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Operational Research within the National Coal Board

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Operational research within the National Coal Board

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The Operational Research Executive of the N.C.B. was first established with one appointment in 1948 and has steadily grown, both in the size of the group – now over 100 scientists strong – and in the range of the work undertaken. One essential feature of its success is the organization of the group as a federation of small teams, each of which works on a continuing basis with a corresponding management team. Equally important is the formal check-back system which analyses the group's overall achievements each year.

Three major studies are described. The first traces the development of a suite of corporate planning models as part of the work of the team providing aids and advice to planners at headquarters. The second describes an 'old fashioned' piece of O.R. – the assessment of the future potentialities of the underground gasification of coal. The third discusses a year's achievements of the team serving one Coal Board area.

It is the N.C.B. experience that a scientific service of this kind, dedicated to the Board's service, but independent of departmental pressures within it, is an invaluable aid to management decision making.

1. Introduction

Operational research in the National Coal Board is an activity that grew directly out of the great founding traditions of the subject. The first scientific member of the N.C.B., Charles Ellis, had previously been scientific adviser at the War Office, and one of his early appointments was to recruit an army O.R. man to establish a Field Investigation Group whose purpose was to undertake similar studies in the Coal Board. The growth of O.R. in the N.C.B. since that time has been steady, gradually broadening its programme of work and the number of staff employed until the present time, when we currently have over 120 people employed in the Operational Research Executive, of whom about 100 are graduate scientists. It is not my purpose here to set out the history of this development, it has already been fully described in *O.R. comes of age* (Tomlinson 1971), but it is important to note that there is a history, which is as long as that of the Board itself. Even at the highest levels of management in the Board, the majority of the staff have been aware of operational research for most of their working lives. They may not all be protagonists of the subject but it is no novelty to them. They know the work that has been done in the past and have a fair idea of the way in which the team operates. Most importantly, its success does not depend on the reputation of one practitioner, nor on the patronage of some individual on the Board. When we are talking about such a subjective field as decision making these are points of some importance, and explains a good deal of what I am advised is an unusually close working relationship between the Operational Research Executive and the Board's management staff.

In organizational terms, the Operational Research Executive is a centrally funded research agency within the N.C.B., serving the needs of all Departments and Areas of the Board, as well as its ancillary activities. It is managed through a board made up of N.C.B. directors and

Board members, the chairman of the Executive Board being the Scientific Member of the National Board. The Executive Board reports to the National Board twice a year, once to seek approval for their research programme and the allocation of funds necessary to undertake it, and once to present a formal report on the past year's work. Since these two elements – the research programme and the procedures for formal accountability – are the main vehicles by which I assess the value of their work and determine the level at which it will continue, it is worth giving them some further attention before I go on to discuss particular examples of O.R. studies.

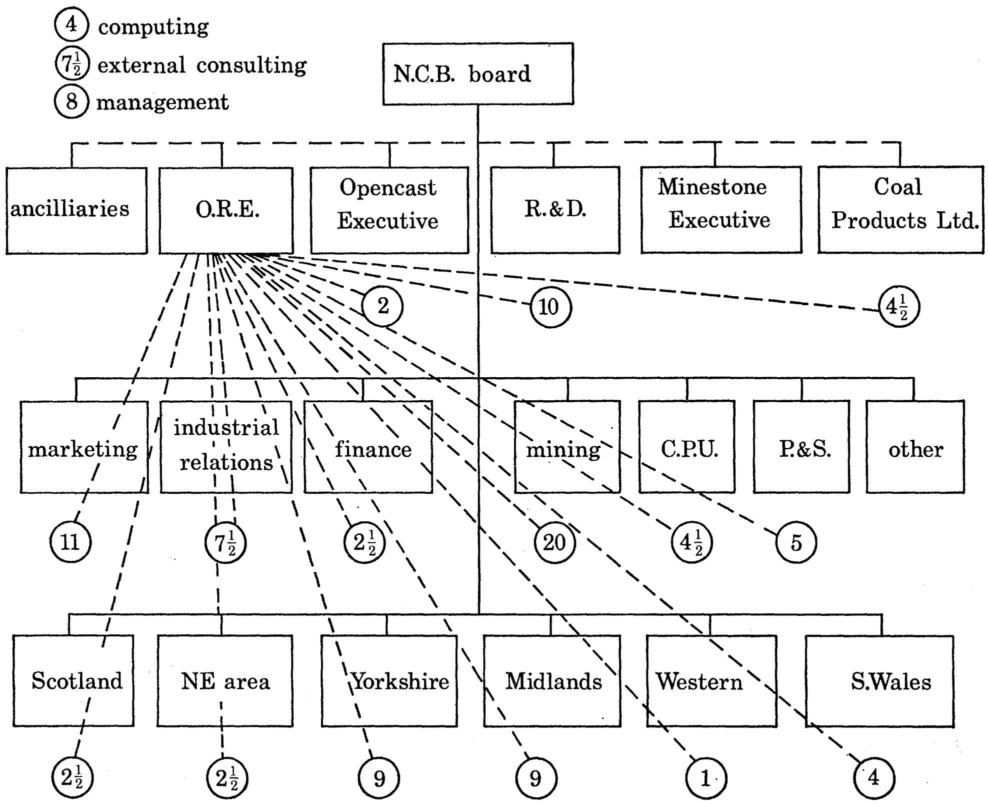

Figure 1.

The way in which the research programme is developed stems from the way in which the work is organized and controlled. Although formal control rests with the Executive Board, in practice the Executive operates as a tightly-knit federation of small O.R. teams operating on a continuous basis for particular groups of management. Thus every production Area of the Board, every H.Q. Department (and indeed some branches within departments) has a small team of 2–6 O.R. scientists working on a full-time basis for them and them alone (see figure 1). The section leader in charge of such a team is responsible not merely for carrying out such projects as may be identified but also for collaborating with the management concerned in the development of an on-going research programme. Thus even at that level, work is conceived in terms of programmes. It is because of this that we can talk of the Executive's research programme as a 'programme' rather than a collection of isolated consultancy projects. The range of that programme is indicated in appendix 1.

The research programme presented to the National Board each year covers in detail about two-thirds of the total budgeted effort, the remaining third being devoted to *ad hoc* work for the Board's production Areas – work which is necessarily controlled on a short-term basis and cannot be planned a year in advance. Judgement as to the level at which this Area effort should be operated is based on the retrospective assessment of the work carried out to which I shall refer shortly. This is not to say that the Area work is entirely isolated from the research programme. There is the strongest relationship between the two; staff regularly interchange, and much of the research programme is directed towards the solution of problems identified by the Area teams in the first place. This balance of effort is of fundamental importance.

