

Operations Research

with special reference to nonmilitary research

The following report was issued earlier this year by the Committee on Operations Research of the National Research Council. It is reproduced here in order to give the Committee's views on operations research the widest possible audience among physicists.

OPERATIONS RESEARCH (or, as the British say, Operational Research) is the name of an applied science, extensively developed during World War II in the British and American armed forces. Its subject matter is "operations", in the usual military or management sense of the word.

The earliest efforts of military operations research had short-range aims, such as increasing the effectiveness of early-warning radar net. As operations research proved its worth, its applications spread, in magnitude and scope, throughout the military effort until nearly every arm of the services of the United Kingdom, the United States, and many Empire forces had set up operations research groups. Accounts of these developments are given in several books and articles, with such case histories as security restrictions permit. (A list will be found at the end of the article.)

In the course of their work, many members of the various operations research groups became convinced that the techniques used are not limited to military applications. They became convinced that *large and complex organizations or activities* are profitable objects, in themselves, for scientific study. This was independently verified by scattered instances of the successful application in business and industry of techniques equivalent to those now known as operations research.

The analogy between military forces and industrial or business organizations is close enough to warrant the assumption that the general principles of operations research, as developed during the war, can be fruitfully applied to business and industrial activities, and to those governmental activities which have an operational character.

The National Research Council, recognizing the great value of operations research, has established a Committee on Operations Research to further its development and application outside the armed forces. A parallel movement was begun even earlier in Britain. British scientists have founded an Operational Research Club, with many distinguished members, to promote the non-military development of operational research. They have

also begun publication of a journal, the *Operational Research Quarterly*.⁵

The Committee on Operations Research of the National Research Council has undertaken a program for immediate action. The steps which are presently foreseen include the sponsoring of conferences on non-military applications of operations research, a survey of existing manpower, formulation of a training program, and publication of topical and fundamental material on operations research. The Committee will not, however, undertake active operations research, nor serve in a consulting capacity, except in a general orientational way.

Publication of this article is one step in this program. It provides a brief description of the main features of operations research, for two audiences: leaders of U. S. enterprise and government, and scientists. The Committee hopes that it will give to the administrative group some notion of how it could be applied to their organizations, and that it will give to the scientists an indication of its principal features without attempting a discussion of techniques. The Committee will welcome questions and expressions of opinion, and will supply further information on request.

What Is Operations Research?

Dr. Charles Kittel,¹ of the Bell Telephone Laboratories, defines Operations Research as "a scientific method for providing executives with a quantitative basis for decisions." Sir Charles Goodeve,³ of the British Iron and Steel Research Association, adopts essentially the same definition. He characterizes operations research as in essence "quantitative common sense" and goes on to say:

"The field of operational research depends on the in-

The National Research Council Committee on Operations Research, which prepared this report, is under the chairmanship of Horace C. Levinson. Its other members are Walter Bartky, Arthur A. Brown, Leroy A. Brothers, Glen D. Camp, Franklin R. Collbohm, Ellis Johnson, Charles Kittel, Philip M. Morse, Morrough P. O'Brien, H. P. Robertson, Walter A. Shewhart, Jacinto Steinhardt, Frederick F. Stephan, Alan T. Waterman, Warren Weaver, Samuel S. Wilks, and Sir Charles Goodeve.

terpretation of the word 'operations' in the definition. In war, operational research was applied to the use of weapons, to tactics, and to strategy. In the peacetime application of operational research, studies are directed, for example, to the use of equipment and manpower, to operating procedures, and to the solution of those many problems faced by management in controlling or operating factories or public utilities, or by Government authorities in planning. The field of operational research is very wide; but it will be seen that it is quite distinct from the field of most applied scientific research, the latter being concerned with new or improved processes, equipment, materials, etc."

Combining various definitions, we may say that Operations Research is the application of the scientific method to the study of the operations of large complex organizations or activities. Its objective is to provide top-level administrators with a quantitative basis for decisions that will increase the effectiveness of such organizations in carrying out their basic purposes. Thus, although the activity consists of research, it is research with a severely practical goal.

