PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Operational Research and Systems Analysis: From Practice to Precept

R. C. Tomlinson

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Operational research and systems analysis: from practice to precept

By R. C. Tomlinson
Operational Research Executive, Coal House, Lyon Road, Harrow, Middlesex HA1 2EX, U.K.

The paper traces the development of O.R. and systems analysis in the United Kingdom since the phrase 'operational research' was coined just before World War II. Despite confusion as to titles and definitions, the subject has grown to the stage where it is used as an aid to decision making in most sectors of industry and government, and where some 200 students receive post-graduate qualifications each year. Although the subject has a strong interaction with established disciplines, it can now claim to be a distinct area of scientific endeavour, bearing a similar relationship to those disciplines as does engineering to mathematics and the physical sciences.

O.R. and systems analysis are usually considered as complementary to each other, but it is more correct to think of them as 'duals'. Thus O.R. is primarily concerned with the improvement of decisions which cannot, however, be studied effectively without a consideration of the systems within which they are embedded; and vice versa. There are a number of distinctive features of the O.R./systems approach in practice. One is that it seldom attempts to supersede the decision maker by proposing *the* answer to a given problem. More commonly a study is directed towards the improvement of the decision making process, e.g. by redesigning that process, by supplying better information or through the provision of improved analytical tools. A second distinctive aspect follows from a realization that the experience and understanding which lead to a decision on a complex issue is developed by a number of people over a period of time. The only way to aid the decision is to play a part in that development. O.R. and systems analysis can do this both through basic research and the establishment of relevant models, particularly if they can be used 'interactively' by those concerned. Successful research in this area requires anticipation of needs as well as the development of special skills, including the understanding of social systems behaviour. To conclude, the paper explores the need for research to improve the methodology of O.R./systems analysis and extend its range of application.

Introduction

The purpose of this paper is to provide an introductory and perhaps somewhat impressionistic review of the progress of the subject and of its present practice in the U.K. at the present time, and to draw some general conclusions as to its nature. I say 'subject' advisedly, since the processes involved go under many names. I think it would be true to say that the first clear exposition of its practice and principles was under the title of operational research, but they have been reinvented many times under a variety of titles: operations research, systems analysis, applied systems analysis, systems science, cybernetics, management science – to name but a few. Others say that they have been practising it for years without need for a name. Over the years the debate seems to have diverged rather than narrowed. Nevertheless, there is a substantial body of scientifically trained workers, who understand their occupation to be the 'in depth' study of decisions, decision processes, and of the systems within which these are embedded, this study being specifically directed towards their 'improvement'. Those involved may disagree on names,

definitions and relativities; they may argue as to who should have responsibility for a particular study, but they recognize the common methodology and respect the common problems of scientific integrity. To avoid factional arguments so far as I can, let me simply refer to Orasa – interpret the mnemonic as you will.

It is for these same reasons that I shall not attempt any rigorous definition of the subject and its boundaries at the outset. I will start with the observations and, ignoring the advice of tradition, move from practice to precept.

In searching for the origins of the subject we need go no further back than to the establishment of the first operational research section at Bawdsey Research Station a year or two before the beginning of World War II and to the blossoming of the subject during that war, first in the U.K. forces, then in the U.S.A. and the other allied forces. This blossoming had two crucial consequences for the post-war world. One was the availability on the labour market of a considerable pool of trained Orasa analysts imbued with a missionary zeal for what they believed without doubt to be a new and revolutionary field of scientific endeavour. Another major factor was the existence in government and industry of senior officials who had been acquainted with O.R. in wartime work and who saw the value of introducing the same function into their peacetime occupation. This was the way in which Orasa was introduced into the basic industries of coal and steel. It is perhaps worth recording that in both those cases the introduction was at the hands of Fellows of the Royal Society, Sir Charles Ellis and Sir Charles Goodeve.

War is well known to provide a forcing ground for new applications of science and Orasa may be considered in this category. Credit for this development has in recent years tended to be focused on Blackett (1974, 1940; Waddington 1973) partly for his personal eminence and partly for the books and papers that he wrote on the subject which, though few in number, were extremely powerful in setting out the basic philosophy of the subject. It needs to be remembered, however, that the development of the subject was just as rapid in those branches of the forces where Blackett made no direct contribution. Nevertheless, Blackett was a true prophet, and Orasa has in the long run only proved successful when it has remained faithful to the principles that he enunciated. I think he would have accepted the following two points as a fair interpretation of his message.

1. *Orasa is science, not technology*

It could be argued that, before World War II, the scientific adviser's job was to give advice on matters of technology. Blackett's rôle, and I imagine that of his peers, was acknowledged to be the giving of scientific advice on matters of policy and tactics, as well as on the technological devices used in the pursuance of the battle. This was, I think, a fundamental breakthrough, and it is relevant to see how this concept has developed since World War II. Within defence Orasa has continued to be seen as primarily an activity for scientists and for many years Orasa was concentrated on 'assessment', a small element of the Orasa process and an activity in which technological knowledge is as important as the skill in analysing complex problems. This 'scientific' tradition may have had the effect of delaying the movement of Orasa into civilian departments where, in general, there was no substantial technological element in policy making. In industry, however, the 'advice' function was seen to be all important and the work that the Orasa workers undertook bore little or no relation to anything done by other scientists within the organization. From the 1950s on, very few Orasa teams in industry had an organizational

relation with the scientific part of the organization. Thus, although the mainstream of thought about both military and industrial Orasa emphasized both science and decision making, there were strong pressures on those coming into the activity for the first time to put their emphasis on one or other aspect of the whole. In the last ten years the practitioners have come more closely together, but decision makers both in government and industry still suffer from these preconceived ideas.