The formal development of the main research programme starts with a general review by the Executive Board of the whole research programme which includes an assessment by the Executive's staff of possible new major fields of work. I should emphasize that management in the Board are well aware that research teams must continually be moving into new areas of investigation, which must inevitably in the early stages be speculative. Following this overall review the Executive Board identify a general pattern within which the following year's programme can be firmed up. Detailed discussions then take place at departmental level to determine a research programme which matches departmental requirements. These individual programmes are formally approved by departmental heads or, where appropriate, by a Board committee. These individual proposals are then considered by the Executive Board, who collate them, suggest modifications as necessary and submit a final programme to the National Board. The result of this, inevitably somewhat lengthy process, is an allocation of effort based on a long-term view of the industry's requirements but meeting in the short term the agreed requirements of departmental sponsors.

No amount of planning is of value to an organization unless it is matched by achievement. It is hardly necessary for me to emphasize the difficulties of judging the achievements of any research team, and the problem is certainly no easier when it comes to operational research. When I first pressed the O.R.E. for a means by which I could adequately judge their effectiveness I was met by two main arguments. The first was that most of their work was unquantifiable, being associated in some way with planning or with policy. In fact in this respect the difficulties of evaluating operational research were precisely the same difficulties as in evaluating the efficacy of policy making and planning in management. Secondly it was claimed that most of the work of operational research was so closely integrated with that of the management teams with whom they worked, that any attempt to allocate savings between the O.R. worker and management generally was bound to be uncertain and divisive.

The arguments are both valid, but that does not mean that the difficulties are insuperable. We have now evolved an accountability system for O.R.E. which provides the necessary control. Each year, the Executive prepares a list of achievements, i.e. brief statements of the results of individual projects completed and accepted by management in the course of the year – last year there were nearly two hundred. These achievements, which are confidential to the Executive Board, have to be formally approved by the Area Director or Head of Department concerned, and are more often than not expressed in qualitative terms. Such a list of achievements in one Area is given in appendix 2, and a selection of the Headquarters achievements in appendix 3. About 15% of these achievements have direct money savings attached to them, though no attempt is made to allocate the savings between management and operational research. In the five years that we have operated this system the Executive Board have been consistently able to report that the total savings evaluated in this way comfortably exceed twice the total cost of the Executive. This means that the remaining 85% of the projects, which are usually those which receive the greatest support from management and for which O.R.E. are most valued, are, so to speak, all 'profit'. The procedure satisfies me that the service is a good investment; it forces staff in the Executive to realize that they must have achievements if they are to continue to be employed, even though those achievements need not be expressed predominantly in financial terms. Finally it ensures that management in the Board takes direct responsibility for the work undertaken under their formal sponsorship and are prepared to speak for any achievements and savings that the Executive may claim.

I have dealt at some length on these administrative matters because I believe that they are vital considerations if O.R. is to be 'an aid to decision making' – at least in an industrial organization – and as a manager I feel that a conference like this should be aware of such realities. Most of the rest of this paper will be concerned with three specific areas of research, but there is one further administrative point to be made, concerning the people that do this work. A major part of the managerial task lies in ensuring that proper resources are made available for getting work done. In operational research those resources are predominantly human, though the cost of computer support is nowadays a far from negligible item. It is our view in the N.C.B. that O.R. should be done well or not at all, and that this requires that the staff employed should be of high calibre and well trained. I will not attempt to justify this, other than to say that busy managers are not prepared to give up their time to research workers of this kind unless they have good reason to believe that it will be worth it. For this reason the Board have always maintained a policy of recruiting their O.R. staff from the same pool of intellectual talent that the universities draw on for their research students, and have insisted that formal training in O.R. methodology is something to be added to this innate ability – as well as guided experience in the conduct of research. We prefer that these two should go hand-in-hand, and for this purpose in recent years we have made considerable use of a part-time master's course in O.R. mounted by Brunel University. Moreover, because O.R. is a research subject in which new ideas are continually being introduced, we encourage all our O.R. staff to take an active part in scientific and professional life, through the O.R. Society and other relevant scientific activities. It is particularly gratifying, however, to find that staff of this intellectual calibre and with this training are able, and indeed anxious, to identify themselves closely and actively with the problems of the Board's managers, to the extent that an increasing number of them are moving over to managerial posts after a few years as operational research scientists. One wonders whether more extensive use of graduates in this way might not be one way of overcoming the general resistance being encountered by industry in the recruitment of high quality candidates from universities.

2. O.R. as an aid to corporate planning

The first series of case studies that I would like to discuss are those concerned with marketing and strategic planning. This is work in which I have taken a particular interest, both because of its importance in relation to negotiations at policy level, but also because I initiated the work in the first place. Its origins go back to the changing market situation in the early 1960s when I was Director-General of Marketing in the National Coal Board. At that time there had been a relatively rapid change from a market where our task was primarily that of allocating the available supplies to customers in the most equitable manner, to a situation where we were in vigorous competition with other fuels which had become abundant in the international market (see Supply, Demand, Stock position in figure 2). It was clear that in order to understand and match the requirements of the situation, new methods of analysis were needed and it was at least likely that the Board's O.R. team could assist in this. However, marketing staff were under very heavy pressure trying to cope with short-term problems and had no experience to guide them in deciding how they could make use of the operational research service. From their

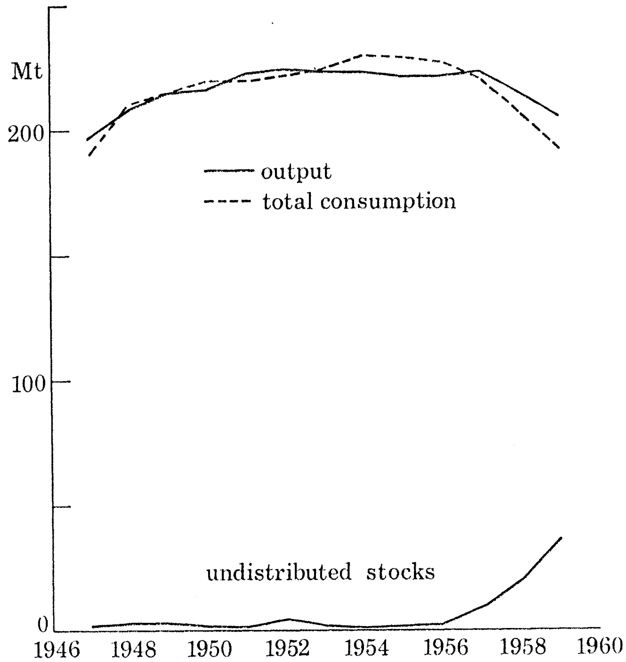

FIGURE 2.

side the O.R. team could see in general terms that the problems were suitable for O.R. attack but were unable to suggest specific problems which would yield short-term answers of immediate value to build up the confidence of the marketing staff concerned. It was decided, therefore, to establish a small team working for the Department for a period of at least twelve months on an entirely speculative basis. They were to identify and tackle problems as they found them, but the main purpose of the exercise was to ensure that by the end of that twelve months sufficient understanding had been developed on the two sides to identify those problem areas where a longer term O.R. contribution could be made. It was a piece of speculative research of the kind that progressive organizations must be prepared to make from time to time, and in this case the gamble paid off almost exactly as predicted. Within twelve months we had a firm research programme, and shortly after that a quarter of the whole of the Board's O.R. effort – admittedly a much smaller effort than is now available – was devoted to marketing problems.

