OPERATIONAL RESEARCH

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DEFINITION AND USE IN WAR

THE term 'operational research' came into prominence during the War to describe what to the Services was a new type of thinking process used to arrive at answers to questions arising out of the operations of war. This thinking process has, however, already to some extent been used in industry under other names. It has been applied to market problems, cost accounting, quality control and works efficiency; in other words, to the operations of industry[1]. It has also been applied to agriculture and medicine. Its successful application during the War is already stimulating and extending its peace-time application.

Operational research has been defined in various ways. I commonly call it "quantitative commonsense"; but more specifically, *operational research is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control.* This definition is based on that put forward by Kittel[2] and is preferable to the more complicated and limited one put forward by Watson-Watt[3]. According to the scientific method reliance is placed only on controlled experiments or on experiences, the observations of which can be analysed. From the analysis, conclusions are deduced, using the rigorous logic of mathematics and statistics.

The applied nature of operational research is shown by its association with executive decisions, and it follows that workers in this field must be closely in touch with, if not part of, executive departments.

The field of operational research depends on the interpretation of the word 'operations' in the definition. This paper attempts such an interpretation by means of illustrations. In war, operational research was applied to the use of weapons, to tactics, and to strategy. In the peace-time application of operational research, studies are directed, for example, to the use of equipment and man-power, to operating procedures, and to the solution of those many problems faced by management in operating or controlling 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.

Let us first look at some of the examples from the Second World War. Operational research was really born out of the 'Battle of Britain'. As is well known, we had in 1940 relatively few fighter aircraft compared with the number that would have been required to defend our shores against an air invader. We had very good fighter pilots and very good aircraft; but, with the equipment and methods used prior to 1940, it would have been impossible to obtain sufficient interceptions to defend our shores. The most important new feature that came in was, of course, radar. This equipment, by giving ample warning, permitted the retention of aircraft on the ground until needed, and then, by plotting the positions of the enemy and defending aircraft, enabled a 'ground control' to direct the aircraft to a position where the enemy could be sighted visually. The planning of this sequence of operations involved careful analysis of training and of operational experiences, and involved also a full analysis of the technical possibilities of the equipment. But the process of combining these factors required mathematical calculations beyond the experiences of the ordinary commanding officer. Accordingly, a small party of half a dozen scientists was attached to Fighter Command, to study and refine the deployment and the operational orders. These scientists learnt how to estimate which were the bad targets and which were the good, and to determine where and how our limited effort could best be expended. Their analyses formed the basis for the operation of the whole defence organisation of Britain. It is estimated that radar itself increased the probability of interception by a factor of about 10; but that, in addition, this small operational research team increased the probability by a further factor of about 2, which together meant that the Air Force was made twenty times more powerful. The operational research contribution, a doubling, was out of all proportion to the amount of effort spent on the research.

An even more startling case was the introduction of Coastal Command to the Battle of the Atlantic. While Coastal Command had a number of successes in the early days of the War, these fell far short of what was needed when the U-boat campaign was renewed with increased intensity during the winter of 1941–42. Prof. P. M. S. Blackett[4], whose name will go down in the history of operational research as outstanding, came into the picture to see what could be done. He built up a small team of scientists at Coastal Command to study all aspects of the problem of air attack on U-boats. Of particular importance was the work of the late Prof. E. J. Williams, who, in the spring of 1941, analysed the previous attacks on U-boats by Coastal Command aircraft. This analysis led to the conclusion that, instead of the depth-charges or bombs being dropped more or less on and about the centre of the targets, there was a serious and not obvious fault in the tactics adopted. Indeed, it later came out that the chances of a successful kill were something like one in a thousand.

The tactics accepted at that time were based on a belief that the best setting for a depth-charge to explode was 100 ft., where the charge would be well 'tamped' by the water. It was also known that when a U-boat dived, it increased its depth at the rate of about 2 ft. a second, and that accordingly it should have been submerged for at least 40 sec. before the depth-charge exploded. (The lethal range of a depth-charge is about 20 ft.) Allowing for the speed of descent of the depth-charge and the forward movement of the submarine, the best time and place to drop the depth-charge could be calculated, using as a point of reference the swirl left by the submerging U-boat. To carry out the attack properly, it would commonly be necessary for the aircraft to frighten the U-boat into submerging and then attack at the appropriate number of seconds later. (In fact, of course, most aircraft went straight into the attack.)