2. *Orasa is problem-oriented, not technique-driven*

It is important in these computer and technique ridden days to remember what it was that the wartime analysts took with them into civilian life. They possessed little more than their scientific, analytical skills, some elementary statistics, and a burning enthusiasm. There were certainly no techniques as we understand them now. In the first ten years of Orasa in the National Coal Board there was only one study which made extensive use of an Orasa technique as we know it now. As we shall see, it was soon realized that Orasa in a civilian environment requires its practitioners to acquire a wider range of knowledge, e.g. in economics and social science, and that there were many techniques to hand to assist in their task. The change in knowledge and technique within Orasa has been so rapid that there has been a tendency to forget that the basic approach has remained largely unaltered. It is only recently that this basic methodology has itself become the subject of serious research. At the heart of the subject practice is still ahead of precept.

The penetration of the subject into the post-war world was steady but unspectacular for a period of about ten years, at which time there was a sudden explosion of activity. This explosion was strongly influenced by four main factors.

The first was the result of the wartime blossoming of knowledge in the realm of statistics. In this country, of course, this was mostly due to that legendary body in the Ministry of Supply, SR17, and the influence that it had on the next generation of academic statisticians. Suddenly, so it seemed, we were able to handle problems which had hitherto seemed insoluble. There were immediate developments in the field of forecasting, queueing theory and stock control. To be sure, theory showed itself capable of outstripping the practicalities – few practical queueing problems can be solved from queueing theory – but the statisticians were not dismayed; Monte Carlo methods were developed and the modern science (if that is the word) of digital simulation was born.

The second factor was the rapid development of the general subject of mathematical programming and optimization theory which has now become a mathematical topic in its own right. Here again, theoretical development has outstripped our ability to apply it to practical problems. Even where this is so, it is important not to underrate the conceptual value of these techniques, which may be as important as their direct application. They enable Orasa workers to understand and explore the structure of problems in new ways, broadening their imagination and their understanding.

The third factor helping the explosion of the use of Orasa in the sixties was the rapid spread of systems thinking, which I personally think of as developing from the appearance of Wiener's first book on cybernetics (Wiener 1948) though the general systems movement is, of course, older than that. At first the direct practical results of this stream of thinking were very disappointing and it is perhaps only in very recent years that control theory and general systems theory have got to the point where they can be seriously contemplated as having a part to play

in decision making in general. Nevertheless, the conceptual understanding has had far reaching consequences, beyond the formal application of the techniques.

The fourth and final factor in the explosive development of the subject was the electronic computer. It is impossible within the confines of this paper adequately to explain the way in which the computer has affected and is affecting Orasa. It is so very much more than simply making it possible to build larger models and do more complex calculations. We are hardly on the edge yet of understanding the effect that interactive computers can have on managerial decision making or of appreciating the difference that computerized information systems will have. The benefit, of course, is not all one way. Computerized information systems are very rigid and can easily ossify an organization. It is easy to forget that the data put into a calculation determines the degree of complexity that is justified. Moreover, the kind of computer systems analysis that needs to be done to get a working computer package is quite different from and often inimical to the research-based systems analysis required to define that system. Attempts to put the two together are too often disastrous for Orasa. These reservations, which we will return to later, should not be allowed to mask the intellectual stimulation that followed from an understanding of the potential of the computer.

As a consequence of these four factors, the subject appeared to change, almost beyond recognition. Individual teams leapt at the opportunities they appeared to offer. Unfortunately, because individual organizations often had many problems of the same basic type, Orasa often became identified with a single technique, a single problem area, or solely with techniques or the use of the computer. This is perhaps an inevitable danger in any team which has a prime task in helping management to absorb innovation – it gets identified with that innovation. It is, of course, such temporary identification of the whole with the part that leads people to reinvent the subject under another name. This, if it does nothing else, should confirm that the subject does exist, and that there is a felt need for it in our generation.

Academic developments

After the foregoing generalities, it will be helpful to chart the progress of the subject by looking at its professional and academic development. The first expression of the development of a new subject is usually the formation of a club or society. The starting point for Orasa was the formation of the Operational Research Club under the chairmanship of Sir Charles Ellis in 1948. In 1953 this was reconstituted as the O.R. Society, which currently has a membership of just under 3000. A year or two after the Club was founded it started the *O.R. Quarterly*; this was taken over by the Society and is now an internationally recognized journal of excellence, having a circulation of some 3000 in addition to the Society's members.

In 1957 the first International Conference on Operational Research was held in Oxford with the main representation coming from France, the U.K. and the U.S.A. (eds Davies, Eddison & Page, 1957). An International Federation of O.R. Societies was then formed which now has triennial meetings, with intermediate regional and sectional conferences. Countries are represented through their member societies, the total membership within I.F.O.R.S. being 27000. More recently a European association of O.R. Societies has been founded within I.F.O.R.S. and a new journal, the *European Journal of Operational Research*, had its first issue at the end of 1976. Clearly both in terms of membership and publication the subject is continuing to develop.

The I.F.O.R.S. related societies are not the only ones catering for scientists in the Orasa field. The Institute of Management Science, The Society for General Systems Research, and the

Cybernetic Society should all be mentioned in this connection, as should the journals *Omega* and *Applied Systems Analysis*. One of the most encouraging signs in recent years has been the realization that these bodies with common interests should work together, a realization that is now being expressed in a variety of actions.

