11) cruise control procedures; (12) weather; (13) many others.

As can be seen, some of these factors were under the control of the attacking force while others were beyond its control. In general, it is more productive to work on the factors over which the attacking force has control.

The analysts soon found that the combat data normally rocorded and reported by the combat units were inadequate for the purpose of operations analysis. Accordingly they set about the task of devising means of obtaining adequate data. They found that some of the attacking bombers carried cameras mounted vertically to take photographs of the bomb falls, primarily for intelligence and publicity purposes. They recommended that additional cameras be carried so that each formation would have a high probability of recording its own bomb fall. They recommended that the cameras be set in operation at the instant of bomb release and that they take a series of photographs of the bombs falling and striking the ground. These photographs were called strike photos. To obtain them it was necessary for the formation to fly straight and level over the target rather than to turn aside as soon as bombs were released. Undoubtedly this resulted in additional battle damage and losses but courageous commanders decided that the information obtained probably would result in sufficient improvement in the bombing that it actually would save aircraft in the long run. In addition to the photographic record each formation was asked to supply bombing data: number of aircraft in the formation, dimensions of formation, number of bombs carried and how they were fused, altitude and air speed over the target, wind and weather conditions, enemy opposition, etc.

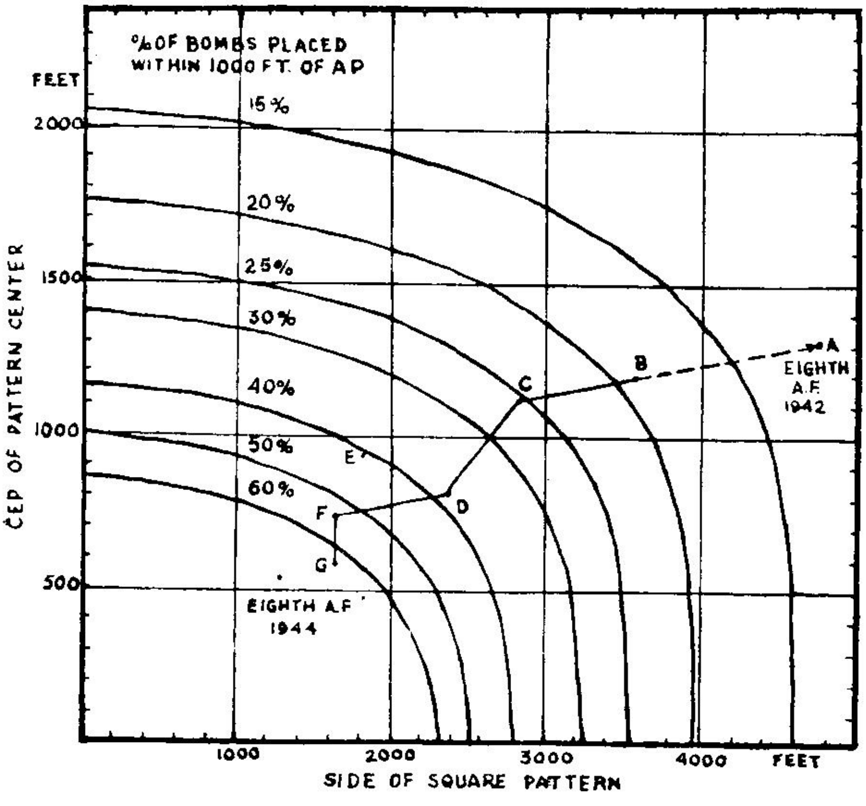
The next step was to decide what to measure from the photographs. After much study and experimentation it was decided to measure the size of the bomb pattern from each formation and the aiming error of each pattern. The definition of the pattern evolved to be a rectangle with two sides parallel to the direction of flight of the formation and two sides at right angles to this track. The rectangle was to contain an arbitrary percentage of the total number of bombs dropped by the formation. The aiming error was then defined as the distance from the centre of this rectangle to the assigned aiming point. Defining the pattern as a rectangle had great advantages from the standpoint of measurement and calculation, an important matter, as the measurement of these photographs soon became a tremendous task occupying the full time of a number of airmen. Each such simplification as this was thoroughly tested to see that it did not introduce unacceptably large errors in the results of the analysis. With the pattern size and aiming error known it was easy to compute the percentage of bombs within 1,000 feet of the aiming point.

Soon after the data began to become available the analysts did several exploratory analyses, the primary purpose of which was to determine how much sophistication was warranted. As is generally the case in analyzing combat operations, it proved to be desirable to keep the analysis procedures extremely simple; the data from combat operations are rarely sufficiently precise to justify the use of sophisticated or complex mathematical treatment. After rather exhaustive examination of the distribution of the bombs within the pattern it was decided that the most sensible assumption to make was that the bombs were distributed uniformly within the pattern. Mean values of pattern sizes and aiming errors proved to be useful and adequate for the purposes of the analysis. A term that proved to be very useful was the circular probable error (CEP), which was defined as the radius of a circle centred on the assigned aiming point and containing half of the impact points.

As the results of the analyses became available they were published in mimeographed form and distributed to staff agencies and bombardment units. The operating groups and squadrons were ranked in these publications in the order of the magnitude of their bombing errors, with the unit having the largest percentage of its bombs within 1,000 feet of the assigned aiming point listed first. The publication of the rankings of the units soon resulted in the development of a very spirited competition among the units. It is said that the units with the larger errors sent their spies into the camps of the units with smaller errors to learn what the more successful units were doing to improve their bombing. This competition alone undoubtedly resulted in a considerable improvement in the bombing of all units.

The analysts themselves made many suggestions that they hoped would result in improvement. Many of their suggestions were accepted and tried out in combat; most of them did result in improvement in bombing accuracy. Figure below shows the progress of the Eighth Air Force bombing accuracy from 1942 to 1944. It will be noted that the figure has plotted along its horizontal edges the sides of square patterns in feet. The actual patterns on the ground were generally irregular in shape although, as has been noted before, they had been measured on the photographs as rectangles. These rectangular patterns must be converted to squares of equivalent area in order to use the chart. Plotted along the vertical sides of the figure are the CEP's of pattern centres, in feet. The contours in the figure show the percentage of bombs within 1,000 feet of the aiming point. The jagged line, lettered A to G, shows the progress of the Eighth Air Force during the period.

Point A represents an estimate of the performance of the Eighth Air Force in 1942. Data were inadequate for the determination of a reliable figure but the patterns often were over one mile long and it was estimated



Progress of Eighth Air Force Bombing, 1942-44 that something less than 15 percent of the bombs were falling within 1,000 feet of the assigned aiming point.

Point B represents the first reliable record and shows slightly less than 20 percent of the bombs within 1,000 feet of the aiming point. The patterns actually averaged 4,600 feet in length and 2,600 feet in width; the CEP of pattern centres was 1,180 feet. At this time the Eighth Air Force was bombing from formations that consisted of some 18 or more aircraft. For defensive purposes these aircraft did not fly in a horizontal plane but were stacked up vertically with some flying several hundred feet higher than others. One aircraft was designated as the lead aircraft and all others were supposed to hold their positions in the formation. The practice at that time was for the lead bombardier to aim his bombs in such a way that the whole pattern of bombs from the formation would centre about the so-called aiming point. The bombardier in each other aircraft also aimed and released his own bombs. Therefore each bombardier had to select some point on the ground, not necessarily a well-defined point, which in his judgment would result in the whole pattern from the whole formation being compact and hitting the target—a difficult judgment indeed !

The analysts, in thinking about the difficulties facing the individual bombardiers, suggested that it might pay to put the best bombardier in the lead airplane and let him aim the whole pattern of bombs in such a way that it would centre around the assigned aiming point. This would require that no other bombardiers actually sight their bombs; they would simply release their bombs when they saw the bombs begin to fall from the lead aircraft. This still would not result in a simultaneous release of bombs as it was clear that the aircraft flying lower than the lead aircraft would see the bombs falling from the lead aircraft earlier than would the aircraft flying higher than the lead aircraft. However, it was thought that bombing on the leader, as it was called, would result in reducing the size of the patterns. The suggestion was followed and the results are shown at Point C. Slightly more than 25 percent fell within 1,000 feet of the aiming point and the CEP of pattern centres improved slightly, from 1,180 to 1,130 feet. There was a very great improvement in the length of the patterns, dropping from 4,600 to 3,200 feet. There was a slight reduction in the width of patterns from 2,600 to 2,500 feet.

Most of the bombs dropped by the Eighth Air Force in World War II ranged in size from approximately 100 to 1,000 pounds. Each airplane could carry a number of bombs of these sizes. The aircraft were equipped with a mechanism that would release the bombs with a time interval between each two bombs. This time interval could be varied. During the period discussed thus far, the practice of the Air Force was to set the interval between bombs such that the whole train of bombs falling from a single aircraft would string out several hundred feet on the ground, with a considerable distance between bombs. By controlling the length of the train and the interval between bombs it was possible to assure a high probability of getting at least one hit on a target if the train of bombs fell across the target. The analysts observed that with patterns approximately one-half mile on a side the density of bombs within the pattern was relatively small; also, the damage being achieved was undesirably small. They recommended that the interval between bombs be made a minimum, called minimum intervalometer. It was also possible to release all bombs at once, called salvo. The analysts suggested that it might be worthwhile to salvo the bombs. Some commanders tried minimum intervalometer and some tried salvo. The results are shown at point D, with 37 percent within 1,000 feet and the CEP of pattern centres 820 feet. The pattern length dropped from 3,200 to 2,600 feet and the pattern width from 2,500 to 2,200 feet.

The competition among the bombardment units and the stimulus of the improvements resulting from the analysts' suggestions created a great deal of interest throughout the Eighth Air Force in improving bombing accuracy. Suggestions for improvements came from commanders of groups and squadrons, from staff officers, and from air crews themselves. Many things were tried and a great many of them had useful results. There is no full documentation of this period although there was a general improvement in the bombing. A great deal of interest and concern centred around the question of salvo bombing. There was some evidence that occasional salvo releases (simultaneous release of all bombs in the bomb bay) caused the bombs to bump into each other just beneath the aircraft, with the result that on at least a few occasions the bombs exploded and caused the loss of some aircraft. The analysts were asked to determine the difference in effect of minimum intervalometer and salvo. This was done and the results are shown at points E and F. E represents minimum intervalometer and F represents salvo. As can be seen, salvo bombing resulted in somewhat better bombing than minimum intervalometer. The patterns were approximately square, being 1,900 feet on a side with minimum intervalometer and 1,700 feet on a side with salvo bombing. The CEP of pattern centres was 940 feet for minimum intervalometer and 740 feet for salvo, with about 42 percent of the bombs within 1,000 feet for minimum intervalometer and approximately 55 percent for salvo bombing. In spite of this advantage of salvo over minimum intervalometer most commanders refused to allow salvo bombing.

Point G resulted when the Eighth Air Force began to use formations of 12 to 14 aircraft rather than the larger formations. There was an increase in the percentage of bombs within 1,000 feet to something more than 60 percent but, strangely enough, it was from a reduction in the aiming error rather than in pattern size, as can be seen from the vertical line connecting F and G.

One productive suggestion made by the analysts is interesting although I don't know where its results appear on the chart. During the course of the analysis, when the analysts were thinking of practically nothing else but their problem, it occurred to them that the width of the pattern was not controlled by the bombardier. They reasoned that excessively wide patterns were probably due to the failure of the pilots to fly exactly parallel paths while on the bomb run. It is clear that a difference in heading of the aircraft in a single formation of as little as a few degrees would result in the bombs separating by a considerable amount as they travelled from an altitude of 20,000 to 25,000 feet down to the ground. When this was called to the attention of the commanders they assembled their pilots and lectured them on precision formation flying, with the results that the pattern widths were promptly reduced.

To summarize the results of the bombing accuracy analysis it seems fair to say that the efforts of the analysts, and practically everybody else in the Eighth Air Force, resulted in a much greater improvement than the commanding general asked for in his original request, namely, "...twice as many bombs on my targets". The actual improvement was from an estimated figure of less than 15 percent within 1,000 feet of the assigned aiming point to something better than 60 percent.

As the number of analysts in the Eighth Air Force Operations Analysis Section increased it was possible to study many other parts of the bombardment operation. Several analysts spent full time studying the problems connected with the selection of weapons for the targets. They analysed the results of German bombing of British targets and the results of the Allied bombing of targets in Germany and the occupied countries. They also studied the results of test programmes from proving grounds and other places. As a result they began to accumulate a reasonably good body of data relating bomb size, type and fusing with effects on targets. It was possible to determine that the best way to attack certain types of industrial installations was to damage the roof structure sufficiently so that it would fall and achieve the desired damage to the contents of the buildings. In other cases it was desirable to uproot the columns and to upset and disturb the foundations of heavy machines. In the first case it was desirable to have the bombs explode at about the level of the bottom chord of the roof trusses. This would require a fuse that would be initiated by the roofing material and would have a delay of approximately one-hundredth of a second. In the second case it was desirable to have the bombs go through the building and penetrate the earth under the building before exploding. This required a fuse of considerably greater delay. By analysing the effects of weapons on targets on a continuing basis the analysts were able to derive some general principles and to make specific recommendations regarding the selection of weapons for targets.

By studying the enemy tactics it was possible for the analysts to recommend configurations for the formations that would result in the best defence against enemy fighters. From detailed studies of our formations and enemy tactics it was possible for the analysts to devise rules for assigning responsibility among the gunners in a whole formation so as to optimize the defence of the formation as a whole. This necessarily had to be a continuing study as the enemy was quite adept at changing tactics to counter changes in ours.

Other analysts made exhaustive studies of battle damage and losses. It was possible from these studies to determine which parts of the airplane were most vulnerable, where armour should be placed to protect crew members, the need for additional guns in the aircraft, and improved tactics. These studies resulted in a considerable reduction in our combat losses.

Studies were made of the causes of operational losses not from enemy action. Early in the war the Eighth Air Force lost a good many aircraft when they ran out of gasoline and were forced to ditch in the Channel returning from missions. Gasoline consumption studies showed that there were considerable differences in gasoline consumption among the various aircraft in a single formation. The lead aircraft, logically, used less than the others (because all others had to jockey to hold position in the formation) but there was great variation in the amount of gasoline used. This pointed to the need for standardized cruise control procedures. Flight engineers were given specific guidance regarding the settings of the various control mechanisms on the engines. These studies not only resulted in a reduction in the number of aircraft lost by ditching but also reduced the amount of gasoline required by a sufficient factor to enable an increase in the bomb load.

By adding together the improvements resulting from all these studies and many others, it is safe to say that *the overall increase in bombs on target was well over 1,000 percent.*

Following the rather spectacular success of operations analysis in the Eighth Air Force there was a rapid growth of the use of analysts throughout the Air Force during World War II. There were a total of 26 operations analysis sections during World War II, including one with each combat air force, and a total of some 275 operations analysts.

I'd like now to give you brief descriptions of a few additional examples of operations analysis in the US Air Force. During the planning of the first low level bombing attack against the Ploesti oil fields during World War II, there was considerable concern over the possibility of the bombers flying into the cables of barrage balloons that were known to be in use at the target. An analyst at the Fifteenth Air Force made some calculations and predicted that if this happened the balloon cable would break before the aircraft wing would shear off. There was rather dramatic proof that his calculations were correct when aircraft returned from the mission with the imprint of balloon cables in the leading edges of their wings. One pilot didn't realize he had struck a cable until he saw the evidence after he was safely on the ground at his home base.

At one time the Fifteenth Air Force was considering an attack on a target that consisted of underground oil storage tanks. When it received intelligence indicating that the underground tanks were covered by extremely heavy reinforced concrete slabs plus 10 to 15 feet of earth there was some doubt that the bombs would penetrate this barrier and reach the target; accordingly consideration was given to abandoning the plans to attack the target. Again, after making a few calculations, an analyst pointed out that a structure as described that would really protect the underground storage tank would cost much more than the tank plus the oil. It was reasoned that there was no such protection and that the intelligence was deliberately faked in the hope that the attack would not be made. On the basis of this study the attack was made and was quite successful.

The B-29's of the Twentieth Air Force in World War II were plagued by engine fires. An operations analyst made exhaustive studies of the B-29 engine fires in the course of which he discovered that the material used in the automatic fire extinguisher built into the engines actually combined with the magnesium in the engines to intensify the fires rather than to put them out. This resulted in immediate changes in operating procedures and later changes in engine construction, with a large reduction in the damage and losses resulting from engine fires.

Because of its success during World War II, operations research has been continued in the US Air Force. Significant work has been done by operations analysts in recent years in the Air Defence Command. These analysts have studied intensively the problem of the air defence of the Continental United States. One of the problems they have worked on with considerable success is that of the identification of aircraft approaching the east and west coasts of the United States from over the seas. A detailed description of these studies and of their results is not possible due to the security classification of the work; however, it is fair to say that the results of the identification study have been quite as spectacular as much of the World War II work—the identification problem has almost been eliminated.

Operations analysts at the Air Proving Ground Command in recent years have been outstandingly successful in assisting their command to improve its capability to carry out its mission. The major job of the command is to test Air Force equipment, from aircraft to airmen's gloves, to determine operational suitability. The analysts have contributed much to the improvement of the testing operations, introducing scientific design and analysis of experiments, recommending improved data recording and processing, and recommending better selection and training of project officers for tests. Another category of problems on which the analysts have worked has dealt with the management of the command: reduction in manpower, more efficient use of personnel, more efficient organization, more efficient production of reports.

Another field of activity of operations analysts in the postwar Air Force, about which little can be said, is the analysis of the effect of the atomic bomb on the Air Force's mission and its capability to carry out its mission. Operations analysts at the Strategic Air Command, the Special Weapons Centre, and at Headquarters, US Air Force, have been quite successful in this field of activity.

A great deal of the effort of operations analysts assigned to Headquarters, US Air Force, in the postwar years has been directed toward assisting the war planners in devising and reviewing war plans. Not only have the analysts assisted the planners in making quantitative estimates of such things as probable attrition and probable bombing accuracy in possible future campaigns, but major effort has gone into the development of techniques for quantitative planning. Here again, it is fair to say that considerable progress has been made.

In conclusion, it seems worth while to see if a definition of operations research can be derived from the examples I have given you.

Certainly, operations research is, as Herrmann and Magee have stated, research on operations. Also, I think it may be concluded that *operations research is a scientific activity* and therefore is best carried out by people with scientific training. Studies should be quantitative if possible.

Since operations analysts are called upon to study a wide variety of problems and problems of great scope and magnitude it is desirable to have as many of the sciences as practicable represented in an operations research group.

Experience has shown that *such problems as I have described yield to solution most easily when the disciplines of several sciences are brought to bear on them.* Thus operations research is team research.

Operations research is an advisory function; its job is to influence decisions, not to make them. The operations research group must not let itself get trapped into doing ordinary staff work.

If you accept the examples I have given you, as reasonably good examples of operations research, you must then accept my thesis that the simplest possible methods should be used. Operations analysis deals with very real and practical problems, the problems of operating officials with responsibility for decisive action.

BUSINESS AS USUAL

" A strange aura of unreality seems to prevail... More than three months have passed since the Chinese launched their large-scale attack in NEFA and Ladakh. During this period, even more massive than the Chinese attack has been the torrent of words exhorting the people of this country to speed up their defence mobilisation and prepare for the switchover to a war economy . . . . the economic motto for the future is to consist of strong exhortations to the people: produce more, consume less, serve more, waste less, work more, talk less . . . otherwise the prescription is business as usual. "

—*The Capital* (*Calcutta*)

Defence and Development in Less Developed Countries

Charles Wolf

The RAND Corporation*, with which the author is associated and where important investigations in Defence Operations Research have been conducted for several years, organised a significant set of simulated games in military logistics so as to maximise the output in terms of US foreign policy objectives of the investments of the US Government by way of economic and military assistance to underdeveloped countries, particularly those on the Sino-Soviet periphery. Case studies were conducted on the basis of the situations as they obtain in Viet-Nam and Iran; but the research was broadly intended to cover the whole of the South East Asia region, consisting of Burma, India, Indonesia, Korea, Pakistan, Philippines and Viet-Nam†. Here we have reproduced extracts from the author's excellent article published in the latest issue of the Journal of the Operations Research Society of America: minus, of course, its political overtones. We have necessarily to look at problems from our point of view, our aim being to optimise the returns from our investments and those of our friends in our economic and military developments, in terms of our own foreign policy objectives.

BASICALLY, this research was concerned with developing a methodology, and attempting to apply it, to answer the following question: How can military assistance, and the structure of defence forces and budgets in the underdeveloped countries, be modified so as to yield about equivalent military effectiveness, and yet generate sub-

* Santa Monica, California USA.

† Economic statistics were built up in support of the thesis. Below is reproduced one of the significant tables in which *Gd* is defence expenditure, *GNP* the gross national product, *G* the total government expenditure, *Gi* the investment on government account and *I*, the gross investment.

Comparison between Defence Expenditures, National Product, Government Expenditures, and Investment (in percent)

Country	*Gd/GNP*	*Gd/G*	*Gd/I*	*Gd/Gi*
Burma	10	38	53	161
India‡	2	15	14	39
Indonesia	5	40	—	160
Korea	8	35	—	103
Pakistan	4	31	46	82
Philippines	2	15	—	34
Viet-Nam	9	39	81	—
	$\bar{X}$=6 Med 5	$\bar{X}$=30 Med 34	$\bar{X}$=54 Med 53	$\bar{X}$=124 Med 82

‡ These statistics are based on 1959-60 Budget estimates. The Budget estimates of the Government of India for 1963-64 would make a material difference to the ratios worked out here.

stantially improved economic and political side-effects? Underlying the question as formulated was the notion that comparing and evaluating alternative military programmes—both military aid programmes and domestic defence programmes in the underdeveloped countries—requires a multi-dimensional set of performance measures: economic and political, as well as military. For the military performance measures, we relied on war games, comparing outcomes in terms of area occupied in a stipulated time period, or the time required to occupy or defend a stipulated area, casualties, and material and property damage. For the economic performance measures, we compared the effects of alternative military programmes on *operating costs* of the defence establishment, on public *capital formation*, and on *skill formation* through technical military training programmes. And for the political performance measures, we used more or less informed judgment and conjecture, concerning the likely reactions of key political groups and of the public, in the countries under study, to various programme alternatives.

The method we developed had five separate steps:

1. We first drew up alternative programmes for spending the same hypothetical budget. The programmes were designed to be of equal cost, but they were significantly different in their content. One programme, which we might call the 'A' programme, generally stressed fairly large, conventionally-armed and trained forces, following rather closely the lines of recent military aid programmes and force structures in the major underdeveloped recipient countries. The other programme, which we may call 'B', consisted of smaller, more lightly-armed forces, with the savings resulting from these reductions used hypothetically for expanding internal security forces, increasing ground and air mobility, providing additional ground and airfield installations intended to facilitate effective mobilisation of all resources if this should be necessary and, finally, expanding the technical training of military manpower.

In effect, the same budget was hypothetically expended in different ways, under the 'A' and 'B' programmes, for initial equipment (i.e., force improvement); for four-year replacement, operating, and spare-parts costs (i.e., force maintenance); for military construction; and for military training at home and abroad. Standard cost factors were used for equipment, maintenance, and training costs, and generous estimates were made for the construction costs of roads, airfields, and other infrastructures in the countries under study where accurate experience factors were not available.

2. The second step consisted of formulating a more or less credible range of threats, covering differing levels of violence including a larger scale invasion. The threats were sketched out in game scenarios that gave the game players a set of initial conditions to start from, as well as a plausible sequence of hypothetical events through which these conditions might have evolved.

The scenarios projected events several years into the future in order to allow time for the hypothetical 'A' and 'B' programmes to be carried out. While effort was devoted to making these projections sufficiently realistic to motivate the play, detailed 'realism' was not the primary consideration in the design and choice of scenarios. The scenarios were kept at a fairly macroscopic level, and details, to provide a semblance of added realism, were excluded if they were judged to be inessential to the games' purpose. Instead, the primary consideration in formulating the scenarios was their *relevance* to the games' purpose from the standpoint of spanning the differing levels-of-violence needed to test the military performance of the contrasting programmes.

3. Next, the research group, consisting of two teams of senior retired military officers, and a *control* team, conducted the game operations, using the military resources available to them to try to achieve objectives specified in the game scenarios, which were then played *seriatim*. The order-of-battle and logistic support resources were markedly different under the two programmes, and these differences were made known to the

opposite team. In formulating strategy and carrying out operations, our team used, in sequence, the two different force-and-facilities packages represented by the 'A' and 'B' programmes, while the enemy team used his 'best' strategy against each of the alternatives.

4. In the fourth step, we evaluated military performance of the alternative packages primarily in terms of the time, area, and casualty measures mentioned before. Occasionally, we also evaluated military performance in terms of the bargaining position of the respective teams when game hostilities were terminated, and the relative probability that a particular contingency would have broken out at all, depending on whether 'A' or 'B' had been implemented in the pregame years. The evaluation technique used standard planning factors and simple quantitative models where they were applicable (e.g., for assessing air-to-air combat, the effects of interdiction attacks, movement of ground forces etc.), but relied on discussion and experienced judgment where they were not. In comparison with other man-machine simulations, this one placed relatively heavy reliance on men rather than machines.

In conducting and evaluating the game, play was divided into segments or phases, usually based on convenient blocks of time or space. Each phase was played under both of the programme assumptions before either of them was evaluated. The reason for this was to minimize the feedback that would have distorted the results if one programme had been played and evaluated *before* the other was initiated.

It is worth noting that the evaluation was less concerned with the *absolute* outcomes (i.e., who 'won' or 'lost', and by how much ?) than with *comparative* outcomes (i.e., how did programme 'A' perform compared to programme 'B' ?). For reasons that should be intuitively clear, one can have more confidence in the comparative outcomes than in the absolute outcomes of an exercise of this sort, because gross estimating errors in evaluating outcomes are likely to be correlated between the two programmes.

5. Finally, independent of the war games, we conducted a separate evaluation of the economic and political side-effects of the two different, but equal costing programmes, 'A' and 'B'. The purpose of the economic evaluation was to provide a quantitative indication of differences between the two programmes in their effects on economic development in the countries studied. The purpose of the more general political assessment was to get at least a qualitative indication of how the alternative programmes would be likely to be received by key groups and individuals comprising the leadership of these countries.

In making the economic comparisons, as mentioned earlier, we concentrated on differences between the 'A' and 'B' programmes in operating costs and hence in budgetary impact, in the quantity of joint-use civil-military capital facilities constructed during the hypothetical pregame period, and, finally, in the numbers of skilled technicians trained. These economic performance measures are admittedly incomplete and only partly relevant. They leave aside, for example, the question of the *productivity for the civilian economy* of the joint-use capital facilities constructed under the 'A' and 'B' programmes, and hence their effect on economic growth. Similarly, they do not include a measure of the *productivity of technical training*, such as the increase in expected lifetime earnings resulting from the technical training in military schools received under the two programmes, another factor of considerable importance for economic development. Exploration of these additional and more sophisticated economic performance measures would have been possible and certainly relevant for the comparisons being made, at some added cost in time and manpower.

What were the results of these comparisons? Let me first consider the general nature of our findings with respect to comparative military performance. First, we found that, between the two fairly sharply contrasting, but still technically tenable programmes, the differences in military effectiveness were neither large nor uniform. In the three-by-two matrix (i.e., each of the two programmes in each of the three differing levels-of-violence) which summarized our military outcomes for Viet-Nam and Iran, it turned out that one programme produced somewhat better military performance in one contingency at one level-of-violence, while the other programme did somewhat better in another contingency. But, more important, the magnitude of these differences did not appear to be very large in any case. In the aggregate, given a reasonably responsible and informed formulation of the contrasting alternatives, factors that were not affected by the programme changes we made (e.g., the terrain, the size of the existing road net, the distance of a major road junction from the border, the loyalty of the indigenous population, etc.) seemed to dominate most of the factors that were affected by the programme changes (e.g., the size and equipment of forces, and the types of facilities).

It should be emphasized that this latter generalization applies only to the stated assumption that we were comparing alternatives that, though sharply contrasting, still represented responsible and technically tenable changes. This does not imply that changes in forces and facilities do not matter; but rather that, if these changes are judiciously designed, they seem to trade off against each other at fairly reasonable rates, leaving military performance somewhat better in some contingencies and somewhat worse in others, but not drastically different in any contingency. In this sense, the factors which were not affected by the programme changes tended to have a dominant and pervasive effect that made the over-all results more similar than different.

Second, we found that the general technique of trying to design a package of forces and facilities to meet a *range* of threats, rather than a single most-likely threat, made considerable sense. The military posture that performed most effectively in one contingency, for example, in the major invasion contingency, did not prove to be most effective in the lower violence contingencies.

Third, we found that, while sharp improvements in military effectiveness did not seem possible within existing budget levels, there appeared to be opportunities for realizing modest improvements by some specific changes in the force-facilities mix in the underdeveloped countries. Such specific changes related to internal security forces, mobility, reconnaissance, and at least some of the illustrative 'infrastructures.'

With this summary of the military performance and evaluation, what can be said about the economic and political side-effects of the programme alternatives? Not surprisingly, the so-called 'B' programmes (which sacrificed large ground forces in favour of smaller, more mobile, technically trained forces with additional supporting facilities like roads, airfields, harbour and communication facilities) showed clear dominance over the 'A' programme from an economic point of view. Operating costs, and hence budgetary requirements, were lowered, thereby freeing resources for developmental purposes—at least in principle. Contributions to 'social overhead' capital were enhanced under the 'B' programme. And finally, the output of trained manpower was increased because of the additional allowance of military aid funds for this purpose. The significance of these economic findings is clearly enhanced by the fact that the military comparison did *not* exhibit dominance for either programme alternative. In this, as in many other decision-making problems, it seems to make sense to base choice on secondary criteria, when the primary criteria, i.e., in this case, military effectiveness, do not show clear dominance for a particular alternative.

A few general comments on the methods that was developed and used in this work should be added. Probably the first point to note is that many parts of the method were judgmental and imprecise, and the conclusions should be interpreted in this light.

Nevertheless, the type of judgmental evaluation we applied has serious limitations. The most serious is its susceptibility to distortion by human errors. Another is that it is expensive, and 'labour-intensive', requiring a fairly large number of experienced military and non-military analysts. Consequently, it reduces the sensitivity testing that could be done, using many different assumptions about the unknown parameters, if the problem could be computerized to a greater extent.

Probably the strongest merit of the methodology used is that it enabled us to join military, political, and economic factors in the analysis, rather than focusing on only one of these alone. In the analysis of major public policy questions, it is worth paying some price in imprecision to gain the benefits of such systems—analytical, interdisciplinary research.

With this abbreviated description of both the method and the principal findings of our study of less-developed countries, a few observations concerning its relevance to contemporary international affairs should be added. The past fifteen or sixteen years have produced more 'sovereign' nations by a factor of three or four than any similar period in history. The quality or 'mood' accompanying their attainment of independence is complex, hard to categorize, and fluid. The notion of 'protest' against Western societies, which is often stressed in discussions of the subject, is certainly part of the quality of this revolutionary outburst: protest particularly against foreign rule, privilege, and arrogance.

In trying to use, direct, and channelize the energy embodied in this elan of protest, the new countries are faced with a massive array of difficult and often conflicting problems, external and internal; military and non-military. Many of the new countries face real and serious external military threats to their survival. If they concentrate on meeting and deterring the *external* military threat, and allocate their resources accordingly, they may become vulnerable to internal *immobilisme*, stagnation, discontent etc.

The internal and non-military problems that they face are no less, and often are more, hazardous for the survival of the new countries: investment and technical shortages, lack of skilled manpower, population overabundance, natural-resource poverty, traditional and cultural inertia, and so on. If, on the other hand, the new countries concentrate their energy and resources on the internal problems, they can become vulnerable to overt military pressure. India may be cited as a case in point. How to maintain a judicious and dynamic balance between measures to counter both the external and the internal threats, with a view toward survival and vitality, is a dilemma that is especially pertinent in the emergence of the new countries.

There is no easy or formulary answer to finding the proper balance between measures to counter internal and external vulnerabilities. But part of the analytical technique for finding better answers, and modifying them as the environment changes, is suggested by the kind of multidimensional systems analysis that was applied in the military assistance evaluation study. In analysing how to meet *military* vulnerabilities and threats, decisions and allocations can be improved by explicitly considering the differential *non-military* effects of various alternatives. If this concept is applied, it should become possible to derive consequential economic and social benefits from military aid programmes and facilities—benefits that the new countries, or many of the principal ones, critically need to draw on.

OR in Defence

Major General BD Kapur*

The British were the pioneers in developing techniques of operations research in World War II. It was Prof. PMS Blackett† the eminent physicist and mathematician, who led a group of scientists and service officers in introducing radar into the field. By careful analysis the scientists worked out as perfect a plan as possible which covered the location of the radar sets, communications between stations and fighter bases, and even the methods for upkeep and repair. Such a system, which would normally have taken months to work out by trail-and-error method, was achieved in a comparatively short time. This brought quick recognition to the scientific effectiveness of Operations Research and it came to be applied to many other tasks. For example, the mass bombing raids were the result of OR conclusions, whose implementation greatly increased the effectiveness of bombing resources with a smaller percentage of wastage in terms of plans lost etc.

SINCE the last war, operations research has become a well known subject in defence and has spread its activities into civil organizations as well. The UK has over 2,000 OR workers, besides an International Federation of Operations Research Societies with 15 countries as members. In the USA, its growth has been rapid and widespread. It is particularly of interest to note its impact on defence. For the Army, an Operations Research Office has operated since the end of the last war under the administrative control of the John Hopkins University. I visited the OR Office in 1958. In addition to senior scientists of mixed and varied disciplines, retired senior army officers were employed to form an integrated team with the scientists. The ORO team sent a large number of their scientific contingents to the Korean theatre, not only to make a study of the operations but also to examine specific problems of the commanders in the field. One of the studies led to the conclusion that the Air Force should use B-29, a heavy bomber, for close troops support. The Air Force thought it would be very wasteful to use a heavy bomber for a ground control job, but when the OR team pointed out by night, B-29 was the only plane which carried the essential navigating and radar equipment to spot them.

Another OR study led to significant conclusions regarding psychological warfare in Korea. Sending of propaganda and surrender leaflets to North Korea did not prove effective because many of the North Koreans could not read. The OR team worked out new material, illustrated with pictures, and small planes equipped with loud speakers flew over enemy lines talking to soldiers to surrender.

Among the major studies which were carried out in the Korean War by the OR group, was one concerned with the actual operations of war, the effectiveness of weapon systems, the Chinese tactics and such other related problems as logistics and the study of the load on the soldier. These were all based on long painstaking interviews under stress of operations and certainly involved risk of death.

In 1962, I visited the Air Force Operations Analysis Division at the RAND Corporation, California (Research & Development)—

*Chief Controller of Research & Development, Ministry of Defence.

†Prof. Blackett was recently here. He was awarded Nobel Prize in 1948 for Physics.

this has been humorously called as *Research and no Development* because no development work is done there. RAND is the most fascinating organization, I have ever visited. An independent organization with 80 percent of the budget being found from the Air Force, it has a total research staff numbering 730 people. The scope of work in so far as the Air Force is concerned, covers "future air force weapons and equipment and the strategies for their use in both offence and defence.... These include accurate estimates of future weapon developments, future human capabilities and behaviour, as well as the economic costs and the social and political impact of each possible system."

Typical problems tackled by RAND are :—

Design of aircraft wing with superior aerodynamic performance at supersonic speeds.

Design of advanced manned bombers.

Use of beryllium and other materials for reducing the weight of aircraft/missiles.

Physiological effect of weightlessness.

Tactical usefulness of vertical or shot take-off aircraft.

Performance analysis and evaluation of ground effect machines.

It is significant that OR studies at the RAND include research in limited war in South-east Asia.

As in the case of the Air Force, the Navy, who call its OR as "Operations Analysis", farms out its problems to Massachusetts Institute of Technology (MIT).

Perhaps it is not realised by many, including defence officers, that in War the officers are usually too encumbered with their duties of command and administration to be able to analyse operations in order to learn ways of improving in the future. Also, such analysis requires experience in statistical methods, knowledge of the laws of probability and familiarity with the techniques for reaching reasonably valid conclusions from masses of inconclusive data. Scientists acquire this experience as a part of their training. Thus *operations research has a tremendous value in the field of military operations.* The operations study is carried out not only of our own forces but also of the enemy forces. On the other hand, the effectiveness of a weapons system is related to the organization and the tactical concepts employed. Change of weapons can lead to change in organization and change in tactics. For optimum utilization of weapons, therefore, the study has to be integrated and all-embracing.

Having surveyed the growth and importance of research in other countries, it would be of interest to examine its impact on defence in India. Recently at a lecture, a foreign expert stated that a sceptical managing director of a firm defined OR as "an expensive way of inviting insults from inexperienced people half your age". Any chief executive who is not *sold* to the concept of OR cannot have different reactions. However, in the Defence Ministry, we have set up OR organizations, both to work on theoretical aspects with a view to evolving new scientific techniques and also to apply the techniques to problems in the field. The Defence Science Laboratory, Delhi has a section concerned with theoretical studies. It has also assisted in certain limited applied OR studies. In addition to this organization, a Weapons Evaluation Systems Group is concerned with the study of the effectiveness of weapon systems co-related to the tactics of their employment and the organizational structure required for their effective utilization. This group is being enlarged to undertake major studies. OR field teams have also been formed in the Army and Air Force to study specific problems in the operational areas.

In the Armed Services there is a never-ending stream of problems for OR to tackle. The investigations may cover such studies as the anti-aircraft defensive systems, weight load carriage problems of the soldier, accuracy of artillery and of guided missiles and psychological warfare.

There is another aspect on which OR can work and that is on questions such as "what is the best way to use the weapons and equipment we have ?" Or to determine the operational characteristics of a new rifle or any other new weapon.

OR workers are a mixed lot of soldiers and scientists of varied disciplines: Physics, mathematics, statistics, psychology, biology, *even economics*. The training of OR as a team is most essential and can only develop through studies embarked on as a group.

At this juncture, in the present state of the nation when military preparedness has become absolutely vital, OR research can make a major contribution to the national military security. Improving its weapons and weapon systems, developing techniques for their employment and assessing the effectiveness of existing systems, are important studies for OR. Its main aim always is the maximization of the effectiveness of the Forces with available resources and this could cover a wide field for evaluation: efficiency in weapons use, in tactics and in strategy. And thus *the role of operations research may be regarded as vital to the defence of the country.*

PRODUCTIVITY

THE ONLY ANSWER TO THE CHALLENGE FROM CHINA

"....The challenge from China is a major challenge, and it can be met only by continuous and hard work. We cannot face such situations by raising slogans or by cursing or abusing the enemy. If we do only this and not put in the effort that is required, we would only be cheating ourselves. The United States and the Soviet Union are considered to be the two mightiest nations of the world. But behind their physical strength lies the efforts of their people on farms and in factories.... Those who shout loudly against the Chinese without doing anything to meet the challenge seem to me to be suffering from a fear complex. What is needed today is a strong will and hard work.... Defence must be organised on a planned and scientific basis.... What is necessary is that people should be trained in defence. I do not like the idea of hiding ourselves in holes like rabbits."

—*Jawaharlal Nehru*

Mathematics and Management Decisions

Rao Sahib D Srinivasan

The solution of management problems often requires a choice to be made between alternative courses of action. In recent years there has been an increased interest in the use of mathematical aids to making such decisions.

HOW does any one ever manage to take a decision in the real world ? The manager has to face three major problems (1) the multiplicity of factors which may bear on the 'decision' (2) the complexity of relationships subsisting between these factors and (3) the likelihood that this whole delicate structure would be animated less by predictable movements than by random perturbations.

Before a genuine attempt at a decision can be made

(4) the decision-taker has to list himself the factors he believes to be relevant; and he will set aside certain other factors considered irrelevant or because the task of taking them into account is too great. (5) the decision-taker has to reflect on the connection that exists between these factors; some of these may be quite straightforward; there may be a linear relationship between the number of machines and output of a shop; while the connection between output and profit is likely to be quite determinable although *aggressively non-linear*; other relationships much more subtle, involving judgment about imponderables (such as 'morale') that are difficult to measure (6) but the major cause of the trouble is the third difficulty already mentioned : random fluctuations in supply, demand, consistency of a product, and so on.

