idealist, always ready to fight against what he deemed morally wrong, without any consideration of his own personal interests. Very kind and helpful to young and struggling people, he was suspicious of nearly everyone in authority and power. If he had lived, on September 2, 1957, he would have completed his eightieth year. It is fitting, at a conference to discuss the scientific applications of isotopes, to remember the man who was the first to see the general theoretical importance of what had been until then scattered observations. Let us honour the memory of a brilliant intellect, an experimenter second to none among the founders of radiochemistry, and an uncompromising champion of his ideals.

OPERATIONAL RESEARCH

IT is just about twenty years since the expression 'operational research' was coined to describe the activities of the Air Ministry research section studying the operational problems of radar. There was rapid progress during the first decade, mainly—and quite naturally—in military applications. The three British Armed Services all had groups in England, and there were many overseas sections. In the United States and Canada development was also rapid, and a tripartite operational research conference on defence matters was held shortly after the War ; similar conferences have since been held at regular intervals, and have been extended in the military sphere to include nations of the British Commonwealth and the North Atlantic Treaty Organization.

Although work of the type now termed operational research has been carried out in industry for the best part of a hundred years, it is only since 1947 that there has been any formal description of this science. An Operational Research Society was founded in the United Kingdom in 1947—initially as a club with members drawn from personnel of the various military groups who had returned to civilian life. An American Society was formed in 1953 and a year or so later came the (American) Institute of Management Science. Societies or groups have since been formed in most of the major Western European countries, and also in India and Japan.

With this widespread interest, it is understandable that suggestions for an international meeting this year met with a ready response. Indeed, this highly successful conference (sponsored by the Operational Research Societies of Britain and America and the Institute of Management Science) for experienced workers in both the military and civil fields was over-subscribed from the start. The Conference was held at Oxford during September 2–6, and the two hundred and fifty members present represented twenty-one different nations, and it was felt that similar conferences should now be held at regular intervals.

At the inaugural meeting delegates were welcomed by Sir William Slater (president of the Operational Research Society). The eminent speakers who followed him avoided any attempt at formal definition of operational research, but spoke with great authority on its basic principles and growing importance in industry, in defence and in the economy of nations. The first four business sessions were devoted to the presentation of papers on methodology and applications, and the final session to development (that is, to the extent of growth of operational research) in the main countries represented. During the week, one session was spent in panel meetings, at which were discussed special aspects of operational research, for example, education and training, or its relation to management. There were a formal dinner and reception on the first night and also informal meetings during the week ; these latter were prosecuted so vigorously that it is doubtful if any delegate got his or her full ration of sleep during the conference. After leaving Oxford, parties visited various British operational research centres. The proceedings of the conference are to be published at the end of the year and can be obtained from the *Operational Research Quarterly* (11 Park Lane, London, W.1).

The largest delegations were from Britain and the United States, and these accounted for twenty-four of the twenty-eight main papers. The conference brought out differences in the approach of these countries to operational research. Judging by the papers presented, interest in the United States is greater in development of mathematical techniques (seven papers) than in applications (three papers), though the methodological papers were usually based on real situations involving decision-making. This mathematical interest seems to stem from universities and research organizations. In the United States much operational research is conducted on a consulting basis by university departments, and this no doubt stimulates academic research. In the United Kingdom, however, interest is in applications (six papers) rather than methods (three papers). It is lamentable that so few British universities show any real interest in operational research. There are many individual workers known by their publications, but some of these are not members of the Operational Research Society and so were not eligible to attend this conference.

If papers are to be judged both by reading and by the interest aroused, then there were outstanding contributions in each session. On the morning of September 3, Mr. H. K. Weiss, of Northrop Aircraft, Inc., presented a paper on "Lanchester-type Models of Warfare". F. W. Lanchester's differential equations are well known from his classical work, "Aircraft in Warfare : The Dawn of the Fourth Arm" (Constable, London, 1916). In Weiss's paper historical data were used to establish the reasonableness of the Lanchester assumptions and then to expand the theory to take into account the movement of forces. It then deals with small combat forces, weapons of greatest effectiveness, and combat between heterogeneous forces. This work all leads to development of optimum tactics between heterogeneous forces. In the discussion it was acknowledged that the simplifying assumptions and unknown values of the relative effectiveness of weapons (killing-rate) cause serious difficulties. It is doubtful, for example, whether the effectiveness of a force is equal to (numerical strength) × (weapon effectiveness), for this assumes that a man who can and should shoot will in fact do so. Another complication is overhitting : a casualty may be due to more than one

hit, each of which is sufficient to incapacitate. For most weapons, however, the probability of hitting with a single shot (or even burst) is very low, and so overhitting is not initially important. In the case of a small force faced by much larger forces and in process of total elimination, overhitting may become substantial but it will not affect the outcome.