The university story is in some ways even more spectacular. There was no university department concerned with operational research before the 1960s. The first chair in operational research was instituted by Lancaster University in 1964. Following this the growth of O.R. in the U.K. universities was extremely rapid in the 1960s, mostly through the provision of courses at master's level. There are currently eight such courses supported through the S.R.C. studentship scheme, and about 100 studentships are awarded each year. The take-up of these places remains very high, and there is no difficulty in maintaining the required academic standard of an upper second honours degree.

The tradition has been that a master's course in O.R. would be a generalizing course for a student who has obtained a good honours degree in a special subject. The aim has been to give people capable of doing research in their own field the skills, the knowledge and the basic understanding of methodology to fit them for research into problems of decision making and organizational systems. Inevitably it is the methodology that gives the greatest problems, since all research remains an art which can only really be learnt by doing it. There are many schools of thought here. Some hold that the best way of teaching a practical understanding of the subject is to involve students in actual project work under the close supervision of academic staff; others believe that it is better done through a traditional kind of master's thesis. Whichever course is chosen, a much greater degree of involvement between staff and students is required in a master's course in operational research than for almost any other post-graduate subject. This is, alas, not reflected in teaching ratios, and this reduces the time available for basic research. This is a disturbing situation and I shall return to it later in the paper.

Another attempt to satisfy the difficulties introduced by the need to give students an understanding of the methodology of an investigation has been through part-time courses. A pioneer part-time master's course in O.R. has been in operation for some years at Brunel University. This course, though open, was designed in response to training needs of the substantial O.R. team of the N.C.B. whose location is conveniently near to the university. The idea has not been greatly copied – Aston has a similar scheme – partly because its success depends heavily on a location which is convenient for a number of O.R. teams with an overall annual intake of 20 or so graduates. Other possibilities in the training of O.R. are through series of short courses. Birmingham University pioneered the idea of short training courses – either as appreciation courses, or for preliminary training for those going into the field. This concept has now reached a sophisticated level under the auspices of the Civil Service, who have helped to arrange a sequence of short courses on particular topics to be held at a range of universities so that students can obtain the necessary training without full-time attendance on a university course.

A more fundamental change, however, is approaching. The assumption that most students coming on to a master's course in O.R. were ignorant of the majority of the topics taught to them is no longer true. Some of the material originally taught on master's courses on O.R. is now being taught to the third year of practically-based courses in mathematics, statistics and economics – some of these, quite erroneously, actually call their courses O.R. Such students receive a simple academic training in techniques, but learn nothing of methodology nor of fringe subjects. Above all they do not get research experience. They are neither equipped to do O.R. in practice, nor

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are their needs met by traditional O.R. master's courses. No satisfactory solution to the problem has yet been found.

All that we have said so far has been concerned with university training in operational research. There are however at least two master's degrees in systems which are not, to my mind, distinguishable in any real sense from courses in O.R. Moreover, there are many more courses supported by engineering, statistics and management departments which overlap heavily with the subject. Moreover, in talking about the universities I have made one – at least one – serious omission. The Open University course on systems remains a unique venture, the quality of its published material is outstanding. Alas for this paper, the results cannot yet be seen for evaluation.

The university interest in the subject is, of course, not confined to teaching – Orasa is research, and can only be adequately taught by those engaged in research. The real difficulty here is that in order to provide the kind of research project that can be tackled by a university lecturer on a part-time basis, or which is suitable for handing to a Ph.D. student, one too often has to put such boundaries round a problem as to convert it from a problem in operational research to a problem in applied mathematics. Major problems in the O.R. field cannot be tackled on this basis. Another difficulty is that real O.R. problems cut across disciplinary boundaries and this also gives rise to difficulties in many universities which are run on severely departmental lines. This is, of course, recognized to be a problem outside the O.R./systems world, and there have been a number of attempts to tackle it. For example, Aston University has a most imaginative scheme for interdisciplinary Ph.Ds. The S.R.C. have recently set up a committee to fund interdisciplinary research projects, which has achieved the remarkable feat of reporting on their work without mentioning the words 'operational research' or 'systems analysis'. There are also a number of research institutes set up to undertake some interdisciplinary work of this kind. The Science Policy Research Unit and the Centre for Environmental Studies might be mentioned in this connection, but there are many others. Unfortunately many such research teams are set up in a vacuum following the broadening of the interests of individual members of the team. They have often not realized that they are tackling problems whose inherent structure is very similar to those tackled elsewhere. For all these reasons, I believe there is a clear need for a central, mainstream, research institute in the Orasa area which could ensure that fundamental and applied research in the subject could be undertaken while, at the same time, providing a central point of enquiry to teams being set up to tackle particular problems.

There is however at least one such international institute, the International Institute for Applied Systems Analysis in Vienna, which is jointly funded through the scientific institutes of many countries, the main contributors being the U.S.A. and the U.S.S.R. It has had many difficulties to overcome (not all of them scientific) and there are many yet to be solved, but nevertheless an understanding of the systems analysis process has developed steadily in its four years of existence and useful results are already beginning to emerge, particularly in the areas of ecology and energy systems.

The practice

The foregoing has in one sense been exploratory, and has talked around the development of the subject without referring to its practice, nor its actual use in assisting decision makers. That is the purpose of the present section.