The decision-maker deals with these by what he calls experience. More specifically he is relying on his brain to estimate and compare probabilities in ways of which he can rarely give a conscious account.

The whole process by which a manager prepares to take a decision is one in which he builds himself a 'model' of the situation in which he finds himself; and 'model' is the word a scientist would use. It makes a useful label for the representation of the situation the decision-taker employs, however formal on the one hand and intuitive on the other.

It should be stressed that no one can take a decision about the *actual situation*; for, he never has enough information. *He really takes a decision about the model of the situation*; and the quality of the decision depends very directly upon the adequacy of the model. An understanding of the situation, which ignores major factors, misconstrues key relationships, or assumes deterministic behaviour in real-life flux of events, is a defective model, which will lead to defective judgments.

Business and industry employ professional model builders to provide models of the situation which will aid management decision. To employ a scientist for this purpose, or a team of professional experts, is to use operational research: the Operational Research team includes scientists of many disciplines (and they may appear to be strange bed-fellows) and the reason for this is the business or the industry which takes the help of the 'OR' team does not want to lose a valuable model in a given situation for want of enough learning to recognise it; and the 'OR' team as a result of cross fertilisation of scientific ideas produces the best model in the end. We also sometimes call 'OR' the science of decision; it should, however, be made clear there is no intention to abrogate the function of management; but, only to make available to management, a rational basis for decisions about matters that are 'decidable' (in the language of the logician).

'Basis for decision' implies that the quantitative aspects are not the whole story in most management decisions. Many other aspects can also enter viz. trade trends, politics, traditions, and other aspects often important and impossible to express in numbers (like 'morale'). It is the responsibility of the management to add these factors to the quantitative basis provided by Operations Analysis. The word 'Operations' in the definition implies to some extent a repetition of some action or some part of an action. The *repetitive* factor in the usual operation is *the factor* that makes it amenable to scientific analysis.

The areas of Operations Research can be summarised under the headings of Probability theory, Symbolic logic, Decision theory, Queueing theory, Linear and Dynamic Programming, Information theory, Game theory, and Monte-Carlo techniques. Mathematical/Statistical tools are extensively employed for various reasons: 'Sampling' guides the researcher in data collection; and statistical inference can tell whether or not an apparent relationship is truly significant or the result of a chance. Statistical relationship tells us whether or not relationships exist, while correlation and regression analysis tells us the extent of relationship. Very recently multiple regression is being used in business in complex problems where many factors and their relationships with each other have to be studied.

Linear programming method reduces the complex mathematics to simple arithmetic pointing the way to maximum profits. LP is also a decision-making tool; for an ideal decision-making situation for management arises under two basic heads: (i) the management should know how much manpower, capital, floor space, equipment, and inventories are available. In other words it should have an accurate measure of its productive resources in terms of demand and (ii) it must have knowledge to assess how much profit or other measurable benefits it could obtain by using a unit of these resources for each available opportunity. Evaluating the benefit or profit that should come from apportioning or allocating available resources to different opportunities, LP provides a 'better way' of handling information used in making decisions.

Dynamic programming is a newly developed mathematical technique which is useful in many types of decision problems. The method of dynamic programming is based on mathematical notion of recursion. The definition of dynamic programming is somewhat vague and it is a technique difficult for a non-mathematician to comprehend; but it is a tool designed for the solution of problems, which are characterised by a common feature namely they involve sequence of decisions in multi-stage processes.

Queueing theory deals with the formation of queues, waiting lines etc. The formation and disappearance of queues requires to be studied as an advanced topic in the field of mathematical probability. It is a little difficult for the non-mathematician to comprehend its niceties. However a person exposed to the concept of a queue is able to recognise the broad areas where this theory could be applied and readily available (or that could be made available) tables can be utilised for the solution of problems—that can adapt itself to the theory and its mathematical models. In these cases complex mathematics is reduced to simple arithmetic.

Mathematics has been turned from the physical world to the affairs of men: economic and military affairs. OR in fact originated with the World War, 1939-1945. The main concern then for the scientists was with 'strategy', and with the application of scientific method to the problem of what to do, and how to do it when faced with an enemy. *An industry presents many features of the battlefield.* For example, a manager (military commander) may wish to stock-pile products (shells) in order to tackle a market (to lay down fire). The size of the stock will basically depend upon the 'stochastics process' of manufacture (armament supply) and the expected rate of supplies (fire). But now there happens to be a competitor (an enemy) with good market research (intelligence service). He plans his attack or forms a strategy based upon the desirability of taking his action when the other side stocks are low. Competitive situations like this are characterised by the fact that two or more individuals are making decisions in situations that involve conflicting interest and in which the outcome is controlled by the decisions of all parties involved. Many conflict situations of the type are present in economic, social, political, industrial, or military problems. When the war time strategic problems appeared, and later industrial problems of strategy, this work proved to be the basis of advanced thinking; and the approach to these problems utilised the 'minimax' principle, which has its fundamental idea the 'minimization of maximum loss.' This led to the development of a branch of mathematics known as game theory.

'stochastic processes'

For a non-mathematician this is a term rather difficult to understand. Yet its field of application is constantly expanding in physical sciences, in engineering, and in industry. Some of the newer applications of probability theory to 'stochastic models' in industry are the storage and service problems. The word stochastic comes from the Greek word, meaning to 'aim'. Our industrial behaviour, once we leave the production line itself, has only one general aim, which it usually attains—more or less, sooner or later. The methods of getting these are the 'Stochastic Processes'. These are the major factors, planning, communicating, maintaining, and so on; above all, stocks and flow. These are the organic features of the factory. If the factory does not really operate as an organic whole, it is because we do not understand the stochastic behaviour of these vital features. 'Stochastic Models' in the hands of OR can provide this understanding.

simulation and monte-carlo method

This technique with great promise for research has grown rapidly in recent years largely because of the availability of electronic computers. It was greatly used in inventory systems, production scheduling system, and waiting line problems. Recently the technique is used to 'simulate' a business in a manner which will lead to a new understanding of the functional relationships involved. *Simulation is essentially a working analogy*; analogy means similarity of properties or relations without identity. When we are able to visualise analogous systems, measurements/observations in one may be used to predict the reaction of others. The technique is to take an established 'model' and the 'model' is operated/simulated by OR much as a game of bridge is simulated when all the hands are spread out on the table, and a 'model' game is played with all the risks and chances taken into account. This is really a scientific procedure, because the model is in action, although real life element of chance is now being introduced by a randomising technique instead of through statistics; this technique is known by the facetious name Monte-Carlo method, a most useful technique which can be put into use by hand (and in really vast problems, by an electronic computer). Its technique can be understood by people who do not understand mathematics. If they can see the model working and producing its answers they can obtain a real insight into the organic flow the model depicts. Hence it is a great advantage.

cybernetics

Like the game theory the Information or Communication theory is a product of the Second World War. The theory owes its origin to Norbert Weiner; and his basic contribution was to recognise the Communication of information as a problem in statistics; and it is his belief (his Cybernetics) "that any organisation is held together by the possession of means for the acquisition of the use, retention, transmission of information". The information theory has therefore profound implications for all who handle information i. e., every one, including machines. This takes us to the subject of automation. The 'Cybernetic model' machine will improve industrial control beyond recognition, because it will be perfectly adapted to its task, without strain, without fatigue, without boredom, and release men from these tedious tasks for better things. Cybernetics is not a model for OR in industry. It is, however, a new scientific and industrial target of immense potential. *Cybernetics will join with atomic energy in reshaping the world*, and OR, industry's best tool and Cybernetics' only mechanism, for working towards this future: OR is thus being crystallised into Cybernetics: and their offspring are the 'Systems Analysis, and Systems Engineering'.

For the purpose of OR, '*system*' *means an organised working total*, a group of interdependent elements united by a common objective. But OR is NOT Systems Engineering. Systems Engineering is the art and science by which nature, men, machines are arranged to form an assemblage united by an interaction and in dependence, to create products from nature materials and energy sources. Systems Engineering aims at strategic objective analysis, judgment, synthesis, and rational design of a complete and usually complex system. Operations Research is concerned with tactical objective analysis of present and future operations, providing quantitative finding for management decisions.

The American approach to Operations Research differs significantly from the British. The experts from the United States were concerned with the elaboration of its technique, and with the study of large working systems with their ramifications, than with the practical case studies and applications in which British are interested. Operation researchers in India have a much bigger chance to penetrate in our industries than their counterparts either in the USA or the UK. OR men in India have a more important job to do, provided they do not flourish in the mystiques too far. Certainly much of what is talked, and occasionally practised under the name of *Scientific Management suffers from wooliness of thinking* and a preference of abstract nouns rather than quantities. *One incidental role of Operational Research in India is to thin out the rosy verbal flog* and stimulate hard thinking as well as offering its own, more recondite mathematical approach to the functioning of productive organisations.

The annual rate of growth in terms of real product over the years of the last three plans is approximately only 1 percent, India, standing perhaps the last of the countries, if their progress is also listed. This is *an intolerable state of affairs. We have within this country technical brains, managerial experience, and skilled craftsmen that are second to none.* We have the power to double our rate of growth. To achieve this goal, however, three things are needed: (1) a proper Government plan for efficiency and growth. (Our five-year plans approach the definition). (2) a genuine determination by management to set its house in order. (3) a readiness on the part of organised labour to eliminate all forms of restrictive practices, given reasonable safeguards.

Production with Optimum Decisions*

DV Gulati†

Every production process can conceptually be thought of as certain resources entering into a process, and then resulting in some products which in turn are associated with profits. Optimum utilization of available resources coupled with sound decisions about the type and quantity of products result in increased profits. Operations Research methodology has made significant contributions in the field of decision making. Such decisions may concern optimum machine utilization, product mix, service facilities in relation to waiting, machine scheduling, inventory, etc. Here, the author has given the outlines of a major OR technique: Linear Programming, illustrating how it helped in optimising output and profits in an Indian foundry.

LINEAR programming enables gains being optimised, particularly in concerns performing multiple activities with limited resources. Based on the assumption of linearity between the activities and resources, input-output co-efficients are worked out, which are then used to set up various constraints and an objective function. Constraints are expressions in the form of mathematical linear inequalities. Linear Programming requires equalities rather than inequalities. The inequalities are, therefore, transformed into equalities, by adding non-negative numbers, which in the language of linear programming are known as "slack variables". An inequality representing a constraint $a_1X_1+a_2X_2+a_3X_3 \leqslant b$, on adding a slack variable 'd' will read as

$$a_1x_1+a_2x_2+a_3x_3+d=b$$

Assuming the capacity of a machine as 100 man-hours and the production programme of the items (A,B,C) taking 92 hours in all at the respective M/C input per unit in man-hours, the balance of (100-92=) 8 man-hours is nothing but slack. Having known the constraints and the objective function, a mathematical computing technique (Simplex Method) is used to get the solution. Based on these ideas, a production programming problem of a foundry was tackled.

This foundry caters to the needs of some of the leading industrial undertakings in the country. Before the study was undertaken, the foundry was manufacturing about 500 different types of castings varying in weight from 1 to 3000 lbs. The various resources going into the making of these castings were calculated in detail.

The foundry had a network of 13 cranes spread over heavy, fly-wheel and medium sections and it was considered that ample crane capacity was available. Oven capacity was also not considered to be a bottleneck.

The objective was to formulate a policy for management for taking decisions regarding acceptance of manufacturing orders or in simple words, how best to use the resources and the process, to classify and select the products to be manufactured in order to maximise the profits. In consultation with the management, the castings they were manufacturing, were classified into six groups (X_1 to X_6). The input-output ratios of the various restricted resources were determined in conformity with the statistical principles.

* The author is indebted to the Chief Adviser, Factories, for permitting the use of work done at the Productivity Centre, Bombay.

† Productivity Officer, Office of the Chief Adviser, Factories, New Delhi.

TABLE OF INPUT RATIOS

Serial Number	Products Description	X_1	X_2	X_3	X_4	X_5	X_6
1.	Molten Metal Input Ratio (lbs)	37.30	203	356	519	1179	1982
2.	Moulding Input Ratio (Man-hrs)	1.63	4.41	0.91	5.55	13.40	16.88
3.	Core Making Input Ratio (man-hours)	0.30	1.32	0.25	6.39	16.00	19.00
4.	Input Ratio of area for light castings (sq. ft.)	2.37					
5.	Input Ratio of area for Medium castings (sq. ft.)		5.91				
6.	Input Ratio of area for Fly-wheel castings (sq. ft.)			25.00			
7.	Input Ratios of area for Heavy castings (sq. ft.)				16.71	33.29	50.49

The above input-ratios were used to develop the following effective constraints :—

Molten Metal Capacity

(A) $37.3X_1 + 203X_2 + 356X_3 + 519X_4 + 1179X_5 + 1982X_6 \leqslant 91{,}200$

Moulding Capacity

(B) $1.63X_1 + 4.41X_2 + 0.91X_3 + 5.85X_4 + 13.40X_5 + 16.88_6X_6 \leqslant 730$

Core Making Capacity

(C) $0.30X_1 + 1.32X_2 + 0.25X_3 + 6.39X_4 + 16.00X_5 + 19.00X_6 \leqslant 250$

Light Section Area

(D) $2.37X_1 \leqslant 2700$

Medium Section Area

(E) $250X_2 + 630$

Fly-wheel Section

(F) $25.0X_3 + 1588$

Heavy Section Area

(G) $16.71X_4 + 33.29X_5 + 50.49X_6 \leqslant 4410$

The following table gives the per unit profit figures which were used to develop the objective function. $R = 1.86X_1 + 10.15X_2 + 28.15X_3 + 32.69X_4 + 88.42X_5 + 148.65X_6$

Product	X_1	X_2	X_3	X_4	X_5	X_6
Per Unit Profit (Rs.)	1.86	10.15	28.15	32.69	88.42	148.65

Slack variables were added to the constraints (A) to (G) and then these linear equalities, alongwith the objective function were cast into a simplex table and solved.

The optimum solution showed that by producing 12 castings of X_6, 64 of X_3 and 105 of X_2 (not requiring cores) and 75 of X_1 (moulds prepared or machine) would increase the daily profits by 141 percent, leaving a slack of 22570 lbs. of metal and 6335 sq. ft. of working area. This was however, not a practicable solution, from the management's point of view, because of market limitations for X_3 and X_6.

In consultation with the management X_6, X_5 and X_3 were limited to 2, 3 and 50 units respectively. With the balance resources, new constraints were developed and simplex technique used to evaluate X_1 X_2 and X_4, maximising the profits. The following programme was then obtained :—

$X_1=161$ (including not requiring cores and M/C moulded)	$X_4=0$
$X_2=107$	$X_5=3$
$X_3=50$	$X_6=2$

This arrangement would increase the daily profits by 68 percent, leaving a slack of 38,226 lbs of metal and 6,865 sq. ft. of working area.

Considering the availability of metal, it was decided to augment the profits further by manufacturing the most common products, i.e., X_1, X_2 and X_4. Fresh equations were developed and solved, which resulted in the following final programme.

$X_1=165$ (including not requiring cores and M/C moulded)	$X_4=67$
$X_2=107$	$X_5=3$
$X_3=50$	$X_6=2$

This indicated an increase in profits by 188 percent and employment of a few more core and mould makers.

Based on the above manufacturing programme, management could now formulate a definite policy for deciding about the acceptance of manufacturing orders from their consumers. The use of linear programming can also be made in many other situations where the aim is to combine activities and resources in such a way as to optimise the overall effectiveness, e.g. 1. Job assignment 2. Transportation 3. Purchasing etc. Experience shows that highly beneficial results are obtained, if the technique is used to tackle problems of wide magnitude. Similarly, there are many other effective techniques of Operations Research which enable management to take sound decisions in complex situations, to bring about overall effectiveness, which is the essence of productivity.

"What your work would be—I do not know how much mercantile experience you have really had. You have been loafing a bit, so far—am I right?......I must beg one thing of you, my dear chap. In your position as brother of the head of the house, you will actually have a superior position to the others; but I do not need to tell you that you will impress them far more by behaving like their equal and doing your duty, than you will by making use of privileges and taking liberties. Are you willing to keep office hours and observe appearances?...."

from Buddenbrooks

Experimental Designs in Operations Research

Iyer & Ray*

In view of the rapid scientific advances in various fields, it is necessary that industrial techniques and methods should be modified from time to time in order to put industry on a competitive basis. This would require constant operations research at factory level on methods of production, materials and machines, efficiency of labour, management, etc. Each of these is affected by several factors at various stages of production. To obtain information on these points a large number of trials is required. This would take a good deal of time, and by the time the results are available for developmental purposes, there is danger that they might become obsolete. This situation can be avoided and the cost of experiment can be kept at a reasonably low level by using experimental designs recently developed for biological and industrial experiments. Such designs have the advantage that the errors will be low. In this note we give some of the important designs which can be profitably used for experiments in operations research in industry specially at pilot plant investigation stage.

THE principle of this design is that the error of the experiments can be reduced by arranging the experiments on the same machine so as to have all the treatments combination tried on all the machines and in all the phases of the experiments. This is achieved by using a number of orthogonal squares and forming Graeco Latin Squares. Two orthogonal squares involving five treatments each are given here. By superimposing these two squares we get a Graeco Latin Square in which all the Greek and Latin letters occur along both rows and columns.

Such designs have been used for many types of experiments in industry.

THE LATIN SQUARE

A	B	C	D	E
B	C	D	E	A
C	D	E	A	B
D	E	A	B	C
E	A	B	C	D

Square 1

α	β	γ	δ	ε
δ	ε	α	β	γ
β	γ	δ	ε	α
ε	α	β	γ	δ
γ	δ	ε	α	β

Square 2

Aα	Bβ	Cγ	Dδ	Eε
Bδ	Cε	Dα	Eβ	Aγ
Cβ	Dγ	Eδ	Aε	Bα
Dε	Eα	Aβ	Bγ	Cδ
Eγ	Aδ	Bε	Cγ	Dβ

Graeco Latin Square

Balanced Incomplete Block Designs

If the number of treatments is large it may not be possible to complete the trials in a plant in a reasonable time. In such cases, experimental error can be reduced by using a balanced incomplete block design. In this design every pair of treatments is

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tried in a number of blocks which is the same for all possible pairs. For four treatments T_1, T_2, T_3 and T_4 a design is given below. In this design it will be noted that any pair of treatments, say T_1 & T_2, occurs in two plants out of four.

1st Plant	2nd Plant	3rd Plant	4th Plant
T_1	T_1	T_1	T_2
T_2	T_2	T_3	T_3
T_3	T_4	T_4	T_4

YOUDEN SQUARE

The Latin square would require the number of treatments to be the same as the number of subjects or plants to be investigated. In case where it is not possible, we can use a modification of the Latin square. A Youden square resembles a Latin square with one or more rows missing and retains the property of a Latin square by eliminating some trends which would otherwise inflate the estimate of experimental error. The simplest of these is obtained by omitting one row or one column of a Latin square.

Fractional Factorial Experiments

In many industrial experiments a complete investigation of some of the unfavourable levels for one or more factors is not of practical interest. Besides, we may be more interested in obtaining the trends at different levels. In such cases the principle of fractional experimentation enables us to reduce the cost of labour of experimentation by concentrating on important combinations, which can be used *for obtaining the optimum* level by interpolation.*

*The details of these designs and their analysis have been given in the book "On the design and analysis of Industrial Experiment" by Davies.

WORK STUDY OF BUCKINGHAM PALACE !

In his televised broadcast from Guildhall on November 14, which had been recorded earlier Prince Philip said: 'To emphasise the vital importance we attach to the idea behind the National Productivity Year the Queen has arranged for a Work Study investigation into every department of her household.'

The investigation will begin early next year. It will affect Windsor Castle as well as Buckingham Palace and extend to such departments as the Master of the Household, the Crown Equerry, the Lord Chamberlain, and the offices of the Private Secretary and the Queen's Treasurer. An undertaking has been given that no one will lose his job, but that any reduction decided upon will be effected through not filling vacancies as they arise.

Computers and Operational Research

Stafford Beer*

THE area of contact between computer technology and operational research is very large. We should, however, beware of getting bogged down in endless discussion of computer activities on mathematical programming. I will risk saying that providing genuinely *operational* research can succeed in mapping real life on to the matrices of the mathematicians, and the multifarious aims of an industrial activity on to their optimizing functional, then the computer calculation is a relatively trivial problem. It is a glib supposition that wherever computers are at work, there OR is done. Unfortunately this is far from true; and many computer installations are less worthwhile than they might be for want of an OR approach to the problems with which they deal. We should of course study the more profound relationship between computers and OR : how is life made different for each of these fields because of the existence of the other ?

What happens to OR because there are computers ? The answer to this is certainly *not* that the OR scientist can now undertake a vast amount of arithmetic that he would not otherwise have been able to tackle. For one thing, he is often better off without this arithmetic anyway—*calculation is no substitute for cerebration.* More importantly, the OR man is the last person who should place the emphasis on the arithmetic of computers, and the first to *consider them as engines of logic.* A computer is an undifferentiated set of logical relationships in which OR can mirror the structure of its real-life problems.

This is what simulation really does. It is not enough to think of simulation as a statistical procedure by which runs of sampled events are constructed experimentally. In their paper, Owen and Tocher bring out this *structural* element of simulation. Concentration on this feature has resulted in a General Simulation Programme, a programme whose generality derives from an adequate treatment of form as distinct from content. This is real OR, of a kind which becomes practicable because of and through the computer.

A programme of this kind provides a language by which to *talk 'simulation' with the computer*, and it is not difficult to translate an actual situation into this language. But the programmer does have to learn the conventions : a kind of autocode is involved. As with any other computer application, however, the nearer the code can be brought to conventional language, the more readily can the programme be exploited.

*United Steel Companies, Sheffield, UK.

"....I was in charge of an analogue computer for some time, one of my students told me. I am still appalled by the number of businessmen who believe that the machine was in charge of me."

—Peter Drucker

New Methods in Mathematical Programming

George B Dantzig*

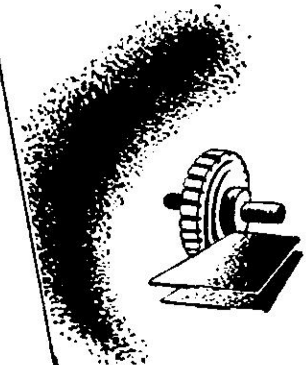
IT is a real mystery that a field that is so full of applications to everyday problems had created so little scientific interest in the pre-war period. *Historically, planning in this world of uncertainty has traditionally endowed those in authority with the 'wisdom' to decide among undecidables.* Curiously the less clearly the objectives were stated, the more impressive it seems were the means chosen by those in authority to carry out these objectives. Indeed, the observing have discovered that the means somehow became the objectives. However, in the last twenty to thirty years many of the obstacles that made planning an authoritarian task rather than a scientific task have been overcome. These are first, the formulation of objectives and familiar relationships in mathematical terms; second, the development of reporting systems and the systematizing of statistical information so that basic data was at hand; third, techniques for solutions of the mathematical models were developed (i.e. theory, numerical analysis, electronic computers). As a result in the last decade operations research —and in particular linear programming—has become possible on an ever-increasing scale. I do not believe there will be any slacking of effort. Indeed, I believe *students of the art of decision-making are about to witness the start of an explosion.*

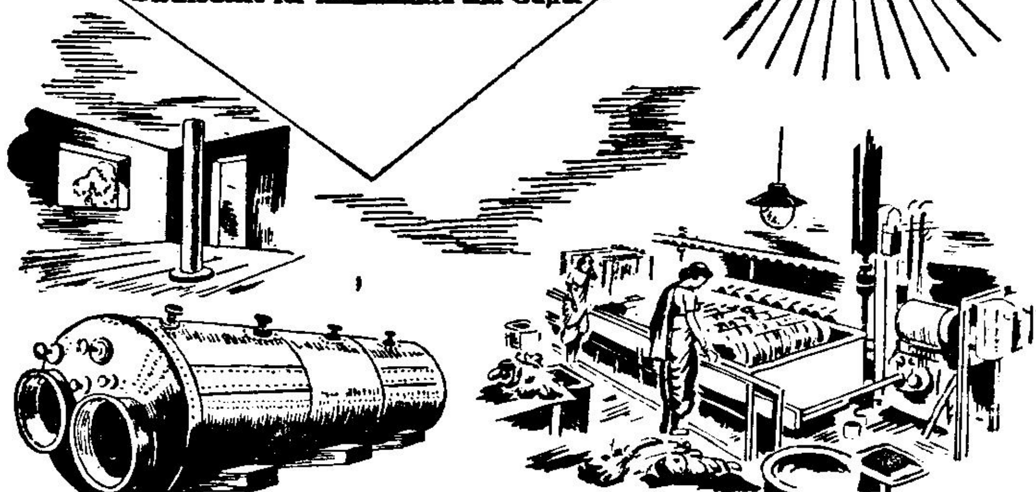
To be precise, the period 1947 to 1958 has been marked by intense development of ideas built closely around the central problem of linear programming. In the last two years these ideas have been extended to a broad area that goes by the title mathematical programming. In the next few years we can expect each of the fields—*network theory, integer programming, non-linear programming, programming under uncertainty*—to become major research areas.

*Rand Corporation, California

What is success? It is an inner, indescribable force, resourcefulness, power of vision; a consciousness that I am, by my mere existence, exerting pressure on the movement of life about me. It is my belief in the adaptability of life to my own ends. Fortune and success lie with ourselves. We must hold them firmly—deep within us. For as soon as something begins to slip, to relax, to get tired, within us, then everything without us will rebel and struggle to withdraw from our influence.

—*Thomas Mann*





Linear Programming and Game Theory

Dorfman & Samuelson

At any time, an economy has at its disposal given quantities of various factors of production and a number of tasks to which those factors can be devoted. These factors of production can be allocated to the different tasks, generally, in a large number of different ways, and the results will vary. There is no more frequent problem in economic analysis than the inquiry into the characteristics of the 'best' allocation in situations of this kind.

WE have just outlined a rudimentary problem in welfare economics or in the theory of production. It is also a problem in *linear* economics, the word 'linear' being introduced to call attention to the fact that the basic restrictions in the problem take the form of the simplest of all mathematical functions. In this case the restrictions state that the total amount of any factor devoted to all tasks must not exceed the total amount available; mathematically each restriction is a simple sum.

This illustration suggests that many familiar problems in economics fall within the scope of linear economics. Like Moliere's M Jourdain and his prose, economists have been doing linear economics for more than forty years without being conscious of it. Until recently economists have passed over the linear aspects of their problems as obvious, trivial, and uninteresting. But in the last decade the stone which the builders rejected has become the headstone of the corner. New methods of analysis have been developed that depend heavily on the linear characteristics of economic problems and, indeed, accentuate them. The most flourishing of these methods are linear programming, input-output analysis, and game theory.

These three branches of linear economics originated separately and only gradually grew together. The first to be developed was game theory, the central theorem of which was announced by John von Neumann in 1928. The main impact of game theory on economics was delayed, however, until the publication of *Theory of Games and Economic Behaviour* in 1944. Briefly stated, the theory of games rests on the notion that there is a close analogy between parlour games of skill, on the one hand, and conflict situations in economic, political, and military life, on the other. In any of these situations there are a number of participants with incompatible objectives, and the extent to which each participant attains his objective depends upon what all the participants do. The problem faced by each participant is to lay his plans so as to take account of the actions of his opponents, each of whom, of course, is laying his own plans so as to take account of the first participant's actions. Thus each participant must surmise what each of his opponents will expect him to do and how these opponents will react to these expectations.

It was von Neumann's remarkable achievement to demonstrate that something definite can be said about such a welter of cross-purposes and psychological interactions. He showed that under certain assumptions, which we shall have to examine, each participant can act so as to be guaranteed at least a certain minimum gain (or maximum loss). When each participant acts so as to secure his minimum guaranteed return, then he prevents his opponents from attaining any more than their minimum guaranteeable gains. Thus the minimum gains become the actual gains, and the actions and returns for all participants are determinate.

The implications of this theory for economics are evident. It holds out the hope of banishing oligopolistic indeterminacy from economic situations in which von Neumann's assumptions are satisfied. The military implications are also evident. And, it turns out, there are important implications for statistical theory as well. Since 1944 the development of these three fields of application of game theory has gone forward actively.

Input-output analysis was the second of the three branches of linear economics to appear. Leontief published the first clear statement of the method in 1936 and a full exposition in 1941. Input-output analysis is based on the idea that a very considerable proportion of the effort of a modern economy is devoted to the production of intermediate goods, and the output of intermediate goods is closely linked to the output of final products. A change in the output of any final product (say automobiles) implies changes in the outputs of the intermediate goods (copper, glass, steel, etc., including automobiles) used in producing that final product and, indeed, in producing goods used in producing that final product, and so on.

In its original version, input-output analysis dealt with an entirely closed economic system—one in which all goods were intermediate goods, consumables being regarded as the intermediate goods needed in the production of personal services. Equilibrium in such a system exists when the outputs of the various products are in balance in the sense that just enough of each is produced to meet the input requirements of all the others. The specification of this balance and its pricing implications was Leontief's first objective.

Beginning with World War II, interest has shifted to a different view of Leontief's model. In this view final demand is regarded as being exogenously determined, and input-output analysis is used to find levels of activity in the various sectors of the economy consistent with the specified pattern of final demand. For example, Cornfield, Evans, and Hoffenberg have computed employment levels in the various sectors and, hence, total employment consequent upon a presumed pattern of final demand, and Leontief has estimated the extent to which fluctuations in foreign trade influenced activity in various domestic sectors. The input-output model, obviously, lends itself well to mobilization planning and planning for economic development.

The last of the three branches of linear economics to originate was linear programming. Linear programming was developed by George B Dantzig in 1947 as a technique for planning the diversified activities of the US Air Force. The problem solved by Dantzig has important similarities to the one studied by Leontief. In any operating period the Air Force has certain goals to achieve, and its various activities of procurement, recruitment, maintenance, training etc., are intended to serve those goals. The relationship between goals and activities in an Air Force plan is analogous to the relationship between final products and industrial-sector outputs in Leontief's model; in each case there is an end-means connection. The novelty in Dantzig's problem arises from the fact that in Leontief's scheme there is only a single set of sector output levels that is consistent with a specified pattern of final products, while in Air Force planning, or in planning for any similar organization, there are generally found to be several different plans that fulfil the goals. Thus a criterion is needed for deciding which of these satisfactory plans is best, and a procedure is needed for actually finding the best plan.

This problem is an instance of the kind of optimising that has long been familiar to economics. Traditionally it is solved by setting up a production function and determining that arrangement of production which yields the desired outputs at lowest cost or which conforms to some other criterion of superiority. This approach cannot be applied to the Air Force, or to any other organization made up of numerous components, because it is impossible to write down a global production function relating the final products to the original inputs. Instead it is necessary to consider a number (perhaps large) of interconnected partial production functions, one for each type of activity in the organization. The technique of linear programming is designed to handle this type of problem.

The solution of the linear programming problem for the Air Force stimulated two lines of development. First was the application of the technique to managerial planning in other contexts. A group at the Carnegie Institute of Technology took the lead in this direction. Second, a number of economists, with TC Koopmans perhaps in the forefront, began exploring the implications of the new approach for economic theory generally. We regard linear programming as a flexible and powerful tool of economic analysis and hope that the applications to be presented below justify our position.

These are the three major branches of linear economics. The relationship between input-output analysis and linear programming is evident. Input-output analysis may be thought of as a special case of linear programming in which there is no scope for choice once the desired pattern of final outputs has been determined.

The connection of these two with game theory is more obscure. Indeed, with the sketches given of the problems handled by the three techniques, it may seem surprising that there is any relationship, and, as a matter of history, the connection was not perceived for some time after the individual problems and their solutions were well known. The connection resides in the fact that the mathematical structures of linear programming and of game theory are practically identical. Is this a pure coincidence? Probably it does not pay to search for an economic interpretation. It may make the connection seem less mysterious if we put it this way: Both game theory and linear programming are applications of the same branch of mathematics—the analysis of linear inequalities—a branch which has many other applications as well, both in and out of economics. The connection is analogous with the connection between the growth of investments at compound interest and Malthusian population theory.

"....It is all a matter of population density: the Irish are 100 to the square mile; the English about 700... My point is this: really, modern industry, the automation which we dare not install here, does not call for millions of machine-slaves. Eire (Ireland) is starting her industrial revolution at a time when the machines can enrich all while enslaving none. Whereas to us it means the spectre of mass unemployment and the dreadful stigma 'redundant'."

—*Edward Hyams in the Irish Diary*

Linear Programming

MV Gopalan*

AN industry may pose a production problem involving a series of current and sequential operations with either fixed or alternative inputs and limiting capacities. Linear Programming is a method of planning wherein an objective function is either minimised or maximised satisfying also the several restrictions posed by the problem. Linear Programming deals with that class of programming problems for which all relations among the variables are linear. The relations must be linear both in the constraints and in the function to be optimised. The general linear programming problem can be described as follows:

Given a set of *n* linear inequalities or equations in *r* variables, it is desired to find non-negative values of these variables which will satisfy the constraints and maximise or minimise some linear function of the variables. To speak in terms of symbols, we have *n* linear inequalities or equations in *r* variables of the form

$$a_{i1} x_1 + a_{i2} x_2 + \ldots a_{ir} x_r \lesseqgtr b_i; \quad i = 1, 2, \ldots, n;$$

We are to find the values of the variables $x_j \geqslant 0$, satisfying the above conditions and maximising or minimising a linear function of the form

$$z = c_1 x_1 + \ldots + c_r x_r$$

The simplex method is an algebraic procedure which through a series of repetitive operations progressively approaches and ultimately reaches an optimum solution. Many kinds of problems may be placed into a framework of Linear Programming. Methods less tedious than the simplex method have also been developed. It must be noted that *the linear programming model is only an approximate representation of the real world.* The model should not be utilised where it is inapplicable. In industrial applications, the transportation method has been applied to a greater extent than the simplex method.

The theory of Markov Processes has been applied to tackle problems in Operations Research (for example, in the theory of queues). Statistical Decision theory plays a key role in determining optimal procedures with allowances for uncertainties in nature. The Mathematical theory of Information developed by Shannon and N Wiener has been applied to many a problem of engineering importance.

*Indian Institute of Technology, Bombay.

". . . time's flight is fabulous: yet method teaches you to save it . . ."
—*Dr. Fanst*

The Linear Programming and Economic Analysis

Samuelson & Solow

Is linear programming something new or just a new name for old methods ? Does it help in analyzing economic and business problems ? Can it solve practical problems ? The RAND Corporation, a private research corporation, whose primary contract is with the United States Air Force, has found linear programming expedient in practical problems and fruitful in analytic procedure. In part this is simply the result of the fact that much of standard economic analysis is linear programming.

IN 1951, RAND and the Cowles Foundation for Research in Economics jointly sponsored *Activity Analysis of Production and Allocation*, a book that dealt with the mathematical and computational features of linear programming. The thesis presented here emphasising the economic interpretation of linear programming has also been prepared under the auspices of RAND*.

Linear programming has been one of the most important postwar developments in economic theory. Its growth has been particularly rapid, thanks to the joint efforts of mathematicians, business and defence administrators, statisticians, and economists. Yet the economist who wants to learn how linear programming is related to traditional economic theory can nowhere find a comprehensive treatment of its many facets. The thesis on which the authors have worked gives the economist, who knows existing economic theory but who does not pretend to be an accomplished mathematician, a broad introduction to the theory of linear programming, or, as it is sometimes called, activity analysis. It hopes also to be useful to the practitioner of managerial economics, and possibly to provide the growing body of mathematicians interested in programming problems with insights into the vast body of modern economic theory.

When asked by the RAND Corporation to undertake this work, we agreed to avoid higher mathematics. We planned to stress the economic aspects of the problem, paying attention to practical problems of computation and giving important concrete applications but laying no stress on them. So vast has the theory become that we have had to be selective, reluctantly deciding to omit many interesting topics and applications. Thus, we have not dealt with the important role of linear-programming concepts in statistical decision theory.

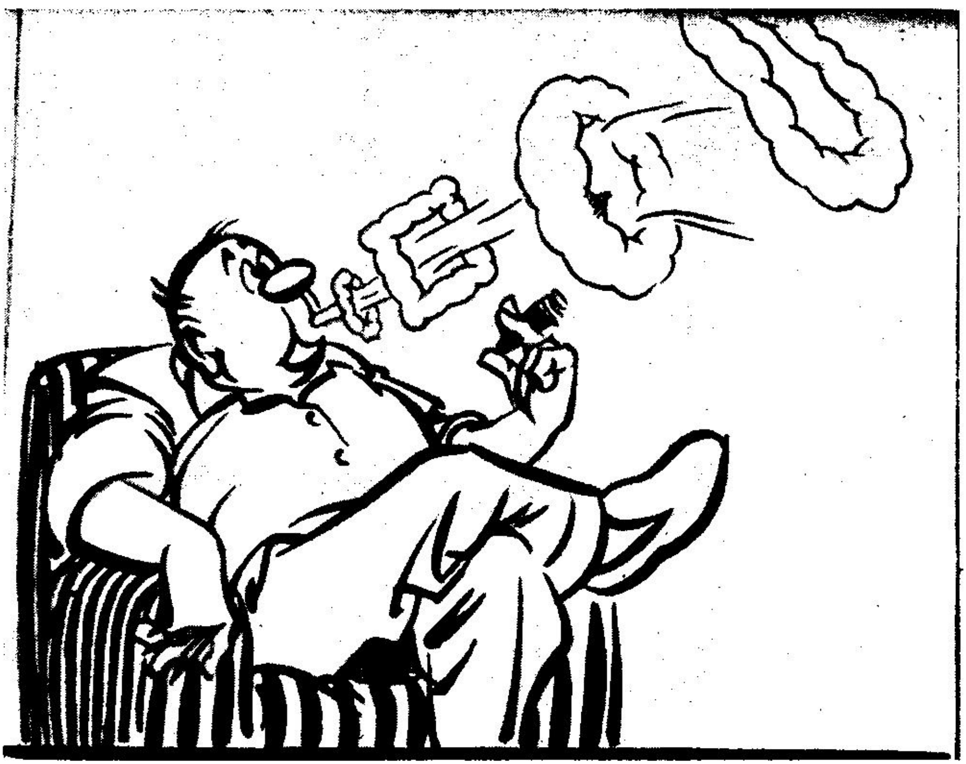
On the other hand, we have gone into the extensive interrelations between the celebrated von Neumann theory of games and linear programming, particularly since every economist will want to know the interrelations between game theory and traditional economic theories of duopoly and bilateral monopoly. And modern economists will be interested in the interrelations between linear programming and modern welfare economics

*For a fuller exposition of the theory please see authors' book on *Linear Programming & Economic Analysis* published by McGraw-Hill Book Company, Inc., New York.

and the insights that linear programming gives into the determinateness of Walrasian equilibrium—as perfected by the recent works of K Arrow, G Debreu, LW McKenzie, and others.

Linear Programming & Economic Analysis can also serve as an expository introduction to the student interested in the Leontief theory of input-output, which has played so important a role in the last twenty years. Similarly, we have treated extensively problems of dynamic linear programming, not only because of their intrinsic interest but also because of their vital connections with the economist's theory of capital—that most difficult field of modern economic theory. Had we more space and time at our disposal we might have added some material summarizing the related 'dynamic programming' methods of Richard Bellman, also developed at RAND*.

* These are extracts taken from the foreword and the preface to the authors' work on **Linear Programming and Economic Analysis,** printed here with a view to create interest among readers on the intriguing connection that has developed between these two disciplines, not popularly associated together except among academicians.



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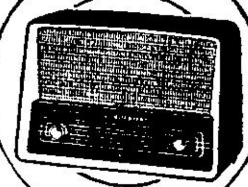

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Application of Dynamic Programming to Maximum Stock Capacity

E Ventura*

THE problem raised was initially to find the optimum capacity level of a warehouse. This warehouse is used as a starting-point for the dispatch to customers and receives its supplies from a factory, located several hundred miles away.