But no brief definition can be expected to convey more than a vague notion of operations research, its subject matter, its methods, its distinguishing characteristics, its significance. Examples of typical problems attacked and solved by operations research groups will provide a better basis for understanding. Several such examples will be given, necessarily briefly, in these pages; others will be found in the books and articles referred to at the end of this article.

Why Scientists?

Every definition of operations research, and every illustration of its use, implies that the men who carry it on are trained in scientific method. It is clearly worthwhile to ask whether this is an accidental phase of operations research, or whether it is essential. Operations research in the military field is closely tied to complex and specialized equipment, the use of which demands technical skill. It is not surprising, therefore, that wartime operations research was carried out by scientists. It might be supposed, however, that the analysis required in non-military operations is more general in nature, and that there is no special requirement for scientific training on the part of operations research men.

This is not the case. The scientific training of an operations research worker is essential for two major reasons: First, since the material with which he deals is in many cases of a repetitive character, a good grounding in the essentials of probability theory and statistics is indispensable. Second, a scientific training tends to develop sound habits of observation and experiment, and makes available advanced techniques of quantitative analysis, which give operations research much of its power and fertility.

We believe that in this field a scientist has unique importance because he has learned that whatever his philosophical views may be, he must in his work as-

sume the existence of a concrete external physical reality, and whatever facts or theories he encounters must relate themselves somehow in his mind to this basic reality.

In fact, if the requirement of skilled application of scientific method were omitted from the definition of operations research, there would be little to distinguish it from many existing management techniques. Quantitative bases for executive decisions are a conspicuous part of the material passing across the desk of every major executive in any large organization whatever. The novelty lies in the scientist's ability to use more refined and powerful numerical techniques, and in his ability to penetrate to the essential variables in a situation, and to relate phenomena to them in a simple and cogent manner.

In this connection, we should remark that very frequently the principal contribution of operations research in a concrete case is to define, or demonstrate the need for, a new measure of performance or efficiency. Such measures provide the executive with new possibilities for control of his organization's activities and for prediction of its future capabilities. The results are sometimes startling in the speed and size of the improvements obtained.

Such a contribution is the result, in most cases, of a thorough theoretical study of the operation in question, combined with some extremely practical observations. For example, some work done on the Royal Air Force's maintenance norms resulted in a very substantial increase in flying hours per month, with no increases in maintenance manpower. The work was done by Dr. Cecil Gordon, a geneticist; but none of it involved principles peculiar to genetics. Rather, Dr. Gordon's training in genetics had developed in him broad scientific habits and techniques, which he applied easily and effectively to this practical problem of maintenance scheduling.

A similar example is that of a study of the difficult problem of determining the pulling power of certain important types of department store newspaper advertising. The problem here was to determine whether the store *as a whole* increased its sales and profits through such advertising. This study was carried through to actual numerical solution; in this case, the work was done by a theoretical astronomer.

Many other examples will be found in accounts of operations research, testifying to the transfer value of a scientific training, and to the existence of important and difficult scientific problems in the everyday operations of large organizations which can be solved by these techniques.

What Problems Does Operations Research Treat?

There are many areas of executive decision in which the scientific method is inappropriate, or at least incapable of providing a solution, given the present state of knowledge. Logical analysis is not out of place anywhere, but there are sharp limitations on the use of numerical analysis and controlled experiment. Success-

ful management of large-scale enterprises or operations involves, and always will involve, delicate judgments on matters of style, or taste, or selection of key personnel, corporate relationships, ethics, and so on. In these fields, the contribution of operations research will be small, if not wholly absent. Operations research does not supplant executive judgment, but rather supplies precise information and useful principles to aid the executive in making decisions. When operations research does suffice for the full solution of a problem, the executive receives an indirect contribution in addition to the direct one in his increased freedom to devote himself to problems which require the exercise of his seasoned judgment. Responsibility for decision must in any case rest with the administrator.

On the other hand, within the broad limits where the scientific method does apply, every problem is legitimately one for operations research, with only the practical requirement that the solution should contribute sufficiently to the good of the organization to justify the time spent in getting it. The operations research worker is scientific adviser to management on any and all operational matters; his duty is to examine any and all relevant questions. Consequently, it is not possible to state in advance what the specific tasks of operations research will be in any concrete organization or enterprise.