The move of O.R. into civilian life from its military origins was on a wide front. In 1953

Goodeve & Ridley conducted a survey in which they identified 45 industries and organizations having an on-going O.R. effort covering the following range of activities: boot and shoe, broadcasting, building, chemical, coal, confectionery, engineering and machinery, industrial consultants, metal, pharmaceutical, social surveys, textile, transport (land, sea and air), and the defence services. Forty-one other organizations reported that operational research studies were occasionally carried out, and these included agriculture, baking, brewing, brick, civil and electrical engineering, department stores, fertilizer, hosiery, lamp manufacture, laundry, metal, petrol, photography, surveys of opinions and behaviour, textiles. Most of the teams involved in these activities were at the time very small.

The situation was re-examined by Mercer in 1968, and by Eilon, Hough & Betts in 1969, both of which papers looked at the penetration of operational research into industry and commerce by looking at the ratio 'O.R. workers/total staff employed' in each of the standard industrial classifications. These papers showed penetration of the subject into most industrial areas, particularly in chemicals, mining, metals, utilities and food and drink. The least use was in agriculture, clothing and footwear, timber and furniture, construction, the distributive and retail trades, and banking and finance. A more recent survey by Rivett in 1967 shows that the banking and finance gap has now largely been filled – it is currently one of the growth areas in Orasa – and that there has been some penetration in the areas of agriculture, forestry and fisheries. For the rest the picture remains much the same.

These general results hide many variations within the individual classifications. Thus, although utilities in general make extensive use of O.R. not all do so equally and some of the use is by staff formally carrying some other title. This is by now a very general trend. Similarly although the engineering and metal industries in general make extensive use of the subject, there are relatively few applications in ship building and heavy electrical engineering and in 'metal goods not elsewhere specified'. On the other side, although the distributive and retail trades appear to make little use of Orasa there have been a number of effective applications in connection with mail order.

For the most part, it is easy to see why the pattern has developed in the way it has. Generally speaking the major users of Orasa are industries dominated by large organizations, with a strong scientific and technical base. The cynic might say that a large organization is more able to afford the luxury of a speculative activity like Orasa. More realistically one might suggest that complexity goes with size, that organizations with a number of similar units can get a multiple return from a study at one of them, and that a relatively small percentage saving is more worthwhile in absolute terms if the turnover is high. Equally, it is hardly surprising that there is less use of rational analysis in those industries which are dominated by taste and fashion, such as clothing and furniture, and where a good deal of the manufacture is undertaken in very small units. The same applies to those major industries where success depends on successful tendering for major contracts – e.g. shipbuilding and construction. It is less easy to understand why there should be so little application in the distributive and retail trades, and one suspects that this may be a matter of definition as much as anything else.

The above picture does not take account of the major contribution that operational research is making to public administration and government at both local and national level. The very extensive work of Orasa in government will be discussed in a later paper (Baldwin 1977), but for completeness one needs to record the rapid expansion of the subject since the reorganization of the Civil Service following the Fulton Report. There has also been considerable use of Orasa

in local government and in the local health services, but the situation here is fragmented. A good deal of consulting work is done for these bodies through their local universities and research institutes, such as the Local Government Operational Research Unit, as well as by staff within their direct employ. But there are some major problems here which – like so many problems of Orasa – are essentially problems of management and decision. However, as the rôle of Orasa is increasingly seen as providing the means for more effective understanding in the development of decisions – a topic that I shall return to later – it is likely that it will have an increasing part to play in local government.

The published literature is of limited value in describing the kind of work that is being undertaken, for the criteria for publishability and usefulness are different – if not actually negatively correlated. Those engaged in successful applied research do not have the same impulse for publication as those in a more academic environment, nor are they often encouraged to do so. When they do publish, it is too often done in such a way as to be misleading with regard to practice. In order therefore to provide a statement for this paper that was not purely subjective, I have written to all non-university members of the Council of the Operational Research Society, and to a number of other practitioners, asking for information on six major projects which they have been responsible for in the last two years. As a result information on some 100 projects was received, as well as a wealth of informed comment. This does not, of course, represent a balanced statistical survey, nor is it possible to provide any simple statistical summary of the findings. It does, however, provide a unique, solid core of information as to what Orasa practitioners actually do, and the way that they interact with decision makers. I shall draw a number of general conclusions – quoting wherever possible directly from the replies.

I should first say something about the group. It excluded Government and the major companies (Baldwin, Ezra, Veldhuis, De Jong – all 1977; Popper 1963) whose work is discussed later. Most of the organizations are large, but three consultancies and three research associations are included. Manufacturing industry, transport, finance, marketing and public services are all included. Few of the Orasa teams involved are large (greater than a dozen), though none were one man bands. From the fact that all concerned have reached some distinction in the subject, they may be considered as coming from the more successful end of the spectrum of acceptance by management.

The first conclusion is that the different teams do such different work that the returns are almost unsummarizable. The actual work is clearly determined by the individual requirements of the organizations, and not by the possession of a particular set of techniques. There are, of course, certain bread-and-butter areas. Problems of stock control, provisioning, maintenance, and vehicle fleet planning are common to virtually all organizations and were tackled by most of the teams. They are areas which are generally seen as a cost, providing benefits measured in intangible terms such as service – consequently they are under continual attention from management. Above all they are genuine systems problems, modellable and – though to a lesser degree than many would wish for – analysable. Having said this, each case was very different indeed and all that was common between them were the basic concepts and techniques. There was, for example, little use of standard computer packages – though this was due, in some part to the fact that large organisations were being considered. In small organizations it may – *faute de mieux* – be necessary to adapt their organization to a package. On the whole, however, organizations do not see these bread-and-butter areas as their central problems, and correspondingly they constituted a relatively small part of the overall effort.