In order to find the optimum capacity level of the warehouse (strategical decision) rules must first be established for the inventory policy itself (tactical decision).

The cost function includes: The cost of transportation by the usual way (waterways) from the factory to the warehouse; a known cost of depletion (stock-out) which is the cost of transportation by the abnormal and costly way (railroads) from the factory to the warehouse; a cost for stocks exceeding the capacity level; handling cost; financial inventory costs.

The cost function is to be minimized through the choice of the decision variable, i.e., the quantity C_i which is requested from the waterways companies at the beginning of month i.

The state variable is the inventory level, S_i, at the end of the preceding month.

The random variables are of two kinds:

(1) Orders from customers for the month i, say X_i (a gaussian variable, the parameters of which, $\overline{x}_i$, have been found by a statistical analysis).

(2) The quantity Q_i actually transported from the factory to the warehouse, which may be equal to or less than C_i, depending, among other factors, upon the favourable or unfavourable meteorological conditions prevailing during month i.

No a priory assumption has been made in the model as to the inventory policy; neither a maximum stock level nor a two-bin system has been postulated from the start. The only rule is to take a decision at the beginning of each month, according to the known stock level at that time, as to the quantity to be asked from the waterways companies as the transport target. The objective is to minimize the expected total cost for all the periods to come.

No hypothesis as to the stationariness of the system has been made, as is generally done in the classical OR literature.

The methods of dynamic programming which have been used here, lead to the determination of an optimum function F through the formula

$$F_i\ (S_i) = \min_{Y_i} \{ L_i\ (Y_i,\ S_i) + \alpha F_{i-1}\ (S_{i-1}) \}$$

where $F_i\ (S_i)$ is the value of the objective cost function for the i periods to come, S_i is the stock level at the start of month i; $L_i\ (Y_i,\ S_i)$ is the expected cost for month i, with stock S_i and decision variable $Y_i = S_i + C_i$; α is the discount rate (<1).

It is shown that a linear function $F_i\ (S_i)$ is a solution of the equation; this leads to the determination of the optimum value Y_i of the decision variable Y_i.

These rules once established, that is once we have established the set of the Y_i from which to substract the known S_i at the beginning of each month, a simulation made for different values of the stock capacity of the warehouse, leads to the solution of the problem raised initially. It has been shown that no increase of capacity was needed provided that the rules are followed. The solution has been applied by the firm concerned.

*Sepro, Paris, France.

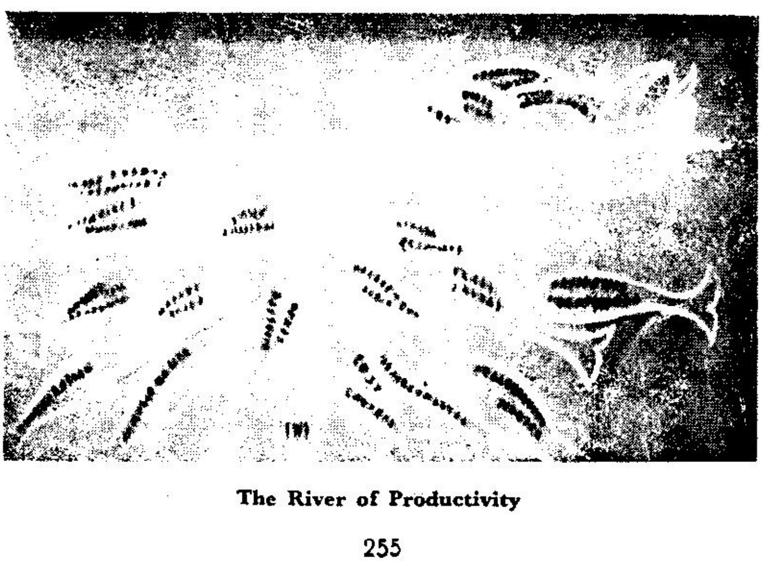
Dynamic Programming and the Calculus of Variations

Stuart E Dreyfus*

PROBLEMS in the Calculus of Variations can be viewed as multi-stage decision problems of a continuous type. Therefore they can be characterized by the functional equation of dynamic programming. The functional equation approach yields, quite readily, formal derivations of such classical necessary conditions of the Calculus of Variations as the Euler-Lagrange equations and the Weierstrass and Legendre conditions. It also reproduces the multiplier rule for the more general 'problem of Bolza'. This new approach also leads to easy and natural physical interpretation of the Lagrange multipliers often introduced to solve variational problems.

More important, dynamic programming yields a computational algorithm for variational problems which is not greatly complicated by inequality constraints nor subject to the stability difficulties associated with the numerical solution of the non-linear mixed boundary value problems generated by the classical variational approach. The existence of a usable computational algorithm for both discrete and continuous variational problems is of great importance in operations research, since economic, as well as engineering, problems often possess variational formulations.

*The RAND Corporation, California, USA.



The River of Productivity

Adaptive System Models

Merrill M Flood*

OR should and will direct more of its attention to the development of adaptive systems, and to systems that are so designed that they learn from past experiences in such a way as to modify their future behaviour and thus continually improve their performance. There are a number of mathematical theories, and other developments, that help to show how to design and operate adaptive systems that 'earn as they learn'. Systematic experimentation, guided by concepts from some of the available theories, can even now help in the design of very complex productive organizations: for example, management gaming and system simulation are useful experimental techniques. It seems to be a bit too early to expect many OR applications of automata theory, but the time *is* ripe for greater use of stochastic approximation and heuristical problem-solving techniques.

OR has been concerned with the design and management of a wide variety of man-machine systems. Some systems studied have been extremely complex, such as an entire industrial firm or an entire national defence establishment. Some systems studied have been relatively simple, such as the procedures and devices for operating a small inventory control system.

OR experience has already shown that certain now familiar models are useful in studying both the very complex and the very simple. For example, the same mathematical queueing model has been used to analyse the workings of a small telephone exchange and the scheduling of a large industrial enterprise. There are similar examples of the versatility of other popular OR models, including mathematical programming, statistical decision theory, information theory, and servo-mechanism theory.

There are several newer models and theories that show promise for future OR applications, but they are not yet proved widely applicable. Among these are game theory, stochastic learning theory, organization theory, theory of teams, stochastic approximation, and automata theory. There are also newly named developments—such as artificial intelligence, cybernetics, management gaming and simulation, heuristic problem-solvers, and self-organizing automata—that excite the imagination and stimulate the endeavour of OR people, but developments that have not yet found widespread application.

Several of these newer models and theories stress the dynamic stochastic adaptive aspects of the complex man-machine systems being designed, or managed. Some of these developments need to be studied in terms of their potential for future OR studies with special stress on learning and adaptation aspects of such systems.

*Mental Health Research Institute, The University of Michigan, USA.

"As I see it, no one can make a man safe but himself."

The Nature and Importance of Models

Henry H Albers*

THE basic approach of operations research is to construct a model of the decisional problem under consideration. A model represents some aspects of an existing thing, event, structure, or process. Models can be classified into three categories: iconic, analogue, and symbolic. An iconic model is a scaled reproduction of the essential features of that which it represents. Toy automobiles, model airplanes, and globes are examples of this type of model. Analogue models portray various properties of something by a different set of properties. For example, solid and broken lines are often used on a map to indicate the kind of surfacing that can be found on the roads. Contour lines are used to show the nature of the terrain found in the area encompassed by the map. The lines and other symbols of an analogue model take the place of the scaled reproductions of an iconic model. Models can be used to determine the most efficient layout and the nature of material flow. They also facilitate the study of comprehensive and complex situations. As Karl W Deutsch has pointed out:

> The only alternative to their use would be an attempt to "grasp directly" the structure or process to be understood; that is to say, to match it completely point for point. This is manifestly impossible. We use maps or anatomical atlases precisely because we cannot carry complete countries or complete human bodies in our heads.

Symbolic or mathematical models can be used to predict consequences to the extent that the logic of mathematics corresponds in some degree to the dynamics of the "reality" it represents. Pure mathematics is a completely abstract system concerned with number, quantity, spatial relationships, and other types of logical conceptions. "The certainty of mathematics," to use the words of Alfred North Whitehead, "depends upon its complete abstract generality. But we can have no *a priori* certainty that we are right in believing that the observed entities in the concrete universe form a particular instance of what falls under our general reasoning. The models of pure mathematics are not directly concerned with empirical problems, and the results do not necessarily reflect "reality". The models of applied mathematics are directly concerned with "reality" and are attempts to derive practical conclusions by the use of abstract mathematical reasoning. The basic process begins with abstractions from "reality" which are then subjected to mathematical analysis. The mathematically derived conclusions are then related to "reality," and an attempt is made to predict the behaviour of the real thing or process.

*Associate Professor of Management, State University of Iowa, USA.

A Record Storage Model and its Information Retrieval Strategy

B Gluss*

SUPPOSE an information storage model is set up in such a way that each record in the filing system is defined by an *h*-digit binary number which is stored on magnetic tape that may be used as input to a digital computer. The tapes are placed in separate classes, which for convenience we shall call rooms. In order to retrieve a particular record or set of records, two types of search may be made : (a) a search for a specific tape in a specific room, and (b) sorts of the tape upon various digits or groups of digits using the computer. Using this model, an information retrieval problem is considered whose objective is to find an approximately optimal strategy for retrieving the desired record or set of records at a minimal expected cost. The strategy defines the rules for determining the order in which searches of types (a) and (b) are made. Assuming certain cost and probability parameters, four successive approximations in policy space can be made and their relative worths determined by Monte Carlo simulations of the process.

Further possibilities for increasing the efficiencies of storage models themselves, to increase the efficiency of storage and retrieval, are discussed in a fuller paper read by the author at the Second International Conference on Operational Research.

With the present-day tendency towards the amassing of vast amounts of data, and with the advent of the high-speed magnetic-tape-input digital computer, it seems natural to consider information storage systems in which the data are stored on magnetic tapes and in which the retrieval is performed by processing these tapes through a computer. The problems then arise as to how the data should be stored on the tapes and what procedures, or strategies, should be used to retrieve any required record or group of records. The author has elsewhere suggested a method of deriving optimal retrieval strategies given parameters of the costs of searching and processing the parameters of the probabilities of the required record being on the various tapes in the storage system ; the method of storage is assumed, and the cost and probability parameters will depend upon it.

*Armour Research Foundation of Illinois Institute of Technology, USA.

As you walk around your department, imagine for the moment that you're somebody else.

Models as Approximations

Glen D Camp*

MODELS are approximate representations of reality. *Model* approximations, as here used, are the conceptual and other qualitative approximations made in formulating mathematical models of operations, in contrast to any *mathematical* approximations which may be made, *after* a model is formulated, in solving it and in determining the sensitivity of its solution to errors in input data and managerial control variables. They include the definition of the supposedly significant variables and, by implication, the rejection of all others as insignificant; the definition of quantitative measures of 'cost' and 'value'; etc.

They permit intangibles and other conceptual complexities to be collected at the highest level for critical scrutiny, instead of permitting these to diffuse to lower levels where essential features may be obscured by purely mathematical or technical complications. By making it possible to formulate tractable and sharply defined mathematical models, they permit precise quantitative work to be done within a well-defined framework of tentative assumptions, and the results of such work often throw light back to the conceptual complexities by determining the sensitivity of these results to different model approximations. This and other conceivable methods of determining the structure and effects of model approximations here have been explored in a fuller paper, where some possibly fruitful directions for further work have also been suggested. These latter include the beginning of a classification scheme for model approximations (aggregation, fluidization, quantization, ignoring constraints, imposing artificial constraints, etc.)

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In a recent visit to this country, Sir Charles Goodeve of the British Iron & Steel Research Association, described Operational Research as "the most expensive way of inviting insults from inexperienced people half your age."

On Models in Operations Research

MP Sastry*

Constructing a model, stochastic or otherwise, can rightly be described as the key function of an operational researcher. A model is an objective representation of some aspects of a problem by means of a structure enabling theoretical subjective manipulations aimed at answering certain questions about the problem. This representation which attempts to establish a correspondence between the problem and the rational thought can certainly be realised by forming a model such as in equations immediately related to an operation in queueing theory, storage theory, farm incomes and so on. For deriving solutions from models, when it is not possible to derive exact solutions, a particular application of random sampling called Monte-Carlo technique can be used with advantage for getting solutions.

IN this article I wish to deal in particular with storage models and make a passing reference to farm income models. The theory of dams and storage systems was first given by PAP Moran in 1954 in the form of a stochastic model. The discrete model considered by Moran can briefly be stated as given below: For a finite dam of capacity K, with random input X_{t-1} during time t–1, having a distribution (p_i), $i=o, 1, \ldots\ldots$, with a finite release namely min $[Z_{t-1}+X_{t-1}, M]$ made just before time t, where the dam content Z_t $[0 \leqslant Z_t \leqslant K-M]$ is specified at times t $[t=0,1,\ldots\ldots]$ by the equation

$Z_t = \min\ [Z_{t-1}+Z_{t-1},\ K] - \min\ [Z_{t-1}+X_{t-1}, M]$, $M < K-M$, the dam equations are given by:

$$P_0 = P_0\ (p_0+\ldots+p_M)+P_1\ (p_0+\ldots+p_{M-1})+\ldots\ldots+P_M\ p_0$$

$$P_1 = P_0\ p_{M+1}+\ldots\ldots+P_M\ p_1+P_{M+1}\ p_0$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$P_{K-M} = P_0\ (p_K+\ldots\ldots)+P_1\ (p_{K-1}+\ldots\ldots)\ldots\ldots+P_{K-M}\ (p_M+\ldots)$ and $P_{K-M+1} = \ldots\ldots = P_K = 0$ where (P_i) $i=0,1,\ldots\ldots$ is the stable distribution of Z_t $\{Z_t\}$ and $\{Z_t+X_t\}$ are known to be Markov chains. Thus it is easy to formulate equations for the stationary probability distributions of Z_t and Z_t+X_t in terms of discrete input distribution. Moran (1956) considered continuous input distributions, but now the solution of the stable distribution of Z_t is found to depend on the solution of an integral equation which is not easy to solve. Therefore he used a one parameter discrete distribution as an approximation to the continuous input and obtained an approximate solution based on it. In this context a two parameter discrete approximation for any unimodel continuous distribution was employed and more accurate solutions obtained for Moran's equations. DG Kendall, HE Daniels, J Gani, NU Prabhu and others took interest in the basic model and carried on further work. DG Kendall has found out the time interval before such a dam runs dry, when its initial content is known. J Gani has given a detailed comparison between the provisioning theory and dam theory. He has considered the general storage function $S(t)$ defined at the time t by $S(t)=I(t)-D(t)-F(t)$, where $I(t)$, $D(t)$, and $F(t)$ are input, output and overflow functions respectively. He has made use of Pitts results relating to the theory of provisioning in his work on dam contents and applied Moran's method of solutions of dam equations in working out problems of provisioning. J Gani and

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NU Prabhu have considered Z_t as a continuous variate defined for continuous time and worked out the time-dependent distribution function f(Z,t) of the content of an infinite dam, fed by a *poisson* input and with steady continuous release ceasing only when it becomes empty. It is of interest to point out that Moran and Gani got solution of dam equations by using Monte-Carlo method.

In recent times a further study has been made regarding the various uses to which Moran's basic idea can be put to. Many authors so far used constant release rule in framing dam or storage equations. Moran's stochastic model for dam contents is generalised in a manner suitable for variable release rules and models are formed to explain the stable distribution of Foreign Exchange Balances of India.

Very little is known about the distribution of rural incomes particularly in India. Any model explaining the nature of distribution of incomes is of particular use. The author has elsewhere explained the distribution of farm incomes of agricultural households in Nagarjuna Sagar Project area of Andhra Pradesh. A censored truncated (CT—) exponential distribution is proposed as a model explaining the distribution. The parameters of the model are estimated using the methods developed by the author for estimating the parameters of Censored Truncated distributions. The model is also tested. In the above study only incomes of a particular area are considered. It may be observed that if a model can be proposed for incomes for the entire country, it will be very useful for conducting operations research on income patterns and savings potential.

THE MOST UNPRODUCTIVE WASTE

In a message sent to the Congress on March 13, 1963, the US President, Mr. Kennedy referred to Unemployment as America's Problem Number I:

"....although American economy was becoming more efficient, it was less able to provide jobs for a constantly increasing labour force and population. We cannot accept this situation. There are 32 million Americans who are still on the fringes of poverty and worse. A nation can waste its resources as surely as an individual can. Without measure, the greatest waste we experience today is that of unemployment."

Role of Operations Research in Management

NP Rao*

Operations Research is the technique which enables executives to take correct and prompt decisions. Models with which operations research is associated have to be so designed as to be capable of rapid evaluation, enabling management to know how a given process will respond to select changes in the factors under control, without waiting for the event to actually happen.

THE function of management includes planning, organising, staffing, forecasting, coordinating, communicating, controlling and the like. In all these fields, operations research is of great value. It is particularly helpful in the fields of product design and development; specification and acceptance of materials; inventory control; inspection and quality control of raw materials and finished goods; marketing; demand analysis; and consumer reaction.

The tools of operations research are known by several technical names: Correlation theory/analysis; probability; queueing; linear programming; inventory theory; servo-mechanisms; information theory; actuaries; and game theory. These are illustrated below :

Correlation theory: how much business do we expect our firm to handle in 1963, 1965, 1968 and 1970 ? All businesses are affected by a number of variables of which the businessmen know by experience, which are the most important for their concern. By correlation techniques it is possible to evaluate their relative importance and to construct a mathematical expression explaining the movement in the series. Substituting assumed future values for the variables, it enables a forecast being made on future trends.

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Probability: the theory of probability based on sampling, enables judgments being made with regard to a whole population on the basis of a scientific selection of a cross-section of the population. It is also possible through probability calculations to evaluate a given occurrence as to its significance. Quality control is itself an application of the theory of probability. It is also helpful in evaluating current events and forecasting the future; e.g. in developing alternative proposals for merit awards; for accident prevention; in solving personnel problems; replacement of equipment; maintenance of stores; staffing of tool rooms; warehouses, and loading platforms.

Queueing: queueing is itself a particular application of the theory of probability. It is employed in order to obtain the optimum solution in cases of irregular demand for service facilities and to minimise waiting and idle time as also the total cost; as for example, in repair shops for vehicles, telephone switching, air lines and rail road traffic, machine break-down, cafeteria etc.

Linear programming: another prominent technique of operations research, linear programming, is employed where the objective is to maximise profit, efficiency and output, which are subject to certain limitations due to government policies, business fluctuations, storage space, and availability of raw materials. This technique has been found useful in the fields of purchasing and store-keeping. It enables management to reduce transportation costs, to allocate purchases amongst different suppliers, to site depots, to make a certain part or to buy it from outside.

Inventory theory: the inventory theory is also useful in the solution of production and purchasing problems. It is known as the 'Economic Lot Size Theory'. Selective inventory control involves the classification of repetitive stores according to their value (ABC analysis), nature, rate of consumption, lead time and ease (or difficulty) of availability. Economic order quantity is determined by the formula: $N = \sqrt{\frac{CA}{2K}}$, when A is the annual requirement in rupees, N number of orders per annum, C carrying cost in percentage per year and K ordering cost (per order). Average Inventory $= \frac{1}{2}A/N$

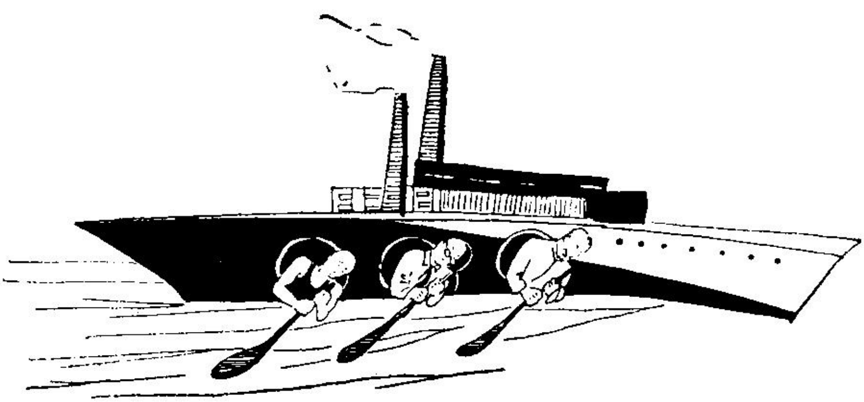
$\therefore KN = C(\frac{1}{2}A/N)$

Servo-mechanisms: this is essentially the utilisation of feedback of current data, designed as a self-correcting device to the mathematical formulae. It enables management to moderate costly swings in the production cycle due to fluctuating demand.

Information theory: the information theory, closely related to the communication theory, and applied largely to the fields of management and engineering, is based on the volume of knowledge and information available within a certain concern, and the communications built up.

Actuaries: the actuarial science has also been found useful in the field of operations research. Normally used in the fields of group insurance, depreciation rates and the like, it can also be used to develop a cheaper product to last, for example, 10 or 15 years, when a company is producing a higher cost product to last 40 years, knowing fully well that it stays in use for not more than 10 years.

Last but not the least, there is the Game Theory in the armoury of operations research, based on 'opposite strategies'. This has become particularly fashionable in recent times...



Let us pull together

Operations Research : an aid to Decision-making

VK Bhalla*

Decision-making, the most important function of management, has been rendered extremely difficult because of the multiplicity of the factors involved in taking a decision. Great attention has therefore to be paid to this decision-making process, particularly because managerial decisions involve commitments for the future. The making of a decision requires a clear understanding of the whole problem, of the factors involved, followed by a formulation of various alternative solutions, weighment of the risks involved in each solution, and finally the choice of the appropriate solution, being on balance the most advantageous for the concern. This in short is Operations Research designed to make decision-making a rational process.

THE normal stages in an OR investigation are: 1. Formulation of the problem, defining the scope of investigation and determining the specific goals to be achieved. The quantitative measure of efficiency relating to each objective must be defined to the extent possible. 2. Determination of the factors which affect the operational situation, whether these are controllable, as also their inter-dependence. 3. Determining the changes that can be made in the situation. 4. The construction of a *model* of the operational situation. 5. The solution of the *model* and its application for making decisions.

The term 'model' does not imply a physical or a mechanical model; very often it is a purely mathematical one constructed in order to analyse problems with the use of such techniques as statistical analysis or linear programming etc.

Take the case, for instance, of servicing facilities at a petrol filling station. Here the customers arrive at irregular intervals and at times create a 'queueing' or 'waiting line' problem. What is the 'optimum' number of facilities required to meet the rush trade and achieve maximum customer satisfaction, involving least waste of expenditure on an unnecessarily large number of facilities ?

This problem is capable of solution by a statistical approach leading to a probability prediction of the effects of a decision along with the risks involved.

Another type of problem that lends itself to an OR approach is of finding the best distribution pattern. Say, we have several production centres which supply various warehouses which in turn supply different consumption centres. What should be the pattern of distribution for achieving lowest cost, commensurate with maintaining optimum stock levels at warehouses ? In solving a problem of this kind a set of equations can be formulated to represent the situation. Mathematical techniques are available for solving this set of equations giving various alternate solutions as well as the optimum solution which automatically gives the course of action involving maximum effectiveness.

Although the value of OR as a technique for solving such problems has been well proven yet the application of the technique

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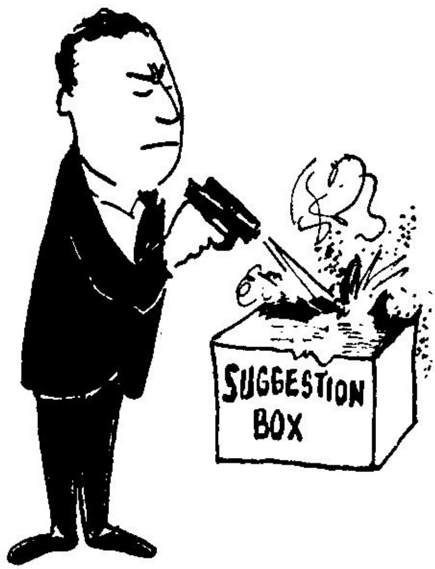
has not been as widespread as it could be. Being new, and also somewhat difficult to understand, the technique is suspect. Managements naturally find it difficult to have faith in something they do not clearly comprehend. Even when they do decide to go in for OR they do not always know how to derive the maximum benefits. Introduction of OR in an organisation is therefore generally opposed by managers. But wherever this opposition has been overcome, results have been very satisfactory, for OR has so much to offer as an aid to decision-making.



Description of Simulation Studies

MP Barnett*

We need a powerful language in which simulation studies may be described. Simulations of non-discrete systems (such as river networks and oil refineries) represent a very important class of problems, but in general the histories of such systems can be approximated by discrete processes, so that the problem of descriptive languages is similar to that of the discrete case. The use of uniform time intervals is more common in the simulation of systems that really are continuous and is adopted in the work of the writer concerned with river problems.

IN the writer's experience of simulating complex econometric systems, appreciable effort is often needed to produce the highly resolved description of the study, in which tests and actions and the topology of flows are expressed sequentially in simple standardized statements. In one particular study, a river system and a policy to be adopted in its operation were described first in the style of a literate administrator, then in a sequence of non-mathematical but highly stylized English sentences, then in a sequence of mixed algebraic and stylized English sentences and then as a Fortran II source programme. The transition from the second of these representations to the third was trivial, involving little more than a substitution of symbols for words; the transition from the third to the fourth was equally trivial, requiring just transliteration to a simplified typography. Most effort was needed to transform the first representation into the second. Moreover, the first representation was much more concise than the others. The provision of programmes that will encode such concise descriptions seems of considerable importance in making computer simulations available to a larger group of workers, in expediting simulation studies, and in easing the traffic problem if such studies are to be communicated frequently to very large computers from remote input stations. The encoding by the computer of such descriptions is by no means trivial, representing a significant subset of the language translation problem. An approach that the writer is adopting, it is hoped successfully, makes use of a 'bootstrapping' process, that depends to a large extent on programmes that can scan texts, and delimit and analyze patterns of symbols of very varied types. These scanning programmes are used to decode sentences of a simple structure, and which describe individual processes that can be executed by the computer. Procedures are being set out in this simple sentence structure that transform into the same sentence structure texts that are expressed in a rather more complicated stylization. This latter stylization is used to describe procedures for simplifying texts that are still more complicated and so forth. An important consequence of this study has been the insight it has provided into the characteristics of a class of machines radically different from present-day computers that would be particularly suited to this and other types of activity, that are dominated by pattern recognition and analysis. ●●

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The Automatic Programming of Simulations

Tocher & Owen*

The effective extension of simulation techniques demands the use of computers and the provision of automatic coding aids. The author has elsewhere outlined a programme of work which had contributed to this extension by devising a simulation language which can be subjected to automatic coding by a Ferranti 'Pegasus' Computer. A master programme has been written which executes the coded statements within a common structure applying to all simulation experiments.

THE structure depends on representing the plant as a collection of machines in various states. A change of state of any machine is an 'event', and the programme predicts successive events and changes the plant state accordingly. The predictions are based on a series of logical rules concerning the necessary states of machines for processes to commence, and uses sampling techniques to determine their conclusion. The simulation language is designed for describing the logical rules.

Experience so far with this scheme indicates a substantial saving of time in writing and testing computer simulations, with no severe loss of running speed. It has been found flexible enough to deal with a wide range of different problems.

Simulation is an old and trusted tool of the operational research worker. During World War II, and since then in all the spheres of activity of OR, it has been used alongside a growing range of analytical techniques. The arrival of electronic digital computers has relieved much of the tedium of carrying out simulations, and in consequence the method is being applied in highly complex situations.

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Often, the use of simulation is criticized, and the common excuse is that existing analytical methods do not cater for the particular complexities of a given problem. It is usually admitted that if a realistic and *soluble* mathematical model of the problem could be formulated, this would be preferred to an approach by simulation. There is, however, a more positive argument for the use of simulation. We take the view that scientific method hinges upon experiment, and that if one cannot experiment with a live industrial system one can still derive great benefit from experimenting with a model of that system. Thus simulation, if it can be carried out with sufficient realism derived from close observation of the plant, is a means of obtaining experimental material. It rarely solves a problem; but it frequently enables the central problem in a complex situation to be identified, and perhaps formulated in mathematical terms.

If OR is to use the technique of simulation experiments, a huge volume of work must somehow be mechanized. It is not enough to have a computer to carry out the simulation itself, for the construction of programmes to take into account the complexities of the problems we are interested in will itself be an almost overwhelming task for each new simulation. ●●

Application of Queueing Theory to Production Problems

NK Jaiswal*

THE efficiency of large scale undertakings like telephone, road transport, railways, shipping, air services, repair workshops, factories, big shopping centres etc. depends largely on their service organisation. This service involves a stream of incoming units and a flow of outgoing ones, after service. If the arrivals and service times are of deterministic type, the behaviour of the system can be easily determined. However, if there are variations in the regularity of arrivals or in the length of time required to service a unit or both, and these variations are of a probabilistic nature, the system fluctuates and the problem of determining the various measures associated with the queueing process such as the length of the queue, the waiting time of a customer etc. becomes more complex and needs the theory of Stochastic Processes for its analysis. This theory so developed helps us in *predicting the behaviour of a dynamic system* under variations in the regularity of arrivals and service and thus enables us in designing a system for optimal performance under given conditions, which is the basic purpose of any Operational Research study.

Some of the important problems relating to industry and production, where such studies are helpful are the following: A problem which frequently occurs in factories, repair workshops etc. is to determine the number of service channels needed to meet a given demand, most economically. Consider for example a situation in which there are 10 welders connected to a power system. Each welder operates independently of the others. The average time of each welding operation is 8 seconds and between each welding there is an average time of 72 seconds. A welder will have to wait if he finds the channels preoccupied and consequently has to remain idle. The cost of this delay for the welders is to be computed and is to be measured against the cost of providing more service channels. From the tables†, we find, for example, that for this problem when

no. of service channel=1, average delay=13.44 secs.
no. of service channel=2, average delay= 1.52 secs.
no. of service channel=3, average delay= .16 sec.

Assuming that it costs b Rs./sec for a welder to wait (this cost includes slower production as well as pay cost) the amount of money that one can save by having two channels instead of one is obviously= (13.44—1.52) b=Rs. 11.92 b. Hence if the cost per second of providing one more channel is less than 11.92 b, the management may improve by having one more channel but if it is less than 11.92 b, the management in spite of the fact, that the welders wait, will find it more profitable to employ only one channel.

Another problem which is mathematically similar but operationally different from the one given above is more commonly known as the Simple Machine Interference problem. An operator is assigned a set of machines to

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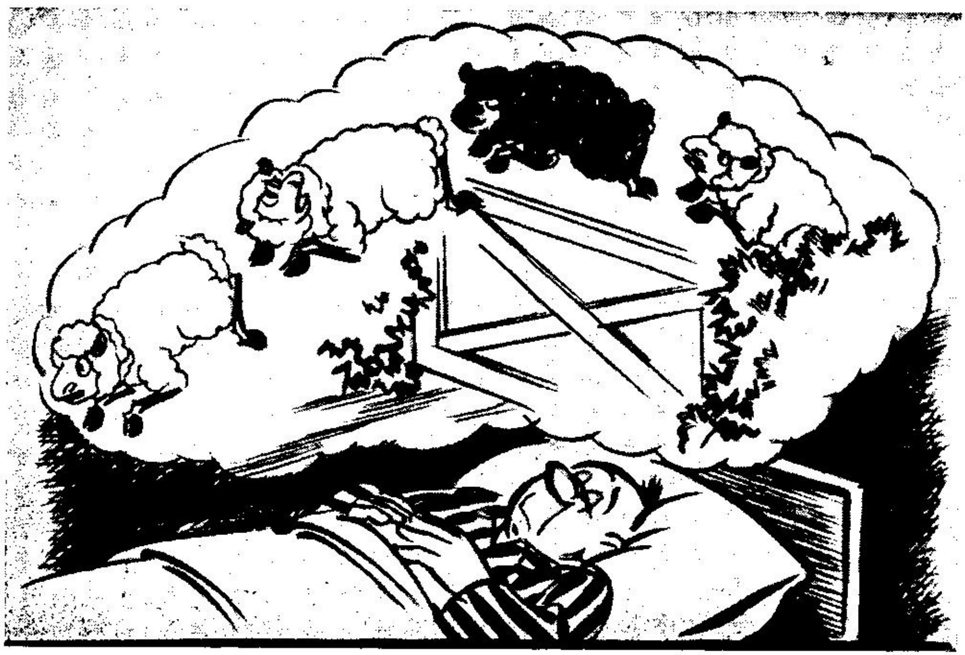
†Finite Queueing Tables, Hazelwood, Wiley; Delay Tables, Descloux, McGraw Hill have been provided from which one can directly read the solution.

look after. If a machine fails whenever another machine is receiving attention of the operator, the first machine has to wait resulting in loss of production. The likelihood of a machine having to wait can be reduced if the operator is assigned a fewer number of machines, but in that case, the operator will be idle for a larger fraction of time. The following table will make this point clear.

Number of machines assigned to an operator	Operative utilisation	Rate of production per machine
6	.602	.815
8	.756	.769
10	.871	.708

A balance between the operative utilisation and the rate of production is to be made keeping in view the costs associated with the operator and the machine idle time. Such type of situations commonly occur in textile industries notably in spinning, winding, and weaving sections and in many other industries where an operator is assigned a set of machines like thread cutting or wire drawing machines etc. Many interesting industrial situations of the type mentioned above have been tackled by the help of this theory and has helped managements in maintaining an optimal efficient service system.



Quality Control

Control of Production

Andrew Vazsonyi*

WE here deal with an area of production control where OR techniques have not yet been extensively applied, but where a great need exists today. Specifically, it is the problem of the day-to-day or hour-to-hour control of a manufacturing complex. When the manager of a simple manufacturing process is confronted with a problem he usually consults a few figures, charts and makes a decision. His solution to the problem might not be optimum, but is probably 'reasonable'. OR has been successful to come up with optimum solutions and to provide more efficient control. However, *in complex production systems the manager and his associates have lost 'visibility'*, and in spite of the fact that a great deal of data is collected, processed, and presented, decisions must often be made without adequate guides. While OR has been successful in some of the aggregate problems, relatively little progress has been made in the important area of detailed control.

One of the stumbling blocks in this field has been the difficulty of defining optima. A solution to this dilemma might be obtained by abandoning the search for optima and search simply for 'good' solutions. Some of the recent 'heuristic' efforts in connection with games can serve as illustrations of the possibilities here.

The heuristic approach might also alleviate some of the apparently insurmountable mathematical difficulties that one encounters in many production control problems.

A further difficulty in this field stems from the fact that the technology of electronic computers has not provided yet *the man-machine interaction needed in the control of production.* The manager and his associates are playing a giant 'game' and need information on a real-time basis. Data on the 'state' of the business needs to be collected, processed, and displayed automatically. Managers must be able to place and retrieve information at will and conduct data-processing tasks when needed. What we need here is to extend the manager's capabilities in dealing with production control.

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DO IT BY PRODUCTIVITY

"....I entirely reject the Madison Avenue Weltanschauugen that you achieve things by advertising, publicity and public relations."

—*Capital's Ditcher's Diary*

Production Control Problem

Melese & Barache

THE authors have in a fuller paper dealt with a dozen cases of production control for firms of different levels in size and activity. It appeared in every case that one of the chief concerns of industrialists and operational researchers was to state the problem clearly. Here we are concerned with the analysis of factors which must orientate research work and condition the problems. A survey of these factors must come before any attempt of solution.

So, it is necessary to answer these three fundamental questions:

What are the problems at stake and the aims to strive for ? (Is it a problem of taking structural options, of finding a method for everyday administration or of finding some means of control ?)

According to *what* criteria must we establish a discrimination between the possible choices (technical, commercial or both) ?

At what level must the problem be stated ? (What are the units of time and of production to adopt, what is the precision to look for, for the best results ?)

In order to answer these questions, it is necessary to analyse the specific factors of the firm, i.e., the type of market, the type of production, the trading policy, the manufacturing process organization.

We are then in a position to state the problem in realistic terms. The importance of the consumer's point of view needs to be stressed, which is not so much the desire to admire the elegance of a mathematical solution as to have a realistic and efficient implementation.

"Talk of taxation destroying incentive for higher productivity should be deprecated and the entrepreneur should regard himself as a commission agent for national wealth."

—CD Deshmukh

Operations Research & the Inventory Problem

RS Chadda*

Operations Research is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control. These scientific methods, techniques and tools of Operations Research were applied, for the first time, to military problems arising during World War II. Later, they were extended to several fields including business, industry and civil government. Some of the business and industrial problems tackled by OR inventory, allocation, queueing, replacement vs. maintenance problem etc. This article deals with the application of OR to the inventory problem.

THE inventory problem is to decide how much of stores should the management produce or procure. In the absence of scientific analysis, decisions as to the quantities to be ordered are taken according to subjective judgment or intuition or even whims of the Purchase Manager rather than according to the requirements of the situation. Take the case of a company that has decided on an *ad hoc* basis to buy every item of stores 4 times a year. In other words, the re-order quantity is 3 months' supply for all stores items. Taking a sample of three items with different levels of annual consumption, their average working inventory is worked out in the following table:

	annual consumption Rs.	*number of orders*	*order quantity* Rs.	*average working inventory* Rs.
A-item	30,000	4	7,500	3,750
B-item	3,000	4	750	375
C-item	300	4	75	37
Total		12		Rs. 4,162

Keeping the same number of orders per year, namely, 12, inventories can be reduced by 39% merely by adjusting the number of orders per year and the order quantity per order according to the usage value of the items, as is illustrated in the table below:

	annual consumption Rs.	*number of orders*	*order quantity* Rs.	*average working inventory* Rs.
A-item	30,000	8	3,750	1,875
B-item	3,000	3	1,000	500
C-item	300	1	300	150
Total		12		2,525

The right approach to the inventory problem requires, first of all, an assessment of all the relevant factors. What happens when we stock items of stores? Stores take up space, and must therefore bear a share of the rent charges. They represent money unavailable for other uses and must therefore bear a share of the interest charges. They involve such other holding costs as handling, insurance, depreciation and obsolescence. The sum total of these costs, compendiously known as the *inventory-carrying-cost*, is considerable and an argument for hand-to-mouth buying. But what is the cost of hand-to-mouth buying? First, there is a cost of

*Deputy Secretary, Committee on Plan Projects

processing a purchase order every time goods are needed. Secondly, transportation for the goods ordered has to be paid for. Thirdly, there is increased inspection cost on incoming materials. These constitute 'ordering costs' which rise with a rise in the frequency of orders. There is an inverse relationship between inventory-carrying-cost and ordering cost. If purchases are made infrequently and, therefore, in large quantities, inventory-carrying-costs are large but ordering costs are small. If, on the other hand, purchases are made very frequently, and, therefore, in small quantities, inventory-carrying-costs go down but, at the same time, ordering costs rise high. To be able to find the optimum order quantity, it is necessary, therefore, to balance these two opposing costs.