Prof. Williams' analysis showed, among other things, the following statistics (see ref. 4) for the number of U-boats visible and having submerged for different times at the moment of attack:

Condition of U-boat	Percentage of all attacks
U-boats visible	34
Submerged up to 15 sec.	27
,, 15 to 30 ,,	15
,, 30 to 60 ,,	12
,, more than 60 sec.	11

From this it is seen that only about one-tenth of the U-boats could be in the depth-range of the exploding depth-charge, when set to explode at 100 ft. The analysis further showed that the volume of the 'probability zone' in which the submarine lay increased very rapidly, indeed, according to the third or fourth power, with the time of submergence. (See accompanying diagram.) This three-dimensional probability zone is that inside which it is almost certain (that is, 97 per cent probable) that the submarine will be found and is calculated by allowing for all possible movements of the submarine inside the limits of its estimated course and speed, turning circle, etc. The inaccuracy with which the depth-charges were dropped also increased very rapidly with the time of submergence, largely due to the disappearance of the swirl. Taking the two together, it was found that, of the one-tenth of the U-boats which were within the lethal range for depth, fewer than one in a hundred were within the lethal range for plan. By setting our depth-charges at 100 ft. we were failing to engage the targets which could be attacked most accurately and which were by far the most frequent, that is, U-boats visible or submerged up to 15 sec., simply to gain the small increase in lethal range of a depth-charge at 100 ft. This is probably as serious an example as we could have of the concentration on bad targets and the disregarding of good. It is difficult to appreciate how it can have arisen until one realizes how ingrained and over-emphasized certain technical facts on underwater explosions had become. In fact, the change to the shallowest possible depth setting was opposed by a number of technical people, until they were shown the full analysis giving the other aspects of the problem. (This case also showed up a good lesson in research management. In accordance with the procedure at that time still prevailing in this section of the Admiralty organisation, orders were passed to the research station concerned to make the necessary alterations in design. The delay which followed led to a visit of inquiry which elucidated the situation described above. When the research people concerned were finally convinced, the 'unsurmountable' difficulties were resolved in a week.)

To conclude this story, within a very short time of the change being made, first to 35 ft. and later to 20 ft. depth setting, one U-boat was sunk and another captured and brought into port, the only enemy submarine captured during the War. The sinkings went up steadily until a year later they reached twenty a month. The Germans within the first month announced to their Navy that we had introduced a new and much more powerful depth-charge. This change brought Coastal Command effectively into the War, and their aircraft, together with the sea-borne forces, with which they were closely integrated, averted defeat in the most critical period of the U-boat war.

My third story has a somewhat amusing side. During the latter phase of the U-boat war, the enemy U-boats in the Bay of Biscay were countering our radar with some success by listening to the transmissions from our aircraft, and diving at the appropriate moment before we could pick up the radar echo. We countered this by special technical devices and managed to maintain a certain low rate of successes against the enemy. The operational research team of Coastal Command showed, by careful statistical analysis followed by model exercises on a games board, that a saturation technique was possible which would take advantage of the fact that the U-boats' storage batteries would not permit submergence for more than four hours, during which time they would move a certain maximum distance. With the required number of aircraft working in accordance with a definite plan of patrol, there would always be an aircraft inside the critical listening range when the U-boat surfaced, and the latter would be forced to submerge before it could properly recharge its batteries. We would thus exhaust our opponent and he would be forced to stay on the surface. Our sightings would increase to about twenty per week, and as we were getting about one kill in every ten sightings, this would mean about two kills a week. The required number of aircraft was twenty-five more than were available for this patrol force, and a considerable argument with Bomber Command followed a request for the additional aircraft. In this argument, a senior Bomber Command officer inquired whether this War was to be fought with slide-rules or weapons. However, a three weeks trial of the full operation was ordered by the Prime Minister, resulting in sixty-seven sightings and six kills. An extraordinary coincidence perhaps; but the 'slide-rule' had won!