For these reasons, the examples which are given here should be looked on as illustrations only, and not as "boundary markers" defining the limit of operations research. The reader may find that concrete examples of possible operations research will occur to him on the basis of his own experience.

In its military applications, operations research is concerned with weapons, tactics, and strategy, as has already been indicated in the quotation from Sir Charles Goodeve's essay.³ It is not difficult to construct analogies to these three divisions of effort, which can be used in discussing non-military applications, and it is therefore useful to consider the military applications first.

Operations research began with a study of radar, taking up such questions as location of antennas, efficiency of operation, and interpretation of signals. Goodeve credits radar with having multiplied the British power in air defense during the Battle of Britain by a factor of ten, and credits operations research with a further doubling of the effectiveness of the air defense system. As he remarks, the latter contribution was the work of a half dozen scientists attached to Fighter Command; the result was "out of all proportion to the amount of effort spent on the research".

Later, operations research workers made a close study of the use and the design requirements of depth charges, anti-aircraft guns, naval mines, and so on. An extraordinarily brief operations research study showed, for example, that if the explosion depth of depth bombs were modified, a fivefold increase in the effectiveness of the air anti-submarine forces could be expected. This increase was obtained.

By analogy with the study of weapons, non-military operations research would be concerned, at this first

and lowest level, with the study of the use and arrangement of machines, signals, controls, and so on. These machines are studied in their working surroundings, under conditions of actual use, and, directly or indirectly, in connection with the activities of the whole organization. Two examples of this sort of work are quoted by Dr. W. S. Glanville, Director of the Road Research Laboratory in Britain: One concerns the effectiveness of pedestrian crossing marker systems, and the other a study of laying road surface materials. Dr. Glanville puts the annual savings resulting from the second study at a million pounds sterling.

American industry, as is well known, has worked long and hard on the design and use of machinery, and this fact may make it appear less likely that further major economies can be developed. History tells us, however, that revolutionary improvements come at unexpected times and in fields that seem to have been exhaustively developed. Putting to one side such major improvements, operations research can add to existing techniques in helping the executive solve the problems presented to him by frequent plant renewal and industrial change. It can help him, for example, to set up measures of efficiency or effectiveness and hence production goals which may be far beyond current norms. And these production goals are frequently attainable when the required changeover of the production process is made. This was the case in the Royal Air Force maintenance problem previously discussed. In this field operations research overlaps industrial engineering and some other disciplines, all having the aim of improving plant efficiency. The difference lies in the method of attack and in its implementation.

The second level at which operations research is effective is the so-called tactical level. According to the dictionary definition tactics is the art of disposing military or naval forces, especially in contact with the enemy. In the air war against Germany, for example, tactical problems included finding the best flying altitude, the best division of payload (among the competing categories of fuel, search instruments, and bombs or other armament), the best methods of attack, and so on.

There is no one best flying altitude, of course. There is only a "best altitude under a given set of conditions". The choice of altitude will depend on the weather, visibility, sea conditions, radar conditions; it will depend on the enemy's lookout effectiveness, air plane speed and maneuverability, and so on. Some of these factors change from day to day, others more slowly. Tactical studies have the purpose of establishing quantitative relationships between the various tactics and the over-all result of the operation of which these tactics are components. When successful, such studies lead to predictions of the effect of changing one or more of these variable components. If, for example, the altitude of the airplane is increased by ten per cent, what will be the effect on the efficiency of the search operation? It has been found that studies of this sort, carried out by operations research methods, frequently permit a rapid improvement in effectiveness. In some cases it pays far

more to improve the tactics than to improve the weapons, and it is almost always easier, faster and cheaper to do so.