The economic order quantity of an item must possess two characteristics: it should avoid or at least minimise shortages and it should result in the lowest possible overall cost. On the basis that no shortages are to be allowed so that there is no shortage or idle time cost to be considered, the determination of the economic order quantity of an item involves the calculation and balancing of only the inventory-carrying-costs and the ordering costs. If A=annual usage in rupees, S=cost of placing an order (for purchased goods) or set up cost (for manufactured goods), I=percentage of total inventory value spent annually to maintain inventory, and Q= economic lot size or order quantity,

buying cost $= \frac{S \times A}{Q}$

inventory-carrying-cost $= \frac{Q}{2} \times I$, and

total cost $= \frac{SA}{Q} + \frac{IQ}{2}$

The total cost may be minimised by differentiating the cost function and putting the result equal to zero. That gives

$$Q = \sqrt{\frac{2AS}{I}}$$

For $Q = \sqrt{\frac{2AS}{I}}$, ordering cost is equal to inventory-carrying-cost, and each

$$= \sqrt{\frac{SAI}{2}}$$

Two kinds of criticisms are generally voiced against this and other mathematical formulae. Firstly, it is suggested that since a formula is only as reliable as the factors entering into it, it is hardly worthwhile using a formula when the correct values of its factors are not known and cannot easily be computed. For example, if the values of S and I in the above formula are not precisely known, the formula is of little value. It must be remembered, however, that a formula can be an effective decision-making tool even in circumstances in which the values assigned to its factors represent no more than approximations. A formula reveals the proper relationship among the various factors and is, to that extent, of considerable value. The formula $Q = \sqrt{\frac{2AS}{I}}$, for example, reveals that when annual usage (A) increases four times, the optimum order quantity (Q) is merely doubled but not quadrupled. In the absence of the formula, one may be tempted to increase the order quantity in the same proportion in which the usage rises. Moreover, the total cost curve is flat about the optimum point so that even a substantial error in order size leads only to a fractional increase in cost. For the order quantity between 65 and 155 percent of the optimum, the cost change is less than 10 percent. Accordingly, it does not make much of a difference even if the factors are not exactly correct. *So long as we weave them into their correct relationship, we are very near the best results.*

The second type of criticism relates to the difficulty of using the formula. It is argued that stores personnel do not possess the skill to use the formula, and, even if they do, they simply do not have the time to make calculations for all of the items in stock. To that, the answer is that the use of the formula is much simpler and easier than might appear at first sight. Since ordering cost and carrying charges vary only with the number of orders and with the value of purchases and not with the nature of the item to be purchased, it is not necessary to calculate the economic order quantity for each and every individual item. For everyday use, it is possible to incorporate economic order quantity data for different levels of annual usage into tables which need not be changed so long as the values of S and I remain the same.

The phrase 'basis for decisions' in the definition of OR implies that the *quantitative aspects are not the whole story in executive decisions.* This is as true of the formula worked out above as of any other quantitative basis provided by OR. Suppose the annual consumption of an item is small and the economic order quantity formula indicates 6 months' purchase at a time, but the shelf-life of the item is only 2 months or so. The Purchase Manager will limit the order quantity to 2 months' supply. There may be other limitations, as, for example, of storage space, finance, etc. which may dictate purchases in quantities lower than the best according to the formula. Equally, there may arise situations in which it would be both essential and desirable to exceed economic order quantities. The formula takes account of the ordinary cost factors but the executive deciding on the quantities to buy must also take account of extraordinary limiting factors and compelling situations.

The Scope of Inventory Control

Eliezer Naddor*

OUR professional journals publish a great number of papers on inventory control. Almost every OR group whether in business, industry, or government, has an inventory project on its list. Special courses entitled production and inventory control, inventory systems, industrial and production controls, etc., are now being offered in American Universities. There is even a claim that,

> 'More operations research has been directed towards inventory control than toward any other problem area in business and industry.'

Yet, in spite of all this great activity, there does not seem to be a universal agreement on the scope of inventory control.

Practically every production system involves inventories in one form or another. Inventories are also frequently involved in many other systems: transportation, allocation, queueing, replacement, etc. In these systems inventories usually refer to materials and products in stock. There are still other systems involving inventories, though not of the kind that the everyday usage of the word implies. In some respects, for example, the following may be considered inventories: men in Armed Forces; stewardesses in airlines; red blood cells in the spleen; a budget appropriation etc.

Control problems also cover a rather wide range: record keeping of receipts and withdrawals; accounting (f.i.f.o., l.i.f.o., etc.); layout and searching; overages and shortages; taxes, insurance, storage; financing; etc.

Should inventory control be assumed to deal with all these systems and control problems ?

Let us see what some authorities have to say on this:

In the paper of DVORETZKY, KIEFER, AND WOLFOWITZ, 'The Inventory Problem', the authors state:

> 'The inventory problem is the general problem of what quantities of goods to stock in anticipation of future demand. Loss is caused by inability to supply demand or by stocking goods for which there is no demand !'

SIMON and HOLT, in their review article on the control of inventories and production, classify research work in the field, as of 1954, as follows:

(1) *Ordering decisions*: procurement of raw materials, parts ordered by an assembly department in a factory, orders of a warehouse on factory; (2) *Production rate decisions*: determination of size of work force, number of working hours, overtime policy, and the like for a factory or department; (3) *Scheduling decisions*: determination of which orders are to be processed through a manufacturing operation, and in what sequence.

Under this classification it would seem that the inventory problem, as defined by Dvoretzky, Kiefer, and Wolfowitz, would fall in the first class. The examples given by them and their subsequent paper, clearly indicate this.

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Ackoff, in his paper on 'The Development of Operations Research as a Science', in discussing 'prototype' processes or systems which seem to have emerged within Operations Research, says:

'By an inventory process Operations Research has come to mean a process involving one or both of the following decisions: (*a*) how many (or much) to order (i.e., produce or purchase), and (*b*) when to order. These decisions involve the balancing of inventory carrying costs, against one or more of the following: order or run set-up costs, shortage or delay costs, and cost associated with changing the level of production or purchasing.'

Ackoff thus considers the 'Ordering Decisions' and some of the 'Production Rate Decisions' of Simon and Holt as 'Inventory Processes'.

The above definitions and classifications seem to be the only ones available in the OR literature. To these the author would like to add the following more specific definitions: (*a*) Inventory is an amount in storage. (*b*) Inventory is measured in quantity units: lb, parts, etc. (*c*) Inventory may be either positive or negative. Positive inventory, or *overage*, refers to an amount not in use. Negative inventory, or *shortage*, refers to an unavailable amount for which there is immediate use. (*d*) Inventory is, in general, a function of time. For a specific item both an overage and a shortage cannot occur at the same moment of time. (*e*) Inventory increases or decreases depending on *replenishments* (input) or *withdrawals* (output). (*f*) An inventory control system is a system in which replenishments can be controlled. (*g*) An inventory control system is characterized by three groups of criteria depending on: (i) overages; (ii) shortages; (iii) replenishments. A criterion is either a constraint or function to be minimized (or maximized): Overage criteria are usually carrying costs, maximum inventories, obsolescence costs, etc. Shortage criteria are usually stock-out costs, probability of occurrence of shortages, etc. Replenishment criteria vary considerably from system to system. Some criteria are: set-up costs, ordering costs, purchasing costs (quantity discounts), labour costs and/or availability, etc. (*h*) Inventory Control deals with methods of replenishment and their effect on overage, shortage, and replenishment criteria.

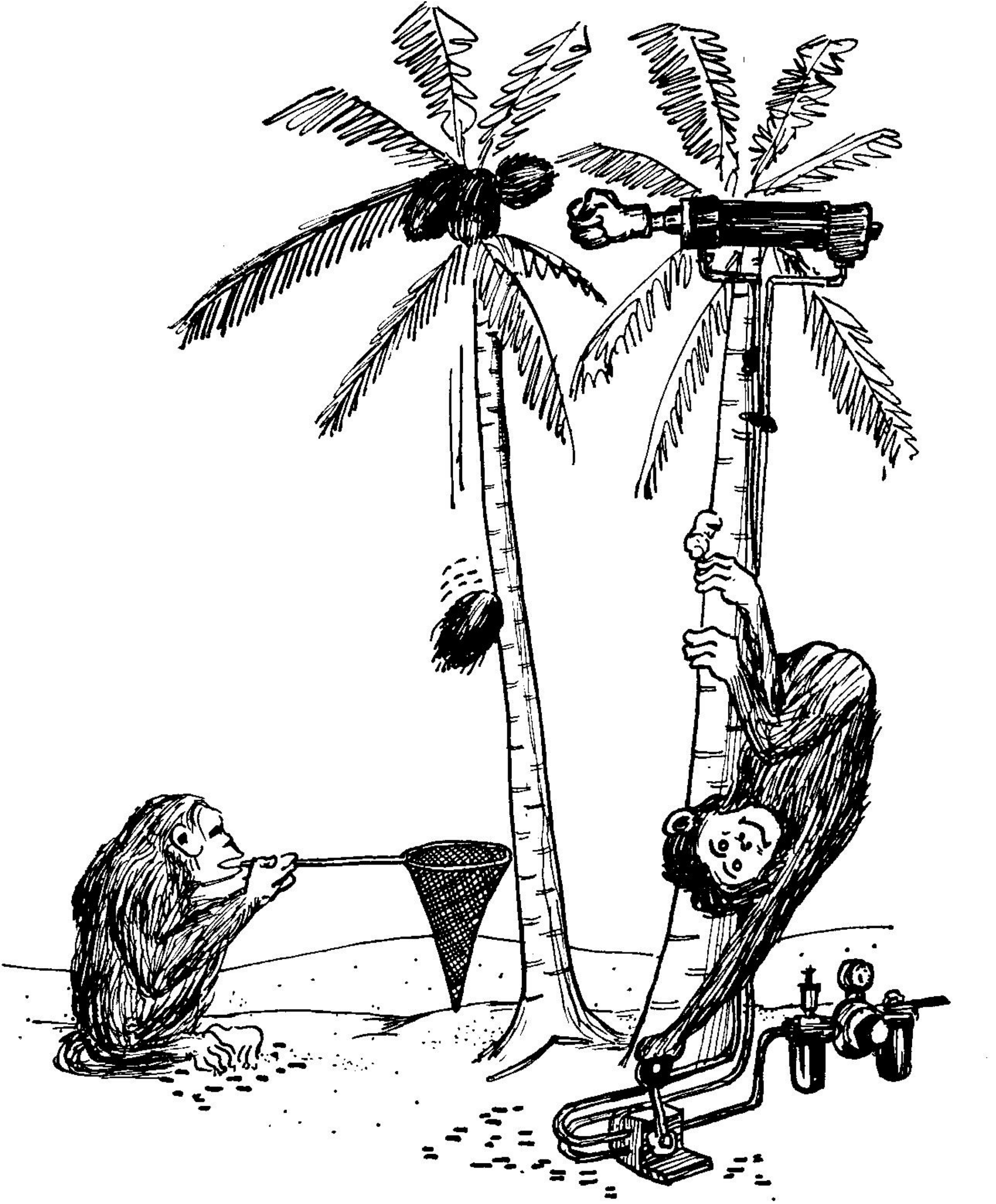
There are a number of systems which satisfy the above definitions but which are not usually thought of as inventory control systems:

In a production control system, for example, one also deals with methods of replenishment and their effect on overages, shortages, and replenishment criteria. The distinction is in the degree of emphasis on criteria. In an inventory control system all the three criteria are equally significant. In a production control system the most significant are the replenishment criteria.

In queueing problems, as another example, replenishments may be considered as the types and numbers of channels, and the rates of service in the channels; overages may be considered as idle channels and shortages the waiting lines. However, here emphasis is on the shortage criteria primarily.

The three criteria which identify inventory control systems also arise in other systems: allocation, sequencing, replacement, etc. In each one of these other systems, however, the emphasis is on some specific criteria, and this distinguishes them from inventory control systems.

It is harder to observe people than to observe things. . .



Monkey Training in Productivity !

The Measurement of Human Factors

RH Collcutt*

Operational Research is concerned with describing and analysing systems for the purpose of advising on the consequences of various ways of specifying and operating them. They may be industrial, military, or administrative and will usually involve both men and machines; this implies that the behaviour of men as integral elements of the systems is understood and susceptible to measurement.

ASSUMPTION are made as to how both the men and the machines will react when large or small scale alterations are made to the system or when one system is substituted for another. Such assumptions I will designate Type 1, and I think it will be agreed that in view of our gross ignorance about the actual behaviour of the 'man' component in these systems, the validity of many of the assumptions made in practice is open to grave doubt.

Even if there were no doubts about these Type 1 assumptions there is also another set, perhaps equally shaky, which are made when the results of a study are presented to management, to the decision-makers. These Type 2 assumptions concern the anticipated reaction of the decision-maker to the report and the recommendations it may contain. There is usually a tacit assumption that since the solutions are rational and logical to the analyst they will by the same count be persuasive to the recipient of the advice. In my own experience, however, I have found this expectation not to be fully justified; there is an embarrassing proportion of occasions when management have ignored or reacted in an unexpected way to advice whose portent was obvious to me.

Worrying about these two types of assumptions in our work has for a long time been an occupational disease of the OR analyst. Sweeping aside inconvenient doubts was perhaps justified in the past by the progress we were making in the exploration of other areas of our subject, the results of which had yet to be thoroughly tested on a wide front. In the course of the expansion of our activities in the last few years we have, however, frequently been exposed to the cold douche of reality in that things don't always work out as we thought they would. There is probably a serious gap in our armoury on the measurement of human factors.

It has been obvious that not very much is known, but it is equally obvious that there are many who are enthusiastically taking up the challenge and are proposing and undertaking many important and interesting experiments. It is at this stage necessary to know whether enough of the total OR effort is devoted to human factors, how the specialized techniques developed by operational research might be applied in this field and to what extent background knowledge of the decision-making process by individuals and by groups (e.g., committees) is a necessary element in an OR man's experience.

In this context Revans' study is particularly interesting in that it deals with situations where machine aspects are negligible—hospitals. It is, however, obvious that for 'ward sister' one could write 'foreman', for

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'disposal of patients' (an intriguingly ambiguous expression) one could write 'output'; in other words, some at least of the principles and techniques employed in this study should be transferable from the hospital to an industrial or a military context. In my opinion there are to date far too few studies of this kind and far too few OR people involved in ventures of this difficult nature, which could materially improve the accuracy of our forecasts regarding the behaviour of systems. In fact, from the point of view of the viability of OR the problem of understanding and catering for the behaviour of decision-makers is to my mind far more important than the elaboration and evolution of even more sophisticated techniques.

Another contribution which may be mentioned here is that of Faverge who has discussed subjective probability with special reference to industrial accident prevention, a sphere in which operational research has long been active. However, I don't think the reference to accidents should divert our attention from Faverge's main theme, subjective probability ; accidents are, as he points out, emotion-evoking events, and in this context I think his concept has implications which go far beyond this particular field. Obviously there is an application to management decision-making. I think it would be agreed that the OR report is based essentially on the notion of objective probability, and it is at the Managerial Committee meeting or in the individual Manager's head that objective probability statements are confronted with the subjective probability structure built up within the one or several brains by past experience. My own experience certainly seems to bear out what Faverge implie : namely that in cases of conflict betw n subjective and objective probability it is the tendency for the latter to lose out.

To some extent Churchman and Ratoosh's fascinating study, although they regard it as preliminary and incomplete, is complementary to Faverge in that their experiments appear to suggest how relatively weak is the impact of objective assessment when confronted with subjectively conceived structures. It occurs to me in this connection that we might learn from the psychologists' studies of skill. They suggest that—certainly in so-called manual operations—*timing* is the all important factor. Perhaps *timing* has as vital a part to play in the OR man's skill, especially at the reporting stage. If, as I think to be the case, there is such a thing as social skill, a skill in communicating with others, is there not good reason to suppose that *timing* is as vital as in manual skillers ?

Most people would probably be willing to admit that their actions are often coloured by emotion; few would be ready to allow that their thought processes are not logical. But, just as OR men are convinced of the logic of their thought processes (and possibly of their being governed by objective probability) so too are management. Porter and McLean's paper suggests in effect that both parties may be mistaken; they attempt to put logical thinking to the test of experiment and show what a surprisingly elaborate and subtle accomplishment it really is. We would be wise not to rely on its automatic occurrence either in ourselves or in managements.

I feel that not enough attention has been paid by OR people to the 'human factor' in many of their problems. I believe we have a lot to learn from the work done in experimental psychology, the results of which may be vital to the success of our own endeavours. I believe also that experimental psychology may well benefit by contact with the ideas emanating from the development of operational research.

Organisations & Goal Revisions

C West Churchman*

Operations research can be viewed not only as an attempt to solve problems via research methods but also to develop new problems and to establish the importance of these within an organisation.

WE begin with a brief characterization of an organization within a means—ends schema. This is not so much a definition as a set of minimal specifications which any group called an organization must satisfy. We then consider an important subclass of organizations whose goal structure is such that to survive they must create new problems. We end by suggesting the framework of research which such organizations require for their long-range planning.

Briefly, the minimal conditions for the existence of an organization are taken to be the division of labour among members of a group in such a way that the members pursue goals which are supposed to aid in the accomplishment of the overall goals of the organization.

More specifically, the following must pertain:

(a) An organization is a group of people (b) The group at any moment of time is pursuing a set of goals (c) The goals are aspects of states of nature at various future points of time (d) The group at any moment of time has alternative policies which it can adopt (e) A policy is a description of that part of the potential behaviour of the entire group which is relevant to the goals (f) Any given policy can be subdivided in such a way that the subdivisions are descriptions of potential behaviour of a subgroup of the organisation (g) Each subdivision of a policy can be viewed as a purposive act relative to a set of goals (h) Each subgroup is motivated to a certain degree to pursue the subgroup goals (i) There is a way to estimate the effectiveness of any organizational design (j) An organisational design is a particular subdivision of the policy and degree of motivation of the subgroups for their goals.

ideal-seeking organisations

We now consider an important class of organizations. These are the groups which are committed to long-range goals. Put otherwise, they are groups for whom indefinite survival is an overriding goal. But 'survival' does not mean the continued existence of a group with a certain name and rules of membership. Rather the survival of the group occurs only if the group continues to pursue the same kinds of objectives. More specifically, an organisation will be called 'ideal-seeking' if its history and prospect can be viewed as the pursuit of an unattainable objective and its practical policies over specific time spans can be viewed as segments of an endless chain of approximations to an ideal.

In detail:

(k) The policies of an organization can be defined in terms of specific time spans (l) The goals of the policies are potential outcomes which may occur at the end of the time span (m) Consider two adjacent time spans T_1

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and T_2; in ideal-seeking organizations the effectiveness of a policy in T_1 is partially measured in terms of its contribution to the effectiveness of policies in T_2 (thus, one goal T_1 is to maximize the effectiveness of the best practical policy in T_2) (n) Consider a sequence of time spans T_1, $T_2 \ldots T_m$. The goals of each time span support the goals in T_m if the maximally effective policies in each time span T_j ($j<m$) produce an increase in the effectiveness of the best policy in T_m (o) An ideal is the limit of a set of goals of a supporting sequence which is unattainable, but can be approximated within any prescribed limit (p) An organization is ideal-seeking if its goals in any time span can be viewed as the maximal support of the policies of the next time span and if the goals of all m past time spans can be taken as the first m terms in the approximations of an ideal. (q) An ideal-seeking organization survives, if, and only if, it can be construed as pursuing the same ideal.

goal change

We turn now to the consideration of the creation of new goals. The above account makes it clear that in each subsequent time span at least some of the practical goals of an organization must change. The problem is to ascertain how this change ought to take place. An example may help to make the nature of the problem clear.

A company makes a five-year plan in which one of the goals is to attain 10% of the market. Suppose at the end of the time period this goal has been attained. Then the company must re-evaluate the goal relative to the next period. It 'knows how' to attain 10% of the market in the situation which pertained in the first period. Should it rest content with this goal, or should it modify it ? The ideal is probably not one of attaining 100% of the market even if this could be approximated. Its ideal may be instead to attain only 10% of the market in *any* situation that may pertain. If this is the case, then its goals in the next period may be defined in terms of other aspects of the business, e.g., in terms of a change in its research-and-development goals.

aggrandizement vs. refinement

This illustration suggests two aspects of the study of ideal-seeking organizations, both of which are important. One is the weakness of studying organizational survival in terms of maximizing along an infinite scale (e.g., maximizing profit, power, personnel, gross assets, etc.). The other is the fact that the ability to attain a goal with complete success is a sign that some of the goals of the organization need to be changed in the next planning period.

It is possible to construe the goals of an organization over its history as attempts to add increments to an endless pile. Such a construction will not satisfy the conditions of ideal-seeking which has been imposed above, because the goals do not approximate any ideal. We differentiate between viewing an organization in terms of aggrandizement (adding increments endlessly) and refinement (approximating an ideal).

We pose the following two assertions: (r) All organizations whose policies over an indefinitely long series of time spans can be viewed as aggrandizements can also be viewed as refinements. (s) Viewing the policies as refinements better enables the researcher (and manager) to ascertain what goals ought to be changed in the next time span.

I feel some uncertainty about both of these assertions, of course. Their defence lies in an analogy with scientific progress. Science apparently can be construed as an ideal-seeking activity. At times its goals have been stated in terms of aggrandizement e.g., to add increments of knowledge. But I believe that the study of the problems of scientific method can be far more fruitfully carried out if we view the goals in terms of refinement (precision) : to make each estimate (measurement or forecast) more precise.

success as minimal learning

Suppose an organization has attained a goal. Suppose, furthermore, that the relative frequency of successful attainment by a given policy in a specific situation is virtually one. But suppose the ideal is to attain the goal no matter what situation pertains (e.g. even though there is a recession, or a depletion of a certain resource). But suppose also that in the next period the situation remains essentially the same. If the same set of goals are pursued by the same policies the organisation will learn nothing additional about the way to attain the goal in other situations. But suppose that during the next period it attempts a more difficult problem relative to which its success is not certain. If this problem is a refinement of the previous problem, then it may very well be that a shift in goals is desirable. Such a shift might maximize the effectiveness of the optimal policy in some later time period. Hence:

(t) If in a given time period the organization is completely successful in the pursuit of a goal, then this is a sign that the goal should be changed and further refinement should be sought instead.

Thus, a company which successfully markets a product in one period will turn to product differentiation in the next. It will do this even at the risk of losing its market share for the undifferentiated product. It does this in order to 'survive' i.e., to learn how to succeed even though conditions change.

Put otherwise, the pathway to successful forecasts is not the extrapolation of past sales records into the future. This primitive form of logical induction is as naive in business as it is in science. In the scientific laboratory if we observe the same reaction over and over, then this is a sign that we should make the experiment more difficult. Otherwise we have no assurance that the reaction will reoccur. But if we refine the experiment, e.g., by measuring the response out to one more decimal place, then the success of the first series of tests is a consequence of the refined model attained by the second series. In the same way, one sound way of forecasting a market relative to a business goal is to try to accomplish something much more difficult.

conclusion

In order to bring the discussion into focus, the following consequences should be noted: (i) Organizations which wish to survive must try to create new problems, not merely solve old ones. With respect to operations research, this means that research for top management should not be conceived as the search for plans that will optimize with respect to 'given' objectives. Research should also take the form of search for means to decrease interest in old goals and create interest in new ones.

(ii) The policy of optimal goal revision is not easy to determine, and an ill-conceived policy may lead to considerable social losses.

There is much to be said, for example, against the goal revision policies of some of our larger companies which have led to expansion after expansion, and the suppression of smaller enterprises, labour movements, and other manifestations of social freedom. The solution is not simply a routine of adding increments to total asset or total personnel, because this kind of goal revision is sterile or else ethically bad. Ultimately certain kinds of routine expansion and merger lead to legal retaliations which partially destroy the organization and therefore thwart its survival aims. But companies ought not to rely on legal sanctions to keep them from following undesirable policies of goal revision. The problem is to find a way to grow in refinement without incurring a senseless and dangerous obesity.

Human Performance in the Solution of Logical Problems

Porter* & McLean†

THE authors have tried to work out a method of assessing the ability of human operators to solve logical problems. The class of problems under consideration can be defined symbolically in terms of two-valued logical statements, when the operator acts essentially in a decision-taking role in their solution. A logical problem-solving machine (e.g., logical computer), of the type first developed by McCallum and Smith, was adapted for the experiments, providing a suitable method of presenting information to the operator concerning his past and present performance in the goal-seeking process. In effect, the situations which were investigated correspond to feedback processes in which the operator provided the monitoring action. Some preliminary results suggest that the operators combine deductive reasoning and intuition in seeking solutions, although it has not been found possible to rationalize their rules of behaviour except in the most general way. It is considered that experiments of this type will have increasing value in the study of the controllability of complex processes.

The study of the behaviour of human operators as elements in feedback control systems has attracted considerable attention, and important information concerning the nature of the motor response of operators in carrying out 'target tracking' tasks has been obtained. And the work of Hick on 'choice reaction-times' has appreciably facilitated these studies by introducing the concept of the information-handling capacity of human operators regarded as complex communication channels. But these investigations, although essentially goal-seeking in nature, do not require much logical reasoning, i.e., decision-taking, on the part of the operators. Indeed, it is most improbable that good tracking ability is correlated with good reasoning ability.

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I like to see the Governor now and then
And take good care to keep relations civil
It's decent in the first of gentlemen
To speak so friendly, even to the devil!

—from the Soliloquy of Mephistopheles

Innovation in Group Behaviour

Churchman & Ratoosh*

Implementation of its conclusions is an important, but neglected, part of operations research. In another paper, the authors have described experiments simulating implementation in small groups who are instructed to run a business firm so as to maximize the firm's profit. Certain decisions must be made for each simulated operating period. After several such periods the group is supplied with a report which claims, correctly, to present a fairly simple method of making the optimal decisions. The group's reception of the report is then analyzed as a function of the structure of the group, the personalities involved and their roles, the origin and the form of the report, and the system of information transmission within the firm.

THE experiments were intended to suggest problems for investigation in larger organizations rather than to arrive at definitive conclusions, and in this the work appears promising. No group yet studied has accepted the report, and the reasons given are similar to those encountered in larger organizations.

From these studies, we see that the most subtle aspect of implementation lies in the concept of understanding. A man does not necessarily understand a solution even though he has been given good reason for it. He may adopt a solution because of time pressure or other stresses, but if he lacks understanding he will naturally be inclined to try other possibilities. We are coming to feel that our studies to date indicate the need for a much deeper analysis of the concept of understanding and for a series of experiments in which methods of developing understanding of solutions can be tested. Some of these experiments may be a good deal simpler than the ones we have conducted to date, and others will undoubtedly be much more complicated.

One result of our experience is that we have come to feel that studies like this that attempt to investigate phenomena of large organizations, in spite of their seeming artificiality and lack of realism, capture extremely well the complexities actually existing in large operating organizations. As a matter of fact, *that is precisely the defect of these studies: they are too realistic.* The problems of large-scale organization seem to be imaged so truthfully in these small groups that an analysis of our results is almost as complex as a study of a large operating system: we find a lack of time on the part of the decision-makers; lack of an over-all perspective; too much attention paid to irrelevant data (e.g., the profit made on the operating statement); an inclination to deviate from an adopted policy; nervous tensions of the managers; reluctance to feel the common bonds of mutual understanding. ●●

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" . . . What is uttered from the heart alone will win the heart of others to your own . . "

—*Goethe*

SHORTER FLAME HARDENING PROCESS

Linear Programming in Textile Industry

JN Kapur*

A TEXTILE Mill has L looms and S spindles. The spindles are capable of producing both rough and fine yarn and the looms can weave both types of cloth. Some of the yarn produced by the spindles is used in the mill and the rest is sold out. In case of shortage of yarn for the looms, it can be bought from other spinning mills. The problem is to allot spindles and looms to fine and coarse varieties so as to maximize profits

Let

- b_1 be the number of spindles required to produce fine yarn for one loom,
- b_2 be the number of spindles required to produce coarse yarn for one loom,
- p_1 be the profit when a loom and its associates spindles prepare fine cloth for one day,
- p_2 be the profit when a loom and its associates spindles prepare coarse cloth for one day,
- p_3 be the profit when a spindle spins fine yarn for one day,
- p_4 be the profit when a spindle spins coarse yarn for one day,
- x be the number of looms allotted to fine cloth production,
- y be the number of spindles allotted to fine yarn production,
- z be the profit function,

then

$$z = p_1x + p_2(L-x) + (y-b_1x)p_3 + [(S-y)-b_2(L-x)]p_4 \quad \ldots (1)$$

$$= x(p_1-p_2-b_1p_3+b_2p_4) + y(p_3-p_4) + p_2L - p_4S - b_2Lp_4, \quad \ldots (2)$$

has to be maximized subject to

$$x \geqslant 0; \quad L-x \geqslant 0; \quad y \geqslant b_1x; \quad S-y \geqslant b_2(L-x) \quad \ldots (3)$$

We have to consider nine different possibilities viz.

I : $S > b_1L$, $S > b_2L$; II : $S > b_1L$, $S = b_2L$; III : $S > b_1L$, $S < b_2L$;
IV : $S = b_1L$, $S > b_2L$; V : $S = b_1L$, $S = b_2L$; VI : $S = b_1L$, $S < b_2L$;
VII : $S < b_1L$, $S > b_2L$; VIII : $S < b_1L$, $S = b_2L$; IX : $S < b_1L$, $S < b_2L$

We consider these in turn

CASE I $S > b_1L$, $S > b_2L$

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In this case inequalities (2) can be represented geometrically as follows:

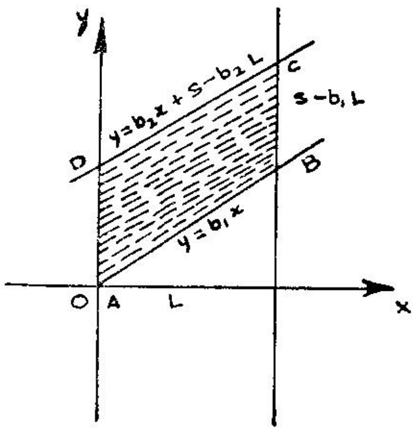


FIG. 1.

The shaded area represents all possible feasible solutions and according to the theory of linear programming, the optimal solution will be given by the points A, B, C or D.

Solution A means $x=0$, $y=0$ so that all looms and all spindles have to be allotted to coarse cloth and yarn production; the coarse yarn of $S-b_2L$ spindles has to be sold out.

Solution B means $x=L$, $y=b_1L$ so that all looms have to be allotted to fine cloth production and the extra $S-b_1L$ spindles have to be used for producing coarse yarn for export.

Solution C means $x=L$, $y=S$ so that all looms have to be allotted to fine cloth production and all looms to fine yarn production.

Solution D means $x=0$, $y=S-b_2L$ so that all looms have to be allotted to coarse cloth production and the extra yarn capacity has to be used for producing fine yarn for sale.

The optimal solution will depend on the signs of

$$P\equiv(p_1-b_1p_3)-(p_2-b_2p_4),\quad Q\equiv p_3-p_4 \qquad ..\ (4)$$

$P \gtreqless 0$ according as the profit on using a loom and associated spindles on fine cloth is greater than, equal to or less than the profit on using a loom and associated spindles in coarse cloth production.

$Q \gtreqless 0$ according as the profit on using a spindle for fine yarn is greater than equal to or less than the profit on using it for coarse yarn.

Remembering the above interpretation of solutions A, B, C, D and of the signs of P and Q, we have the following nine cases

Subcase	Signs of P and Q	Optimal Solution
1·1	$P>0,\ Q>0$	C
1·2	$P>0,\ Q=0$	Any point on line B C
1·3	$P>0,\ Q<0$	{ A if $P+b_1Q\leqslant0$ B if $P+b_1Q\geqslant0$
1·4	$P=0,\ Q>0$	C
1·5	$P=0,\ Q=0$	Any point in shaded region
1·6	$P=0,\ Q<0$	A
1·7	$P<0,\ Q>0$	{ C if $P+b_2Q\geqslant0$ D if $P+b_2Q\leqslant0$
1·8	$P<0,\ Q=0$	Any point on line A D
1·9	$P<0,\ Q<0$	A

CASE II $S>b_1L$, $S=b_2L$

In this case solutions A and D coincide, otherwise the result of Case I holds

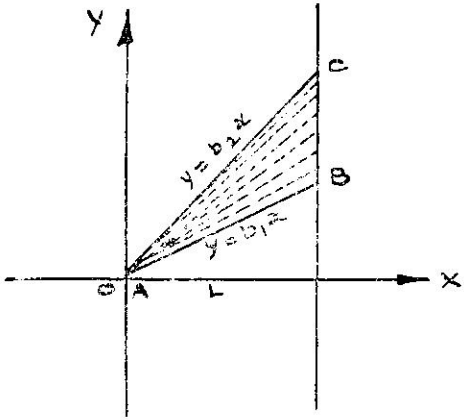


FIG. 2.

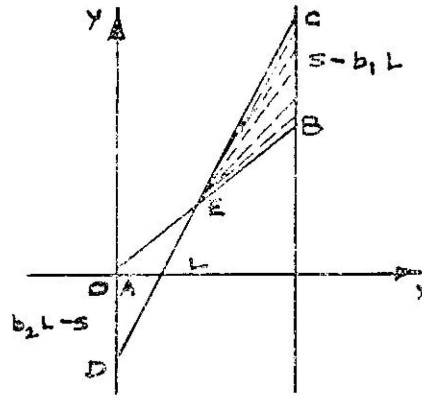


FIG. 3.

CASE III $S > b_1L$, $S < b_2L$

In this case the shaded area gives feasible solutions and the optimal solutions are given by B, C and E. Solution E corresponds to

$$x = \frac{b_2L - S}{b_2 - b_1}, \quad y = \frac{b_1(b_2L - S)}{b_2 - b_1} \qquad \ldots \qquad (5)$$

In this case, the following subcases arise:

Subcase	Signs of P and Q	Optimal Solution
3·1	$P>0$, $Q>0$	C
3·2	$P>0$, $Q=0$	Any point on B C
3·3	$P>0$, $Q<0$	{ B if $P+h_1Q \leqslant 0$ { E if $P+b_1Q \geqslant 0$
3.4	$P=0$, $Q>0$	C
3.5	$P=0$, $Q=0$	Any point in $\triangle$ BCE
3.6	$P=0$, $Q<0$	E
3.7	$P<0$, $Q>0$	{ C if $P+b_2Q \geqslant 0$ { E if $P+b_2Q \leqslant 0$
3.8	$P<0$, $Q=0$	E
3.9	$P<0$, $Q<0$	F

CASE IV $S=b_1L$, $S>b_2L$

In this case solutions B and C in Fig. 1 (pre-page) coincide, otherwise the solution of Case I hold

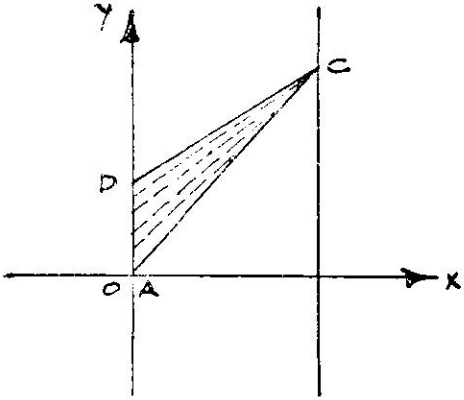


FIG. 4.

CASE V $S=b_1L, \quad S=b_2L$

In this case lines AB and CD coincide and any point on line AB is a feasible solution.

Also

$$z=(p_1-p_2) \quad x+p_2 \ L$$

If	$p_1>p_2$	the optimal solution is B
If	$p_1<p_2$	the optimal solution is A
If	$p_1=p_2$	any point on AB gives an optimal solution

CASE VI $S=b_1L, \quad S<b_2L$

The only feasible and therefore optimal solution is given by points B and C which coincide i.e. the optimal solution is

$$x=L, \qquad y=b_1L$$

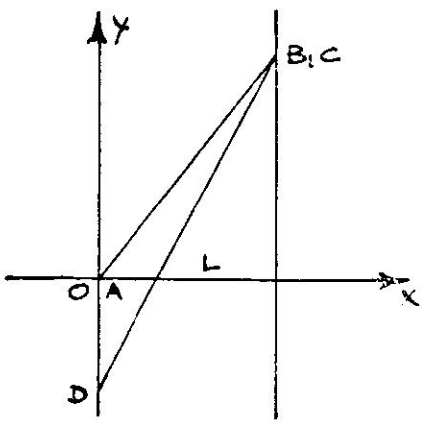


FIG. 5

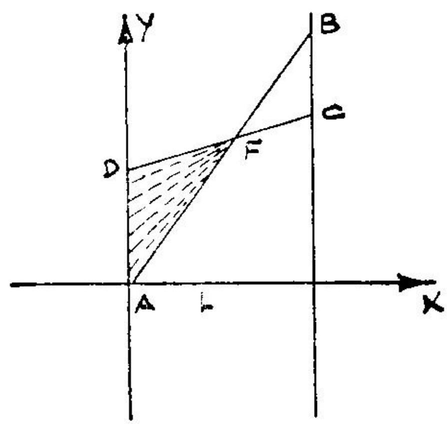


FIG. 6

CASE VII $S<b_1L, \qquad S>b_2L$

In this case the shaded area in Fig. 6 gives feasible solutions and the optimal solutions are given by A, D, F.

Solution F corresponds to

$$x=\frac{S-b_2L}{b_1-b_2}, \quad y=\frac{b_1(S-b_2L)}{b_1-b_2} \qquad .. \qquad (6)$$

The following subcases arise :

Subcase	Signs of P and Q		Optimal Solution
7.1	$P>0$,	$Q>0$	F
7.2	$P>0$,	$Q=0$	F
7.3	$P>0$,	$Q<0$	$\begin{cases} \text{F if } P+b_1Q\geqslant 0 \\ \text{A if } P+b_1Q\leqslant 0 \end{cases}$
7.4	$P=0$,	$Q>0$	F
7.5	$P=0$,	$Q=0$	Any point in shaded region
7.6	$P=0$,	$Q<0$	A
7.7	$P<0$,	$Q>0$	$\begin{cases} \text{F if } P+b_2Q\geqslant 0 \\ \text{D if } P+b_2Q\leqslant 0 \end{cases}$
7.8	$P<0$,	$Q=0$	Any point on AD
7.9	$P<0$,	$Q<0$	A

CASE VIII $S<b_1L$, $S=b_2L$

The only feasible and therefore optimal solution is $x=0$, $y=0$ i.e. solution A which coincides with solution D.

CASE IX $S<b_1L$, $S<b_2L$

There is no feasible solution in which all the looms can be used with the yarn produced in the mill. In this case some yarn has to be bought from outside and p_3, p_4 represent the losses per spindle due to buying yarn from outside rather than spinning it inside the mill and let yarn equivalent to z fine spindles and u coarse spindles be purchased, then

$$z=p_1x+p_2(L-x)-p_3z-p_4u \quad .. \quad (7)$$

also

$$b_1x-z+b_2(L-x)-u=S \quad .. \quad (8)$$

$$b_1x-z \qquad =y, \quad .. \quad (9)$$

so that

$$z=p_1x+p_2(L-x)-p_3(b_1x-y)-p_4[b_2(L-x)-(S-y)]$$

or

$$z=x\,(p_1-p_2-b_1p_3+b_2p_4)+y(p_3-p_4)+p_2L+Sp_4-b_2p_4L \quad .. \quad (10)$$

Thus the objective function is the same, but inequality constraints are changed. These are

$$x\geqslant 0,\quad L-x\geqslant 0,\quad b_1x\geqslant y\geqslant 0,\quad S-y\geqslant b_2(L-x) \quad .. \quad (11)$$

The feasible solutions are given by the shaded area in Fig. 7 and the feasible solutions can be C, G or H where

$$\text{C is} \quad x=L, \qquad y=S \quad .. \quad (12)$$

$$\text{G is} \quad x=L, \qquad y=0 \quad .. \quad (13)$$

$$\text{H is} \quad x=L-\frac{S}{b_2}, \qquad y=0 \quad .. \quad (14)$$

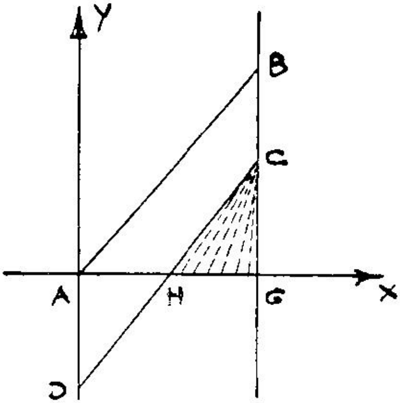


FIG. 7.