In requesting information, I asked that where possible the projects should be placed in one of three categories:

(1) Where the studies are used as part of the input to clear-cut once-off decisions (e.g. Do we build this plant? How big should it be?).

(2) Where the purpose of the study is to provide decision makers with a 'system' (e.g. a general method of calculation such as a simulation package, or information system, or a control system).

(3) Where the end-point of the study is to assist in policy formulation (e.g. assessment-type studies; the development and use of corporate models, etc. etc.).

I postulated that the subject was changing from an emphasis on the first, and becoming increasingly involved in the third. On the whole this hypothesis was confirmed, the split in effort being of the order 15–50–35. But the classification was less helpful than I had hoped, because surprisingly large numbers of the projects would not fit simply into one classification. Typical of the involvement in a once-off investment decision is the following:

> As well as studying the logistics of proposed layouts and the amount of equipment (e.g. cranes) required, the studies included an examination of scheduling problems and information flow and the need for intermediate process stocks. The results, based mainly on hand simulations and probability calculations were reported verbally to regular (about once every three weeks) meetings of a senior development committee and short written reports were also issued. The proposed plant layout was modified to take account of the results as they became available and the final plan is completely different from that in existence when the project was started.

This is an important example in illustrating how most planning processes develop over time – involving an accumulation of information and opinion. If Orasa is to have an impact it must be involved in the process of development. The decision as to whether to build the plant or not is often less important than the question – what plant?

Another reason that the simple classification is not appropriate stems from the fact that management – at least in those industries which make good use of Orasa – are inventive at turning tools to a variety of purposes. Thus we have an 'Engine logistics model':

> This model is used in all modes of operation. It is regularly run as a workshop loading forecast. It is used as the basis of many marketing campaigns and is also used extensively to examine the implications of any changes to the basic operation of vehicle fleets (e.g. reliability, utilization, repair lead times, spares availability, etc.).

Perhaps a more useful categorization would have been to consider the following three classes of use, namely (A) strategic (or policy) planning; (B) tactical (or operational) planning; (C) operations. A quick analysis indicates that the projects were split more or less evenly between these three categories. This is a healthy situation, since good decision making is necessary at each level, and those advising at one level need to be well aware of the problems at other levels.

Some examples in each category may be of interest:

Divisional planning model (A) – for production planning department used for monthly, annual and five-year plans and one-off decisions. Largest project undertaken by the unit (> 20 man-years); operational for over four years. Benefits? Our turnover is around £300M/year!

Commodity purchase planning (A). This is a large-scale computerized system which predicts the

effect on chemical composition and price of our stocks of vegetable product, starting with existing grades and taking into account sales forecasts and forecasts of future crop qualities from the many growing areas of the world. It enables the departmental management to decide their buying strategy in the purchase of millions of pounds of product each year. The system has been in use for nearly two years now and is regarded as an invaluable aid by the department. It was demonstrated to them by us as a going system and took about two man-years to develop.

Data handling for planners (A). We have provided one man full-time for the maintenance of a high-level language planning model. The client is now familiar with the system, and pressure of data and the need to review alternatives has convinced him the back of an envelope is no longer adequate. The planning team develops the model continuously, top down, as the Group's details change. Reception – they invented it.

Budget allocation (B). We are currently developing a system to advise the Managing Director on the allocation of our global budget between individual branches. The organization is desperate for this project to be a success since it is clear to almost all concerned that current subjective methods of deciding the appropriate allocation are very suspect and also divisive. Because of the enthusiasm for this project, we expect the model which we will eventually produce to be accepted.

New product facilities simulation (B)

Area of application: a new product will be built in a mixture of new and existing plant. Appropriate facilities must be built within a strict budget. A simulation model is being used to ensure as much production as possible from the available capital and to develop the necessary control rules for the facility.

Form of presentation: a regularly updated report is produced showing the latest plant layouts and expected production rates, etc. Other documents are circulated indicating areas of the plant (or control rules) which may cause production problems if left in their present form.

Management reception: after a slow start, the value of simulation has become apparent and the whole planning procedure now revolves around the simulation.

Scheduling information systems (C)

Problem: the supply planning function had a problem in coping with requirements and status information, concerning shipping, inventories and production. These data are needed to initiate transport movements between the refineries and the marketing terminals.

Solution: parallel working with the present operators identified the bottlenecks on information movement and deficiencies in their methodology. Physical records were replaced by c.r.t. images driven by an on-line computer system. With the use of a real-time clock facility all routine reductions in inventories are handled automatically and projected many days ahead.

Status: working and in daily routine use. Extensions of similar methodology to other areas planned.

Rostering model (C)

This takes information on projected workload variability for a given ground task force and also the set of rostering constraints and produces an optimum roster for the men involved. It has been used to produce specific rosters for operation and it has also been used to evaulate the costs of proposed new elements in the rostering restraints. In some wide studies that are currently

under way some important areas have already been covered with extensive use of the model (O.R. being heavily involved in the task force and the negotiations) and very substantial savings in manpower requirements have been made. The results were presented at each stage in terms of typical rosters together with the manpower implications. The outputs were made available freely to the staff side during the studies and suggestions from the latter were evaluated in just the same way. Management have been very enthusiastic about this support in a rather sticky and complex area.