One other paper in this session should be of interest to the British public. It was a description by Messrs. J. Stringer (Central Electricity Authority) and K. B. Haley (University of Birmingham) of work in hand to reduce the cost of transport of coal to power stations to a minimum. The use of linear programming showed how some saving in cost of transport might be achieved. The effect of the loss of this business on another nationalized concern was not discussed. This paper also contained an account of an interesting mechanical analogue computer for solving linear programmes.

The afternoon session on September 3 was even more mathematical than that in the morning. The papers by Mr. T. C. Koopmans (Cowles Foundation for Research in Economics) on water-storage policy, and by Dr. R. M. Oliver (Broadview Research, Inc.) on control of production and inventories both contained much of mathematical interest. Comment on both, however, referred to the assumptions made in the mathematical model rather than to the mathematics itself. Mr. Koopmans's paper is of interest to those who heard the papers presented at a recent Royal Statistical Society meeting on queues.

Dr. J. H. Engel (Operations Evaluations Group, United States Navy) aroused more general interest with his paper, "Use of Clustering in Mineralogical and Other Surveys". His presentation, too, was much to be commended for its clarity and precision. In any search the first run will produce some spurious results and some misses. Further rapid runs will produce similar effects but will tend to confirm genuine signals. Such confirmed signals will then be the basis for more detailed examinations of areas in which prizes may be found. New fast searches are cheap, and detailed searches are expensive. It is likely that there is an optimum balance between effort on fast searches and detailed examinations giving maximum result per unit of expenditure. The paper read was confined to a special case in which the number of prizes in the area is known. A hypothetical numerical example given as an appendix to the paper illustrates the salient points. An (n,s)-clustering technique implies n coverings by fast search and a cluster of s contacts as the minimum required to justify detailed ground search. As in many other operational research studies, the answer is sensitive to the criterion. Applications of this theory do require accurate knowledge of equipment performance and costs, which are both matters of some difficulty.

The first session devoted to applications of operational research produced two papers of great general interest. All sufferers from traffic jams in Britain must be grateful for work on traffic flow. Mr. J. G. Wardrop (Road Research Laboratory) gave a paper on the "Traffic Capacity of Weaving Sections of Roundabouts". This described experimental work and its validation by observation of actual traffic conditions. The experiments were made at Northolt Airport during 1955–56, and some of the experiments were presented in film form. The main conclusion was that, in good conditions, about 800 mixed vehicles per hour per ten feet of weaving width can pass through a roundabout of normal design. Cycles, darkness and wet weather all reduce flow. Police control, however, appears to expedite matters. Much smaller flows may be encountered in some circumstances, as when two main streams meet and both turn right. Interference from adjacent roundabouts would also cause reduction. If this work is used as a guide to roundabout design much benefit should result. This type of analysis could be extended to show when roundabouts should be abandoned in favour of fly-overs, clover-leaf junctions and so on.

The other paper of particular public interest in this session was that by Messrs. J. C. R. Clapham and H. D. Dunn (National Coal Board) on communications in collieries. This attracted headlines in the daily press. In brief, underground communication in collieries was found to be inadequate for safety warnings and the cost of satisfactory improvement, on a national scale, is estimated at £5,000,000. Amortized over a reasonable period, this looks like only a few pence per ton on the price of coal—a very small premium for the safety of the men involved.

The second session on applications of operational research contained one paper that produced a long stream of commentators. This was on the "Level of Protection afforded by Stocks", by Messrs. John Harling and M. J. Bramson, of ORbit, Ltd. Stock control is a management function particularly susceptible to mathematical study and has, at one time or another, attracted the attention of many operational research workers. In the simplest terms, the object of this paper is to show the level of protection against run out of various levels of stock when the supply and demand functions to and from the stock are known. In this case delivery times were normally distributed, whereas demand from a production line was Poissonian. Cost of running out, that is to say, of stopping the production line, was not readily calculable. This paper represents an advance on previous published work in that it takes into account vagaries of delivery. Most stock control assumes constant lead time from order to delivery—and indeed delivery at fixed times is not unusual. However, circumstances can arise when vagaries of delivery are the main contribution to size of stock for a particular level of production.

The last paper of the session was by Mr. J. K. W. Slater (National Institute of Agricultural Engineering) on "The Collection of Data on the use of Machinery on Farms". This could well prove to be one of the main foundations of a study of how British farm productivity can be raised. It shows the dimensions of the problem clearly. For example, the average size of farm in England and Wales is only about 100 acres. More than 20 per cent of farms are less than 5 acres, though many of these very small farms must be exceptional in equipment and intensity of operation. Any idea of heavy investment on small farms (say, 100 acres) is likely to be ruled out on economic grounds, particularly in hill regions. Is it too much to hope that more thought will be devoted to understanding the problems of these farmers ?

Looking back after a week or so, this conference seems particularly satisfactory for the international unity achieved. By the end of the week national delegations had fused most successfully and happily with one another. The feeling of common aims towards progress transcends everything else.

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