The following subcases arise :

Subcase	Signs of P and Q		Optimal Solution
9.1	$P>0$,	$G>0$	C
9.2	$P>0$,	$Q=0$	Any point in CG
9.3	$P>0$,	$Q<0$	G
9.4	$P=0$,	$Q>0$	C
9.5	$P=0$,	$Q=0$	Any point in the shaded region
9.6	$P=0$,	$Q<0$	Any point in GH
9.7	$P<0$,	$Q>0$	C if $P+b_2 Q \geqslant 0$ H if $P+b_2 Q \leqslant 0$
9.8	$P<0$,	$Q=0$	H
9.9	$P<0$,	$Q<0$	H

KEY FOR THE TABLE (page 302)

Solution	Looms for fine cloth	Looms for coarse cloth	Spindles for fine yarn	Spindles for coarse yarn
A	0	L	0	S
B	L	0	b_1L	$S-b_1L$
C	L	0	S	0
D	0	L	$S-b_2L$	b_2L
E, F	$(b_2L-S)/(b_2-b_1)$	$(S-b_1L)/(b_2-b_1)$	$b_1(b_2L-S)/(b_2-b_1)$	$b_2(S-b_1L)/(b_2-b_1)$
G	L	0	0	S
H	$L-\frac{S}{b_2}$	$\frac{S}{b_2}$	0	S
A point on BC	L	0	between b_1T and S	between 0 and $S-b_1L$
A point on AD	0	L	less than b_2L	greater than $S-b_2L$
A point on GH	between $L-\frac{S}{b_2}$ and L	between $\frac{S}{b_2}$ and 0	0	S

When $P=0$, $Q=0$, all feasible solutions give the same profit and are therefore optimal.

Summary of Results

TABLE FOR OPTIMAL SOLUTIONS

CASE Signs of P and Q	I	II	III	IV	V	VI	VII	VIII	IX
$P>0, Q>0$	C	C	C	C	B	C	F	A	C
$P>0, Q=0$	Any point on BC	Any point on BC	Any point on BC	C	B	C	F	A	Any point on line C
$P>0, Q<0$	A if $P+b_1Q\leq 0$, B if $P+b_1Q\geq 0$	A if $P+b_1Q\leq 0$, B if $P+b_1Q\geq 0$	B if $P+b_1Q\leq 0$, F if $P+b_1Q\geq 0$	A if $P+b_1Q\leq 0$ C if $P+b_1Q\geq 0$	B if $P+b_1Q\geq 0$ A if $P+b_1Q\leq 0$	C	F if $P+b_1Q\geq 0$ A if $P+b_1Q\leq 0$	A	G
$P=0, Q>0$	C	C	C	C	B	C	F	A	C
$P=0, Q=0$	Any point in shaded region in Fig. 1	Any point in shaded region in Fig. 2	Any point in shaded region in Fig. 3	Any point in shaded region in Fig. 4	Any point in line AB	C	Any point in shaded region in Fig. 6	A	Any poin in shaded region in Fig. 7
$P=0, Q<0$	A	A	E	A	A	C	A	A	Any poin in GH
$P<0, Q>0$	C if $P+b_2Q\geq 0$, D if $P+b_2Q\leq 0$	C if $P+b_2Q\geq 0$ A if $P+b_2Q\leq 0$	C if $P+b_2Q\geq 0$ D if $P+b_2Q\leq 0$	C if $P+b_2Q\geq 0$ D if $P+b_2Q\leq 0$	B if $P+b_2Q\geq 0$ A if $P+b_2Q\leq 0$	C	F if $P+b_2Q\geq 0$ D if $P+b_2Q\leq 0$	A	C if $P+b_2Q\geq 0$ H if $P+b_2Q\leq 0$
$P<0, Q=0$	Any point on line AD	A	E	Any point on line AD	A	C	Any point on line AD	A	H
$P<0, Q<0$	A	A	E	A	A	C	A	A	H

Operations Research in the Textile Industry

N Subramaniam*

The aim of Operations Research is to help Management decide, scientifically, its policy and action. This article indicates some OR applications in the textile industry. In this connection, it would be of interest to note that one of the early applications of Linear Programming was made in an Indian textile mill.

A MAJOR decision which textile management has to make periodically relates to what fabrics to produce and in what quantities. Alternative courses of action are considered, keeping one eye on the total profit to the firm and the other on the sales potential of the fabrics and the machinery available for the production of quantities decided upon. Whatever the process of reaching the final decision, no questions are usually asked as to whether the decision was the best under the circumstances. The reason is not far to seek. A better solution than the one already reached is not often obvious. Operations Research has developed methods by which through a systematic process the best decision is reached with a guarantee that it *is* the best.† It has been reported that the use of such Operations Research known techniques as, for example, Linear Programming, in American Industry has led to increases in profit of 10 to 20 percent. Additional advantages claimed as a result of OR have been to aid top management by making planning sessions a routine affair, making it easy for them to redirect promotion efforts into worthwhile channels etc.

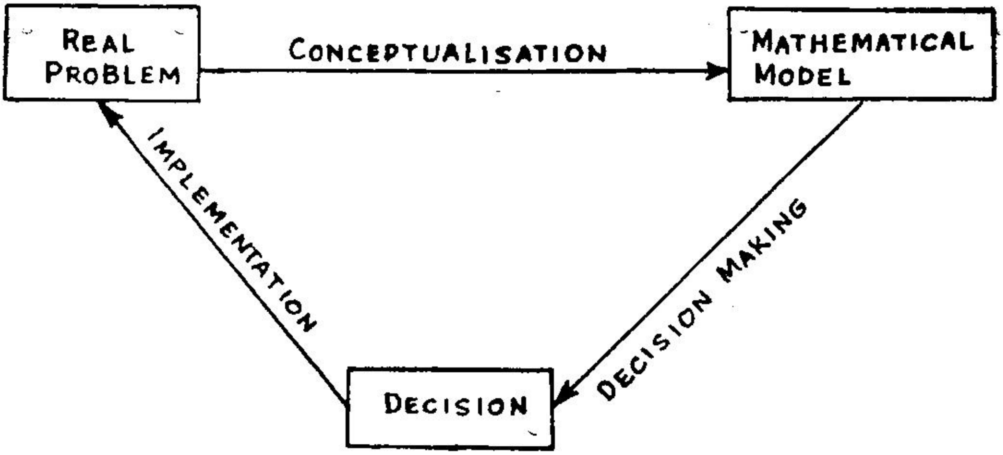
*Ahmedabad Textile Industry's Research Association.

†Usually, Operations Research scholars do not put it in such categorical language. OR, so they say, furnishes the basis (as also the techniques) for such an all-round ordering of total resources so as to create conditions, which lead in a determined manner to an optimisation of over-all results. (*Editor*)

Certain features of Operations Research may be noted with reference to this application of OR in production planning. The goal is to reach decisions *which can be implemented with* the greatest advantage to the concern. In between, the first step is the conceptualisation of the real problem in terms of a mathematical model and the second is the use of the model for decision-making. OR is schematically illustrated on the next page.

Another area where OR has been used in the textile industry is the field of inventory. A textile mill has to keep inventories for a variety of reasons. Sometimes customers require delivery in less time than it takes to manufacture. Secondly, seasonal fluctuations in sales may be sharp and a mill does not have sufficient capacity to meet high demands. Lastly, a mill may have to maintain a reasonably constant level of employment all through the year despite fall in demand for some of its products. The problem before the management is to determine how much goods to produce in anticipation of customer orders so as to minimise losses arising out of distress sales at the end of the season while providing adequate inventories to meet customer demands. In solving this problem, methods for measuring the chance that cloth manufactured for inventory is sold before the end of the season are used.

The British Cotton Industry Research Association was given a problem by a firm,



burdened with large stocks on hand for a considerable length of time and of simultaneous shortages of some cloths as a result of limitations on the production capacities available. Analysis of the demand for various types of cloth enabled reduction being effected in stock-holding costs. Decisions on stock levels which would result in minimum costs or maximum profits, when costs were associated with both stock-holding and shortages, were also reached through use of mathematical models.

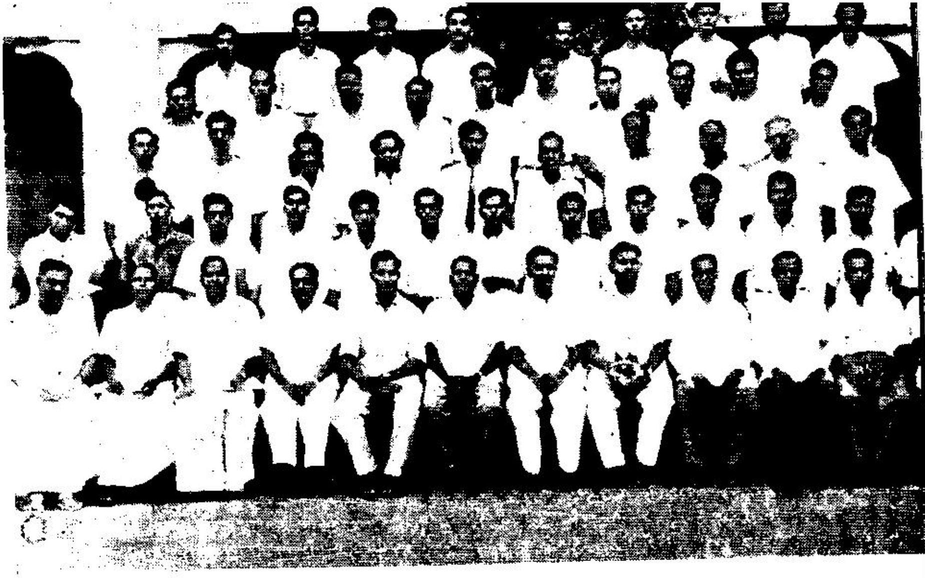
Yet another area of applicability of OR is in the purchase of raw materials. Management has to decide on purchases to meet production schedules. As a general rule it buys at least what it needs immediately. Also, if it feels that the market price is high it buys the very minimum with which it can carry on. At lower prices, it gets more than is necessary to meet immediate needs. The management decisions in this area are (1) *What price* to buy at ? (2) *How much* to buy at ruling prices ?

OR has provided methods for reaching decisions of this type in a systematic manner.

As prices increase a mill that has booked its capacity well ahead of time finds that more profitable business has to be refused because of delivery difficulties. OR methods have been applied to establish price levels (for specific sorts) at which offers to buy are rejected. Such levels are available for successive points of time. American industry is reported to have derived considerable benefits by working out such policies.

OR in textile industry has been a very recent activity. Pioneering work has been done by a firm of Accountants in America by the name of Arthur Andersen & Co. The Cotton Board Productivity Centre and the Shirley Institute in UK are doing much to popularise OR approach in solving textile management problems. In our own industry this activity has only begun. ●●

Sir Frederick Bouman suggested that the hangman showed too great a consideration for murderers about to die: 'Before they are hanged, they should be flogged.'



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'S Seminar Team leader
t Calcutta

APO Participants in Leather Tanning & Finishing Course at the Central Leather Research Institute, Madras

Operations Research in Textiles

RM Phatarfod*

Unlike Statistical Quality Control, Operations Research has not been widely applied in the Indian Textile Industry, the main reason being the lack of competent and trained operations research workers. It is for this purpose, SASMIRA organized last year a training course in operations research for textile industry, and proposes to organise another course this year. Operations research has a vital role to play in textile industry. The following paper outlines some of the techniques of operations research which have been used in the textile industries of the advanced countries and which can be used to advantage in the Indian Textile Industry.

IN the textile industry, as in other industries, operations research can be applied both at the industrial engineering level and the management level. Industrial engineering problems are relatively restricted in scope, whereas management problems may be almost unlimited in scope. The latter, may, for instance include complete sales, production and stock policy of a company having several mills.

At the management level the most useful tools of operations research are Linear Programming, Inventory Control and Sales Forecasting, whereas Queueing Theory and Evolutionary Operation can be used to advantage by the industrial engineer. Linear programming in a textile mill is particularly useful in the coordinating of sales goals with productive capacity, so that the combined efforts of selling and producing will lead to an optimized result in terms of final mill profit; hence *a mill producing a large variety of sorts can effectively use linear programming for profit planning.* The reasons for this are as follows:

1. Each sort of fabric affects, very differently, the productive capacity of the various mill processing departments: some sorts require more time for carding, roving and spinning whereas others require more weaving and finishing time.

2. Each sort has a different market potential and profit margin. Often a sort with good profit margin may be uneconomical to produce in large quantities, if its productive requirements in carding, drawing, roving, spinning or weaving tend to create bottlenecks in one or several stages of processing. *Linear programming evaluates the elements of production facilities, profit margins and market potential with regard to each style.* From this evaluation an optimum production combination yielding maximum over-all profit, can be obtained.

Sales anticipation curves as an aid in management's coordination of sales, production schedules and inventory build-ups can be of great use in the textile industry. The benefits, obtained from the use of sales anticipation curves in management planning vary, however, with market factors. The sales anticipation curves aid in planning production and building up inventories in such a manner as will minimise undue excess or embarrassing shortages of stock. Analysis of patterns and trends from past sales records will often yield valuable guidance to future action, policy and decisions. At the industrial engineering level, an industry's technical problems cannot be solved entirely in the

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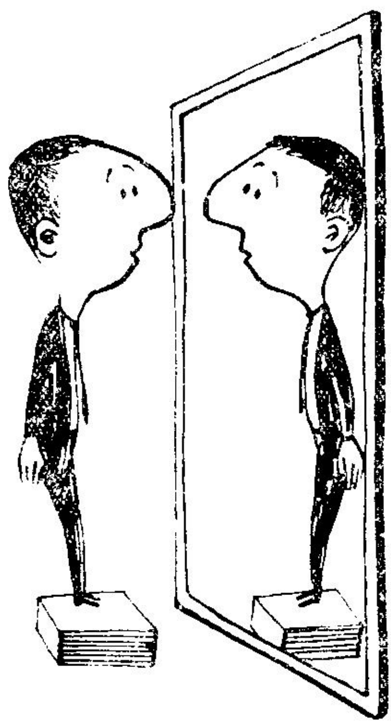
laboratory; they *must be studied through to the point of application in the factory.* Operations research comes as a handy tool for this study.

In the textile industry, OR has taken several forms.

First, there is the mill experiment. The best mixing of cotton for a given yarn, the best roller settings to use, the best size to put on the warp, the best speed ratios, tension, twists and other variables cannot be specified accurately by general research done at some central institute. The results of the general research give some guidance but final results must take into account particular conditions at the individual mill; hence *systematic mill experiments are necessary.* A systematic procedure, which helps the mill man in his process research to find the best settings is the relatively new technique of "Evolutionary Operation" or EVOP, for short, originated by GEP Box for Imperial Chemical Industries and used in the manufacture of synthetic fibres. In subsequent processing (spinning, weaving and finishing) profitable applications of EVOP have just begun to be explored. The programme involves the introduction of routines for systematic small changes in the levels at which process variables are held. After each set of changes, the effects on quality, waste, yield and production are reviewed. Based on this review further changes are planned, aimed at *gradually 'nudging' the process towards these multivariable adjustments that lead to the attainable optimum.*

Secondly, the Theory of Queues has direct application to the problem of Machine Interference, which occurs wherever one operative attends to a number of machines which stop independently so that if two stop together one has to wait for attention. In textile industry, this occurs in spinning operation, and in winding and weaving sections. Knowledge of the Theory of Queues enables one to solve such problems as the number of spindles per operative for a particular count of yarn, the number of looms per weaver for a particular sort etc. ● ●



Know Thyself!

OR Technique in Engineering Factory

MSK Eswaran*

Operation Research is the application of scientific method to the study of alternatives in a problem situation with a view to providing a quantitative basis for arriving at an optimal solution in terms of a desired target. It is an organized activity with a more or less definite methodology of attacking new problems and finding solutions. In OR, a clinical approach is necessary in order to solve the problem in the right perspective. Hence the emphasis is on scientific method, on the use of quantitative data, on targets and on the determination of the optimum means of reaching the target. OR, of course, uses mathematics, but it is not a branch of mathematics. It utilises the results of time and motion study, but it is not efficiency engineering. It introduces new equipments, but it is not an adjunct of a development theory. It is more than Quality Control.

OPERATION Research helps in taking basic decisions as to the extent to which quality can be sacrificed in the interest of cost savings, the level of product performance required by competitive factors, and the need for quick production and delivery. OR has also been confused with systems engineering. The latter deals primarily with changes in equipment models whereas the operations analyst is primarily interested in making procedural changes. Systems engineering aims at development of components, changes in design and alteration or perfection in the existing model. Operations Research deals with problems relating to organisation and methods pertaining to operational problems.

While OR uses all productivity techniques, it has also developed its own techniques, of which the brightest is Linear Programming. It is based upon the assumption that a linear or straight line relationship exists between variables and that the limits of variation can be well determined. In a production line, factors like units of output per machine, per hour, direct labour cost per unit of output and the number of operations to be carried on for making a component may have linear relationships, within certain limits, such as machine capacity etc. Linear programming helps (i) organise the facts and information about a problem; (ii) analyse all possible alternative solutions to the problem; (iii) select the right course to follow under particular conditions; (iv) plan the definite steps in order to arrive at better results; and (v) remodify and re-evaluate the plan for changed conditions.

The usefulness of Linear Programming may be illustrated from a concrete example: factory produces two products. Each product requires processing in two departments i.e., a press shop and a finishing shop.

The relevant data are as follows:—

Capacities per day in units

product	*press shop*	*finishing shop*	*contribution margin p/unit*
X	300	180	Rs. 3.00
or			
Y	150	300	Rs. 3.75

*Cost Accountant & Statistician, JK Business Ltd., Calcutta.

The limiting factor for Product Y is Material. Owing to this limiting factor, maximum production of Y per day will be 120. The objective is to find out the product combination that maximizes *total* contribution margin. The equation that can be derived from the data will be

3.00X+3.57Y = TCM (Total Contribution Margin) and this has to be maximized.

The basic relationships can be depicted by the inequations as under:

Press Shop	: $2X+Y \leqslant 100$ percent of capacity
Finishing Shop	: $3X+5Y \leqslant 100$ percent of capacity
Material shortage for Product Y	: $Y \leqslant 90$ Units per day
Because negative production is impossible	: $Y \geqslant 0$ and $A \geqslant 0$

Algebraically the optimum result can be got by working with the coordinates of the polygon. The basic steps are:—

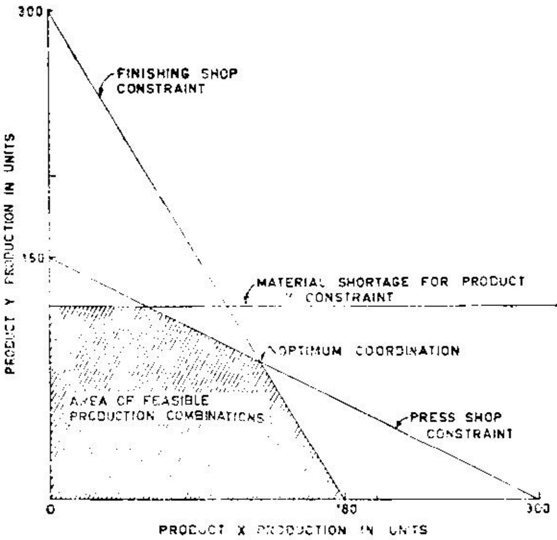
(a) Start with a possible combination

(b) Compute the profit

(c) Shift to another possible combination to find out whether it will improve the result obtained by (b). Keep on shifting from coordinate to another coordinate until no further improvement is possible.

It should not be taken for granted that production of Y should be maximized owing to its greater margin per unit. The reasoning should be based on the limiting factor. The key to the optimal solution rests on the relative rates of substitution and profitability per unit (hour or day) of productive capacity. Examining the graph it can be found out that at coordinate points (129, 85) we get the optimum solution.

LINEAR PROGRAMMING – A GRAPHIC APPROACH



Combination

Test Order	*Coordinate points*	*Product X*	*Product Y*	*Total contribution margin*
1	0,0	0	0	Rs. 3.00 (0)+3.75 (0) = 0
2	0,120	0	120	3.00 (0)+3.75 (120) = 450
3	30,120	30	120	3.00 (30)+3.75 (120) = 540
4	129,85	129	85	3.00 (129)+3.75 (85) = 705.75*
5	180,0	180	0	3.00 (180)+3.75 (0) = 540

*Optimum result

Operations Research & Steel Industry

R Gopalkrishnan*

Operations Research is a subject very difficult to define precisely: some management officials term it as a wonder drug whereas others decry it as a charlatan cloaked in mathematical parameters. It has been called quantitative commonsense...art of giving bad answers to problems to which otherwise worse answers are given. In recent times Operations Research has emerged as a powerful tool to effective decision-making. Changing economic pressures, increasingly complex technological developments, and the more intricate labour relations have all forced executives to look up to Operations Research for effective, efficient and harmonious functioning of organisation. Operations Research gives a real opportunity to consolidate all the segments of operation from production and research to accounting and industrial engineering.

IN the basic industry of the making, shaping and treating of steel, Operations Research has varied applications. Even though most of the problems demand the use of computers, for day-to-day business, ordinary paperwork provides reasonably good results. The observations here pertain to the steel industry, but they can be applied to any industry with similar problems.

The operation of a steel mill has been taken as a sample problem. Certain type of steel has to be made from various kinds of raw materials and has to be processed through hot rolling, cold rolling, annealing, normalising and other operations. To arrive at an optimal programming, all possible permutations and combinations of the operations and materials have to be studied simultaneously. By taking the cost factor as the objective, the following can be taken as the restrictions imposed on the process. 1. Limiting capacity of the operational facility 2. Minimum amount needed for each product 3. Quality and quantity requirements 4. Delivery requirements 5. Limitations on fuel availability and 6. Limitations on raw material availability.

The development of an optimum burden for the production of pig iron in a blast furnace is an interesting linear programming problem. This is a *Diet Mix* problem where the objective is the end product: pig iron of rigid chemical composition and this has to be derived from an appropriate mixture of iron ore, coke, limestone, etc. This problem is also associated with another important feature: the conversion of iron bearing input materials into pig iron and slag. The iron ore used for the purpose possesses different characteristics. This makes the demand for the corresponding requirements of coke and limestone. Therefore the common unit required for this problem is the "amount of ore required per ton of hot metal". To arrive at this figure of "ore per ton of hot metal", it is essential to know about the iron and manganese content of the ore. From the iron plus manganese content of the hot metal and from the assumed reduction of manganese into the hot metal (which can be got by experience), the theoretical amount of iron ore required

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for producing a ton of hot metal can be arrived at. To this theoretical amount, an assumed excess of about 25% is to be added for the flue losses. This is to be supplemented further by another 2% for efficiency loss. Thus the amount of ore per ton of hot metal is obtained.

Now, for every input of ore, the corresponding amounts of coke and limestone have to be obtained. These can be obtained from the coke rate of the furnace and by Flints method. Then the coke rate has to be adjusted for change in slag volume and ore fines. Final correction is to be applied for other materials in arriving at the coke rate.

From metallurgical calculations, amount of flux (limestone) can be readily obtained. The next step is to find the cost per ton of hot metal. This consists of the total sum of the cost of iron ore, coke rate and limestone. Similarly, costs are determined for other types of ores.

Having arrived at the costs of various types of ores with predetermined metallurgical properties, one can readily obtain the optimum loading of the blast furnace so as to produce pig iron of suitable specifications at the lowest cost.

The metallurgical requirements of the pig iron and the availability of certain ores can also be included in the problem. The former will help to evaluate the restriction on production, whereas the latter can evaluate the price structure of the various ores. This problem can be solved by Simplex technique and the major portion of the work is the formulation of the problem. The collection and determination of the data needed constitute a major task but the final solution is very easy to achieve.

In addition to the above, the demand for slag cars and ladles for blast furnaces, moulds in steelmelting shops, wagons for shipping and other problems can be solved by the proper use of Operations Research.

Operations Research enhances the adeptness of an executive to make optimum decisions by providing him the necessary and adequate scientific data.

"Nirvette rather than malevolence seems to characterize the handling of personnel affairs . . . "

OR in Fuel Research

A Ghoshal*

If Operations Research be viewed as the science of problem solving by applying available scientific methods we would find that scientists and engineers of all disciplines do some form of OR in their everyday work. In fact, "we often recognize important work as operations research only after it is done"†. This paper gives a resume of some of the work done on OR in fuel research, especially in India, but none of the work reported was recognized as OR when it was done.

THE problem of how best to forecast the energy requirements of the country was studied at the CFRI. There are two methods of forecasting the energy requirements of the country as a whole viz. (i) by relating total energy (commercial) consumption to national income (at 1948-49 prices) and the index of industrial production on the basis of the past data and predicting future requirements from the regression equation on the assumption of stipulated levels of the national income and index of production; (ii) by computing the energy consumption per unit of production for different items of production, and hence to calculate the total energy requirement on the basis of production levels in industry, agriculture, domestic sector, etc. Both the approaches have been attempted by the C R F I. On the assumption that the index of industrial production increases at the rate of 10 percent p.a. the requirements of energy (commercial) for 1965-66 and 1970-71 came out to be 193 million tons coal e.g. and 242 million tons coal equivalent. If, however, the index increased at the rate of 15 percent p.a. the requirements of commercial energy would be 200 million tons coal equivalent in 1965-66 and 250 million tons coal equivalent in 1970-71. By following the second approach, the energy consumption for producing broad units of production in different industries was obtained; e.g. for producing tons of ingots the consumption of energy is of the order of 1.8 to 2.0 tons of energy of which 80 percent is contributed by coal; for producing 100 tons of wheat flour 11 to 12 tons of energy are consumed; for producing 1000 lb. of yarn in a cotton textile mill, about 1.7 tons of energy are consumed, etc. A detailed energy survey has been proposed to collect information directly from factories. A complete picture of the material content of different items of production is the first prerequisite for industrial planning; the data over a number of years gives us an idea of the productivity in the industries concerned.

*Central Fuel Research Institute, Dhanbad.

†Flood, MM, Presidential Address CRSA, Operations Research (10) 1962, p 423.

investigations at pilot plants

Various statistical investigations are done at the pilot plants to assess the effects of different factors on the products and to ascertain how most economically experiments can be conducted. In the experimental coke ovens there are three ovens of different widths, viz. 14 inches, 16 inches and 18 inches. An investigation was done to see whether the width of the oven affected the properties of coke produced out of the same variety of coal. At each oven 19 replicate tests were done, and from the results obtained an analysis of variance was performed. It was found that the width of the oven did not affect the physical property of coke. To ascertain whether this inference is general, more such investigations should be done on different coals.

Another problem was to ascertain the minimum number of revolutions to be given to a mixture of coal blends (for the manufacture of coke) in a mixer such that mixing was efficient. It was found from the designed experiments that it was uneconomic to make more than 50 revolutions, because further revolutions did not add significantly to the efficiency of mixing.

optimization problems

In industrial planning, it is required to solve many optimization problems. For example, a problem is to allocate washed coking coal from 8 washeries to 6 steel plants by the end of the Third Plan, in such a manner that the cost involved in transporting coals is the minimum. This problem can be tackled with the help of linear programming. In the real problem, there are various quality restrictions arising from the fact that coals of specified quality are used in each steel plant and secondly, there may be restrictions on certain routes. Lastly, the production of 8 washeries is insufficient to supply the requirements of steel plants, so it is necessary to install another washery in a suitable locality. The complex problem of allocating coals from washeries to steel plants with all restrictions in view and of selecting an optimum site of the ninth washery can be solved by the Simplex method. Since this method involves a number of equations which can be solved only with the help of a large computer, a somewhat simplified version of the problem was worked out by the transportation method. With proper adjustment, the transportation method can also take into account the restrictions, and it can also be used to decide the optimum site of a plant. With programmes of rapid industrialization in the future, the usefulness of such optimization studies has greatly increased.

storage problems

Fundamental studies have been made at the CFRI on the mathematics of operations research, especially in the theories of storage and queues. In the industries there are various storage problems which can be solved through a mathematical approach. All big plants, e.g., steel plants, cokeries, washeries, etc., are required to provide adequate storage capacity for their raw materials and products. Generally the decision to provide new storage capacity has to be based on relatively subjective information. The determination of the optimum storage capacity can be formulated as a storage problem depending on the distributions of the input and the output. In the absence of analytical solutions, such problems can be solved by simulation on an electronic computer. *Monte-Carlo simulation is to generate data by random sampling from specified distributions*, e.g., exponential, gamma, normal etc., both for input and output items. These data are used to forecast what would happen with various trial capacities, and hence it is possible to decide the optimum capacity.

Soon after Theodore Roosevelt started on a lion hunting trip to Africa, a notice was posted in the New York Stock Exchange. "Wall Street," It read, "expects every lion to do its duty."

OR in Road Transport

GK Sant*

Operational Research is generally defined as the application of scientific methods to the problems of operational efficiency. In transport the technique was first evolved during the Second World War with particular reference to aircraft operation. It was extensively applied to the problems of road traffic congestions in the UK and the USA and suitable models have been suggested to meet the traffic congestion in relation to width, length, curvature and crossing of the roads by Tanner (1961) and Miller (1961). Operational research has also been applied in London Transport for studying passenger habits, the incidence of breakdowns of buses and accidents and in the economy of fuel consumption. An account of these studies is given by Menzler (1953). In India practically no work has been done on the application of operational research to road transport problems except by Jaiswal (1961) who investigated theoretically the methods of forming Queues at the bus stops.

IN India it is only after the 2nd World War that nationalised road transport services have sprung up in different States and today nearly one-third of the fleet of passenger buses has been nationalised. With the growth of nationalised road transport, problems of standardisation, rationalisation and co-ordination have come up involving investigations and studies in the various aspects of road transport operations. For solving some of these problems, the need for operational research is keenly felt. It is proposed to indicate here the scope of operational research for effecting economy and improving efficiency in the road transport services operated by the different States in India.

maximum utilisation

Scheduling and linear programming are often resorted to in operational research. For effective utilisation of the fleet not only the maximum number of vehicles are required to be put on road leaving the minimum for repairs and maintenance and for emergencies like accidents and breakdowns but each vehicle should be made to operate maximum mileage during the day. The index of maximum utilisation is, therefore, given in terms of seat miles produced for carrying the traffic in respect of passenger transport and in terms of ton miles in respect of goods transport. For achieving the maximum utilisation of the fleet, the technique of link diagrams is employed wherein scheduling of buses from depots is so arranged as to meet adequately the traffic needs at various points of the routes and, at the same time, to obtain maximum mileage from each vehicle during a day. Simultaneously, with the scheduling of vehicles, linking of crew duties should also be arranged in such a way as to get maximum utilisation within the limitation of time prescribed by the labour laws. Thus the technique of scheduling and linking of vehicles and crews is of vital importance for achieving economic results in road transport operations. The higher utilisation of vehicles not only reduces the capital cost but it contributes towards reduction in the overhead cost on interest, insurance, taxes and other overheads. During the process of linking, problems some-

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times arise that in attempting to increase vehicle utilisation, crew utilisation gets lowered and *vice versa*. Similarly, increased utilisation of vehicles sometimes may result in lowering the load factor or *vice versa*. In such cases the relative economics of the constants involved has to be weighed for achieving the most economic results. Thus the maximum utilisation of vehicles and crews is of utmost importance for higher productivity in road transport.

design of experiments

When more than one quality of material is available in the market, problems often crop up to select a quality which would give the best performance under a given set of operating conditions. Particularly in road transport various makes of vehicles, tyres, lubricating oils, camel backs for retreading of tyres, etc. are available. Testing of quality from the same manufacturer periodically is necessary in view of increasing use of indigenous material in manufacturing processes. For selection of the best material, experimental tests on scientific basis have to be employed. Technique of design of experiment developed by Prof RA Fisher could be usefully employed in such cases. In the Maharashtra State Road Transport Corporation, controlled experiments designed for studying comparative performance of vehicles of different makes and tyres of different manufacturers are in progress. In the conduct of such experiments, considerable precautions have to be taken to maintain comparability of data over a period and to conform to the normal operating conditions. Another experiment to assess the cost of operation on different types of road surface has also been conducted by the Maharashtra State Road Transport Corporation. The data obtained from these experiments are analysed by the technique of "Analysis of Variance" for selecting a quality with significantly superior performance.

sampling technique

Sampling technique has also to be resorted to on occasions to tackle *ad hoc* problems of the Management. Traffic surveys on a sample basis have often to be undertaken for assessing the intensity of traffic on a road or in a region for planning the optimum requirement of vehicles. Origin destination surveys are carried out in bigger cities for determining the pattern and the mode of travel of people. Sampling technique is also applied for studying the financial implication of varying fare structure and freight structure on the earnings of a road transport organisation.

technical research

The economic utilisation of material used in transport industry such as fuel, oils, tyres, spare parts, assemblies etc. is of vital importance for achieving efficient operations. OR in the fuel system is necessary to reduce fuel consumption, such as optimum conditions for maximum productivity from fuel with regard to speed, road surface, load factor, driving technique, air temperature, wind, humidity, conditions of tyres, etc.; admixture of petrol and H.S.D., type of fuel for power unit in relation to variable incidence of taxes and duties. Effect of degree of the viscosity of lubricating oil, road safety measures, improved methods of vehicle and tyre maintenance, evolution of bus body designs economical and most suited to different types of climatic conditions in India, evolution of suitable types of paints under different weather conditions, standardisation of equipments, components and auto parts for the depots and workshops, are some of the problems which need to be investigated in the laboratory scale and confirm the results on the field scale. Testing of materia in a laboratory for its quality before rejecting any sub-standard material is also necessary for getting the best results. The conference of All India State Transport Undertakings at Mahabaleshwar in October 1962 decided to establish a central institute for conducting research on road transport problems.

defence needs

In the context of defence in relation to Sino-Indian border, operation of automobile vehicles at high altitudes and extremely low temperature may present some difficulties. These need to be tackled by Operational Research in regard to the systems of fuel, oils, radiator, etc. It is expected that these are being attended to, in the Defence Laboratories.

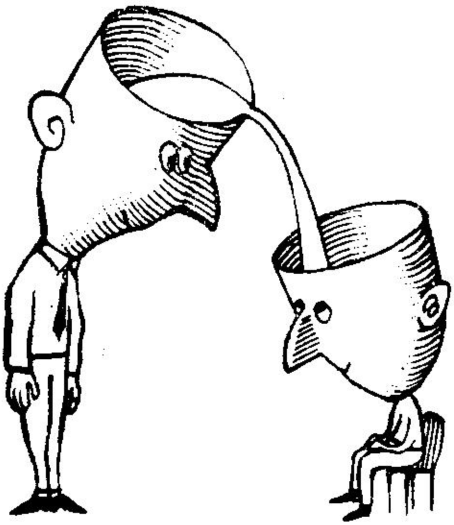
inventory control

Suitable models have been suggested for the inventory processes for the purchase and sales organisations in UK & USA. In road transport, large quantities of auto parts, tyres, lubricants and batteries are required to be purchased for the maintenance of a large fleet by nationalised road transport undertakings in India. Suitable inventory models need to be evolved for stocking, purchasing and distribution of auto parts and other stores to various operating units. For deciding this policy, the pattern of consumption of stores, for different makes of vehicles at different stages of the life of vehicles under different types of road conditions obtainable in India, has got to be assessed precisely for regulating the supply of parts and reducing the stock-holding to the economic minimum. There is a need for evolution of suitable inventory processes to tackle this problem. The importance of this needs no emphasis for reducing the burden on foreign exchange in India.

work studies

The technique of works studies has often to be resorted to in the workshops of the road transport undertakings. In the automobile workshops where the work of body building and reconditioning of vehicles and assemblies is carried out, work study can effectively be undertaken for saving in manhours and increasing production. In the Central Workshop of the Maharashtra State Road Transport Corporation at Dapodi, some work studies have been undertaken for increasing production and reducing the cost of production.

The above are some of the problems which need to be tackled through operational research in the road transport system in India. With the growing need of road transport on a large scale, both for civil and defence requirements, there is considerable scope for operational research for improving the economy and efficiency of the road transport operations in India.



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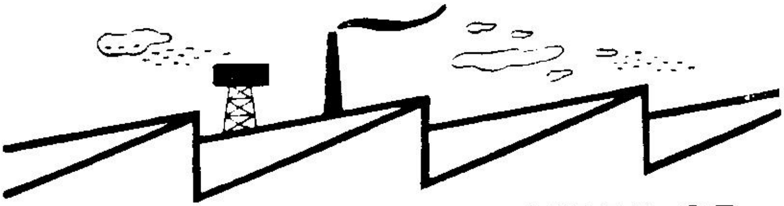

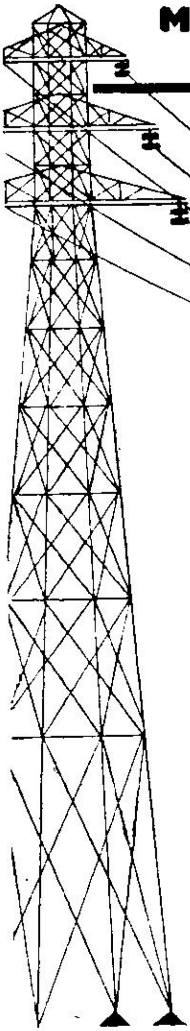

Development of Operational Research

Rahman* & Venkatesam†

Operational Research, as has been aptly described by Ellis Johnson "has established itself as an activity that can and does bring new attitudes, new concepts and new techniques of research". The fields it has come to cover are wide and range from warfare to problems of productivity, industrial programming, even national planning.

IT would be difficult to say exactly when and where this new branch of science developed. It can, however, be safely stated to begin as a distinct attitude during World War II, when pressed by the strong attack of the Germans, the Allies on both sides of the Atlantic, started looking at science, as a weapon to help them to win the war. More than any other, four British Scientists were responsible for the development of the subject and for the beginning of what could be termed as the invasion of the slide rule in the army. These were Blackett, Bernal, Zuckerman and Williams. It would be worthwhile to mention in brief their work.

Prof. Blackett's work began at the instance of General Pile in 1940 when a discrepancy was noticed in the performance at the testing stations and the gunsites of the radar equipment. This observation became the basis of operational studies of weapons in general to know their effectiveness. Later in 1941 Prof. Blackett took up the problem of detection of submarines by the radar equipment and the anti-submarine warfare.

Prof. Bernal's work was connected with civil defence and aimed at evaluating bomb damage. He began the collection of comprehensive data on damage and carried out a systematic analysis of it. An interesting feature of this study was the collection of data through field observers, through interviews of survivors, to make a proper assessment of damage.

Prof. Zuckerman's work related to estimating the casualties of bombing. He worked out the ratio between the number of casualties and the bomb load dropped. It may sound a bit odd that such a study was found necessary to be carried out during the war time, but its real significance lies in improving the population morale by reducing the exaggerated fear of large scale bombing.

Professor Williams' work related to the combating of the U-boat menace. He found that the depth charges, exploding at 100 feet depth were particularly ineffective, and the lethal range was about 20 feet. This knowledge was arrived at by the analysis of data collected for this purpose and included such factors such as sighting the U-boat, the time taken to release the bomb, the time taken by the charge to travel towards the target, the manoeuvrability of the submarine during this time, and the behaviour of the charge. This led to the development of a new depth charge and the firing pistol, which raised the efficiency of anti-submarine attack to 400—700 percent.

These examples could be multiplied from the other side of the atlantic, but suffice to say that by *before VE day a total of 365*

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scientists were working in various capacities in operational research for the army.

In America the initial experience and ideas of men like Conant, Vannevar Bush and those of the Air Force personnel who were stationed in UK were concretised in the letter of General Arnold in 1942 recommending to all commanding generals to form operations analysis group. By VJ day 26 such groups with some 400 scientists were working with the US Air Force.

With the end of war, the problems of peace began to be approached with the same attitude. To begin with, it was felt that the role of operational research was to supply the management with quantitative data to arrive at executive decisions. However, as has been pointed out by Trefethen, the development of operational research in the UK and the USA followed different lines. Dr. Trefethen has rather rightly pointed out that due to the existence of Industrial Consultants in America, a certain tradition of quality control and time and motion studies, the newness of operational research as contrasted with the UK, it was not fully appreciated and this became a hinderance in a way.