The domestic market

The first major study undertaken by the O.R. team was in the domestic market in the early 1960s. There was a dramatic change in this market when competing fuels suddenly made major inroads into coal's position as the prime source of heating in homes. There were many reasons for this. One of the major reasons was the widespread introduction of smokeless zone legislation which made it illegal in specific areas to consume bituminous coal on the open grate. There were other factors: the drive towards central heating, which was supported by extremely vigorous promotional activities by the competing industries; and slum clearance, which tended to replace terraced houses with open fires by blocks of flats with central heating. Of course, we knew the general reasons for the decline in the domestic market, but we knew very little about the relative importance of the factors concerned, nor were we certain how much they were

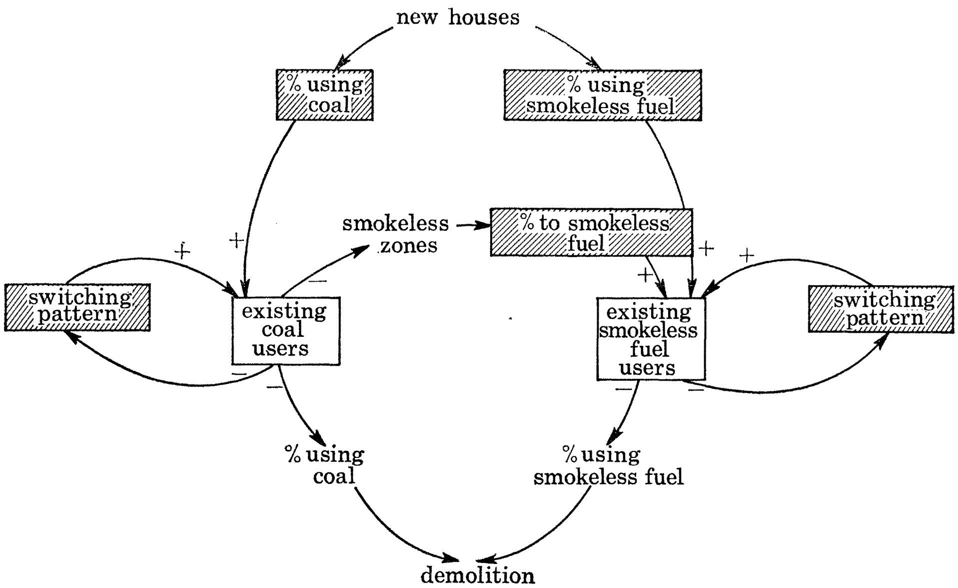

FIGURE 3. Domestic marketing 'model'.

affected by advertising. A careful analysis was needed if we were to mount a counter-attack, but the fragmentation of the market made this very difficult. At the time it consisted of about 30 million tonnes of coal a year consumed in over 13 million households, a high proportion of which received their coal from distributors who were themselves small businesses of the 'man and a cart' type. Moreover, changes in consumptions were largely the result of changes in appliances which involved a considerable capital outlay so far as the household was concerned and where there was an inevitable time-lag between advertising pressures and any decision to buy. There was little central information about forward plans with regard to new housing or smokeless zone legislation. Moreover, because of the nature of the market a large number of people were involved on the distribution side; decisions could not be taken and implemented by one man at the centre and research findings needed to be widely known and disseminated. Accordingly we set up a domestic market study team which consisted of representatives of Marketing Department, O.R., Computer Services and outside consultants. This team planned the campaign and the research and were involved in the work as it went along, so that when the time came for implementation they would have already acquired the background knowledge necessary. Attitude surveys were made, studies of appliances' sales figures carried out and surveys of Council smokeless zone intentions and other factors were incorporated into what became known as the domestic market model (figure 3). This was never in fact a single model but was rather a suite of small models enabling us to look at demand against various assumptions five years ahead and to maintain a general intelligence system based on market research as well as methods of estimating the effect of the various marketing weapons at our disposal.

Although the problems facing us in our domestic marketing are now very different from those encountered ten years ago, the domestic market model and O.R. involvement in it continues to this day.

Electricity market

In contrast with the domestic market, the electricity market is extremely integrated – in that the whole of our coal used for electricity generation (and that represents some 60% of our output) goes to one of two authorities, the Central Electricity Generating Board and the South Scotland Electricity Board. However, the fact that it is highly integrated does not mean that the generation system is easily understood – for it remains extremely complex. In 1965 when our first serious O.R. study of the electricity market was made, there were over 300 power stations supplying electricity to the general grid. The amount of electricity generated within the system varies widely through each day, with stations being continually brought on and off load. The system is operated by the C.E.G.B. according to a rationally developed merit order system and considerable use is made of computers both in analysing and controlling the overall system. In theory, therefore, the situation is ideally suited to model building. Because electricity is our major customer it is of course of vital importance to us to know the likely consequences of a variety of factors on coal demand, from the short-term consequences of the failure of a power station (which may require us to find an alternative supply point for the entire output of a colliery) to more strategic questions such as the consequence of relative price changes, or the construction of a further nuclear station. This looked to be the ideal application for a modelling approach, and in 1965 we started our first attempt at a model of the electricity market. This took some twelve months to develop and it was used in the first six months of 1967 to study half a dozen policy questions, including:

(*a*) the way that coal demand was sensitive to variations in electricity demand;
(*b*) the consequences of an overall limitation on oil burn;
(*c*) the effect of different station building programmes on coal demand.

Although this first model gave useful general indications it was found to have serious weaknesses, the main one being that although it gave a reliable picture of national demands, it did not give reliable modelling of the demand for coal from particular groups of pits. This was, of course, an expected consequence of the original design, but it was only when the model started to be used that it became clear just how important such information was. The answer lay in increasing the size of the model to allow, for example, for regional variations in demand and to give more detailed information about the capacity of some parts of the grid and coal supply systems as well as to make allowance for local variations in the control of the developing system by the C.E.G.B. These features were incorporated into the Mark II model which went into operation during 1968 (figure 4).

At this time the National Coal Board was under investigation by the National Board for Prices and Income, who were both examining a need for an immediate increase in coal prices and also undertaking a more general study of pricing policy. In the course of this work they wished to determine the effect of certain possible pricing policies and asked if they could use our electricity model as an element in their analysis. This was very useful to us in that it provided external confirmation as to the general validity of the model. Such checks on validity are hard to come by.