One of the most common points of comment by my correspondents was in connection with the use of models and relations to the computer. Virtually every project mentioned here made extensive use of computer models, and often the main visible output of the study was such a model. The effect is exaggerated because the emphasis has been on major studies, representing about 75% of the total work effort – though a smaller proportion of the number of projects worked. Despite this extensive use of the computer, very few of the Orasa teams are part of the computer department, and those that were remarked on the difficulties that this gave rise to – partly because of the different way in which computer systems analysis is undertaken and controlled, partly because of the importance of the Orasa team's independence in the eyes of management. Indeed a number of the studies were undertaken to provide some objective assessment of the computer facilities required by management, which could not well be done by those responsible for operating those facilities.

Equally interesting were the comments regarding relations with management. It is clear that the way in which Orasa is used and understood has changed over the years. The following extract makes this point well:

> Two points occur to me. The first is that one needs to have a realistic view of the difficulty of moving into areas about which the O.R. group knows little. It takes time to grasp new situations however bright a person is. Thus we have found that a lot of our work develops from previous work where we have built up some knowledge, experience and reputation. Personnel is a good example here, where our planning work has led on to other studies – in fact we have something of an ongoing consultative role, so we are in a position to spot problems as they develop rather than waiting to be presented with a well structured problem to solve.

This is another important point that I shall take up in the next section.

Finally, something needs to be said about the amount of effort devoted to these projects. More than half had over a man-year of effort devoted to them – one as much as 24 man-years. As virtually all of the teams were subject to rigid control systems, this is itself an indication of the perceived worth of the work to the organizations concerned. (This point is discussed further in a later paper by Sir Derek Ezra.) Despite this, it is surprising how many of the projects later accepted with acclaim, were started as speculative ventures by the Orasa teams. The need to have some discretionary time in the budget of a research team has been proved once again.

Precept

So far this paper has discussed the origins and development of Orasa (but mostly O.R.) in the U.K. from World War II to the present time. My attempt now is to bring all this information about practice together – to try to develop some precepts.

In the first place I can no longer delay a discussion of the relative positions and functions of operational research and systems analysis. Here I must use my own definitions – which are:

1. Operational research is the scientific study of decisions and decision processes, directed towards their improvement. (Specifically, it is *not* the set of mathematical techniques commonly used in operational research.)

2. Systems analysis is the scientific analysis of systems. (Specifically, it is *not* the construction of a suite of computer programs for a specified task, nor is it 'systematic' analysis, i.e. the breaking down of problems into very small components.)

The two are clearly not identical. O.R. deals with some decision problems that can only distantly be described as systemic. Systems analysis is concerned with all systems, and not just decision systems, or indeed organizational systems. If, however, our attention is confined to decision making in social or organizational systems the overlap is very great. Organizational decisions are embedded within the organizational system. The likely consequences of a decision can only be explored if one first analyses the behaviour of the whole system, or at least that part of the system affected by the decision. Similarly an analysis of an organizational system which does not recognize the importance of the decision nodes within it would be an absurdity. Conceptually, one must think of the decision and the system as being in the situation of mathematical duals and operational research and applied systems analysis in the same rôle.

This 'duality' is clearly seen in the names of the teams involved in my questionnaire. O.R. and systems both occur frequently, and you could not differentiate in the work they do. 'Systems analysis' does not occur because its current industrial and commercial usage is almost entirely confined to the development of computer packages for routine use. In fact, as has been noticed, a direct conflict of approach is often noticeable between computer systems analysts and Orasa workers.

The second point to note, in trying to characterize the subject, is that it is both 'applied' and 'multidisciplinary' – in the sense that it draws extensively from a range of knowledge and skills developed in the traditionally accepted academic disciplines, e.g. mathematics, statistics, computer, economics, psychology and sociology. This inevitably gives rise to some argument and discussion as to whether it is a discipline in its own right. (My use of the word 'subject' has been deliberate.) So far as I can make out all the arguments that arise in this connection are the same as those that have been raging, and still rage, over the status of engineering and its relationship to the 'hard' sciences. Take a piece of what is taught or researched, and a case can be made out that it belongs elsewhere. Take the totality, and something quite distinct emerges. So with Orasa.

It may be worth taking the discussion of 'disciplinarity' one stage further. Traditionally, most early descriptions of Orasa have stressed its 'interdisciplinarity'. The wartime teams had been made up of any good scientists that came to hand, regardless of discipline. This was an accident that was seen to have positive virtues – because of their different backgrounds they saw problems differently and the differences proved to be of positive value – we now call it synergy. In the early days, recruitment to industrial groups deliberately set out to maintain this variety of approach within the team. This is no longer entirely true. With the advent of formal training in Orasa there is some danger that this catholicity of approach may be lost, particularly if – as seems likely – the tendency to bring that training into undergraduate courses increases. One can go some way towards this by bringing specialists in, but it must be emphasized that merely to aggregate interdisciplinary teams without Orasa experience is simply putting the clock back.

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There is knowledge, experience and methodology to draw on, and we should not deliberately encourage people to reinvent the wheel, particularly as the result is not always circular in shape. Nor, one must emphasize, is it sufficient systematically to divide a problem into bits appropriate to various specialisms with some loose administrative control but little technical interaction. That is the antithesis of systems analysis. Where the size of the problem is such that it needs to be divided into parts for analysis, that division needs to be done on systems principles not through the functional skills of the participants.