The major work in the UK was carried out at the Shirley Institute on cotton industry and boot and shoe industry, railroad and street transportation problems and coal industry. The success of this work led to the further development of operational research in industry with the result that *now over 40 groups are working in industry in the UK.*

The other reason for the success of operational research in the UK is that industries as a whole, instead of individual factories, were covered, which engendered a generalised outlook and laid the foundation of industrial change and progress. In America, the limitation of work in individual factories came in the way of publication of results of research due to the fear of benefiting the competitors. Over-specialisation and extreme mathematical treatment may also have been another contributory factor.

Besides its use in industry, the new technique was also utilised in a number of socio-economic problems which came up after the war. Operational research has come to be used in a very large number of areas such as problems of traffic, question of deciding a suitable fare structure for public transport, or industrial process like ore-handling. It is also being utilised in problems of manufacture such as how much of store is to be maintained, to determine the quantities of raw material and their phasing for a particular quantum of production, and the question of sales and production.

Its use has now extended to academic spheres, such as the problems of communication of information, socio-economic fields and national planning. The real development of operational research in the national field was carried out by Prof. Mahalanobis in India when he used it in national planning.

The beginning of operational research in India dates back to the establishment of a unit of operational research in 1949 at the Regional Research Laboratory, Hyderabad. It was soon followed by the establishment of working groups in Defence and the first industrial utilisation was by the Ahmedabad Textile Industrial Research Association Laboratory. This was followed by its utilisation by Prof. Mahalanobis in the Planning Commission.

The utilisation of operational research by the laboratory at Hyderabad and Prof. Mahalanobis represent new lines in the field of its application, and represent the most important contribution of India to its international development. The former related to scientific research and its correlation with industry and the latter to national planning.

The contribution of Defence Science Organisation, under Dr. DS Kothari, has been significant particularly in the field of organisation. It has organised two conferences of experts from the areas of Defence, Science and Industry. It has also taken an active part in the organisation of the Operational Research Society of India in

1955. The Society has been functioning with many units in different cities and is affiliated to the World Federation of Operational Research Societies. It has tried to bring home to industry the importance of operational research. It has also collected data about the work done in different industries, academic and industrial institutions in India on operational research, and the facilities available in different places.

The utilization of operational research in India is of the utmost significance. As Russell Ackoff put it, unless operational research is utilised, the industrial and technical mistakes committed elsewhere are likely to be repeated. Further, a country which is faced with limited resources has no other alternative but to use operational research for their efficient and effective utilisation.

A man was arrested on the charge of robbing another of his watch. There was so little evidence, however that the judge quickly said: "Discharged." The prisoner stood still in the dock, amazed at being given his freedom so soon, "You are discharged," repeated the judge. "You can go." Still no word from the prisoner, who stood staring at the judge. "Don't you understand? You have been acquitted. You are free. Get out!" shouted the judge. "Well," stammered the man, "do I have to give him back his watch."

OR in India

HC Arora*

There has been in recent years an increasing awareness of the importance of OR in India. A seminar on OR was conducted in Bangalore in Jan-Feb 1957 by Mr. RL Ackoff, the distinguished international authority on Operations Research. This stimulated OR workers to start an organisation. Accordingly, the OR Association of Bangalore was established in March 1957. The Operational Research Society of India was formed in mid-1957. The Society was unanimously elected to the membership of the International Federation of Operational Research Societies (IFORS) Paris, on 1st January 1960.

THIS institutional development has led to systematic interest in OR in India. A technical session of OR was arranged as a part of the Third Defence Science Conference held in Delhi in April 1958. The first conference on OR was held in Delhi in 1959. A symposium on OR was organised at the 48th Indian Science Congress, Roorkee, 1961. The Operational Research Society of India assists teaching institutions and business organisations in organising short-term and regular training courses in OR. The Productivity Centre, Ministry of Labour and Employment, has developed training programmes and organised some seminars on OR. Special Reorganisation Unit of the Ministry of Finance, Organisation & Methods Division of the Cabinet Secretariat and Committee on Plan Projects of the Planning Commission have included lectures on OR in their training programmes. The importance being now given to OR in India can be realised from the fact that the Central Government have appointed an adviser on OR to the O&M Division, Cabinet Secretariat. Courses for training OR workers have been initiated in many technical institutions: Indian Institute of Technology, Kharagpur, Indian Institute of Sciences, Bangalore, Indian Statistical Institute, Calcutta etc. Department of Mathematics and Statistics, Delhi University, has started giving courses on OR as an optional paper to MA (Maths.) students since August 1962. The new Institute of Management at Calcutta proposes to have an OR Department. NPC has also devoted some serious attention to the problem of initiating training in OR. The Indian Conference of Productivity Personnel arranged by NPC during May 1962 set up a group of 12 persons to examine the question of introducing OR in Indian industry. The group has recommended that NPC may assist any of the institutions, which are organising OR training programmes or which may like to do so (including professional bodies like the Institute of Costs and Works Accountants and the universities or industrial research institutions) by obtaining the services of suitable specialists. Further, NPC programmes include training abroad in OR methods in such specialist institutions as the Case Institute of Technology, Cleveland, Ohio, USA, and the British Iron and Steel Research Association.

The Indian Institute of Agricultural Research (ICAR) has used OR techniques

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in rinderpest eradication scheme (mass vaccination of cattle and buffaloes). After analyzing the relevant data collected for assessing the progress of the campaign with a view to improving the efficiency and economy of field work and controlling the efficiency of a large scale operational programme, the study has concluded that the smallest party of workers is generally the best and considering the normal litre of vaccine produced at IVRI, its production costs and cost of filling an ampoule, it is preferable to have ampoules of half and one-fourth the normal size.

Data collected from a large number of wheat producing districts in India have been subjected to OR treatment. The model in relation to the food problem suggests that amount of wheat exported from a district not only depends on the price level (conventional economic theory) but also on the amount of surplus wheat. A small operational research unit has been constituted in the Central Food Technological Research Institute. To begin with only limited studies are being carried out covering the production efficiency as related to technological problems. Two preliminary studies in pineapple and orange segment processes have been undertaken to gain the confidence of the industry as well as familiarise research workers for further studies. Besides, these studies reveal some relationships on the size of the fruit and the total output and also the effect of seasonal variations in the output which can help increase productivity.

The Regional Research Laboratory, Hyderabad (CSIR) has been using OR methods since 1949. An important part of the work of its OR Unit is to study and bring about internal co-ordination between research, administrative and auxiliary services in the laboratory. The OR Unit also studies the effect of various policy decisions on the progress and direction of research and assists the executive in arriving at decision. Lately, the laboratory has carried out OR studies in the field of utilisation of cotton seed and its by-products.

Prof DS Kothari initiated the study of OR in defence problems as early as 1949 when he was Scientific Adviser to the Ministry of Defence. OR field studies are being carried out at the Statistics and Operations Research Division of the Defence Science Laboratory. Considerable theoretical research has been undertaken on problems in queueing theory. The Naval Research Group situated at the laboratory premises is engaged in the economic retention period of surplus stores etc. Some practical work in weapons allocation and evaluation is going on in the Weapon Evaluation Group and the Defence Science Laboratory.

As regards private industry in India, one or two major industrial and business concerns have made a beginning by having OR scientists on their staff. To mention one example only, the management research unit of the Tata Iron & Steel Co. Ltd., Jamshedpur have undertaken some OR studies. The practical application of social and industrial psychology was brought out in AK Rice's celebrated Ahmedabad experiment, which raised production and reduced scrap in Calico Mills. Field investigations dealing with factory lay-out problems, work-in-progress, inventory problems, etc. are being progressed by the Productivity Centre of the Government of India. A number of OR studies have been carried out in Indian industries in Bombay: in a foundry regarding capacity assignment and product-mix and in an engineering workshop regarding materials handling problems and the significance of materials handling with regard to the overall effectiveness of work organisation in a crane utilisation study.

In the field of planning, pioneering work has been done by Prof PC Mahalanobis.* He has identified the problem of allocation of resources in development planning as one of the most fruitful fields for application of OR methods. He has introduced the approach of OR to planning in India. The part played by OR models for planning in India was indicated in his paper presented

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at the Second International Conference on OR in September, 1960. It may not be out of place to mention here that Regnar Frisch and J Sandec have used linear programming for solving problems in India, both making use of input-output tables constructed at the Indian Statistical Institute. This line of work may prove to be of considerable practical value, when more statistical data becomes available.

The techno-economic surveys carried out by the National Council of Applied Economic Research use in a way some of the OR techniques for planning purposes. The greatest asset of OR approach to planning in India lies in breaking down barriers between different disciplines and providing teams working together to produce better solutions.

OR is being used in Railways. Waiting or queueing problems of passengers for tickets at booking windows or trains queueing up in marshalling yard, waiting to be sorted out are tackled by OR techniques. In 1952 Mughalsarai junction became a serious bottleneck in the movement of coal in northern India. A piece of OR carried out in the field showed that every time a train was broken up on the hump of the marshalling yard, the shunting engine had to return from the crest of the hump to the rear of the next train by a clear line before it could commence the next shunting operation and this took at least 10 to 12 minutes between the marshalling of two successive trains. By providing a second overlapping shunting engine in the rear of the next train it was possible to reduce this interval to a minute or two. In this way the humping capacity of the yard was amplified by over 50 percent. New norms of speed have been evolved to appraise performance of railways on the basis of OR analysis. A rational study of thousands of pairs of points between which traffic could be moved by the two-routes—Patna and Mokameh—by grouping into seven zones of constant load differences, made it possible to assess the overall difference between the quanta of traffic hauls by the two routes and provided a basis for a rational choice of Mokameh site for the location of the Rajendra Bridge on the Ganga.

The average load of an empty train has been raised from about 70 to 84 wagons by studying the problem of traffic flow in the Karanpura coalfields of the Eastern Railway and overcoming the difficulties of sending light engines to bring empties as also the capacity limitations of single lines to allow the movement of required number of empties.

The extensive rationalisation of the loading and marshalling in bulk, has enabled the flow to be regulated without bunching and congestion which used to occur previously: coal for the three power houses in Calcutta which was moved piecemeal is now collected into one train in Andal Yard by pooling the wagons of all the power houses. The train is then consigned to the power house nominated having regard to its requirements, wagons already on hand awaiting release etc.

The Indian Statistical Institute and the Indian Standards Institution have taken several measures for the promotion and development of Statistical Quality Control (SQC) which is one of the important techniques of OR. It has helped many factories to reduce wastage, re-work, scrap and to improve the quality of manufactured products and the efficiency of machines and operations, etc. The adoption of this technique in India is growing. The Committee on Plan Projects of the Planning Commission is exploring the possibilities of introducing it in public enterprises.

The OR Group set up recently by NPC has suggested that the following problems may be taken up for investigation in India with the help of OR techniques: (*a*) Railway Wagon turn-around, marshalling yard operations, freight train routing (*b*) Operation of multipurpose dam reservoirs (*c*) Determination of optimum mining limits (*d*) Location of depots, and warehouses of large distributing agencies (*e*) Defining operations and process control in the jute and chemical industries etc (*f*) Distribution of coal from various sources to different consumption centres (*g*) Production-smoothing problems in the steel and engineering industries.

OR in India is in an early stage and needs careful nursing and attention from all directions so that the scattered work done here and there is coordinated together and further experiences gained to develop it into a body of systematised knowledge and techniques for solving different problems thrown up by the process of development.

"In operating an investment policy, Labour should rely heavily on a fifth pillar—the nationalized sector of industry—which should cease to be a desperate instrument for restraining demand and become a dynamic lever for promoting growth. . .Finally, there should be what might be termed a 'control pillar'—a deliberate and planned increase in the quality of our national manpower, above all at the highest level. . ."

—The New Statesman

Operations Research–an Attitude or a Method

Srinagabhushana & Ramanna*

There is a lot of glamour attached to the title "Operations Research". Clearly conceived, OR is nothing but "multi-dimensional industrial engineering": multi-dimensional in approach; multi-dimensional in the problem attacked; multi-dimensional in the techniques employed and multi-dimensional in the technicians attacking the problem. The big question before us is as to whether, at a time when even the less sophisticated techniques such as Work Study and suggestion schemes are not fully absorbed, we should hurry into such a highly sophisticated technique calling forth such a complex multi-directional approach, wherein the lag between application and results would be considerable. Even in the more advanced countries operations research is not yet a common-place technique. How about less advanced areas ? Looked at thus, Operations Research provides the best area of conflict between the bulls and the bears of the Productivity-technique-stock-exchange.

IN a developing economy, which in fact means a deficiency economy where everything is in short supply and anything sells almost at any cost, there is hardly a powerful urge or incentive to use any modern management or organization techniques. In some cases their existence itself is not appreciated and much less the need for it realised. No wonder then that it is not recognised by many that it is precisely in the circumstances in which we are placed that Operations Research and similar techniques are of the greatest assistance because it is necessary that the use of every available facility should be optimised with a view to get maximum national benefit. This refers to problems of distribution like electricity, rail and road transport, location of industry, movement of goods, mine prospecting and many problems of the kind, taking the country as a whole, as well as to industrial undertakings.

*Operations Research Association, Bangalore

The history of Operations Research has shown that it is in a sense *a war baby*: it is sheer necessity that forced nations to evoke this comprehensive scheme of operation under the stress of struggle. Communications system, servo-mechanism have all come to play a prominent part in modern Defence and Offence. Our complacency in this behalf has been seriously disturbed by the logic of bitter events. It is, therefore, necessary that every available technique should be pressed into service so that the best use is made in quick time of all resources and services enabling us to *speak soon from strength*—physical, moral and spiritual. It is necessary to bring to the notice of the Port Trusts, Railways, Road Transport Services, distribution centres etc. *what Operations Research can do* and how it should be utilised so that the *returns to the nation* are maximised. A flexible plan should be drawn so that quick changes could be made according to needs. In Planning, in adjusting resources to results and in a variety of other matters of national importance Operations Research could be of great practical value. The first step, however, is to *arouse Operations Research consciousness* among those charged with responsibility for organisation, planning, administration and management.

While there are productive techniques of which the country is becoming slowly but steadily conscious, Operations Research being a combination of disciplines is more comprehensive both in conception and execution and therefore it often takes time to reach solutions and yield results. This very fact itself attaches great significance to Operations Research as a method which embraces several phases of a problem.

One approach to the problem would be to *look upon Operations Research as purely academic* until such time that the less sophisticated techniques are absorbed with an accelerated tempo; and develop operations research in the various associations of management and productivity councils in a somewhat academic manner for the sake of building up knowledge. No technique can for long be the idol of its hero worshippers unless backed by constant—if not increasing audience. This perhaps will be the difficulty for operations research unless an area of practical application is found as progress is made. And its practical application today is of the highest importance.

Another approach would be to select one or two or three definite places for application, where we would be ensured of the fullest cooperation, until returns come. There could, perhaps, be *no better area to this than the National Productivity Council itself.* The question for the Productivity Council would then be as to how best to utilise its financial resources so as to maximise the growth of the productivity movement, this problem being viewed purely from the operations research angle. Perhaps, nothing less will provide a better solution than to start at the above point, publish the results of the benefits obtained, and go further into the different areas.

Yet another practical approach is to look upon the subject as one needed for the development of an attitude. The very study of operations research gives an orientation to the thinking of management personnel in the right direction. Just as disciplines in Humanities and Sciences are essentially needed to develop a full bloomed civil servant, in which capacity he rarely uses directly the knowledge of the subjects of such previous study, so the study of operations research is a *must* for the development of a full-fledged executive.

Yet another approach to the subject during the developmental period could be the single man with multi-personality approach. Perhaps, this is a difficult thing to conceive of at the present moment. The way it would be worked out would be on the following lines: A Manager with a broad education in Psychology, Economics, Statistics and the theory of general management including organisation structure, policies, planning and controls would, when he took up the problem of framing a broad model, take one aspect of a problem at a time and work himself up so that his personality predominates for the moment in the broad discipline. For example, in the computation of an incentive model, while considering the psychological aspect the Manager would forget that he knows anything more than Psychology. He would assume for the moment that he has been a Psychologist called into the plant. He would discuss the question with Psychologists, thus allowing the psychological aspect of his knowledge to predominate over the other aspects. Similarly when he took up the economic characteristics, he would work himself up to assume the role of an economic survey expert called into the plant. But this requires determination and, in a lighter way, could be thrown out as ridiculous.

The coming to a decision on the basis of the above alternatives would depend on: (1) the question of development in managerial techniques already reached by the plant; (2) the nature of the urgency of results needed; in other words, *the extent of lag that could be allowed between the initiation and the results*; (3) the enthusiasm for the subject itself.

There are certain plants in India already attempting to apply operations research, but such plants are few; and even in these plants the extent of application is restricted. On the basis of the above it would be most desirable that during the process of development the following approach is made to the subject :

- Setting up of a group of people interested in operations research at two or three places in India
- Co-ordinating the work of this group with the already existing Operations Research Associations if any
- Encouraging existing organisations utilising management techniques to develop Operations Research outlook
- Providing problems which would demonstrate to the different managements the value of operations research
- Finding funds to move this activity to success during the initial stages without an expectation of any compensation
- Getting of one or two foreign experts to run programme for the above groups, in addition to others that may be interested at the time
- Taking up one or two problems in the public utility undertakings like Transport and providing facilities for the above group in conjunction with the expert to provide solution to the problems.

"I want my nephew to start at the bottom — so I'm putting him in charge of you"

On Elegance in Operations Research

David B Hertz*

The examination of elegant work is proper in the study of methodology. Operations research is a science directed at determining certain kinds of societal relations and developing means of deciding on courses of action in a social environment. The work in the field can be examined to expose its innate characteristics. The work described by operations researchers is that of exploring the role of decision processes in social units, finding relationships, describing these in terms of systems or parts thereof, which have technological stability, developing, constructing, and conducting experiments.

OPERATIONS researchers are led to various tempting avenues, none of which seems elegant. Mathematical hypotheses, where non-measurable quantities are proposed as being mathematically related, or the converse, non-definable operators relating measurable quantities; minimizing the fact that operations research deals with social decisions; and finally, emphasis on measuring are among such paths. It must be recognized that *inelegant work is not necessarily wrong*, useless, or even unimportant. When OR work is done professionally by a good craftsman in the field who uses imagination and avoids fetishism of method and technique, there will occasionally emerge that beauty which his fellow scientist calls elegance.

At the First International Conference on Operational Research it was suggested by Churchman, Goodeve, and others that OR might be used to find out what was meant by the scientific method and what was the proper use of science and scientific manpower. Sir Charles Goodeve pointed out that, since the nineteenth century, science had been selling itself on the basis of technical achievements and the method by which these were accomplished was not being questioned. He added that the rise of operational research once more makes the question urgent. It seems quite proper at this Second International Conference to examine what has been done in published work in operations research in a critical sense and determine whether or not we can lay bare at least some of the characteristics of the enterprise in which we are commonly engaged. In particular, I am interested in finding out something about the methodology used in achieving solutions to operations research problems, and especially methods which seem particularly appropriate to the solution of a significant problem. Where the methods produce results which evoke a response of considerable admiration, for their depth, clarity, refinement, and perhaps generality, the work itself may be called elegant. ●

*Arthur Andersen & Co., New York, USA

"If the norm is death, you have to be perverse to be alive...."

An Introduction to Systems Analysis

Stanford L Optner*

Today, there is no general systems theory which has been applied to business. In almost all institutions, business is taught much as it always has been. It is among our most undisciplined areas of knowledge and has exhibited slow, uninspired improvement over the last fifty years. Our future business managers are being taught vocational skills in the absence of "think processes" which would equip them far better for reality problems. A "think process" in this context would be a tool of analysis or synthesis which would enable the competent executive to solve his problems with a high degree of reliability. General systems theory supplies such a vehicle.

THE need for a general systems theory has become increasingly evident. Some companies are so large they are no longer understandable in the simple, descriptive terms of their formative years. As a result, corporate objectives frequently work at cross purposes with current policies. The typical executive is forced to attack his problems as if they were an endless number of special cases. What is needed are general concepts about the nature of business operations that would assist him to abstract the properties of an individual problem. A tool of this kind would make the problems of business more accessible to the analyst.

Our expanded industrial technological frontiers have not been reinforced by the development of large numbers of business trained, technically oriented personnel. Industry needs more men who have the combination of a good general education, business experience in more than one field, and supplementary training in some academic discipline. These broadly equipped persons would be well prepared to attack today's massive corporate problems. It is true that many companies send their executives back to school for short-term refreshers or orientation in new fields. This activity undoubtedly increases managerial capability. However, the absence of general theories in business penalizes executives who would like to find a frame of reference through which they could do more effective problem analysis and decision-making.

The superficially similar characteristics of systems have naturally led researchers to apply the tools of scientific disciplines in less disciplined fields of endeavour. Sociology, anthropology, history, economics, and political science are areas of study coming under the scrutiny of specialists who have exposure to more than one field of knowledge. These specialists are searching for general theories to improve the organization of knowledge about a particular area of study. For a pertinent example, my recent work in the area of city planning† has demonstrated the usefulness of the systems approach; reaction to this material indicates that systems analysis has some usefulness for professional planners.

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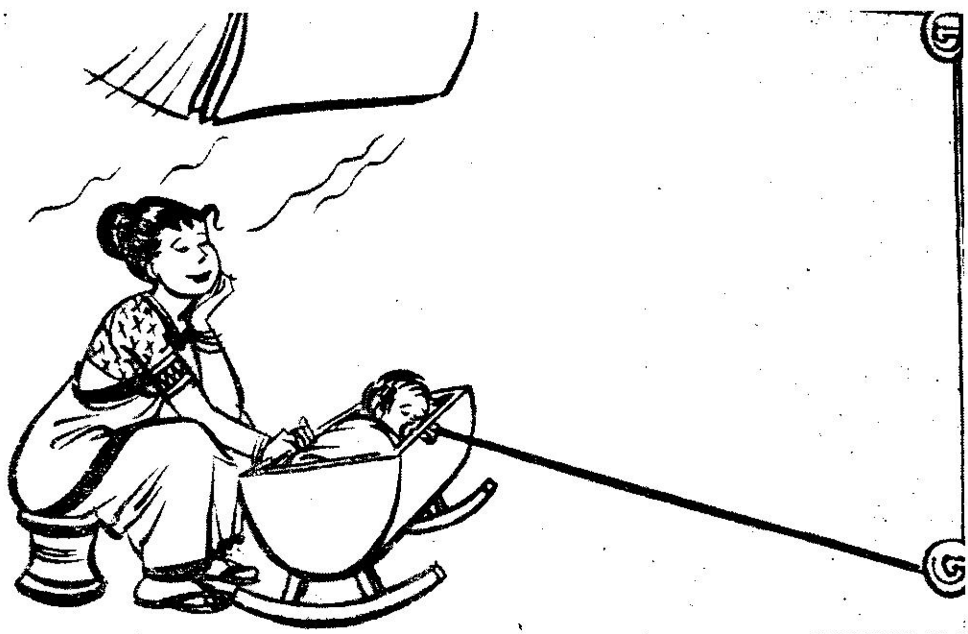
†Stanford L Optner, Report on the Feasibility of Electronic Data Processing in City Planning, to the Department of City Planning, City of Los Angeles, 1959.

My effort to attack the problem of a general systems theory in the business management field began in 1956 with the development of case material for an extension course to be offered at the University of California at Los Angeles. Subsequent to this, the opportunity to test the usefulness of a systems approach in business became possible in a variety of industrial problems which I encountered as a consultant. In addition to providing a useful frame of reference in complex problem areas, the systems approach became a powerful analytic tool in problem identification and problem solving. It has, however, to be confessed that we have only begun to explore the possibilities of a general systems theory for business. We have yet to evolve a practical means of understanding and applying the fundamentals of systems analysis in the business environment.

In a relatively few years, computers have caused a major revolution in data processing. Wherever data is to be processed, systems analysis becomes a major consideration. After the first rush of electronic dizziness, it has become evident that the effective design of systems is still the fundamental requirement of successful computer applications. Computers have had a special impact on the growth characteristics of industry. The use of electronics has tended to force companies towards centralization of data processing, although decentralization is taking place in manufacturing, engineering and marketing areas.



PRODUCTIVITY AT HOME!

Operational Research

RS Varma*

Operational Research is today recognized as an Applied Science concerned with a large number of diverse human activities. To be precise, an operation uses some valuable resources like men, money, machines, time, effort, etc. The outcome of the operation has also some value. An Operational Research worker is required (i) to minimise the input value for a specific output, or/and (ii) to maximise the output value for a specific input or and (iii) to maximise some function of these values, for example, the profit function (difference between output and input values) or return-on-investment function (ratio of output and input values).

QUITE a large number of definitions of Operational Research have been given from time to time. The latest I have come across may be quoted here:

"Operational Research is the attack of modern Science on Complex Problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternate decisions, strategies or controls. The purpose is to help Management determine its policy and actions scientifically."†

In fact, Operations Research has to deal with the interplay of various sciences like Physics, Chemistry, Mathematics, Biology, Statistics, Engineering, also Economics and the other social sciences. It cannot, therefore, be called an organized body of knowledge in the same sense as any of the subjects mentioned above. *Operations Research has to measure a complex process in a dynamic state* and accordingly a person making observations may change his usual methods and also his rate of working. Here we are reminded of Heisenberg's Uncertainty Principle: "when an Electron is observed, *the action of the observing instruments themselves interferes with the behaviour under observation*".‡ It is preferable, therefore, to take into account indirect measurements of fact; hence the use of Mathematical & Statistical techniques affords a most powerful and efficient method for tackling problems of Operational Research.

Operational Research had *its birth in a military context* and, undoubtedly, it *plays an important role in military problems*, both in peace time and during war. Apart from this, it has to face the problems of industry and management. However, Operational Research has today to meet the ever-growing needs of various human activities. The exploration of space may present still more complicated human requirements.

In India, a major Operational Research effort is needed in the field of education—primary, secondary and university. We are likely to get a good dividend, if some scientists who know the ABC of Operational Research are asked to devote themselves exclusively to each of these aspects. The work on these lines may probably throw light on *the vexed problem of the wastage of scientists in the country.* Again, there is the necessity of developing and promoting industrial acceptance of Operational Research. In fact, we should

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†September 1962 Issue of the Operational Research Quarterly (London).

‡Italics ours.

have a unit of Operational Research in every major factory and industrial concern in India. Finally a matter of national importance and urgency today is the study of Operations Research in civil defence.

Any complex system has always a certain number of parameters which determine the system. These parameters may not be accurately known and hence we have to estimate them by probabilistic considerations. It is well-known that all processes in business involve uncertainty. Statistical methods are, therefore, widely used in Operational Research. This does not, however, mean that every Operational Research problem involves the use of Statistics. *Linear Programming is mostly a deterministic technique.* Stochastic processes have recently been of very great use in Operational Research.

We may, perhaps, say that *Science, Engineering & Economics double in about seven to eight years' time.* With this tremendous growth in these basic subjects, Operations Research, dealing with the interaction of these, has naturally to extend its frontiers of applicability to meet the growing complexity of human activities. I will here quote some examples from the Science of Mathematics. There is an urgency to have a deeper understanding of communication and decision through human organization and this brings us to the important branch of Mathematics or Operational Research, namely "Information Theory". If we go a step further, we come to Cybernetics, which is the "Science of Control and Communication in the animal and machine". All forms of behaviour in so far as they are regular or determinate or reproductive come within the orbit of Cybernetics. To enable us to have models for the analysis and synthesis of many complex man-machine systems, Automata theory and the language of automata are necessary. *Linear graphs and other topological methods as also combinatorial Algebra are being increasingly used in scheduling and programming situations.* Today, the demand for better computational methods for solving problems on computing machines has tremendously increased the field of numerical analysis. Many problems connected with circuits, allocation, etc. can be represented in terms of Boolian Algebra. Servomechanism theory and differential equations serve as a model of a more precise and useful representations of management concepts. Although, a good deal of work has been done on each of the above topics in Mathematics or Operations Research, still there is the necessity of very intensive study if we want to come to a stage of development for quick management applications.

How are then we to meet our requirements ? The first and foremost task is the training of suitable persons in Operational Research. Attributes like ability to work with people, ability and willingness to make decisions, the development of integrity and a sense of responsibility for the profession chosen, have to be developed. The Case Institute of Technology, Cleveland, Ohio, has given a good lead in this task. Besides the venture at other places in India, Mathematics of Operational Research is now being taught at the M.A./M.Sc. stage in the Department of Mathematics & Statistics of the Delhi University. Also quite a large number of teachers and students are currently engaged in basic research in this important branch of Applied Science.

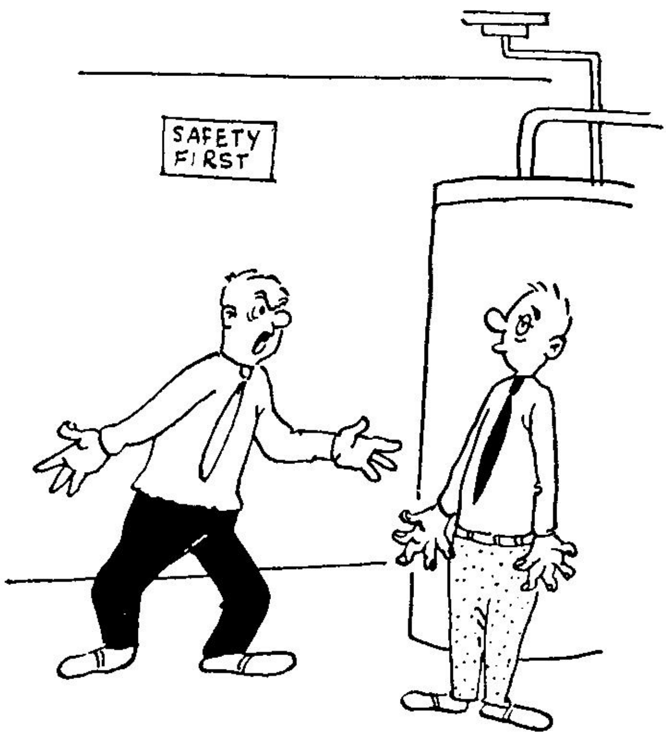
What we think we see — both in people and in things — is often only an assumption....

Fraud & Operations Research

WITH the aim of applying a mathematical method to the problem of fraud prevention, a very straightforward approach has been adopted: during a given interval of time the administration and its customers are likened to two players; the customers have a probability p of being checked and the administration a probability q of being faced with a fraudulent person; the unit cost of checking is a constant c, the sum risked is x, and if the fraud is discovered, the penalty is y, a function of x (more particularly y will be h times x, h being a parameter).

If one takes into account the finite reaction time of the players, one is led to alternate 'massive' controls and 'light' controls (in order to keep both fraud and the cost of controls within reasonable limits) and to define an intermediate optimum. This supposes that the effect of controls on fraud is an adequate Markov process.

On the whole it appears that anti-fraud measures do not derive from the various sampling theories, but from much more recent theories of operational research. ●●



"I don't know why I hired you in the first place, Edwards ! — you're all thumbs !"

Operations Research

HC Arora*

OR is a modern approach to decision-making. It is difficult to say when OR actually began but its central concept was developed during World War II. Since then OR studies in every sphere of human activity e.g. business, industry, social sciences etc. have made great strides in the industrially advanced countries during the last two decades.

OR both as a concept and as an approach has been defined in narrow as well as broad terms. OR is the attack of modern science on complex problems in the direction and management of large systems of men, machines, materials and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with a view to predict and to compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management determine its policy and actions scientifically.

OR is neither some form of black magic nor a panacea for management problems, nor is it intended to replace the battery of tools: accounting, econometrics, marketing research, O & M, quality control, scientific management, systems or industrial engineering, statistics, work study and the like. OR can mean many things to many people. There are many common but not fully valid impressions about OR.

It is concerned with an essentially practical aim: optimising the performance of a system regarded as given for the purpose of the problem. It is only a scientific approach for making better decisions. It is prescriptive, not descriptive. It prepares for action.

*Statistician, Indian Institute of Public Administration, New Delhi

Some distinguishing characteristics of OR are stressed such as: use of a team, rigorous training as a pure scientist, ignorance about a problem; study of operations as a whole and building a model.

Some OR methods have proved to be very useful because they have provided rewarding results at reasonable costs while others are still in development stage. These methods have two fundamental points in common: their ultimate goal and the basic pattern they follow. The ultimate goal of OR is to measure the relative worth of alternatives on the basis of accurate estimates and to provide the executive with a rational basis for making decisions with precise data, rather than on the basis of intuition. OR does this by providing the tools by which several alternatives may be tested and by using models (mathematical etc.) for determining the most desirable alternative. OR uses special procedures designed to be effective for the class of problems by which it is confronted. Its basic pattern is divided into the following six phases:

- (i) formulating the problem and defining the objectives
- (ii) constructing a model (mathematical etc.) to represent the system under study
- (iii) deriving a solution from the model
- (iv) testing the model and the solution derived therefrom
- (v) establishing control over the solution
- (vi) putting the solution to work: implementation

Important techniques include: linear or non-linear programming, resource allocation models, waiting or queueing and sequencing models, systems theory, replacement theory, game theory, and competitive models, inventory models, simulation and Monte-Carlo techniques and information theory.

The model of the business as a system is oriented to thinking in terms of inputs, process and outputs. This perception of the business often leads to a better grasp of the most effective combination of inputs to achieve desired outputs, the organisational processes involved and the functioning of the whole enterprise as an entity at its optimum level of performance.

An operations researcher not only studies the whole of a problem but tries to understand how the specific problem fits into the larger background. OR people are scientists, not experts. Particularly useful in OR is a man who is broad rather than deep, who is competent in one or more specialties (like mathematics, statistics etc.) but whose interest transcends his own specialisation and who likes to combine different ideas to form the sort of synthesis that approximates any situation in the real world. What is required is an enquiring mind with the ability to detach itself from the problem and to understand the interactions of different kinds of factors and information.

Applications of OR are largely successful when dealing with problems involving certainties or repetitive processes. OR can deal with less success with uncertainties e.g., problems involving human motivation or behaviour. The major objective of OR is to improve management decision-making. OR can assist the executives to correct a troublesome function or to make an operation more effective or to communicate to others the reasons why operations are running well and even for considering innovations. It should be evident that operations researcher with his quantitative tools will not replace the executive as a decision-maker. Executives will still shoulder full responsibility for making decisions. Through OR, they will be afforded the comfort of more pertinent scientific information. In special situations, it does offer valuable assistance to decision-making, by analysis of the problem, development and comparison of alternative solutions. It is often possible to suggest modes of decision which are demonstrably superior to the intuitive method.

Although OR is still a relatively young discipline, loosely defined, sometimes vaguely practised, and generally hard for a layman to comprehend, its future appears bright.

"....One expects that the Emergency will help strengthen the Administration, sharpen its tools and make it more capable of working to schedules and producing results in time...."

(Tarlok Singh—"Yojana")

The Assembly Line Problem

Kilbridge* & Wester†

THE assembly line problem comprises two separate sub-problems: (*a*) the 'cycle-time problem', and (*b*) the 'line-balancing problem'.

The cycle-time problem is to choose the optimum extent to which the assembly task should be broken down. This is done, to a first approximation, by minimizing the total of four cost factors: (*a*) learning cost; (*b*) handling-time cost; (*c*) balance-delay cost; and (*d*) quality-loss cost. The costs of learning and quality-loss favour shortening the cycle-time, while the costs of handling and balance delay favour lengthening the cycle-time.

The balancing problem is to apportion the work among the stations of the line as compactly as possible, while considering the restrictions on the order in which work elements may be performed, and without exceeding the chosen cycle-time at any station. Three kinds of ordering restrictions are considered: (*a*) restrictions on the ordering of components; (*b*) fixed facilities restrictions; and (*c*) restrictions of position. Such restrictions interfere with the commutability of work elements and increase the difficulty of attaining optimum line balance.

We have worked out a general theory of progressive assembly, suggesting a method of solving the cycle-time problem and presenting an heuristic technique for calculating optimum line balance. The standard technique of assembly in the flow production of manufactured items is the conveyorised line. Operatives are stationed along the line, on which moves the frame of the product being assembled. The total assembly job is broken down into elements of work and assigned to the various stations of the line. As the product progresses down the line each operative adds to it his share of the work. The technique is called 'progressive assembly'.

Determining the optimum assembly solution, that is, setting up a line for the least-cost system of assembly, is the 'assembly-line problem'. It comprises two separate sub-problems which must be solved sequentially: (*a*) the 'cycle-time problem'; and (*b*) the 'line-balancing problem'. The cycle-time problem is that of choosing the optimum extent to which the total assembly task should be broken down. The balancing problem is to apportion the work elements among the stations of the line as compactly as possible, while considering the restrictions on the order in which work elements may be performed, and without exceeding the chosen cycle-time at any station.

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†Armour Research Foundation, Chicago, Illinois, USA.

Operations Research

SBS Sharma*

During the last 30 to 40 years, scientific developments regarding human organisations and systems have taken great strides. We take human systems here as that of man-machine organisations invented and established by one individual or a group of them. These man-machine systems are not independent self-growing entities. They are linked in various ways to the economic and cultural climates of a country, nation or society. Many current problems that have now raised their head are due to this interaction of men, machines and environments.

DURING the Second World War, problems of War strategy and logistics posed formidable questions to Generals and War veterans. These men of war—practical and quick-acting—are no doubt soaked in the science and art of warfare. Even for these men, the immensity and complexity of the total system of men, machines, money and materials was simply over-whelming. They followed methods based on their experience and intelligence. No doubt, better and better ammunition, missiles, transport, bombers and several other scientific products were at their disposal. With all that, the best of war brains failed to solve effectively many problems that stared at them.

At this stage came in the famous *Blackett Circus* of the British War Admiralty. Prof. PMS Blackett—the famous Nobel Laureate Physicist—was called in to solve some major war field problems, perhaps to the dismay of many a 'Practical Genius': "What a scientist capable of only laboratory experimentation and dialetics of theoretical interpretation can do with a specific clear cut *practical* war problem ?" However, Prof. Blackett organised a team of scientists consisting of men from different disciplines like Physics, Mathematics, Statistics and Social Sciences. They successfully tackled many of the operational problems of the War, and put forward alternative solutions to the executives of the War Bureau. Mr. AP Rowe of the Air Ministry Research Station in UK christened this work as *Operational Research*.

*Indian Telephone Industries, Bangalore.

After the war, OR moved on to industrial circles to tackle problems in the different fields in industry from Marketing to Industrial Location. OR however stands on a different plane altogether when compared with the other techniques. The main difference between OR and other industrial techniques is two-fold: (i) The 'Wholistic' approach and (ii) The 'team' approach. The idea is to view the Company or Industry as a whole. OR function requires: crossing out departmental authorities; varied collection of data; rights and powers to go deep into problems, perhaps challenging previous decisions; and takes time to study, interpret and formulate. For all these, powerful management backing, sustained interest and a lively team are necessary.

There are certain misconceptions that OR studies, methods and problems are terribly complicated and highly mathematical and that ordinary people cannot take up problems of this type and only outstanding scientists can do it. There is also a confusion of thinking as to the types of problems that could come under OR banner. Leaving alone the classical developments, the history, and the methodology, it can be seen that in industrial conditions, many problems in which certain novel and unorthodox thinking are put to use, can be considered to be coming under OR, for example, industrial experimentation with statistical methodology. One more point is the implication of the words *Operations Research.* Perhaps these particular words may be unfortunate for orthodox scientists to call this as Science but it sounds well for industrial men. From operation warfare to machine shop operations of milling and turning, all are operations. Operation means action, working, financial transaction, piece of surgery, strategic manoeuvre: and Research means search, inquiry, endeavour to discover facts by study or investigation. Looked in these ways, *OR is nothing but applied research* as different from pure research. Many of the day-to-day investigational work in Industries is in the shade of OR. But then, OR becomes too diluted to become a Science. It becomes frivolous ; hence the idea of a structure of a Science with its own theories, hypothesis, and models. OR in other words gives theoretical foundation to investigational work which enlists the help of all other sciences like Economics, Engineering, Mathematics, Physics, Statistics, etc. It has a *macro-cosmic approach to problems* instead of a restricted narrow, microscopic view.