One interesting consequence of this was that the N.B.P.I. praised the model, but criticized us for having developed it. Surely, it was suggested, two nationalized industries need not duplicate their effort in this kind of way. This is clearly a matter of some general importance with regard to the use of models as an aid to decision making and it is worth indicating the lines of our reply. The first answer is that the C.E.G.B. did not in fact possess a model that was the 'ideal' version of our own. The purpose of a model is, after all, to assist in the solution of the problem as the decision maker sees it, and the C.E.G.B. see their problems in a different light from those of the N.C.B. They are in fact different problems. It is a dangerous assumption to believe that one model can solve all problems, and there is in fact no surer recipe for failure in model building.

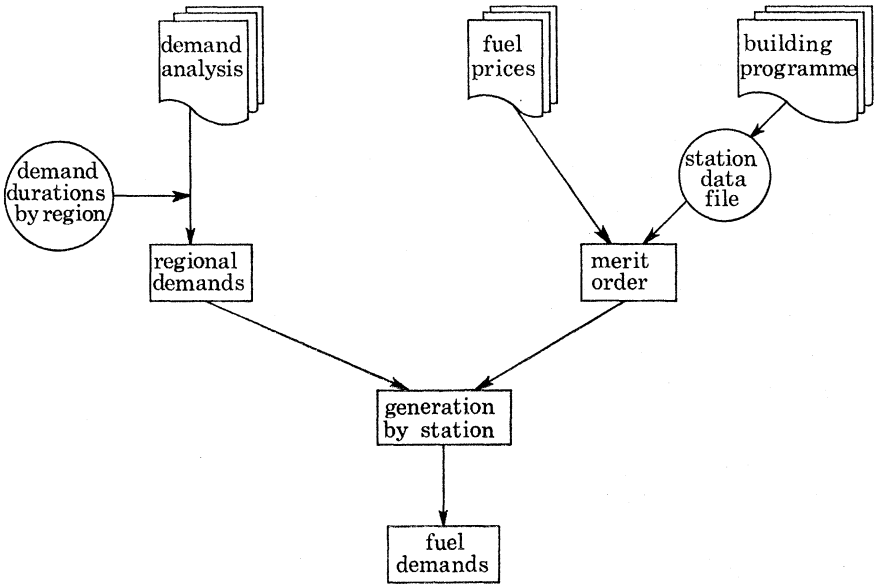

FIGURE 4. Electricity model.

The effort involved to develop a model which would have satisfied the requirements of both of us would almost certainly have been greater than that required for us each to build our own models. The second part of our answer is that what comes out of a model is very much a function not only of the data put into it, but also of the assumptions built into it. Inevitably the N.C.B. make different assumptions from the C.E.G.B. and in particular wish to explore a different range of assumptions from the C.E.G.B. For this reason again it seems better for us to go our separate ways. That there may be a strong case for a more general model I would not deny, but that would not merely look at coal and electricity, and would require the kind of central energy agency which does not currently exist in the U.K.

Following the above development, the electricity model is in continual use and indeed Mark III is now developed which differs from Mark II primarily in terms of computing efficiency. It is perhaps interesting to note that a series of runs to explore 14 alternatives which would now cost between £150–300 is less than one third of the cost of the equivalent runs with the use of Mark II. We use this model on at least a dozen major policy studies each year.

National production planning

So far I have referred only to marketing and marketing strategy. I must now come to the national planning of production. Before 1968, planning was coordinated at a national level by laying down general policy and then reacting to investment proposals from Areas. In 1968, however, a new series of national planning exercises were instituted in which each Area provided planning information about expected output, productivity and investment for each colliery. For the first time this provided us at Headquarters with the necessary raw material for consistent forward planning. The problem with such an amount of data for some 300 collieries was simply to sort out how to handle it. A planning committee was established at H.Q. with representatives from all the relevant departments, and the O.R.E. were brought in to advise on and develop programs that would sift and present the information from these n.p. exercises in a form that could be used by policy makers. Basically this was a matter of sorting and listing. On a number of occasions attempts have been made to develop optimizing programs for the n.p. information but these have never been found to be of much value to the planners. This is due partly to the inherent uncertainty associated with the data, and partly to the fact that the number of major decisions are very few. Again this system continues to the present day with O.R./systems support.

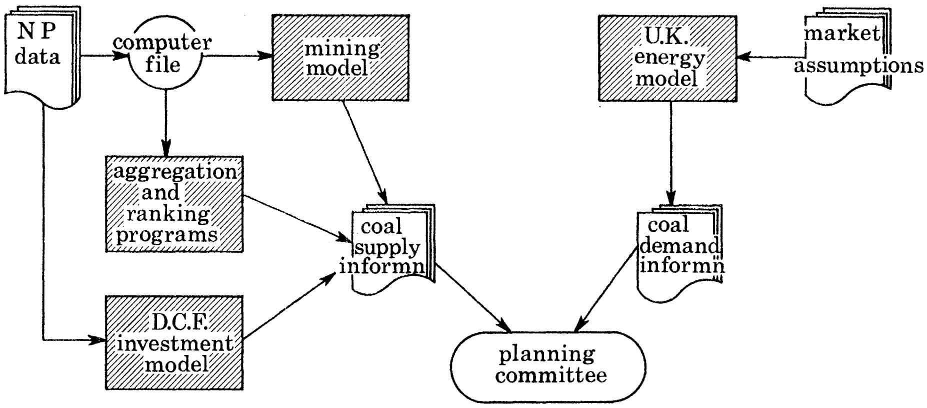

Figure 5. O.R. involvement in M.T.D.P.

Strategic model

The n.p. exercises which we have just described are purely concerned with internal planning of investment and production. However, as the energy situation in the 1970s became more and more complex, it also became necessary to develop a more systematic approach to the question of overall strategic planning. To meet this need I instituted a small Central Planning Unit (C.P.U.) in 1973 and shortly after this had been instituted we found it desirable to bring in the O.R.E. to start developing a suite of models as a background for the Unit's calculations.

It might be thought at first that this was at last the opportunity to develop a large overall optimization model. In fact, however, our previous experience of such models in connection with regional planning had left the O.R.E. with considerable doubts as to their range of applicability in the mining industry and had certainly left management with some doubts as to the validity of such models. It was therefore decided to develop a suite of simple 'what if?' models which could be used by the C.P.U. and others to do straightforward adding up calculations very quickly, but more importantly to enable alternatives to be easily explored (figure 5). There are a number of models available in different stages of development, an energy model, a mining model, a reserves data bank model, a financial model, and so on. In practice these are often used in conjunction with the major marketing models to which I have referred. These models were used in the preparation of *Plan for coal* and are now used regularly throughout the year to contrast and compare the consequences of different assumptions related to energy growth, gas availability from the North Sea, and similar problems.