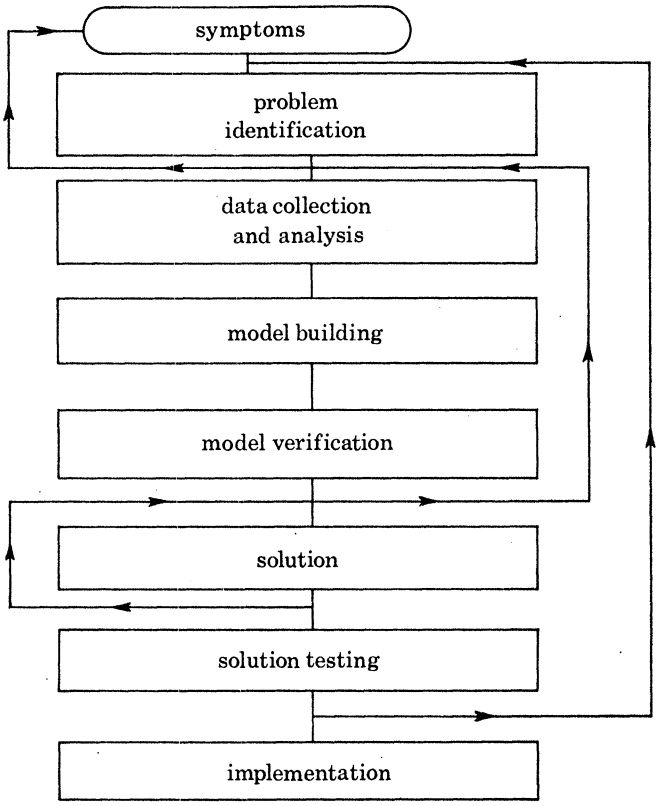

FIGURE 1.

The third point, then, is to note the extent to which it has become necessary to modify the formal description of the methodology of Orasa. Until a few years ago, a description of the process would have been along the following lines:

'Problems start as a set of symptoms. Even if a manager states the problem in specific terms, it will be necessary to identify why he is concerned, and whether the answer to the problem he has stated will in fact alleviate those symptoms. So the first step is problem analysis and identification. One must then collect and analyse the necessary data, at which stage it then becomes possible to construct a model of the situation. This must then be verified. Following this, a solution to the problem is proposed, which must also be tested. Finally, there is implementation, the responsibility of the decision maker, but with the involvement of the scientist.'

It would be admitted that in practice, no investigation ever went as simply as that. Each stage can lead to redefinition of the previous stage, so that in order to make the process realistic, one needs to insert a whole series of feed-back loops, as shown in figure 1.

The description is still of value for pedagogical purposes. But it assumes that the problem being worked upon is unique, constant in time and separable from other problems. These assumptions are simply not true in most practical environments. Problems exist within a time space continuum of other problems. Moreover, decisions are not taken objectively at a point in time, they are formed (or made) over a period of time. To complicate matters further, the actual decision is dependent on the alternatives put before the decision maker, which may be decided at a level in the organization well below the Directors. To be effective, an Orasa worker must not merely examine the whole decision making process, but make a number of inputs to it at more than one point. Thus, he must recognize that he becomes part of the system himself.

This needs further exploration. Let us therefore return to our original description of the Orasa process and consider the rôle of the model, which remains central to the approach. (The use of explicit models is what distinguishes the Orasa approach from that of other investigators; their validation makes it scientific.) The model is increasingly taking on an importance that was not previously envisaged. Traditionally the model has two important functions. First of all it has to be exposed to the decision makers as an open statement of belief, and secondly it becomes the scientific basis for analysis. The change arises as a result of the process of validation, which often ultimately rests with the planners and decision makers themselves. The very arguments that take place as a result of this validation are quickly found to be altering not only the models, but also the attitudes and understanding of the decision makers. This process is further enhanced when the models are used interactively, since they then play a still larger part in educating the planners. It is not uncommon for the model to be redundant after it has been validated, for by then it is part of the 'unconscious' understanding of the planner.

As one of my correspondents has said 'The object of the work is to provide the basis for thinking rather than the thinking itself; in other words, we do not worry about making objective functions explicit, but leave it to the user to discover what are his implicit objectives by calculating through a series of "what if" questions.'

This does create difficulties, as another correspondent indicates: 'I myself feel that the "scientific method" still lies at the heart of O.R., with its sequence of hypothesis, measurement and theory. If a move to "policy evaluation" means that we are applying it to larger and larger issues, that is all to the good – if, on the other hand, "policy" means that we are going from the concrete to uttering vague generalities, then we are abandoning O.R.'

What we are raising here are again matters which need careful research, not least in the fields of philosophy and ethics, though the process described here is closely akin to the ideas of Popper (1963). Once again practice is leading the way for precept.

This brings us to my fourth point, which is the relation of the Orasa scientist to the decision maker. Clearly, he is increasingly in the kind of cooperative relationship envisaged by Blackett, but to a different degree. This may be illustrated by the way in which models are used in practice. Until a few years ago, it would be assumed that the routine use of any model should be a management task. The Orasa analyst would have a responsibility for developing it, teaching its use, giving advice even, but as a research worker not responsible for routine he should then move on to his next research problem. As increasing use is made of planning models, however, the situation has altered. Although models are available, accepted and used by the planners– often interactively – the situation remains as complex as ever. The models help no more. The Orasa worker still has a part to play – indeed now that the models exist he can play a part that was impossible before. They are tools which remove some of the obstacles to scientific thought –

but they are no substitutes for thought. Accordingly the models often stay with the Orasa teams, who may have to take responsibility for maintaining them.