The great benefit of OR development in present day is the fact that it provides a good antidote to modern craze for specialisation. It is ridiculous to think of an ailment in any part as *entirely* due to that part only. Hence, a capable investigator (for that matter, Research worker) looks at the complaint of part trouble both from the point of view of the part and also the complete body. Approaches like Work Study, Statistical Quality Control, Production Planning and Control, Cost Control, Production Design, Tool Design, Market Research etc. look at problems from the departmental point of view but OR brings them all together and tackles problems from the Company or body point of view.

One more important impact on industrial circles due to OR is *the leverage given to scientific and theoretical sophistication.* Industries in India are far isolated from universities and research institutions. It is high time that a liaison is established between institutions of learning and research and industries. *For this to gain momentum, OR is the first step.*

OR is a very fine tool but its actual usage depends upon the needs of the circumstances. Where problems can be tackled by intelligence, experience and commonsense these sharp tools may be superfluous. Only when we find that the usual means are not able to solve our problems, we go in for advanced sophisticated techniques. In Indian conditions, industrial problems are to be thoroughly analysed with *correct* facts and figures, and then in many cases straightforward thinking with commensense, will lead to solutions. Techniques like Quality Control, Work Study and Scientific Management are to be ingrained deep into our industrial systems and organisations, before we get on to OR activities. However, we have to keep an open mind to these new innovations.

"Creating industrial relations which work, requires as much skill as creating a car that sells . . ."

Production Rate Variations and Forecast Errors

Douglas A Bly*

BY repreated simulation of a manufacturing system responding to random demands and operating upon forecasts of these demands, the author has in a fuller paper† published eslewhere evaluated the combined effects of management policies regarding objective inventories, production periods, and restriction on the alteration of production rates. The results of the simulation were worked out in terms of average inventories, inventory failures, and deviation of production rates for a total of seventy-two combinations of policies and forecast errors. From the results of these repetitive simulations it was possible to observe how the improvement of forecasts would reduce the costs of operating the system and provide some insight into how various combinations of policies would effect the total system.

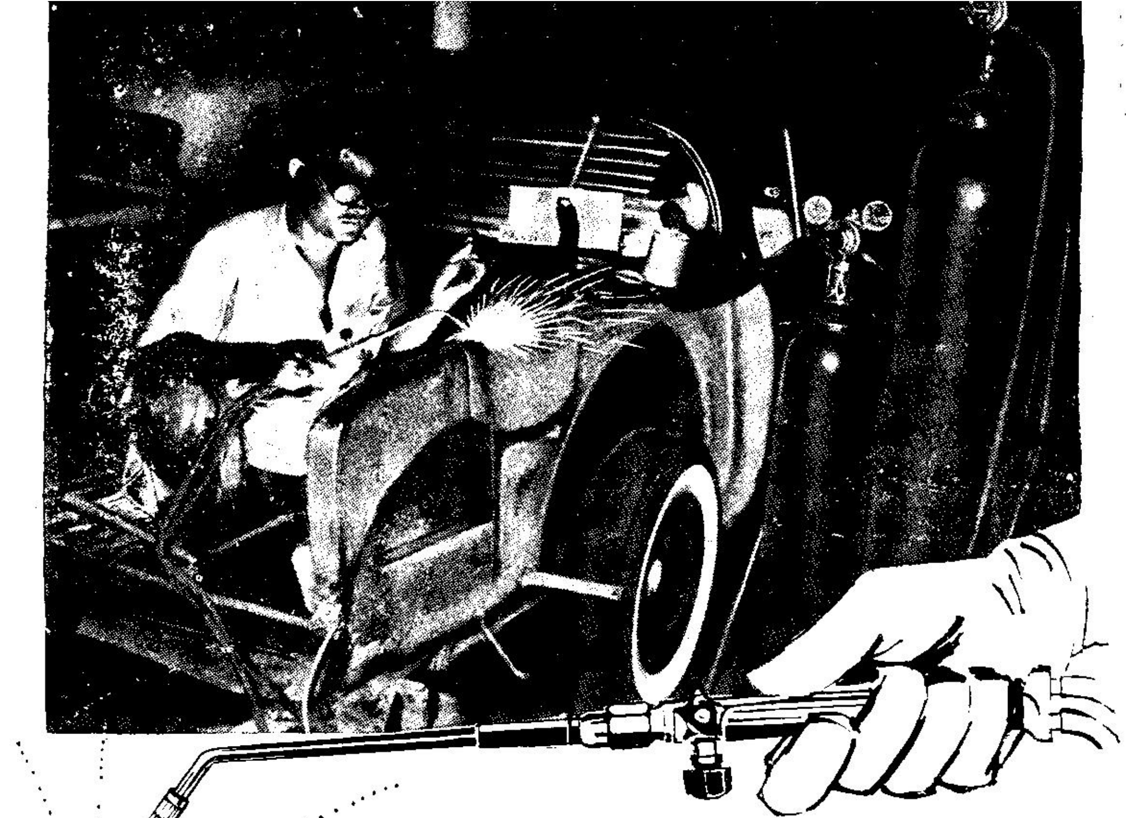
Since exact demands are seldom known very far in advance, most companies find it necessary to carry an inventory of finished goods. The control of inventories in the retailing and wholesaling fields and in raw material for manufacturing organizations is rather thoroughly described in the literature available today. The processor of raw material into another form for resale has a somewhat more complex problem than any of the others mentioned, since he must not only balance the cost of carrying inventory against the penalty cost associated with the failure to have goods available but must also include the cost of altering the production rate to match consumption. If the manufactured line is broad and the labour and equipment versatile, then no additional cost may be enountered if the reduction of the production rate of one item can be matched to an increasing rate of another item. The extent of the flexibility available is a measure of the importance of this factor.

With these factors in mind, we have simulated the operation of a manufacturing system which plans production on forecasts of future demands, modified by the current inventory position. Our simulated system operated under a variety of conditions, some controllable, such as inventory policy, length of the production cycle and restrictive changes on the alteration of production rates, all basically expressions of management policies. Other conditions, such as the accuracy of forecasts, are partially controllable, and still other conditions, such as the arrival of demands. are completely uncontrollable. By simulating the operation under a considerable variety of combinations, we were able to observe the influence of policy decisions and, although cost evaluations were not attempted, some economic implications could probably be generalized.

*Texas Instruments Incorporated, Dallas, Texas, USA.

†Paper read at the Second International Conference on Operational Research in France 1960.

"I'm so toxic that the flowers wither when I go into the garden."



A Company in Trouble

Kenneth C Jasper*

MANY small and medium size companies in this country often find themselves in a precarious position. A manufacturer of Metal Consumer Goods in Northern India was in this unfortunate position: high sales activity but no profit. Matters reached a stage where a meeting of the Board of Directors had to be called to decide whether the operation should be continued. The Managing Director was, however, anxious not only to continue the operation but to change it over to a profitable basis, if possible. He, therefore, sought out the services of an NPC Management Engineer, who made a survey of the plant and its operations and submitted a report, outlining his recommendations for bringing the company on to an efficient and profitable basis. The survey revealed the absence of several basic management practices necessary for the efficient operation of a Manufacturing Plant. Among these, the most damaging were found to be:

1. Management Shortcomings: The top management not only lacked technical knowledge but there was total absence of known management objectives. The principal cause of the low morale was the free and somewhat autocratic criticism which top management personnel levelled at the factory engineering and supervisory staff. Often the criticism was baseless or unwarranted arising out of the lack of knowledge of what was involved or required in the production operation. The top management openly expressed lack of confidence in the factory management staff and actually interfered with the manufacturing operations through direct orders to junior factory staff and even to the workers, in a manner that was counter to the direction in which the factory Production Team was heading.

2. Costs & Expense Distribution: The top management lacked elementary knowledge of the principles of cost and budgetary control. Factory accounts were burdened with items of expenditure which normally should not have been chargeable to the factory. This practice resulted in an abnormal burden or overhead rate far beyond that considered normal for the industry and the field in which the product had to compete. Moreover the burden rate was found to be excessive for the volume of product being produced.

3. Process Planning: When the operations started some four years ago the product was copied from an existing product. Not then, nor at any time since, has management seen the necessity of preparing detailed drawings of the individual parts with the manufacturing tolerances and specifications spelt out for future reference, direction to the shop, or control of product cost and quality.

The absence of processing or operational sheets was also noted. Hence a great variation in methods, speeds and feeds as well as machine routing was apparent. This resulted in varying production rates in selective assembly as well as widely fluctuating costs.

4. Tooling: The survey revealed a complete lack of understanding of the principles of interchangeability in manufacture. The tools, jigs and fixtures so

*Senior Management Consultant, George Fry Team attached to NPC

necessary to maintain a high level of efficiency and machine utilisation were also missing. Due to absence of drawings, very few dimensions were closely held and selective or individually fitted assembly was the order of the day.

5. Production Control: Under the operating conditions observed there was no realistic method of production planning and control. Hence, much time was lost due to short runs, changes, jobs started without enough stock to fill the order, etc.

6. Work Study—Methods Study: The time required to do each operation was not known, so production rates varied greatly from day to day, as did the unit cost. The method was left to the operator, who often varied the sequence, depth of cut, rate of feed and handling from piece to piece.

The solution to these manifold problems lay in *management becoming truly managers* and using Scientific Management Tools. This Survey resulted in these specific recommendations:

1. Management Shortcomings:

(a) Management must display confidence in the staff they have selected by defining the responsibilities and the authority necessary to carry out their responsibilities. If the present staff cannot be given this confidence then Management has the responsibility of replacing them with persons in whom Management can have confidence or of training them to perform as required.

(b) Top Management's responsibility to the plant function includes the development of a sound, forward thinking plan of operation with known production forecasts, schedules, quotas, objectives and realistic target dates for their accomplishment. In developing such a programme for production, the Plant Manager and his staff must be a party too and an integral part of the programme.

(c) Periodic follow-up by Management and reports by the Plant Manager to Top Management must be made to *determine progress, as well as problem areas.* The follow-up and reporting, to be worthwhile, must be on the basis of measured factual data, not on assumption or conjecture, to be worthwhile.

2. Cost Determination: The establishment of a standard cost system and operating budget will do much toward setting up a true picture of the efficiency of the factory operations and get a factual measure of the performance of the plant management staff. At the same time the exact cost of the product will be known. Obviously the standards to be worthwhile must be measures and not set by comparison with past performance or some other variable or intangible data.

It is equally desirable that the Head Office operations should and can be included in the budget plan to give the Board an equally effective factual check on the overall operation.

3. Process Planning: An effective system of process planning must be implemented at once and made the full time responsibility of a trained Engineer who will direct, supervise and prepare

(a) Detailed Engineering drawings of each part giving (1) Dimensions (2) Tolerances (3) Finishes (4) Materials (5) Special information.

(b) Operational, process, route sheets for each part giving (1) Operational sequence (2) Operational instructions (3) Machine to be used (4) Tools, jigs, fixtures, both standard and special (5) Feeds and speeds (6) Inspection gauges (7) Set up time (8) Production time in hours per 100 pieces per operation (9) Special information.

4. Tooling: Design and build the jigs, fixtures, cutting tools and inspection gauging specfiied by the process planner. To achieve first: interchangeability; second: greater machine utilization and efficiency.

To arrange for tool maintenance, sharpening, etc. to be performed by (1) one Tool Grinder instead of by each operator. Tools will be ground to drawing specifications to assure repeated maximum performance.

5. Production Control: Design a system of production planning and control which will provide *visual production control, scheduling* and *machine loading*. The system must be designed to utilize as its basis the operational route sheets, management production forecasts, and provide a basis for inventory control to meet management's objectives at a minimum cost.

6. Work Study—Methods Study: The development of measured production standards and efficient methods of work is a full-time responsibility. Hence this function should be assigned at once. The entire effectiveness of efficient management rests on this fact finding, data gathering, standards developing techniques. Future successful incentive development and application depends entirely on this function.

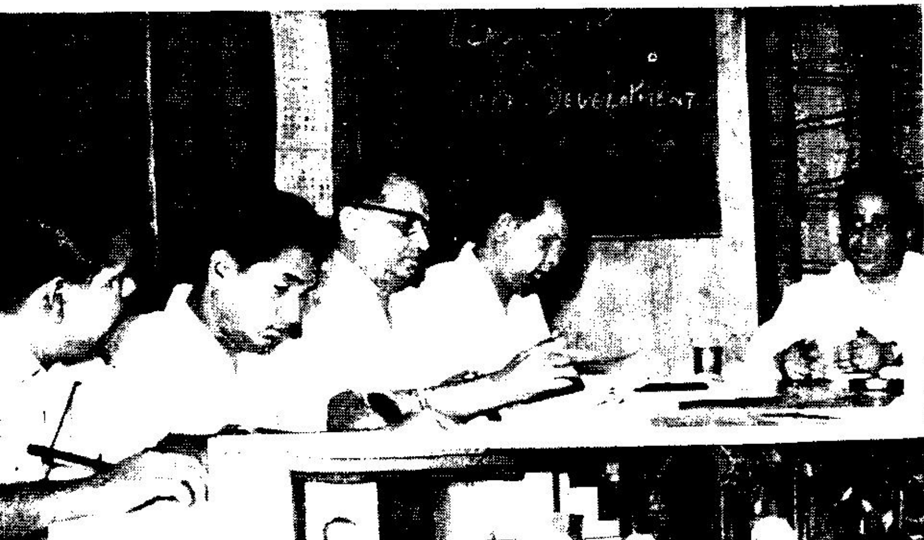
A sample project applying the principles of methods study, time study, process planning and tooling as recommended revealed a productivity increase of 245% and a reduction in cost of 60% to be possible. This would, when applied, turn a loss operation into a profitable one; especially when the additional reductions in cost and overhead are realised through full implementation of these management tools.

PRODUCTIVITY !

Every Fourth Child born in the World is Chinese !

"How many children have you ?" asked the census taker. "I've got three," said the citizen. "And that's all there will ever be." "What makes you so positive?" asked the visitor. "I'll tell you why there won't never be but three," said the man. "It's wrote down in this here book I'm readin' that every fourth child born in the world is Chinese."

Participants in
Method Study Course
in Gujarati
at Ahmedabad



Participants in
Management Developme
Course at Bangalore

JS Seminar
Team
t Calcutta

Trade Union Representatives participating in Tamil Course in Industrial Safety

* *

Participants in APO Course on Leather Tanning at the Central Leather Research Institute Madras

Increase in Productivity

The National Productivity Council has during the last five years of its existence —the 6th year began on 12 February 1963—done a very large amount of project work as an integral part of its training programmes. These projects involve a good deal of rationalisation, simplification and systematization of Production Operations: the very substantial increase in Productivity thus accomplished has, however, seldom been publicised. This lack of publicity has two disadvantages that people seldom come to know of the large volume of ground level work that the NPC has been doing. Secondly, industrial establishments do not come to know of the very large possibility of increasing Productivity by small and relatively inexpensive readjustments brought about on a common sense basis in the working of industrial concerns. Here we have brought together in summary form some of the projects which the NPC did through its Regional Directorate at Bombay as an integral part of INDUSTRIAL ENGINEERING IN-PLANT TRAINING PROGRAMME. The course was conducted by Mr RJ Williams, US-Aid (George Fry) expert attached to NPC and Sri MN Unni Nayar and Sri HA Jhangiani who were associated with Mr Williams in conducting the course.

Electronic Equipment

A VARIETY OF electronic equipment is produced for use in the field of atomic energy. Production has increased ten-fold during the past five years, creating a need for placing the production operations on a more systematic basis. Several projects were undertaken with this end in view, at the Electronics Division of a public sector establishment.

1. A modified design has been made to simplify the fabrication and assembly of a geiger tube stand. Implementation has resulted in a saving of 50 percent in material cost and 50 percent in assembly time.
2. The mechanical design of a scintillation head was analyzed with a view toward simplifying its fabrication. A new design has been used, resulting in a reduction in fabrication time of 50 percent together with a 25 percent reduction in material cost. Other recommendations, to be implemented, will reduce the material cost by an additional 45 percent.
3. At the present time instruments produced are intended to be 'self contained' units, each operating directly from the mains. However, with increased equipment demands from colleges and medical institutions, the need for standardization of units, elimination of unnecessary duplicate components, and for a smaller, cheaper unit became apparent. Using the techniques of methods study as a guide for designing an improved unit, a more simple and compact gamma ray spectrameter was drawn up, built, and tested satisfactorily. It was determined that the cost of the improved unit can be reduced by 20 percent or Rs. 2,000 each. Annual savings on this unit are determined to be Rs. 1,50,000.
4. In the rapid growth of the electronics production division, no systematic paper-work procedure has been designed. A study is currently under way to simplify, clarify and otherwise develop the necessary procedures to operate the organisation effectively.

Toiletries

An Oil Mill, in its toiletries section, produced, among other things, hair oils, shampoo, liquid soap, and glycerine. It was desirous of increasing the production by approximately 100 percent. Production capacity was available, but the bottleneck was in the filing and packing of the toiletries. Considerable back-tracking and otherwise excessive handling and delay existed. A revised layout, minimizing the handling was prepared, some operations were found unnecessary and were thus eliminated. The improved operations will permit the proposed 100 percent increase in production. Only minor alterations are necessary, and no major capital expenditure is required.

Dye-stuffs

A study was made of the high wastage in a chemical plant producing textile dye-stuffs. While it was possible to salvage a large portion of each defective batch, it was felt desirable to find the reasons for spoilage and to eliminate these causes as far as possible. It was determined that a lack of process control was the primary factor. Recommendations were made and are being implemented which will lead to a decrease in the loss by an amount of Rs. 1,80,000 annually.

Humidifiers

A Light Engineering Company manufactures a line of humidifiers and axial flow fans. Two types of humidifiers were found to account for 68 percent of the production; and improvements were therefore sought in the manufacture of these items. Recommendations were made, and subsequently implemented, to provide a suitable work-place layout for assembly operations, to provide certain jigs and fixtures, and to simplify many operations. Savings at the rate of Rs. 10,750 annually are being realized.

A machine was designed and built to file the grid teeth on the humidifier. The filing operation was both a bottleneck operation and one in which it was difficult to maintain persistent quality. The new machine, built in the company workshop and chiefly from scrap materials, does the filing at four times the previous rate. Annual net saving for the machine is Rs. 8,400. Four additional machines are now being fabricated.

Paper Conversion

A Mill converting waste paper to a variety of finished papers was desirous of increasing production by 100 percent in order to meet market demands. Three major problems existed, and these were studied as a part of the course project work. The trouble spots were:

1. Handling of raw materials
2. Handling of finished goods
3. Lack of a coordinated scheduling and control programme for production.

After a careful study of materials handling at both the raw material and finished goods ends, recommendations were made for the use of simple handling equipment to ensure a smooth and timely flow of materials at double the present rate. In addition, averages of Rs. 10,400 annually at the raw material end, and Rs. 900 annually at finished goods end were effected. The recommendations are being implemented.

Due to a lack of adequate coordination between sales, production and maintenance the full capability of the plant's production equipment could not be realized. Irregular production was the result of both inadequate long range sales planning as well as inadequate maintenance scheduling. Deliveries were frequently late. A production planning and control system was devised which would provide the necessary coordination as well as exercise control over the progress of production. Detailed results are not yet available, but within the past two months production has increased and late deliveries reduced. It is also anticipated that savings will be effected on raw material procurement due to more careful planning.

Pharmaceuticals

A Pharmaceutical Company manufactures a variety of pharmaceutical specialties. Two liquid tonics constitute about 60 percent of the total production. Since they contain alcohol, they are manufactured, bottled, and cartoned under the direct control of the State Excise and Prohibition Department. Repeated additions of new manufacturing equipment in the Bonded Laboratory have made that area an extremely congested section of the works. The sales godown was likewise crowded and there was an excessive amount of handling noted. Sales were running 20 percent over the previous year.

A study was undertaken to evolve improved handling and storage of finished goods. Recommendations have been made to handle the finished bottles in groups of ten rather than singly, to improve the trolley design for greater capacity, to revamp the storage shelving arrangement, to improve the mode of packing for shipping, and to re-layout the sales godown. Most of these recommendations have been implemented. *Savings of the first year are estimated to be Rs. 1,13,000 with greater savings thereafter.*

Railway Wagons

A Railway Wagons Manufacturing Company, employing approximately 500 employees, has gradually grown up in quarters which formerly housed a woodworking manufacturing concern. As additional items of equipment were procured they were set up in whatever space was available, and as a result the layout has become rather ineffective. Production costs are high.

Some items of equipment have been rearranged. Stocking racks for materials have been located near some machines. A monorail and trolley track have been installed to facilitate handling heavy channel members. *Net annual savings due to an improved layout and better handling amount to Rs. 42,000.*

A number of method changes have been made. Punches and dies have been substituted for individual drilling operations wherever possible. A required angle section could not be made from standard stock, but had to be cut, marked, gas cut, chipped, ground, and drilled. It is now made from flat stock which is punched (8 holes) and cut to length in one operation, and then bent to the correct angle on a hydraulic press. An improved welding sequence has been developed for welding brake beams. The annual savings on such method changes already implemented amount to Rs. 58,000.

Nationalized Transport

The Central Workshop of a State Transport System is responsible for furnishing to its divisions an adequate number of repair assemblies. The supply position for some assemblie has been gradually deteriorating. A study was undertaken to determine ways to increase the output of electrical assemblies, particularly starters and dynamos. Methods improvements in the reconditioning of starters and dynamos were made with the following results: 1. The four months backlog of starters and dynamos awaiting repair has been eliminated. 2. The rate of output has been increased by 50 percent. Field coil rewinding has been increased by 500 percent, permitting the workshop to assist other transport systems. 3. Recommendations have been made for improved maintenance procedures at the division level to extend the life of starters and dynamos and thus reduce the reconditioning requirements.

Structural Steel Fabrication

A Structural Steel Fabrication Company fabricates a variety of structural steel units in two main shops, a light fabrication shop and a heavy fabrication shop. In the former it was desirable to provide for an immediate increase in capacity of 33 percent with a minimum of expense for additional equipment. It was further desired to provide for a subsequent expansion programme with a 230 percent increase over the present capacity. This expansion is to take place over the next 4 to 5 years.

A rearrangement of existing equipment was recommended which reduced handling, reduced delays, and provided for easier operations. The new layout will not only provide for the 33 percent increase, but also provides savings of Rs. 39,300 per year. A layout, together with a summary of minimum equipment requirements, has been prepared to provide for the 230 percent increase in capacity. This project was undertaken to permit an orderly expansion with a minimum of disruption.

It is desired to establish a production planning and control system for the heavy fabrication shop. At the present time almost all orders eventually become "rush" orders, resulting in excessive handling and a compounding of delays. The study is still in progress, but it is anticipated that a substantial reduction in fabrication time will be made. This will give an improved delivery schedule to the customers.

Textiles

Several projects were undertaken to increase the productivity of materials, machines and labour of a textile mill which had old equipment located in old facilities. With the application of work study, it has been able to achieve productivity gains in several areas ranging from 8 to 166 percent. At the same time wage increases have been made ranging from 8 to 97 percent.

Projects undertaken included the following:

1. A study of spindle assignments led to the establishment of work standards where none existed before. Production increases ranging from 22 to 60 percent have been registered.
2. In colour winding a similar study was made with increases ranging from 30 to 50 percent.
3. A study of the cheese winding indicated that considerable time was being spent by the operatives in securing fresh yarn. Storage bins holding 100 pounds of yarn were provided under the machines. The same bins held wooden bobbins and empty pirns. Spindle assignments were increased after methods study.

   Total savings: Rs. 3,20,000 annually.

4. In the reeling department it was noted that the speed of the reels could be increased without an appreciable increase in breakage. At the same time the yarn traverse was reduced which permitted the addition of 10 spindles, or a 25 percent increase. It is now determined that the machines may be modified to extend the reels by 2 feet to add another extra 10 spindles. This gives a further increase of 25 percent.

   Annual savings at a rate of Rs. 95,000 have already been achieved. After the existing machines are extended, the additional annual savings will amount to Rs. 33,700.

5. The old method of cleaning pirns was a hand operation where a long steel needle was used to dig the dirt from inside the bobbin. Compressed air is now used to blow out the dirt. A work station was designed for easy operation. A productivity increase of 450 percent has resulted.

6. Another study involved the handling of soft wound cheeses. In the former method there were frequent delays in the transporting of the cheeses to the dye-house as well as damage to the cheese. Eleven hand-trucks were built to facilitate the transport. The cost of the trucks was recovered within four months with subsequent annual savings of Rs. 7500.

"...The enterprise is to keep afloat on an even keel; the sea is both friend and enemy; and seamanship consists in using the resources of a traditional manner of behaviour in order to make a friend of every hostile occasion...."

—*Prof. Oakeshott*

The Case of XYZ

VKS Menon*

XYZ ELECTRONICS Ltd produces devices used in radio and recording equipments. It is mainly a *one product company* even though it makes four varieties to satisfy the slightly different specifications of its four major customers. The company's accounting procedures are primitive. Its sales are handled by one man. It has no purchasing department and buys on hunch. Also the production manager works as the purchasing agent. Competition has increased and XYZ does not dare to raise prices. Its profit margin has been steadily declining even though its sales volume has been going up. The situation is that the firm is on the edge of bankruptcy.

What is the reason for this ? The production manager is smart, has modern equipment, good layout and materials handling facilities. Plant efficiency is good and wage rates, comparable. Freight is no factor, as the product is small and light. The selling expenses are low, too.

Complete analysis of the functioning of XYZ shows one big fault: no inventory management. Buying patterns are erratic and expensive. There is no sales forecasting, no coordination among sales, purchasing and production. Inventory management is an integral and important function of management and should not be overlooked. Since periodic sales forecast is a *must* in inventory control, it was decided that XYZ should have an annual sales forecast to be revised every quarter, oftener if necessary. Besides the forecast, the whole process of production planning was analysed to determine correct inventory levels and materials requirements. Purchasing was to be based on the results of this analysis. The old buying pattern showed that 12 or 13 separate purchases were made annually. This meant a high administrative and clerical cost and low discounts. It was, therefore, decided to make purchases only four times a year.

The production manager was so much interested in having enough parts always on hand, to facilitate production, that he usually bought too many parts. The production manager was relieved of the buying function which was then entrusted to the sales manager.

By producing one product instead of four slightly different ones each requiring separate stocks, the inventories were cut to half and still they were at safe levels. This necessitated a market survey to see if the same product could be used by all the four customers and the answer was in the affirmative.

A perpetual inventory set up for maximum and minimum quantities was maintained for most costly items and for parts which were critical and difficult to procure.

The costs were now down: XYZ could make their prices competitive and still improve their profit margin. ● ●

*Assistant Director, NPC Regional Directorate, Bombay

An Idea-Page in NPC Productivity Journal

We are thinking of introducing an Idea-Page in this Journal. Whenever you come across a new idea, a new gadget, a new 'something' of productive possibilities, please write a few words to us communicating the idea (and the source).

THE inauguration of the 'IDEAS' page by the NPC is just another step forward in which the NPC hopes to promote the free interchange of IDEAS with proven productivity gains.

Each day there are hundreds, if not thousands, of problems being solved by engineers and other operating personnel throughout Indian Industry. Through the interchange of these problem-solving 'IDEAS' or gadgets, other plants having similar problems may either solve their problems or be led to the solution through the thoughts stimulated by 'YOUR IDEA' printed in the NPC Journal.

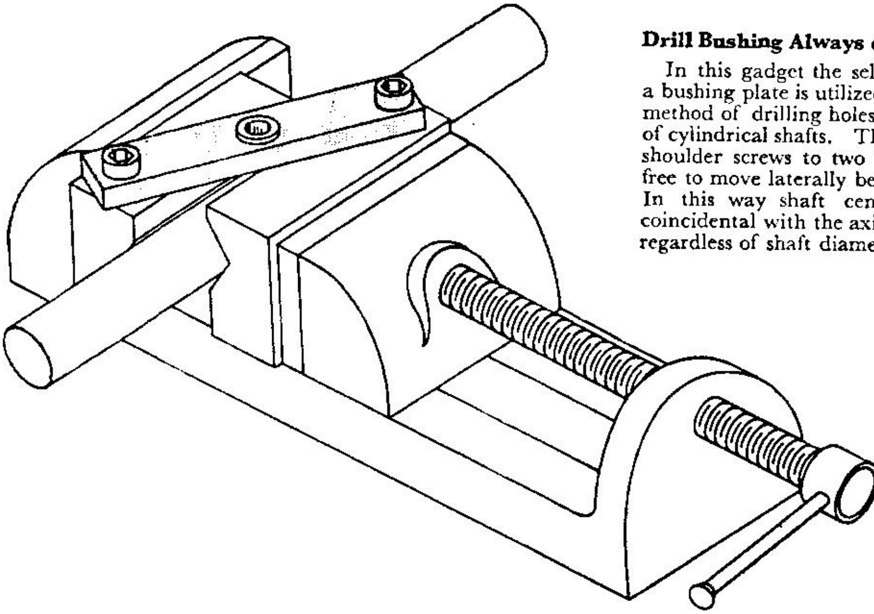
These 'IDEAS' may be submitted to the 'IDEAS EDITOR' of the NPC Journal, who will select those for publication. Each 'IDEA' must be submitted on 8"×11" bond paper (white), typed, triple spaced, one side of the page only. (Number all pages). All explanations must be held within 300 words maximum and accompanied by a line (inked) drawing on vellum 8"×11". All unnecessary details must be left out of both drawing and explanation. Be sure that all copy submitted is clearly identified as being yours.

The example printed on next page, has been taken from the 'American Society of Tool and Manufacturing Engineers' Journal for October 1962, and is displayed as the 'IDEA' the NPC wants from the Readers. Send yours in *now* !!!

"Hard work, high thinking, adventurous excitement, and a great deal more that forms a part of this or the other person's spiritual bill of fare, are within the reach of almost anyone who can dare a little and be patient . . ."

—*RL Stevenson*

A PRODUCTIVE IDEA !



Drill Bushing Always on Shaft Centerline

In this gadget the self-centering action of a bushing plate is utilized to provide an easy method of drilling holes through the center of cylindrical shafts. The plate is secured by shoulder screws to two V-blocks which are free to move laterally between two vise jaws. In this way shaft centerlines are always coincidental with the axis of the drill bushing regardless of shaft diameter.

Patrick Newman
Jamaica, N.Y.

Question Answer Service

Manning for Maintenance in Steel Plant*

Question: **How is manning for maintenance done....The most baffling problem is the estimation of workload due to breakdown. This occurs suddenly and unexpectedly. It constitutes a major portion of the workload, sometimes coming upto 50-60 per cent of workload in a steel plant....I am interested in the mechanics of analysing and estimating breakdown hours and manning for the same. I have heard that some advanced statistical methods are adopted to do this estimation. I am interested to know about these methods.**

—HN Subba Rao, Bhilai

TWO NPC Experts have given the answers printed below:

(A) It is true that the estimation of breakdown maintenance workload is relatively difficult, as compared to preventive maintenance figures. For this reason the concentration is usually on preventive maintenance, so that the breakdown maintenance may be largely eliminated.

*This question is supplementary to the question-answers printed in the last issue of the Journal, page 164.

However, if the problem is to be approached in the manner of the Operations Research analyst, then the mere knowledge of breakdown requirements is of lesser importance. In OR the analysis is concerned with optimums or minimums, in such things as costs, size of work force and the like. For example, using certain mathematical procedures it becomes possible to optimize repair crew size; to determine the mean fraction of the time a repair crew will be busy in the shop with a known number of machines; to determine whether one or several crews are more economical; and for determining the optimum period of time for P.M. for different degrees of variability of breakdown-time distribution.

The techniques associated with these determinations are not readily explained in such a short note, but reference to various books of OR will provide full details. One of the best in this respect is "Queues, Inventories and Maintenance", by Philip Morse, published by John Wiley, being a "Publication in Operations Research No. 1". Chapter 11 of this book deals exclusively with the problems you have stated, and I suggest a reference to that work. The book is written with an assumption of a rather extensive knowledge of the queueing theory, and it will be difficult to understand otherwise.

Good luck in your pursuit !

—Prof. RF Bruckart*

(B) *First*: I would approach the manufacturers of the various items of equipment or the users of similar equipment to find out:

(*a*) What parts fail.

(*b*) What life we may expect or with what regularity can we expect certain parts to fail. By doing this I would determine what items I would stock as repair items as well as gain some idea of the maintenance load from a manpower standpoint.

Secondly: Being in operation I would employ the *Work Sampling* technique to determine my actual manpower requirements. This is the statistical method normally used in these matters.

Because of the lengthy and detailed explanation on Work Sampling I suggest attendance in a Work Sampling Course or reference to several good texts on this subject.

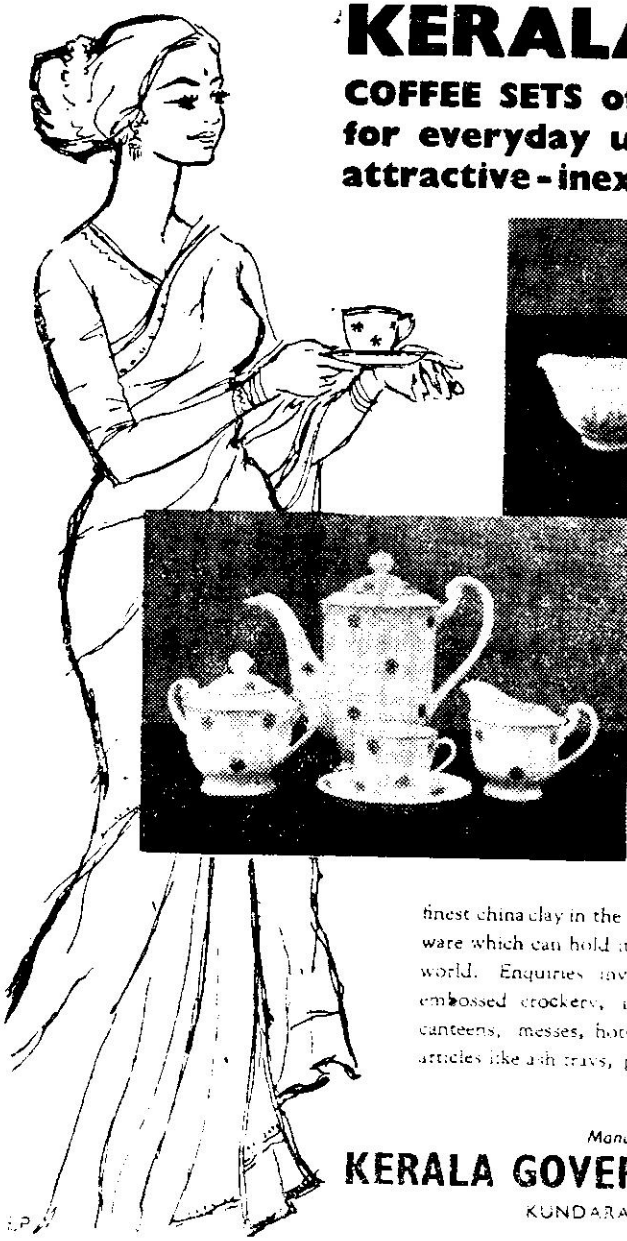
—Kenneth C Jasper†

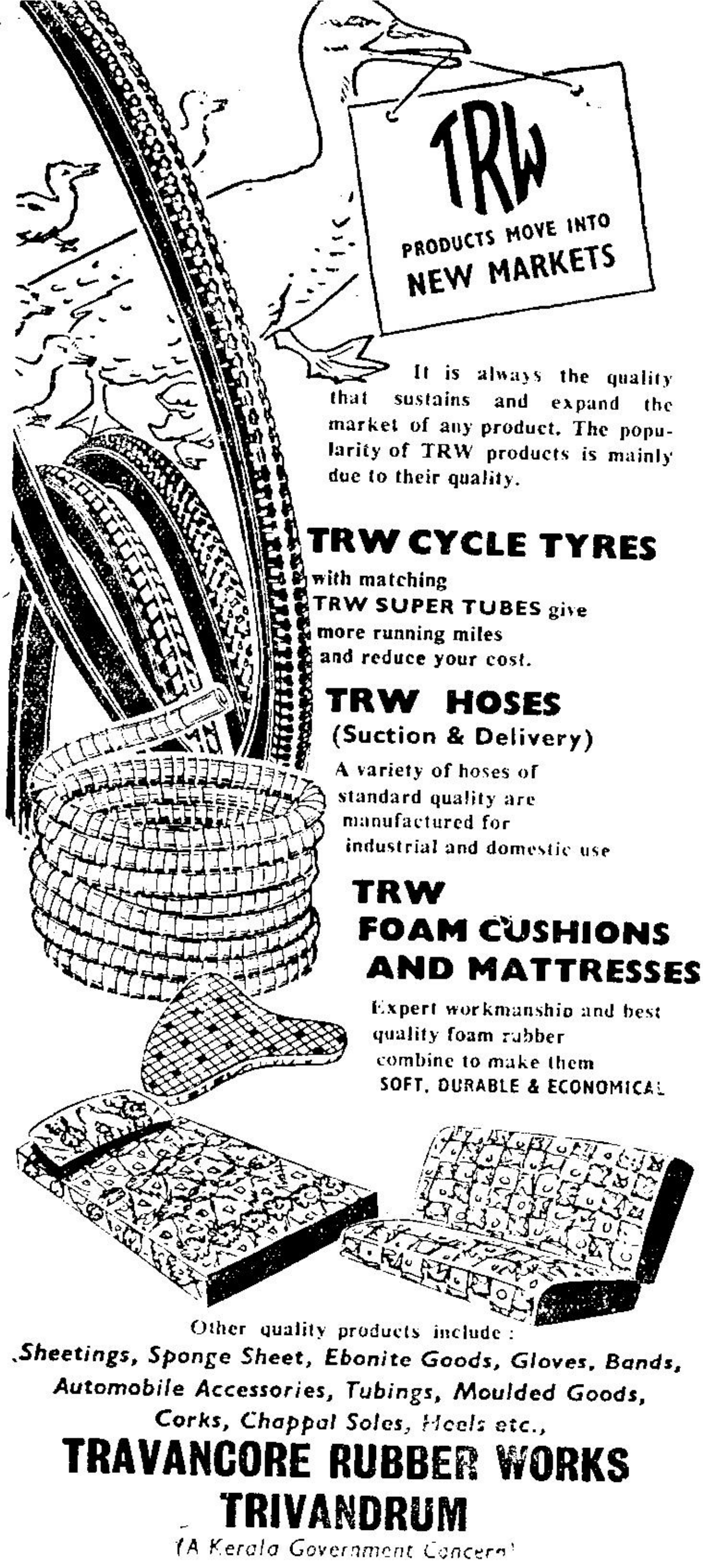
*Industrial Engineering Consultant, NPC

†Senior Management Consultant (US-AID) George Fry Team attached to NPC.

"Ah, if we could only die temporarily !"

—*Tom Sawyer*




TRW
PRODUCTS MOVE INTO
NEW MARKETS
It is always the quality that sustains and expand the market of any product. The popularity of TRW products is mainly due to their quality.
TRW CYCLE TYRES
with matching
TRW SUPER TUBES give
more running miles
and reduce your cost.
TRW HOSES
(Suction & Delivery)
A variety of hoses of
standard quality are
manufactured for
industrial and domestic use
TRW
FOAM CUSHIONS
AND MATTRESSES
Expert workmanship and best
quality foam rubber
combine to make them
SOFT, DURABLE & ECONOMICAL
Other quality products include :
Sheetings, Sponge Sheet, Ebonite Goods, Gloves, Bands,
Automobile Accessories, Tubings, Moulded Goods,
Corks, Chappal Soles, Heels etc.,
TRAVANCORE RUBBER WORKS
TRIVANDRUM
(A Kerala Government Concern)

Forecasting & Control of Costs

MK Rustomji*

There are many companies abroad such as ICI, J Lyons, Dunlops, Kaiser Steel, Daimler-Benz and National Cash Register Co., which forecast their profits and ways and means five to seven years ahead. Forward thinking and forecasting of this type is not generally done in India because it is felt that with changing conditions such forecasts would not in any way reflect the true position in the years to come.