It is perhaps worth pointing out that the O.R.E.'s rôle in this work is much more than just that of model builders. In order to build a satisfactory model one must do a great deal of research to structure the problem, and sometimes this research, with the understanding it develops, is as important as the model itself. Once the model has been developed there is the continual task of adapting it to new questions and new situations and then trying to understand the problems that such adaptations throw up. We find that research is continually in progress and that only half of the effort of four scientists working in this area is directly concerned with model development.

The wider scene

Inevitably as the producer of one of our indigenous sources of fuel, we find it essential to understand the complexities of the overall energy situation. The use of models as I have described them is a vital part in obtaining this understanding. This takes time as the history of our work, which can be seen on the attached sheet, shows. No doubt with our present knowledge of model building and the way in which models can be used, we could now make faster progress but not that much faster, since the real value of this work depends on the growth of mutual understanding and confidence between policy makers and model builders. Starting from scratch is inevitably a slow and sometimes painful matter.

Because we are operators on the international scene it is equally important for us to know what it being done elsewhere and indeed to be actively involved in some of this international work. In particular it may be of interest to refer to the leading part that we have taken in the study of the coal option, which is part of the energy project being undertaken at the International Institute for Applied Systems Analysis. We believe we should play our part in the development of the science as well as in the politics of the subject. It is perhaps worth recording that there is no central research body in the U.K. setting out to develop a suite of satisfactory models of the U.K. situation which would enable similar dialogue to take place at home.

3. Underground gasification of coal

The next study concerns what one might call an 'old-fashioned' piece of operational research. Although the bulk of the Board's production comes from deep-mining methods with an additional 10 million tonnes from opencast mining, we have always been aware of the need to investigate alternative methods of working. Operational research has a part to play in the evaluation and assessment of these new technologies. In these assessments there must be some evaluation of what the technical base is likely to be. This involves a survey of any past or present experiences that would be useful in estimating the technical developments of the future. Consideration must also be given to the final product, whether this be coal or some other form of energy, and its place in the market or national energy pattern. There must also be a costs comparison with other technologies that may be available to do the same job. Nor would a technology be thought worthwhile, without some other overriding consideration, in which the energy balance was comparatively poor. Environmental effects must, naturally, also be taken into consideration. Within the industry itself there lies a possible 'market' in terms of suitable seams and conditions. Finally, the assessment would highlight major obstacles that might have to be overcome before the technology could become viable or have a major effect upon the industry and would suggest the time-scale and costs of the R.&D. required to overcome these obstacles.

How then to cover all these factors? There are, in fact, a number of alternative detailed developments usually available in any broad technological grouping. Rather sophisticated techniques, such as decision trees, may therefore be thought suitable for assessing the best path for future development. However, data are normally scarce in this field and many of them subjective. Hence our view is that we only use simple models where appropriate, for instance in cost comparisons, to study the effect of varying parameters.

These applications are 'old-fashioned' in the sense that they involve the same type of approach as that of war-time O.R., i.e. a collection of such data as are available and their analysis and presentation in such a way as to make a comparison with alternatives more easy and the effect of varying parameters to be seen.

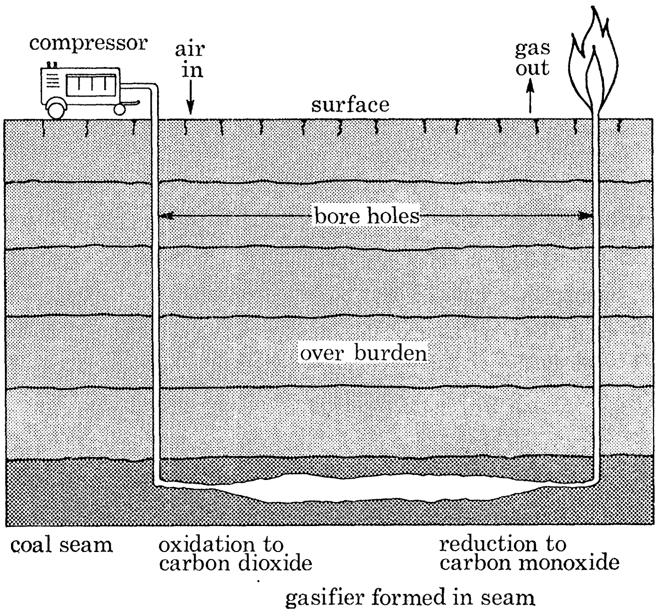

FIGURE 6. Underground gasification of coal.

Recently the Board commissioned the O.R.E. to reappraise the technique of underground gasification of coal (figure 6). We, in this country, first took an interest in the process one hundred years ago when Siemens first suggested the idea and Ramsey did some small-scale experiments just before the First World War. Work really started, however, in 1949 with trials in Worcestershire and Derbyshire. It began in the face of the post-war crisis and was abandoned in the fuel glut of 1959. It was useful experience and valuable basic data were obtained. When, in 1974, the country faced another energy shortage the Board felt it was opportune to reassess the process and decided that its purpose would be best served by carrying out a thorough paper study rather than by committing itself immediately to more costly practical work. We were, of course, aware of the world-wide resurgence of interest in underground gasification and also of the technological advances that have occurred in the drilling field since 1959.

In evaluating the process a critical view had to be taken of:

1. The technical capability of the process to supply gas at a steady rate in the quantities and qualities required.

2. The cost of the final product and its sensitivity to various cost factors.
3. The comparison of underground gasification costs with those of other energy sources.
4. The availability of suitable coal reserves and the efficiency of utilization of these reserves.
5. The potential uses of the product gas.
6. Environmental and safety effects.
7. The resource use of capital and labour.
8. The energy account in comparison with conventional mining.

Underground gasification had then to be compared with the other energy sources available to this country to see how and it if would fit into the general energy pattern.

The method adopted was to build a simple economic model of the process and to use this model to predict gas production costs based on feasible methods of operation in the suitable sets of conditions of seam thickness and depth that we hoped to discover. The model was constructed entirely on the basis of proven technology although, in the later stages, some extrapolation along likely lines of development did take place to give some indication of the way gas costs might change in the future and to suggest promising avenues of development. In building the model care had to be taken to keep it as flexible as possible so that it could accommodate the widest possible range of seam conditions and process variables.

The assessment of the prospects for the process had to be in the context of the current and future energy situation and in the light of investment that has already been made for the future. It is not really within the scope of this paper for me to go into details of the results of the assessment. Suffice it to say that the cost of the gas produced lies at the upper end of the range of energy costs available to Britain but it is not wildly expensive. It would not be competitive with conventionally mined coal and oil or natural gas in the immediate future. There are no grounds for recommending the immediate development of underground gasification in Britain. However, when our oil and natural gas reserves become depleted and we need to exploit deep-lying coal seams (below 1000 m), then the process may well have a part to play. We need, therefore, to keep it as an option for the future, to maintain a watching brief on developments in other countries, and to decide at the appropriate time whether to embark on the necessary programme of active research and development.