All this breeds a deepening confidence and understanding between Orasa men and planners and decision makers – an understanding that depends very little on their formal organizational relation – for which there seems to be no common pattern at all. But it creates difficulties with regard to objectivity, which of course remains a prime scientific requirement. Perhaps strangely, the problem is one that worries the scientist more than it does the manager, who values that objectivity as much as he does the scientists' sharpness of mind. He soon notices if it is lost. Nevertheless for the Orasa worker himself this remains the central problem for his scientific credibility. How to be sufficiently involved with the decision making process to understand it and make an effective input, while being far enough from it to study it objectively. It is a tight-rope that he is doomed to walk.

The fifth point that I should make is that the Orasa teams are widely spread throughout industry, commerce and government, undertaking work at all levels in the organization – strategic, operational planning and operations themselves. This can be said without making absurd claims for universal success or acclaim. Indeed, as one correspondent has said, the way to be successful in Orasa is to refuse to take any credit at all. What is more surprising, however, is that the subject is still very much in a state of transition. One of the reasons for this goes back to the management/Orasa relation. A number of groups have now been in existence for ten years or more in continuous association with the managers concerned and they find increasingly that problems are being exposed more often at the point where ideas are still fluid and real impact can be made. This has been helped to some extent by the fact that practitioners no longer try to force large, black box, optimizing models on their clients as they used to. (These met with resistance for many reasons. They were not understood; management knew very well that the models contained many assumptions whose importance they could not gauge; optimizing solutions usually appeared too late when much of the process of decision making (as opposed to decision taking) was completed.) The use of 'what if' models, and the general availability of computer terminals, etc. has accelerated this process.

Another factor leading to the feeling of transition has been the increased awareness of the problems of size and complexity in present society. Orasa workers have a major opportunity here if they do not fall into the trap of the experts, and try to *tell* the decision makers what to do. Their task is to improve the decision process, not replace it.

Before going on to the next point some reference needs to be made to the possible contribution Orasa has to make to what might be described as the 'soft' areas of decision making where individual and group behaviour play a major part, including of course most political decisions. There has always been a belief amongst Orasa scientists that they should be able to make some contribution in such decision processes, a belief which may be said to have taken its first public form in a joint conference on 'O.R. and the social sciences' held in Cambridge in 1965 (ed. J. R. Lawrence 1966). There are two ways in which such a contribution might be made. The first is through the identification of 'hard' elements in the 'soft' process. One perhaps extreme example of this is the use of global models as an aid to policy formulation, exemplified by the work of the Systems Analysis Research Unit of the Department of the Environment. This is essentially the same process as has already been described above in relation to the use of models in management/union negotiations in connection with rostering. Much work needs to be done in extending these concepts to other, more overtly political, situations but it is not difficult to consider possible

areas of application, e.g. planning enquiries and union/management negotiations. The rôle of games in this context has also not been adequately explored.

The other approach to these 'soft' problems is to tackle them head-on, to determine the structure and dynamics of the decision making processes and to determine the way in which alterations in those processes will affect the form of the decision. The leading exponents of this approach have been the Institute for Operational Research who have particularly worked in the area of local government and health service planning. Some interesting work has also been undertaken at I.I.A.S.A. in connection with their work on regional development (Tomlinson 1976). Reference should also be made here to the work of P. B. Checkland.

Work in this area is still in its infancy but enough has been achieved to be hopeful that much more may be achieved. However, the potential value of this approach must not be over-stated. No one wishes the normal political processes of decision making to be taken over by the scientist, still less by the computer! The virtues of inspiration and commonsense will still predominate as well as the vices of prejudice and dishonesty. If, however, Orasa could help eliminate even a few of the unintended miseries induced by our present decision making procedures, that would be progress indeed.

My sixth, and final, point relates to research. Orasa can be classified as 'R&D' in the sense that the phrase is used for the R&D activities in industry and government. Some of it is development, making use of proven research to provide something that actually works. Some of it is research, with a small 'r' – tackling problems to which the solution is not clear, and where there is a possibility that the desired end point cannot be achieved, but not really leading to an increase in fundamental knowledge. Relatively little of it is Research with a capital 'R', tackling fundamentally new problems or trying to reach a basic understanding of what we are doing. That remains, as ever, the function of the universities and of the research institute. As I have already indicated, I am not altogether happy that the research currently being undertaken is advancing us fast enough (I am not criticizing its quality). Partly this is because of the unduly high amount of effort that university Orasa staff have to devote to tutorial and supervisory work in their laboratory, which consists of real-life organizations often physically remote from the university. Partly it is because the nature of the subject is such that the problems are large and complex, and need to be studied by teams. Indeed there is abundant evidence from within the industrial groups that there is a critical level of effort below which no useful progress can be expected in a basic systems research problem. Such teams could probably best operate within a research institute, where they would interact fruitfully with each other, and which could also operate as something of a clearing house to the increasing number of researchers in varying fields who are tackling from scratch systems problems for which some methodology already esixts.

Conclusion

The purpose of this paper has been to try to give a picture of the current state of O.R. and systems analysis in the U.K. at the present time. Other papers will discuss in more detail the state of knowledge in the subject, and the way in which it is applied. It is clear that there has been considerable progress in making use of the Orasa approach in many medium sized and large organizations, as well as in the public service. Where it is used effectively it plays a part in major strategic decisions, as well as at the more operational level. It is a subject still in the course of evolution, particularly in developing an understanding of the way that decision making processes can be modified. Progress continues to be made in extending its range of

application, particularly into some of the 'softer' areas of organization and decision making. Much research is still needed.

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