WITH the modern techniques of sales, accounting and industrial engineering, it is possible to make reasonably accurate forecasts even as far ahead as seven years. The forecasts would indicate a trend and they must undergo a continual process of revision, say once every six months. The advantages of making such long-term forecasts are: firstly it enables Management to know the profits made by the various divisions of the company under varying conditions of sales and production. The Accountant by means of his techniques can translate all the forward thinking of Management in terms of one common factor, money, and give Management information about profitability and financial requirements. The other advantage is that it enables Management to think well in advance of all the numerous factors that go towards making a productive unit. Requirements of electricity, water, roads, movement within Works, housing of employees, transport of employees, training and development of executives to meet the expanding needs of the organisation, can all be planned ahead sufficiently and action initiated. Forecasting helps in planning for capital requirements and for directing the company's Research and Development activities. Many companies abroad are spending as much as 5 percent of their total turnover on Research and Development and this can only be justified if a company looks years ahead.

*Controller of Accounts, Tata Engineering Locomotive Company, Jamshedpur; Leader, NPC Team on Cost Accounting & Financial Control

Looking ahead five or ten years, particularly in the context of a rapidly expanding economy, also helps to establish ancillary industries. Forecasting ten years ahead should give a guide as to the possible demands in the years to come and would be of help to entrepreneurs, setting up new industries.

Forecasting is broad and is in general terms: it cannot be used for control of costs and control of day-to-day operations. For such controls we have Budgets and Standard Costs. Budgets are for short-term periods—they are usually made a year ahead and are broken down into monthly periods when reports of actual performance are given against the budgets.

How costs are controlled is illustrated in the examples which are discussed below. These examples are mainly from the engineering industry, but the principles will apply to most other industries.

The cost of direct materials is an important element in the total cost of a product; it might be anything from 50 to 80 percent of the total cost. The Designers who design the parts and lay down specifications, the Methods Engineers who determine the methods of manufacture and the Material Planners who work out the material requirements making reasonable allowances for off-cuts and wastages, have an important part to play in controlling material costs. They virtually set up the 'standard cost' of the product and they should be very cost-conscious. Once the standards are set, the materials are issued to the shops on pre-printed requisitions. However, if any extra material is required or if any items are scrapped during manufacture, they are recorded separately. These separate reports are sent to the Accounts Department and reports are brought out on 'excess over standards'. This is a 'built-in' system of control. The tendency today for controlling costs is to concentrate mainly on exceptions or variances from planned or standard quantities.

There are many other aspects of material control: ensuring that inventories are kept as low as possible consistent with the needs of production, buying at the most economical rates, making long-term contracts say a year or two ahead, keeping alert the whole time for substitute materials which might be suitable and which might be cheaper. There is great scope for saving costs by way of better materials handling.

Industrial Engineers by means of time and motion study set up performance standards and determine standard manhours of each operation of work to be done. The actual performance of labour is compared with standards and efficiency figures are brought out which enable Management to keep control over direct labour cost of a product. The important thing to remember here is not so much the money cost of direct labour. The money cost of direct labour in a product costing Rs. 31,000 may be only Rs. 250. Direct labour in most engineering factories work on very expensive machine tools and use very expensive services. If the efficiency of a direct workman is say 50% as against 100%, it means that organisation is getting only half the value out of the expensive machine tool he is working on as against getting full value.

Overhead expenses such as indirect labour, indirect materials and administrative costs are controlled by means of Budgets. Each section of a Works is made a Budget Centre and all the costs directly relating to that Budget Centre over which a Sectional Officer has control are estimated in advance and made into a budget after due examination. Budgets are made in consultation with the departmental officers and the accounting control is through reporting the actual expenditure against these budgets periodically and examining the reasons for the variances for taking corrective action. These Budgetary Control techniques are of great assistance to Management for decentralising responsibility and authority, which is so necessary for expansion and yet retaining control.

In India this is a specially important element of expenditure, in that the cost relationship of this type of labour and staff to direct labour is much higher than abroad. This type of expenses is difficult to control and often goes out of hand. Everyone knows about the famous Parkinson's law. There are no set rules for controlling this expenditure, but many techniques are available to the Managers for control of indirect labour. The Industrial Engineering Section can examine the work done by indirect staff and set up standard strengths. Another way of controlling these costs is to develop some sort or ratio—the number of men in direct departments to the number of men in indirect departments. The simplification of clerical and administrative procedures will also help in controlling indirect labour costs. Marks & Spencers in the UK, who are one of the efficient organisations in the country, abolished stock records in their departmental stores and relied instead on a system of visual control for re-ordering purposes. They found that the saving in many hundreds of clerks working on stock records far and away offsets the additional loss which they might incur through not having records. Perhaps the most effective means of checking the rising costs of indirect labour and expenses is to be very strict about sanctioning additional staff. An atmosphere should be created regarding the so-called non-productive staff.

The most effective method of controlling indirect materials and tools is to set standards of consumption for each department. These standards can be set up by examining the past actuals and by determining budget allowances for each level of production. For major items, Cost Engineers can make a special study for setting up standards.

What I have tried to illustrate is that every organisation must have a proper 'built-in' system of control. When the systems and procedures are organised they should be so worked out that there is an automatic system of check and double check from the point of view of avoiding and highlighting waste when it does arise. It is much better to work on such principles as against having a poor system with an army of accounts clerks who may be able to point out mistakes many weeks after they have been made. It must also be emphasised that cost-consciousness does not only concern the Accounts Department. Cost-consciousness should be in the thinking, day in and day out, of all Managers. Because, in the last analysis, it is they who are responsible for setting standards for material, standards for time, for consumption of indirect material, utilisation of equipment etc. If Managers are not cost-conscious in setting up standards or utilisation of material or ensuring that the efficiency of their men is at a high level, the Accounts Department cannot really do very much to rectify matters.

An ignorant precinct worker announced to his ward boss that, as a reward for his doorbell-pulling activities for the party, he wanted to be made post-master of his town.

"No, that kind of job is not for you," the boss said. "Why, you can't read and write." "I don't want to be assistant post-master" the guy replied. "I want to be post-master."

Costing and Budgetary Control

KB Large

For centuries all that the owner or manager of a business expected his accountant to tell him was: what he had spent, what he had received, what he held, what he owed, what he was owed and how much profit he had made. This was usually an annual exercise and in those leisurely days worked well enough. Further traders could do a little costing for themselves, for they knew what they paid for a thing and could therefore readily decide how much they must sell it for to make a profit, of course, within the limits set by the demand-supply/equation.

AMONGST the earliest forms of Cost Accounts must be the Voyage Accounts of the Merchant Adventurers. Quite obviously an annual account of such a business would serve no useful purpose whatsoever and the practice was and still is, to make a separate account for the voyage, to which were debited all the expenses incurred in preparing for and prosecuting that voyage, the proceeds realised being credited to the account, the resulting profit, or loss, thus being shown up. In present day language such accounts dealt with direct costs only: there were no overheads to worry about. Later this system of several merchants combining together to fit out and fill a ship for a specific voyage gave way to the merchants selling their goods in a recognised market abroad and finding a shipowner willing to transport their goods to that market or to the country in which that market was situated. The shipowner continued to maintain voyage accounts, the credits being only the freight charged for carrying the merchandise, but as he had several ships in operation it became necessary to have some sort of headquarters for arranging the various voyages, victualling his ships, securing cargoes, both outward and return, and generally organising the whole business. The expense of these headquarters, as well as the overseas agents, could not be charged to any specific voyage and was therefore apportioned over each voyage: in other words, overhead expenses came into being. Along with this, shipbuilding developed along similar lines, and in this process Job Costing was born.

The Industrial Revolution brought its own problems. For many years manufacturers were content with an annual account which showed them the outcome of their year's work. In the early days, the cost of labour was cheap and so the manufacturer could judge from his knowledge of what materials (and their cost) went into the final product, whether the amount he was obtaining for it was sufficient to give him a satisfactory profit. With the increasing cost of labour however and more particularly the increasing competition, it became no longer sufficient to use this rough and ready method of deciding if the price offered was acceptable or not and a more careful system of ascertaining the cost became necessary. For many items Job Costing proved too cumbersome for the several intricate processes involved and Process Costing came into being.

Under this system it is possible to ascertain the mounting cost of the article as it passes through one process after another: the system of costing must follow the progress of the article from its raw to its finished state, the cost of the raw material increasing as wastes and losses occur in each process and the cost of passing it through each process steadily mounting in addition. Furthermore, quite frequently, other raw materials are added as it passes through later processes and these too must be added to the rapidly increasing cost. As costs increased and more particularly as competition intensified, it became increasingly necessary to produce more accurate and detailed cost accounts so that the cost of each process and the effect of that process on the increased cost of raw material was known. As competition further intensified, much business was rejected because these costs indicated an uneconomic selling price until it came to be realised that most of the wastes produced during the various processes had some value, either in the business itself or to those outside it. So these wastes had to be valued, and a suitable reduction made in the cost of the processes from which they were produced.

However, like Time, Competition does not standstill and it speedily became necessary for further refinements to be made in the Costing System if business was not to be rejected owing to an apparently uneconomic price being offered. Managements came to realise that there were certain fixed Overhead Expenses which continued irrespective of the volume of the day-to-day business (excluding of course changes necessary to meet permanent expansion or contraction of the business) and thus was developed Marginal Costing where each item sold is regarded as contributing towards the recovery of these fixed overheads. It was appreciated that some items yielded a very much higher profit than others and provided sufficient of these could be sold, the less profitable items could still be traded in to swell the volume of business and increase final profits. In this system of costing, only the Direct Costs are charged against the various products and the acceptance or rejection of the price offered is dependent upon a careful appreciation of the overall contribution to fixed Overheads and Profit made by all the products dealt in. Thus if Product A costs Rs 10,000 to produce but sells for Rs 15,000; Product B Rs 20,000 and Rs 25,000 respectively; Product C Rs 15,000 and Rs 17,000 respectively: whilst fixed Overheads are Rs 10,000, it follows that Product D, if sold at slightly over the actual cost of production, is bringing in that much extra profit, whilst at the same time bringing stocks-in-trade into use and preventing them, perhaps, from deteriorating in storage. In this system the greatest care is necessary to ensure that all Direct Costs are charged against the appropriate product as otherwise it could easily happen that the item in fact costs more to produce than it is being sold for; such costs as special packing or expensive freight charges or elaborate marketing arrangements can be all too easily overlooked.

All the foregoing, however, deals with ascertaining the cost and profitability of an item after it has been made and sold, but before the decision can be taken whether to undertake such business, an estimate of all these expenses must be made and provided profits are sufficiently large, reasonable accuracy in such an estimate is sufficient. Unfortunately, like the poor, competition is always with us and profit margins are seldom large and never sufficient so as to allow of big mistakes in these estimates. Just how to prevent such mistakes has exercised the minds of managements for decades; dismissing the person responsible for making the mistake, whilst encouraging others to be more careful does not redeem the loss already suffered and in these days of keen competition a scientific approach to the problem has become necessary; hence the system known as Budgetary Control.

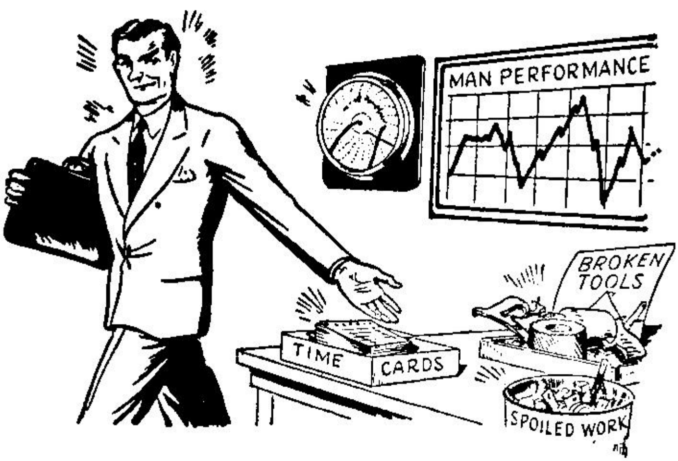
In this system, the complete expense of running the business is worked out in advance and a computation made of the resulting position at the end of the period, usually one year. Based on this it may be decided for instance that certain repairs which have been budgeted for will have to be deferred; the old *decor* of the Board Room will have to be put up with for another year or possibly that it can be brought forward a year ! This

Budgeted Forecast also reveals the probable cash position at the end of the period so that the matter of capital expenditure can also be controlled. It will be appreciated however that such a forecast must be most carefully worked out: rough and ready estimates are insufficient. At the same time it is necessary to ensure that the figures are produced sufficiently quickly to be up-to-date and that the cost of producing them does not outweigh the advantages obtained.

As its name implies this Budgeted Forecast is then treated as a Budget and the various managers are authorised to incur expenses within the limits budgeted for and provided they do and the sales realise what has been expected, the end result is assured. Unfortunately events seldom work out so well; unexpected expenses arise—the deferred repairs prove to be incapable of deferment—sales do not come up to expectations—demands by workers hold up production—Government restrictions delay the purchase of materials, and a hundred-and-one other things can happen: it is then necessary to prepare immediately a revised Forecast showing what the end result will be in view of these changed circumstances.

This budget also is a measure of the performance of those responsible for the various activities of the business. Having been prepared on the basis of what should happen it provides a yardstick against what has happened. At the same time it provides each foreman, manager etc. with control figures against which he can measure the performance of his own department almost whilst it is happening.

In conclusion, it must ever be borne in mind that each business develops along its own lines. Many have been using the various systems described for many years, though probably not designated by the names given to them above. Others have gone even further. New names are evolved to designate ideas and systems which have been in practice for very many years. Systems are revised to emphasise different aspects of the business: costing and accountancy must keep pace with the business they serve.



" None of these costs concern me. "

Productivity through Cost & Budgetary Controls

MS Srinivasan*

The objective of productivity drive is to achieve cost reduction by planning for the best use of available resources and facilities at the command of the enterprise. To achieve the objective of cost reduction and to keep account of trend of costs and pattern of resource utilisation, budgetary control and cost control serve as useful tools of productivity.

BUDGET is a coordinated plan of action towards a final goal envisaging the acquisition and utilisation of resources. The objectives of final goals are to be laid down in advance; the physical resources and monetary needs are to be determined for physical and financial planning. Budget thus provides a programme of balanced needs and a measuring rod for actual performance. Budgetary control is a means of regulating the activities with a view to ensure that deviations from the goals and the expenditures thereof are minimised except in the context of flexible business conditions. Budgeting thus helps the management to find the most profitable course of action with minimum financial outlays and costs.

For the operation of the budgetary control, certain financial facilities are needed : these include (1) a satisfactory organisation with fixation of responsibilities matched by authority (2) adequate accounting and other statistics (3) research into product development, methods of production, material utilisation, sales organisation, financing and other areas of business operations and (4) requisite machinery in the form of a budgetary control department, which can draft a coordinated budget, keep account of progress and analyse the causes for variations.

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In applying the technique of budgetary control, it is essential to consider the factors of periodicity, policy-formulation, developing details and control means. The factors to be considered are the rate of turnover, production period, market conditions, method of financing, length of accounting periods and model periods such as seasons and peak periods. Development of policies for budgets has to cover elements such as volume of operations, pricing questions, credit policy, sales efforts, production methods, product varieties and patterns, personnel needs, capital expenditures and financial structure. The policy formulation is subject to impact from economic conditions, activities of competitors and reactions of consumers, and has to be based upon proper interpretation of information.

The components of a budget are worked out by grouping together the managerial personnel and executives concerned at the point of execution and control. The sales budget which constitutes the origin in the whole system is to be formulated by a group consisting of the Sales Manager, the Works Manager, Financial Controller and Cost Accountant in the light of an analysis of the sales performance and market research data. The production budget which emanates from the sales budget is to be drawn in sufficient detail by the Works Manager and the Financial Controller. The details relating to the material requirements, labour required and production cost as furnished by the production budget should form the basis for the drawing of the detailed material budget, personnel budget, plant and equipment budget and cost of production and expenses budget etc. The entire system will have to be knit into the fabric of a financial budget which constitutes the basic tool of control over the financial outlays.

The budgetary control function extends to all the areas of the business including production, personnel, sales, finance and research. The operation of the budgetary control is to be made effective by three-fold measures (i) working out detailed plans and programmes and scheduling of operations (ii) implementation of budgeted plans and (iii) obtaining of periodical performance reports and preparation of budget reviews. The budget review reports are intended to highlight the points of deviation with a view to initiating investigations and devising corrective measures.

The contributions of the budgetary control towards increasing productivity are traceable to the maximum use of plant facilities, the most economical use of working capital, prevention of wastage by regulating the usage of resources, fixation of responsibility for adhering to schedule of activity and building up of better coordination. It compels the management to explore the possibilities and to plan a course of action towards continuous increases in productivity.

Cost control implies the regulation of business operation by an equation of measured performance against the costs. As a twin tool of productivity with budgetary control, it provides the basis for executive action directed towards cost minimisation.

The principles through which the cost control system operates are five-fold:

- The fitting of the accounting system to the organisation so that information on input factors, expenses and efforts are accumulated at each stage and responsibilities are identified;
- Classification of the costs and accounts to show the nature of the expenditure;
- Determination of standards for performance, output and expenditure. These yardsticks should be kept uptodate for measuring actual results;
- A system of periodical reports to throw light on the problems and findings of cost control;
- A management set-up that would utilise the cost reports, trace the areas of inefficiency and implement measures for rectification.

In the matter of these principles, there should be substantial built-in facilities in the organisation when cost and budgetary controls are applied simultaneously.

Cost control operates through a comparison of actual costs against predetermined standards in respect of stores, work-in-progress, parts, finished products, labour and material costs. The maintenance of perpetual inventories, reporting on labour-time utilisation and daily reports on production and performance are necessary parts of the system. The standards for material input in terms of quantities and quality, for labour performance, for expense details and rates of operation of machinery and equipment are essential features. It would also be essential to lay down limits for permissible variations in performance and quality, wastages, and defectives. The value of the system would be realised through a stream of cost reports and performance reports so that the management should be continuously posted with the progress towards the goals. ●●

"An efficiency expert is a guy who is smart enough to tell you how to run your business and too smart to start his own."

Recent Literature on Productivity

GOYAL, SK, **Costing and Cost Control,** published by Nicobar Udyog Pratisthan Calcutta, 1962, pages 260, price Rs 12.50.

THIS is an excellent addition to the Indian literature on Cost & Budgetary Control. In a series of small, well-written chapters, the author has covered practically the whole range not only of Cost & Budgetary Control, but also all other issues and problems that go along with it. There is practically no technique of productivity that the author has not in some way covered. Besides, the author has made a pretty successful attempt at putting this subject in the context of a general analysis of business organisation and management. Technical details of industry, transport and marketing have been given wherever necessary. In the introduction the author has tried to put the whole idea of productivity, particularly the techniques of Cost & Budgetary Control into the general context of economic growth. It is a matter of personal pride for us that the NPC PRODUCTIVITY Journal and above all its eminent Chairman, Dr PS Lokanathan, have been quoted to substantiate the main thesis of the author. The author has emphasised higher productivity and economic growth going together, the importance of the size of the market and the need for cost consciousness. He has quoted extensively from the convocation speech of the late Dr JC Ghosh at the Conference of the Indian Institute of Cost & Works Accountants. Probably one illustration from Dr Ghosh's speech is worth repeating here :—

> "I happened to be in a plantation at California run by an intelligent farmer. He told me that he had in his employ some Sikh peasants from India and, because of their capacity for harder and more intelligent work, they had been paid about 10 dollars a day as against 8 dollars which Italian workers were getting. He also told me that, though these peasants would not be getting more than one dollar a day in the Punjab, he was paying them 10 dollars a day, and in spite of this fact he was able before the war to send out oranges to the Calcutta market and compete with the produce of the Punjab. I wondered, and was keen on knowing the secret of his success. There is no end of labour-saving devices. Manure, insecticides and water were being applied in accordance with the most modern scientific knowledge. The result was that each acre of plantation was producing 400 boxes of 250 perfected oranges. There lies the secret. The productivity per manhour has been increased enormously by modern technical appliances and the fertility of the soil has been raised to unheard of levels by scientific management."

The author has added a whole chapter on PRODUCTIVITY, which in its economic and technical details is worth reading. Some facts are also given in this chapter regarding the functioning of productivity organisations, but the most significant is a quotation from the deliberations of the ILO meeting :—

> "The purely technical components of higher productivity are like a lifeless mechanism which depends upon external pressures and attractions to start and to keep it in motion. There must be forces present in the economy compelling the changes and improvements involved and attractions which will make those improvements economically worthwhile".

"It is the presence or absence of these forces, pressures and opportunities which make the difference between a dynamic, expanding economy and a stagnant economy, and not the presence or absence of any abstract body of technical or managerial talents, technique or 'know-how'."

The book has a number of case studies, a whole appendix on terminology of Cost Accountancy, a bibliography, etc. Probably, a little editing particularly at the beginning and at the end and a compressed introduction might have added to the value of this book. The author is bound to improve it in the revised edition, which he proposes to bring out. Even as it is, no student of Cost & Budgetary Control can afford to do without this book. In fact, it is a good reference publication for every productivity expert.

WHEN HOUDINI FAILED

Houdini, the magician and escape artist, could get out of any jail, handcuffs, or straight jacket—all except one, so the story goes.

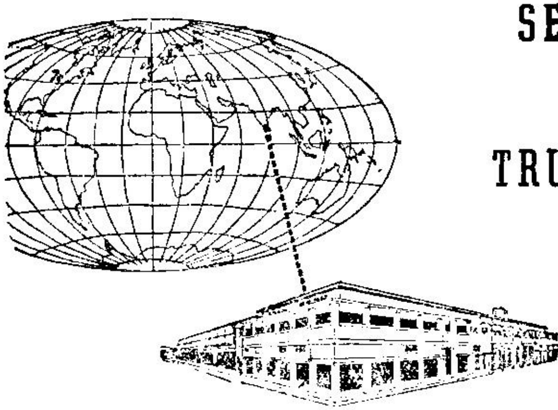
That one place was a little jail in the British Isles. Houdini worked at the cell-lock for more than two hours. He worked with that terrific speed that usually unlocked doors in 30 seconds but he could not get the lock to spring.

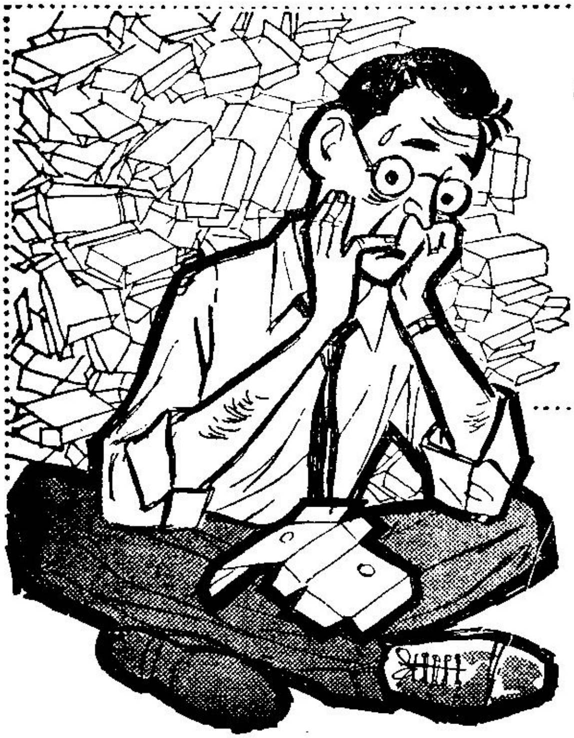
Finally, tired out by his strenuous efforts, he fell exhausted against the door. It swung open. It had never been locked.

Life is something like that isn't it ? We build up in our minds barriers that do not exist. We lock ourselves up in the jail of failure by doubts and fears that live in our imaginations.

Some of us have stopped trying because of past failures. We think there is no use. We think that the door to success has been locked against us. Maybe if, instead of sitting down and giving up, we just leaned against the door, it would swing open.

—*Kemper*





Improved Equipment Utilisation

AA Niazi*

A study to investigate and improve equipment utilization merits particular attention at this time of emergency. Even otherwise, an improved machine utilisation has a higher priority in our productivity programme.

IN an engineering industry the cost of a machine-hour is usually about Rs 2.50 and that of a labour-hour only about Rs. 0.50. The cost of idle machine time can be estimated in context of the fact that idle machine time occupies anywhere from 15 to 40% of the shift period. Not only our machines remain idle for this period but the existing methods of work leave ample scope for improvement. Take the case of a company which has to meet an order of 18,000 pieces per year, working on a machine which produces only 10 pieces per hour. It may be practicable by some of the methods indicated here to increase the output from 10 to 15 pieces per hour. This means a saving of Rs. 1,286 (nearly 29%) on account of machine time and Rs. 257 on account of saving in labour time. If all of this is paid to labour as incentive, it would mean an increase in their emoluments of over 21%. Besides saving in terms of money the company can also create potentials for extra production equivalent to 514 hours of work by machine and man. It is now common knowledge that improvements of this type can easily be brought about by the techniques of work study : production study, work sampling, man machine chart, etc. These techniques are designed to establish the total cycle time of work; the causes for idleness and contribution of each cause in terms of time. Rectification of the situation by elimination of causes or by reduction in severity of the cause is mainly a problem of managerial decision and action, associated with better planning, scheduling, maintenance, incentives, standardization and sometimes through minor changes in the equipment itself. Before, however, these managerial decisions could be taken, it is essential to know how much, where and why time is lost. The techniques of production study and work sampling help to provide this information. The following case studies are illustrative of the application of these techniques.

The author was associated with a study made of the operation of folding finished cloth on a machine in a textile mill. This machine was producing about 11,000 yards in a shift of 8 hours. Five machine shifts and 15 operators were thus engaged to produce 55,000 yards a day. Company desired to step up production to 65,000 yards either by increased machine utilization or through a larger number of machine shifts. Production study revealed that stopping machine, cutting cloth, shifting folded pile to folder's table and re-starting machine after every 150 yards, mainly accounted for the idleness of machine. This was substantially reduced by increasing the pile of cloth from 150 to 300 yards, made possible by a change in cam lever spring to give the mechanism enough strength to hold 300 yards in a pile. This obviously increased the duration of the working of the machine. Further, a stool was provided for the operator to slide cloth on to it instead of placing it on folder's table behind. Operators were also provided with stools to sit on while the machine worked to reduce their fatigue. This enabled a further considerable reduction in the time spent by

*Asstt. Director, NPC Regional Directorate, Bombay

workers for rest. Such slight modifications in mechanism and methods enabled output per machine shift to be increased from 11,000 to 18,000 yards.

Another study in a textile mill again showed how a simple improvement in organisation could without any investment in men or machines bring the company a sum of over Rs. 19,000 per year. In the loomshed of a textile mill, it was found that about 56 loom hours were lost in every shift because of the machines stopping while weaver went to godown to bring weft. This could be easily avoided by combining the work of weft distribution and empty pirns collection. The whole shed was divided into sections with one man made responsible for both collection and distribution work. He was provided with a trolley with space for both filled bobbins (weft) and empties. Each man was required to go to the central points of his section of loomshed. Weavers nearest to that point handed over empties and collected weft from the worker. Such simple improvements are possible over an infinite range of activities and hold out the maximum hope for increased productivity without any appreciable investment.

Another method of attacking the problem of machine utilisation is the construction of a man-machine chart drawn to give a synchronised graphic representation of the activities performed by men and machines simultaneously during the completion of a cycle of work. This chart helps in a thorough examination of the method enabling it to be changed by slight modifications in mechanism, by provision of appropriate tools, jigs and fixtures or by mere readjustment of sequence to arrive at a better synchronisation. The theory behind it is extremely simple : An operator does quite a good deal of work (make ready etc.) while the machine is not working. This is what we call external work. Then there is internal work which is done by the operator within machine time : may be related to work of that machine or to the operation of another machine. Time for which a machine is actually working—doing what it is designed to do—i.e. turning, pressing, cutting, weaving, mixing and so on, is machine time. The cycle time is composed of the total external work plus machine time. Obviously if the cycle time itself could be reduced, machine utilisation will automatically increase. This could be done by conversion of external into internal work, elimination or simplification of some part of external work etc. Baling of cloth in a textile mill with help of a press, six persons and a scale will serve to illustrate use of man-machine chart. Two operators, in observed situation, brought small packs of cloth from the stamping section and the clerk weighed them. Four men worked on the press, two on each side. They prepared the bottom and top coverings, placed the packs on press, operated the press machine and removed the bale after stitching and strapping it. Bottom covering was formed of wooden plank, heavy hessian, a *chatai*, light hessian piece and lastly polythelene. Top covering consisted of the same materials but the sequence of placement was naturally reversed. All the activities were carried on simultaneously and it was necessary to find how they synchronised before any attempt could be made at improvement. The man-machine chart was prepared which showed that the machine was utilised for only 63% of the cycle time, 37% of the cycle time being consumed in preparation of bottom and top-coverings (external work). It was further found that for preparation of one bale packs were formed into a bale at 4 places. The chart also indicated imbalance in the workload of operators. The situation indicated potentialities of improvement by provision of a new trolley. The suggestion by company engineer for keeping covering material in roll form on a stand with spring cutters needs attention. This requires a modification in design of wooden plank and use of bituminous paper instead of *chatai*. Details of working on this case would be :

> One man moves the truck to a place, between press and stamping department, puts a wooden plank on forks, draws bottom covering in the form of multilayer sheets from rolls, stretches on plank and cuts it at desired length. The truck

is then moved to stamping department where he loads packs on the bottom covering. Top covering is placed in a similar manner when the trolley comes towards the scale. For weighment the trolley is moved on the scale, which is sunk to ground. The truck is then moved to the press, forks shovelling the bale to the press as the press platform rises up to receive it. The truck is taken out and goes on to repeat the same operation.

This manner of working would mean that the press will be used entirely for the purpose of pressing. The cycle time for preparation of one bale can be reduced from 274 to 164 seconds (increase of productivity by 40%). It also relieves two operators to be put on some other job.

The case studies described above show the power of these techniques to detect spheres for improvement which appear considerable throughout the industrial economy of this country. A systematic and continuous adoption of these techniques among others would help in a fuller utilisation of resources, so urgently called for at this time of defence mobilisation.

HOW FOREMEN CAN CONTROL COSTS

Equipment Utilisation Control

MN Gupta*

Threat to our frontiers has raised the importance of equipment utilization. Unfortunately too much emphasis is laid by management on labour productivity. Though it cannot be denied that labour productivity plays a very important part, the importance of equipment productivity etc. cannot be ignored. To augment our production especially defence production without letting other industries suffer, the capacity available by better plant utilisation should be made use of. Import of any equipment at this stage will mean considerable drain on foreign exchange required for defence purposes.

PROPER planning of work programme should be done before a particular job is run so that plant and workers can be kept supplied with jobs without having to wait. This will avoid waste of time due to lack of work, lack of materials, lack of tools, jigs, etc. To make the advanced planning successful, maintenance of proper control on inventories corresponding to the current level of production is essential so as to avoid machines going idle for want of materials, tools, etc.

Although quality control does not directly help in better utilization, yet improved quality, less rework of defective parts and fewer rejections improve equipment utilization. Besides reduced overall cost of inspection, it can be known whether the process is under control, and corrective measures can be taken before many defective parts are produced. This will lead to better machine utilization.

To have maximum equipment utilization, the capacities of different machines doing the same work should balance. Method Study, to eliminate all the unnecessary operations and Time Study, to fix standard times for various operations, are necessary to increase plant productivity and to balance operations. Machine utilisation can be further improved by proper incentive plans.

Invariably cycle time for any operation consists of productive time and unproductive time like loading and unloading, fixing job etc. The lesser the unproductive time the more is the equipment utilisation. Use of proper attachments on machines will lessen unproductive times while use of correct tools, speeds, feeds etc. will help in reducing productive time.

Plant layout plays a very important part in balancing out operation times and departmental loads. By carefully planning the layout and by suitable selection of materials handling equipment, production bottlenecks limiting equipment capacities can be removed.

Last but not the least important is morale prevailing in the shops. Strikes, go-slow techniques etc. are great detriments in obtaining optimum plant utilisation. *There is no substitute for good morale* and management by rational thinking and sympathetic outlook towards labour can develop morale in the shops.

The total time taken by an equipment to complete a given job is the sum of setting time and actual operation time. Ideal equipment utilization demands the setting

*Chief Industrial Engineer, Kesoram Rayon, Tribeni.

time to be reduced to a minimum consistent with the need to keep down the investment in jigs and fixtures to a minimum. The most economic lot size considering the overall economics of the process should be determined before equipment capacity can be calculated.

The most important element, however, in equipment utilization, is preventive maintenance. The majority of durable equipment requires during its service life a flow of maintenance expenditure which as a rule rises considerably and irregularly with its age and use. If the maintenance of equipment is not done carefully, service life of the equipment is reduced considerably, and it becomes more and more uneconomical to operate the equipment as time goes on. Further, in a dynamic age like ours, the equipment may become obsolete* even when the equipment is not physically deteriorated to the point of replacement. Thus the economic service life of the equipment which would be the actual life also is not the same as the estimated one and in general it is always less. For economic production, equipment should be used for its economic life only, which can be known through breakdown analysis or use of MAPI formula etc. which takes into account maintenance costs, production costs and other relevant factors.

In the end I may add that as the management gets more enlightened, the control of equipment utilisation in our factories will receive the attention it deserves. What is advocated is not attention to this aspect to the exclusion of any other, but a balanced attention to every aspect of industrial activity, of which the control of equipment utilisation forms certainly an important part—much more important than what is suggested by the attention it is receiving at present. Apart from the advantages which will accrue directly from this control, it will contribute indirectly towards increasing the efficiency of industry by eliminating wastefulness from its operation. It will further lead to a streamlined flow of production. Streamlined human relations depend to a considerable extent upon this flow and consequently the morale of the factory also is affected indirectly by effective control of equipment utilisation.

*The economics of this factor would logically work out rather anomalously. If a large part of equipment is likely to become obsolete rapidly, it would be economical to use it recklessly! *(Editor)*

They do not seem to realise that O and M or Work Study are not poultices to be slapped on a trouble spot now and again, but to be used as specialists to diagnose trouble and then to prescribe the proper remedies.

Extract from 'Time and Motion Study'.

Vendor Quality Control

Naunihal Singh*

In the US economy, a very large number of industrial concerns manufacture a comparatively small part of the components that enter into the final assembly of the products, which bear their trade name. Their theory is : "Vendors must be treated as part of our manufacturing organisation." On account of mass production and the extraordinary complexities of new product lines (missiles, aircraft, electronics, etc) this practice of drawing for components on a number of outside concerns, involves a conformance to quality specifications that would not be possible without vendor quality control.

IN purchasing on a large scale from outside, the most crucial factor is the price: not the quoted price, but the total true cost to the user, which should include cost of inspection and material review, cost of contacting Vendors, the associated production problems and delays, user complaints and difficulties etc. In the USA, vendors are therefore rated on Quality, Delivery, Potential Performance etc. They are all *statistically indexed* so that the user knows the true cost of dealing with each one of them. Fair practices are laid down: apart from normal commercial ethics, the user provides clear and detailed specifications, offers technical advice etc; and the vendor maintains quality control facilities to ensure (prompt) delivery consistent to specifications, makes efforts at constant quality improvement and is progressively efficient in operation, ensuring competitive cost to the User.

In case of major procurement items, multiple sources are stimulated to ensure quality supplies at competitive prices. It is advisable to do the following for profitable Vendor Selection :

Use existing inspection in assessing the performance of the vendor on items being currently produced over a number of lots.

Determine reputation for Quality with other customers.

Survey of Vendor's facilities, potential and procedures.

Compiling of Approved Vendor list of current and potential vendors. From this information the Purchasing Department can assess a vendor from a quality standpoint in addition to price and delivery.

In order that this function should be efficiently performed, a concern must have a well organised purchasing department of its own, coordinated in its functioning by a technically staffed quality control group. Technical ability, however, must go alongside good public relations in which the group acts as a conductor, not as an insulator. Further, while the group must have the basic authority to ensure continued conformance to quality, technical matters must continue to be delegated to appropriate levels. The engineering department should be drawn up to the maximum possible extent and there must be a continuous feedback of information. The 'right of private domain' is inconsistent with Productivity. . .

*Deputy Director, Small Scale Industry, Ministry of C&I, New Delhi.

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Sd./- DH Butani
Signature of Publisher

April 1963

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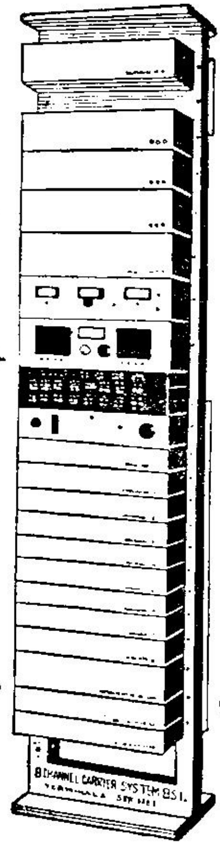

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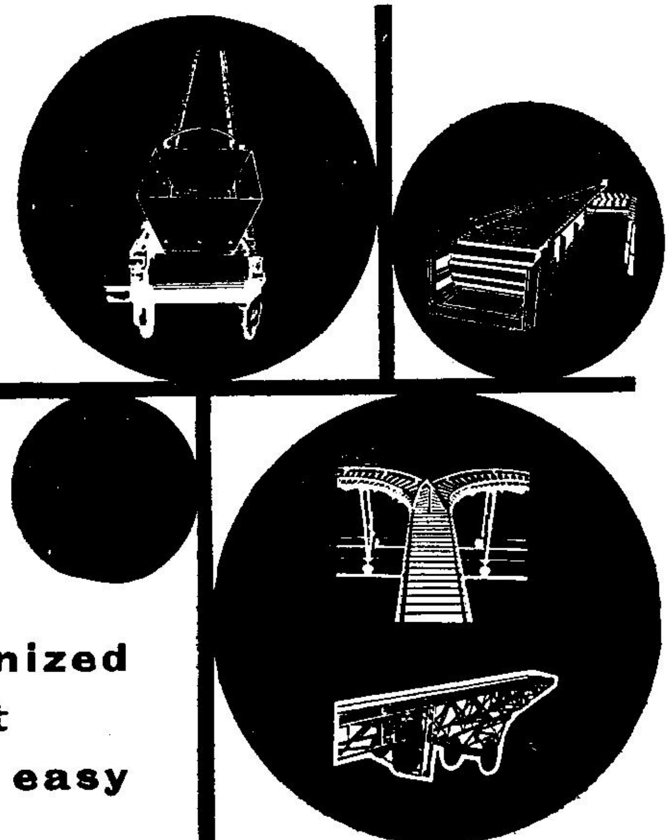

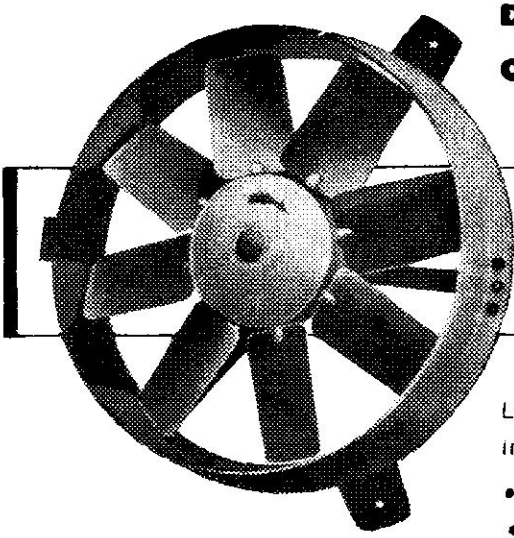

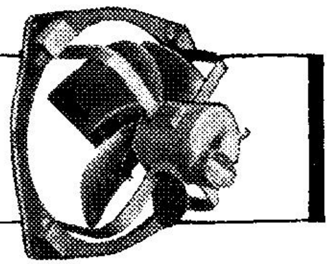

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