4. Work in a Coal Board Area

Having discussed in some detail two major fields of study concerned with policy making at headquarters, I wish to conclude with a discussion of work undertaken for management in the coalfield Areas.

Let me first say something of the way in which this Area O.R. service is organized. Each Area of the Board has allocated to it a team of two or three O.R. scientists who live and have their office within daily travelling distance of the Area office. So far as the management are concerned, the work is coordinated by one of the Deputy Directors. The formal mechanism for this is usually a meeting every three months, at which individual projects are discussed, new prospects considered and priorities agreed for the future. Informal contact is of course much more frequent than this, as is the contact with the management responsible for sponsoring each individual project. From the operational research side, the section leader reports to a Group Head who controls the work as he would for any other section in the O.R.E. He also ensures that the Area team do not work in isolation, that they consult with O.R. staff in other Areas and with those in the research sections who may have particular skills and experience relevant to a problem being tackled in the Area. Indeed, it is often convenient to hand over a problem to a research section to undertake. The work programme for the Area as a whole is reviewed on an annual basis by the Managing Director of the Operational Research Executive, who completes the double line of control by visiting the Area Director at least once a year to discuss the programme with him and to obtain his formal assent to the list of achievements.

The purpose of these arrangements is simply to provide each Area with the benefits of its own operational research service. These benefits include a close understanding of the personalities involved, and of the general background as well as the fact that the team is working on problems chosen by the people who have them. This is done, however, without losing the advantages of control and breadth of experience that can only be obtained from the large team.

By its nature this Area work is diverse, and its range can best be indicated by appendix 2, which sets out the list of achievements for one Area in 1975–6. (Although there have been some textual alterations to make the list suitable for publication, this is the complete list in the sense that it covers all the twenty-one achievements, large and small, formally approved by the Area Director and submitted to the Executive Board as part of the accountability procedures of the Executive described earlier.) Clearly it is not possible to discuss each project separately – I am not qualified so to do – but some general points are worth making.

First of all the range of problems extends from the grand to the trivial. Many would say, and indeed have said, that it is no proper task of a highly trained scientist to examine problems of parking cars at collieries, or to identify the number of contract buses to be used for workmen's travel. As a highly trained manager I do not accept this argument! Small problems are as worthy of serious consideration as large, provided, of course, that the time taken up in their consideration is not out of proportion to the potential savings. We find that there are indeed positive advantages in having our operational research team involved in studies of this kind, in that they are seen by management to be concerned with 'real' problems, not just 'interesting' ones. The matter has to be controlled, of course, and the O.R.E. use three criteria by which such projects should be judged. In the first place they must really need doing, i.e. they must relate to a problem on which management have to take a decision and do not know which decision to take. In the second place the O.R. man should never do somebody else's work. If there were someone else at hand who can do the task adequately, O.R. should not be involved. Finally the undertaking of small *ad hoc* projects should not upset the overall balance of the work. These small projects must never be seen in any sense as the main justification of the employment of an O.R. man, but in practical terms they greatly enhance his value.

The second point that I would make is that a considerable number of achievements resulted from joint studies, and particularly from joint work with the Area Method Study Branch. One of the most common questions asked about O.R. is its relation to other specialist activities and in particular whether there is any overlap. The simple answer is that some overlap does exist and where it occurs the two work together. The distinctions are sometimes difficult to define in words, but our management seldom find it difficult in practice.

A third feature of the list is the way in which many of the problems cut across formal departmental boundaries. Although individual projects are really sponsored by one of the main Departments, mining, engineering, finance, marketing, personnel, etc., it is rare that the information required for its solution derives entirely from that Department. Moreover, the solution will often depend on some knowledge of those functional skills. The interdisciplinary aspect of the work is as important here as in the work I have dealt with earlier.

Finally, I would like to point out how closely this Area work relates to the work of the research sections. Some half dozen computer packages developed by these sections were used in reaching the achievements listed; others involved consultation with the research sections and indeed some of the projects were undertaken by the research sections themselves. This point is important, because the integration of the whole O.R. activity is one of the important features of our success as we see it. The same staff work at different times on all aspects of the work and are treated alike. If any of the work *does* become routine it becomes a task for management staff. In operational research management themselves are both the scientists' laboratory and his source of data. And, so I am told, no scientist can get far without data and the ability to test his hypotheses.

There is one further thing I should say about our Area work in general, that the work programmes of the O.R. teams differ widely. I have quoted from what was perhaps the most wide ranging list of achievements for 1974–5, but I am not saying that it was the best. Each Area has its own worries, and approaches them in its own way. They carry the responsibility themselves, and that includes the decision as to where they feel they can best use O.R. In one Area the O.R. team spent virtually its whole time doing a series of careful, detailed statistical analyses to determine for the Area Director the main outlines of Area policy for the next five years and just as important, pointed out that certain apparently invidious statistical comparisons with other Areas should be ignored since they were determined by the nature of the Area, not management inadequacy. In another Area, there is no resident O.R. team but a coordinated range of studies by H.Q. research sections has been planned to look at some medium term problems which are fundamental to the Area's future. This flexibility is one of the great advantages derived from the present organization. It enables us to tackle problems as they develop by whatever means may be appropriate.

5. Conclusion

In this paper I have tried to give an idea of the way that operational research is organized in the National Coal Board, what management expects from it, and how its activities are planned and controlled to ensure that these expectations are achieved. I have touched on three very different areas of study and I should perhaps have emphasized that this choice was to some extent arbitrary. I could equally have described the work on provisioning, or on colliery exploration, or the service provided to some of the Board's ancillary companies. The details would then have been very different, but the conclusion would have been the same. The Operational Research Executive provides a scientific service to management that we find invaluable.

I am indebted to Mr L. Grainger, Board Member for Science until May 1977, and Mr R. C. Tomlinson and his colleagues, for their assistance in the presentation and preparation of this paper.

Reference (Ezra)

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Appendix 1

The O.R.E. Research Programme 1976/7 (excluding work for Areas, C.P.L. and consultancy)

Mining

Colliery model. To develop the colliery model used on Staff College courses, as a tool for colliery planners.

Size of mine. To examine the influence of a range of factors in determining the best size of a new mine or colliery extension.

Exploration. To assist in the allocation of rigs, investigate the value of seismic exploration and help in the design of exploration strategies.

Development. To investigate factors affecting rates of advance, to develop improved control rules, and to assist in planning development strategies at particular collieries.

Underground transport of coal. To maintain and develop the Simbelt, Simloc and Simbunk programs, and to study cost-efficiency in design of transport systems.

Materials transport. To extend the existing work on a cost-breakdown of transport systems, to include problems of management and design.