A second definition of tactics, suitable also for non-military applications, is "a procedure for gaining some end". If we combine this with a rephrasing of the previous definition, we have a good basis for building up non-military analogies: "Tactics is the art of disposing of forces in actual operations according to definite procedures for gaining some end." The actual operations contemplated in the definition may concern production, or sales, or training, or some other activity. The tactical problems might concern the scheduling of processes, or the optimal utilization of plant facilities, or the routing and control of traffic, or the conduct of a sales campaign. As in the military case, solutions of such problems cannot be valid for all times and conditions. The executive who uses them in formulating policies must be keenly aware of these limitations. It is the duty of the operations research worker to see to it that he is, and to furnish appropriately modified results whenever changing conditions make it necessary. Properly executed, these tactical studies can provide administrators with a firm quantitative basis for decisions, whenever such a quantitative basis is appropriate and attainable.

Studies at the first, or material level rise in a natural manner to studies at the second, or tactical level. Similarly tactical studies give rise naturally to a third type of study—the strategical. Strategy, in the military meaning of the term, is the art of managing armies or other large-scale forces, in such manner as to compel the enemy to engage in battle under conditions favorable to the strategist.

Operations research can help at this level by making rapid calculations of the amount and kind of force required for specified complex operations. Such calculations must in every case be based on a solid foundation of material and tactical studies, which provide the necessary numerical knowledge. An outstanding example of strategic operations research is the work done by British and American scientists on the Bay of Biscay campaign against submarines. Operations research teams designed and helped to execute the "unclimbable fence" patrols, which succeeded in sighting practically all submarines that went out of or came into the Bay. About half of all the submarines sighted were attacked, and of these roughly one fourth were sunk. This loss was sufficient to force the enemy to modify his strategy drastically, but this did not help him as his new strategy had been foreseen and prepared for.

After what has been previously said concerning the analogy between military and non-military problems at the tactical level, little need be added here about the analogy at the strategical level. Strategy in its non-military sense should include the planning of campaigns, the broader problems of organization, the estimation of plant requirements, studies of plant location, studies of markets, certain aspects of personnel and of labor relations problems, and so on. Large-scale problems of this sort necessarily involve a large number of subsidiary

problems that are not amenable to complete quantitative formulation. For the solution of problems of the latter sort, operations research has little to offer, and it is important to the future of this young applied science that its practitioners make clear to those using it that it has the same limitations as does the scientific method in general.

This does not mean that operations research is of no value at the strategical level. It does mean that operations research should be applied only where it is applicable, to those parts of the broader problems which are suitable for a quantitative treatment. Used in this way, operations research will be of signal aid to the administrator by removing certain problems from the field of his attention and by providing him with clearcut numerical data bearing on other of his problems. With these aids he will be better equipped to face the broader strategical problem, with its many intangible aspects.

Is Operations Research a New Field?

One is tempted, at first, to say no. Heiro consulted Archimedes when Syracuse was besieged, and Napoleon made use of technical advisers. Many alert business executives have long used research procedures, not only for their technical problems but for broader aspects of their activities. Quality control, time and motion analysis, efficiency engineering—are these not operations research?

The answer is that they are parts of operations research, but only parts. And it is essentially true about operations research that one cannot subdivide it and still have it. For operations research is more than the sum of scattered activities, even though each such activity is one of its parts.

The things that make operations research an essentially new field are principally these:

(1) *Its Inclusiveness.* Operations research deals with problems that are organization wide, and it deals with the *whole* of such problems. It may very likely concentrate study on certain parts, but it does this not because these parts are easy or attractive (which would often be the case in pure science), but because over-all examination has revealed that these parts are the critically important ones. Operations research uses the widest possible set of tools. It may utilize such studies as would be made in time and motion analysis, but it also uses the insights of the statistician, the psychologist, the mathematician, the engineer, the physiologist, the specialist in probability theory, etc., etc. And it *puts all these together*, into one over-all and interrelated analysis.

(2) *Its Direct Relation to Management.* Operations research ceases to be operations research if tucked away in some obscure corner of the organization chart. It has to be built in at the top, having unimpeded access to information, having direct cognizance of over-all problems, and having direct relations with the policy-determining and decision-making levels.

The novelty of operations research lies, then, not in the use of certain specialized scientific techniques, but

in the broad scientific approach to the problems of the organization as a whole. It lies also in the new conception that emerges of the relationship that can fruitfully be established between management and science. This relationship should be cultivated with skill and tact on the part of both administrators and scientists, in the interest of increasing the efficiency of operating organizations, with consequent economic and social benefits.