Coal preparation. To continue the development of improved cost models of coal preparation plants, and to undertake studies of blending systems and automatic control.

Monitoring and control. To assist M.R.D.E. in their installation of control computers at pits, to provide a systems service for those pits, and to assess the results.

Assistance for M.R.D.E. To provide a general O.R. service for M.R.D.E. with particular reference to the assessment of future requirements and the problems of systems reliability.

Marketing

Domestic market. To provide a general service, with particular reference to forecasting demand and the problems of promotional policy.

Electricity market. To maintain computer models of the electricity generating system and to use them in the study of policy issues.

Coking market. To maintain the coking model and to examine the problems of matching supply and demand in the future.

Pricing and market planning. To assist in developing price systems which improve the Board's marketing position while meeting its revenue objectives, and to coordinate long-term market planning.

Surface transport. To study 'merry-go-round' train systems, the supply of railway wagons, future transport requirements and the rationalization of transport facilities.

Regional marketing. To coordinate marketing studies which cut across Area boundaries.

Materials and equipment

Purchasing. To assist with the evaluation of annual tenders for major contracts and to provide a general O.R. service.

Stores. To assist in the development and assessment of the automatic provisioning system.

Regional provisioning committees. To provide a service to R.P.Cs, particularly in connection with the establishment of service exchange systems and with the improved utilization of equipment.

Workshops. To study problems of forecasting, and to develop improved indices of performance.

Plant pools. To develop improved methods of allocating plant.

Opencast mining

To provide a general service to the Opencast Executive, particularly in quantitative statistical research and in developing computerized aids for site planning and budgeting.

Personnel

Conditions of service. To investigate problems associated with overtime and holidays.

Craftsmen. To explore the future requirements and availability of craftsmen.

Behavioural studies. To examine problems of supervision and communication at collieries and workshops.

Manpower planning. To improve the existing Manplan programs, and to assist in problems of manpower supply at new and expanding collieries.

Corporate modelling

Strategic planning. To develop the existing models and assist the Central Planning Unit in their application to problems of national policy. To maintain contact with other institutions undertaking modelling work in the energy field.

Financial modelling. To assist in the development of the general budget system, and to collaborate in producing appropriate Headquarters financial models.

Technical assessment

Coal utilization and conversion. To continue studies associated with the long-term use of fluidized beds and the appropriate production and use of different forms of energy, including substitute fuels and hot water.

Scientific control. To undertake studies as required, particularly in connection with underground fires and other aspects of safety.

Appendix 2. O.R.E. achievements in an N.C.B. area in 1975–6

1. A study was carried out to determine whether to keep open a slurry burning power station providing power to a grid serving eight collieries following a series of breakdowns in 1974–5 resulting in a financial loss. Although the power station would continue to make a loss on paper, its closure would in fact have cost the Area £50 000 p.a. It will remain open.

2. The O.R.E. team were appointed to the Area Energy Conservation Committee, whose remit was to achieve a 5% reduction in fuel costs in 1975–6. Their main rôle was to collate figures concerning energy consumption and devise methods of measuring savings. By use of relations derived from this analysis, fuel consumption at collieries and other activities was monitored and scope for savings highlighted. The Area achieved the savings required of £500 000 p.a.

3. A study was made of the economics of extending a computerized planned maintenance system currently in operation at two collieries to the whole Area. This would have cost £100 000 to implement and additional computing costs would have been £120 000 p.a. The derived benefits would not justify this level of expenditure and the system will not be extended.

4. A study was made of the future requirements for washery capacity for both deep mined and opencast coal in one part of the Area by using two possible sets of future production figures

covering the next five years. A number of plans were considered, the best of which showed estimated savings of £400000. The technical feasibility of this proposal is now being considered in detail.

5. A general study has been carried out to assess the impact on Area internal railborne traffic of British Rail policy to cut their conventional fleet of mineral wagons. A number of schemes for reducing dependence on an external supply of wagons were examined. One of these showed that the introduction of rapid loading facilities at one colliery would result in some 100 wagons being saved and a reduction of £40000 p.a. in running costs.

6. Assistance has been given in operating a computerized network package for the control of a major reconstruction. The network has been recast in response to changes so that the desired completion date can be achieved.

7. A joint exercise with Method Study was undertaken to examine the coal clearance requirements at the same major reconstruction. It was shown that the planned facilities should be satisfactory subject to certain conditions, which were identified.

8. The cost of conveying coal by two alternative routes through a new area of workings at colliery B was compared. It was shown that up to £150000 capital expenditure on safety equipment would avoid additional running costs of £55000 p.a. on a longer route through old workings. These figures have been incorporated into the planning proposal.

9. At colliery C the use of O.R.E. coal clearance computer programs made it possible to show that siting a large 750 tonne central bunker at pit bottom would allow a saving of £185000 over the distributed bunkerage initially planned. It was also proposed that a mini-computer system developed at the Board's Mining Research and Development Establishment should be installed. These recommendations were accepted by the Area.

10. Following a proposal to open up substantial new reserves at colliery D, studies were undertaken to determine the cost of using the existing shafts as opposed to a new drift. Recommendations were made and accepted but they were overtaken by other planning changes.

11. A study was undertaken to assess the alternative sites for a new large central washery. The results are being incorporated in planning proposals.

12. A survey of new recruits was carried out to establish what had prompted their applications. We obtained a number of interesting results without, however, being able to draw concrete conclusions regarding the effectiveness of the different advertising media.

13. The O.R.E. manpower planning computer model, Manplan, was used to study the age structure of officials over the next five years at each colliery and in the Area as a whole. The number of new officials that would have to be recruited was also identified.

14. A joint study was undertaken with the training officer at colliery E to examine the use of contract buses for conveying workmen to and from the pit. It was shown that the number of buses could be reduced from 5 to 4 with virtually no change in the service given to the men. The scheme will be implemented with an annual saving of £5000.

15. Assistance was given in implementing a computerized budgeting system which had been developed jointly by the O.R.E. and the Board's computer service. It was used satisfactorily on part of the year's budgeting process and showed that the system allowed for greater scrutiny of input figures by Finance Department and provided more flexibility of response to changes requested by Headquarters.

16. A study was undertaken into the methods of allocating proceeds back from a central washery to the supplying collieries which seemed to be operating unfairly. A test wash and

weighing was designed by O.R.E. and carried out at the washery. Following this a new system of allocating proceeds has been devised and is currently under consideration.

17. The method of dirt disposal at colliery F is by an aerial ropeway to the tip 2.5 km from the pit. This tip has only a limited life and a joint exercise with Method Study Branch showed that alternatives could increase the cost of dirt disposal by 50%. However, an alternative generated by the study showed that it would be possible to extend the life of the existing tip by eight years with a small capital outlay. This alternative has now been adopted by colliery management.

18. A joint exercise with Method Study Branch into the congestion at the entrance/exit to colliery G recommended that the only practical means of eliminating the congestion was by the provision of extra parking facilities and the construction of a one-way system through the colliery.

19. A study of the bunker requirements at a colliery following a reorganization scheme showed that an extra £120000 spent on bunkerage could allow additional output valued at £900000 to be cleared.

20. A number of joint exercises with Method Study Branch have been undertaken to determine changes and improvements in coal clearance systems at collieries. The O.R.E. Simbelt programs were employed, with Method Study providing the data and O.R. assisting with the computer input and interpretation of the results.

21. A computer-based model was developed in 1974 to enable the Area rapidly to evaluate the financial and physical implications of different long term strategies. This year the model has been thoroughly tested, its running time improved, and it has been decided to examine the consequences of one future production pattern in the Area.

Appendix 3. A selection of the achievements of the Operational Research Executive for headquarters sponsors 1975–6

1. Area staff used the Simbelt and related programs (developed to examine belt and bunker capacities in underground conveying systems) over 200 times during the year, in the course of applications at about 50 collieries.

2. Simbunk 1 (a program written to study control problems at collieries) was applied at eleven collieries, in eight cases by Area staff with O.R.E. assistance. The results of these studies indicated gains of the order of 2% in R.O.M. capacity through introducing a bunker control scheme.

3. Program writing was completed on the main simulation block of Simbunk 2, an improved version of Simbunk 1. The program input and output blocks were written jointly by O.R.E. and Compower. Preliminary testing of the blocks was completed.

4. A short study was made at one colliery into the costs of alternative belt/bunker systems for dealing with fluctuations in production flows. The results indicated that a large capacity belt system would cost some £20000 p.a. less than the inbye bunker system proposed at this colliery. The study showed that further research was worthwhile in this field.

5. A comprehensive computer system has been implemented which monitors the deep-drilling rigs and produces rig drilling schedules and barcharts for Areas, and methods have been developed for estimating the costs of drilling various boreholes by different rig contractors. This project has enabled HQ to improve coordination on a national basis of the increasing Area and HQ drilling requirements.

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6. A computerized training exercise incorporating the interactions between the important underground activities at a hypothetical colliery, 'Dukeswood', was used successfully on the Mining Management course held at Chalfont in November 1975. The exercise is to be used without major changes on future mining management courses. The experience gained in developing this model of a hypothetical pit is now being used in the development of a general colliery model, and trial applications at two collieries have begun.

7. Simprep (a computer program developed to explore the design of coal preparation plants) has been maintained and used on ten projects in Areas in the last year.

8. Progress on all O.R.E. provisioning studies was regularly reported to the Headquarters Coordinating Group for Provisioning, and a revised report giving recommendations on purchase, maintenance and overhaul of surface mobile plant was circulated to Area Directors for action.

9. A study was carried out to help with the setting up of a service exchange scheme for the majority of certain capital items for the whole of one Coal Board region. Recommendations were made to each Area on the purchases required to set up regional and Area pools. Implementation of the scheme should be completed by September 1976.

10. We were asked to carry out an examination of the system by which the Board appraises Areas' plant purchase programmes. Our recommendation was implemented and we were involved in the Headquarters' meeting with Areas in which the information was appraised.

11. The O.R.E. have continued to assist Stores Branch in the development of automatic provisioning methods. Further work has been carried out on the development of the cyclic review provisioning system, which is being introduced to allow for provisioning on a national basis.

12. As last year our computer programs were used to assist Purchasing Branch in the evaluation of certain annual tenders. The programs worked satisfactorily in every case and the O.R.E. were represented on the three main tender panels. Savings can only be assessed directly where contracts are ordered on an item basis, and are up to 2% of the contract value.

13. Use of the colliery manpower planning model has continued in two Areas.

14. A study of craft requirements in one Area has yielded guidelines. These will be tested and refined in another Area.

15. In two Regions of the Board, work has developed on behavioural studies and experiments at Workshops. Assistance has been given with courses for Workshops staff, and attitude surveys have been completed at four Workshops.

16. A six-year demand forecast for domestic solid fuel was produced; this was based upon survey data from March 1975 and was similar to previous forecasts in its analysis.

17. The computer simulation model of the C.E.G.B. operating system has continued to be extensively used on a widening range of problems. During the year the model was used to assess the effects of price rises on the coal-burn in 1976–7 and 1977–8, to examine the implications of different electricity sales growths over the next ten years and to indicate likely regional demands for the matching exercise carried out by Marketing Department.

18. A specific exercise aimed at examining the problems in one Coal Board Area was undertaken for Marketing Department. The dependence of the Area on the resolution of the problems at a particular power station was analysed and the implications in terms of the stocking over the next two years identified.

19. Further development of the computer model of the demand for coking coal has taken

place, incorporating a revised data base and the results of the analysis of the demand for Iron and Steel.

20. Working in close cooperation with the Marketing Department we have produced a system which highlights by region the likely surpluses and deficits of individual coal types five and ten years into the future. The first run of the system was undertaken in the autumn. It was generally agreed that the basic approach was right and the exercise should be repeated annually.

21. A study was carried out of the movement of electricity coal in one region to power stations via 'merry-go-round' trains. Linear programming techniques were used to derive guidelines for coal flows which made the most efficient use of the system and to quantify in terms of reduced coal deliveries the effect of various restrictions. The results were of use in N.C.B. negotiations with B.R. and the C.E.G.B.

22. A study was made of the competitiveness of transporting energy in the form of coal, which entails transport costs, or electricity, which involves transmission losses. This has relevance to the economics of siting new power stations.

23. A 'general budget system' has been developed to provide a standard computer package for budget calculations while maintaining adequate flexibility to cope with individual Area's needs for specific calculation and output. The system was tested in the preparation of 1976–7 budgets for each Area, and will be refined and developed in the coming year.

24. The economics of generating electricity in fluidized bed power stations has been re-assessed and compared with pulverized fuel generation for a variety of conditions. Savings in energy costs (through a higher conversion factor and reduction of coal washing) mean that fluidized bed stations generate more cheaply than pulverized fuel stations in most circumstances. A model to perform the necessary calculations is being kept available, so that the situation can be regularly reviewed with minimum effort.

25. A major study assessing underground gasification was undertaken by a joint team in which O.R.E. staff occupied leading rôles. The results of the study were presented to the Board who accepted the recommendations.

26. In partnership with P.A.D.B., substantial progress has been made in producing a mathematical model of the spread of fires in underground roadways and of the influence of ventilation and roadway size and linings on a fire.

27. The existing interactive models of energy and mining have been maintained and run for the Central Planning Unit as requested. C.P.U. have made frequent use of the energy model in their consideration of alternative possibilities in the energy economy. The flexibility of the model has been demonstrated by its use for runs for Scotland and the use of the model has been extended up to the year 2000.

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