It is true that operations research, in the present meaning of that term, was practiced by a few trained scientists in widely scattered industries long before its military use. But it required a world war and the emergencies of a Battle of Britain for its independent development as a new applied science.

What Kind of Scientists Are Needed?

Experience in military operations research has shown that special kinds of talent and personality are required for its successful prosecution, in addition to an indispensable scientific point of view acquired in one of the sciences. The operations research scientist must have, above all, a flair for the practical, a special talent for sorting out, from all the alluring and promising problems that he encounters, those that have the greatest practical bearing. This means that he must nicely balance the time and effort (and hence the cost) involved in attacking a given problem against the economies to be expected from its solution, at the same time taking account of the likelihood that a solution will be achieved. He must have a personality that will permit him to deal successfully with all ranks in the organizational hierarchy, from top to bottom.

In order for the non-military applications of operations research to achieve a significant fraction of their potentialities, it will be necessary to provide scientific manpower in considerable quantity. Among the younger scientists and research students there are no doubt many who have the necessary qualifications and who would be attracted to the field of operations research if better informed concerning its nature and the opportunities it offers. One purpose of this publication is to provide such information about operations research. Those scientists interested in more detailed information will find it in the references at the end of this article, especially in the book by Morse and Kimball.⁷

Conclusion

At the present time the military applications of operations research are being carried on and developed by the armed services. The non-military applications, however, have not up to this time received any organized support and encouragement, and continue to be carried on only sporadically in isolated organizations.

It might be thought that at this time, when we live in a shadowland between war and peace, only the military applications of operations research should be cultivated. This is not the case, for two reasons. First, an increase in the efficiency of operating organizations,

both industrial and governmental is at least as important during a war, or a pseudo-war, as in times of peace. Second, the expansion of non-military use of operations research will inevitably increase the number of scientists trained in this field, and these scientists will be available to the armed services in case of subsequent need.

In fact, at a time when mounting defense requirements are putting an increasing strain on the economy and its manpower resources, the non-military development of operations research takes on added importance. For to the extent that it is successful in increasing the efficiency of business and industry it will contribute to the easing of this strain.

With this point of view in mind the Committee has outlined a program of action. It is prepared to promote the establishment of operations research wherever it gives promise of increasing the efficiency of large-scale operations or activities. It proposes to interest, as a first step, a number of enterprises—industrial, business, governmental, or other—in the experiment of setting up operations research programs, under as ideal conditions as possible. In the setting up of such experimental programs the Committee will act in an advisory capacity, when called upon to do so, and in particular it will do everything in its power to aid in securing operations research scientists of the highest quality to insure the success of these preliminary experiments. From the longer point of view the Committee hopes to take part in the development, on a scale commensurate with the expansion of the field, of facilities to attract and to train younger scientists, and to carry on research in the methodology of operations research.

The Committee is prepared to act as a clearing house for information. Questions, comments and suggestions for the further development of operations research will be welcomed.

Communications should be addressed to: Committee on Operations Research, National Research Council, 2101 Constitution Avenue, Washington 25, D. C.

Selected Bibliography

1. KITTEL, CHARLES. "The Nature and Development of Operations Research", *Science* (Feb. 7, 1947), 105.
2. "OPERATIONAL RESEARCH IN WAR AND PEACE", *Advancement of Science* (Jan., 1948), 4.
3. GOODEVE, SIR CHARLES. "Operational Research", *Nature*, No. 4089 (March 13, 1948).
4. BLACKETT, P. M. S. "Operational Research", *Advancement of Science* (April, 1948), 5.
5. HORVATH, W. J. "Operations Research—A Scientific Basis for Executive Decisions", *American Statistician* (Oct., 1948), 2.
6. CROWTHER, J. G. and WHIDDINGTON, R. *Science at War*, London (H.M.S.O.), 1947.
7. MORSE, P. M. and KIMBALL, G. E. *Methods of Operations Research*, Technology Press (MIT)—John Wiley & Sons. 1951.
8. OPERATIONAL RESEARCH QUARTERLY. Operational Research Club; 25 Buckingham Gate, London, S.W.1.