Productivity in electricity generation and supply

PRODUCTIVITY IN ELECTRICITY GENERATION AND SUPPLY

BY

A. BRADSHAW, C.ENG., M.I.MECH.E., A.M.B.I.M.

SUPERVISOR:

M. J. SARGEAUNT, M.A., C.ENG., M.I.E.E., F.I.PROD.E.

SUBMITTED FOR THE AWARD OF MASTER OF SCIENCE

OF LOUGHBOROUGH UNIVERSITY OF TECHNOLOGY

NOVEMBER 1976

ACKNOWLEDGEMENTS

The author wishes to thank Mr. M. J. Sargeaunt for his valuable advice and assistance in the supervision of this project, and colleagues of the Central Electricity Generating Board who have helped by providing references and supporting information for this research.

SUMMARY

The generation of electricity to meet demand at economic cost depends upon the number, quality and effective utilisation of people involved in the processes. Manpower in this industry is divided into industrial, administrative, technical and managerial sections and one of the objectives of this project is to consider methods of assessing optimum levels of staffing within each section, necessary to achieve economic electricity supply.

By comparing actual manning levels, against levels predicted by the methods developed in this project, a measure of relative productivity can be achieved.

The methods have been developed to find relationships between the technical factors which determine the manning patterns, and the performances achieved which are dependant on efficient utilisation of manpower at all levels.

Methods of forecasting manpower requirements are also considered in this project, which are based on future predictions of plant mix and performance, and electricity demand.

Similar methods could be applied to forecasting other resource requirements in the generation and supply of electricity to enable realistic predictions to be made for use in corporate planning at national or regional levels.

C O N T E N T S

CONTENTS

PAGE

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES CONTINUED

LIST OF TABLES CONTINUED

1. INTRODUCTION

1. INTRODUCTION

The Electricity Supply Industry of England and Wales comprises, with the exception of the Russian industry, the largest interconnected electricity system in the World.

Since the early fifties the writer has been employed within the industry. During this period the standard size of generating units has risen from 30 MW to 660 MW, with attendant benefits of economies of scale. Thermal efficiencies have risen from an average of 21% to 31.5%, with the most efficient generating units achieving 36.0%. Installed capacity has risen from 22,343 MW in 1958 to 58,523 MW in 1975.

Over the past twenty five years the generating plant of the electricity supply industry of England and Wales has developed from a state of being manually operated and locally controlled to central automatic control and operation and in some cases to computer controlled operation.

Following early commissioning problems with the 500 MW and 660 MW generating units, the "availabilities" of these units have risen appreciably. In 1975 the 47 units of these outputs installed in 13 (7.7%) power stations produced 43.8% of the electricity generated by the C.E.G.B.. The length of time taken to achieve a satisfactory "availability" for this size of generating unit is generally in excess of five years and follows similar experiences of the American Industry.

In 1964, as a condition for an annual wage rise, government policy required a work measurement exercise to be introduced for the industrial staff. By the early seventies the majority of industrial staff had been integrated onto a pay and productivity scheme and manning levels had fallen in the United Kingdom industry during the late sixties and early seventies by approximately 51,000 or 35.8%. During the early seventies administrative staff were subject to a clerical work measurement exercise, only the technical and scientific staffs have yet to be the subject of any type of measurement or productivity scheme. A job evaluation exercise is being formulated at the time of writing, by the Boards and the Electrical Power Engineers' Association, the Union representing the technical and scientific staffs.

When research for this project was commenced, in late 1973, there appeared to be virtually no international comparisons or national comparisons, of performance of the electricity supply industry available.

One international comparison of generating costs and thermal efficiencies had been published, in which it was stated that a true comparison and analysis of the results had not been made, due to the problems of measuring the effects of several variables. Variations in age of plant, types of firing, proportions of hydro power between countries, were quoted as factors which made a true comparison difficult. The recently published Plowden Committee of Inquiry Report quoted comparisons of thermal efficiencies in a manner similar to that of the international comparison mentioned above. The Report also stated that although the Electricity Council and C.E.G.B. prepared memoranda summarising information available to them, they had not presented a reasoned appraisal of the industry's performance, or showed that they made systematic and regular comparisons of their performance.

In addition to involvement in operation and commissioning of generating plant, the writer had been instrumental in preparing and implementing the Pay and Productivity Scheme at a major power station. An interest in manpower productivity and industrial performance stimulated the writer to investigate manpower productivity methods of assessing the performance of electricity supply industries.

Several variables were considered in assessing thermal efficiency and manpower levels. Typical of these variables were age of plant, thermal efficiency, utilisation, generating unit size and station capacity.

In considering these variables it is necessary to find relationships and effects of them on manpower levels and thermal efficiency. There is a degree of inter-relationship between for example utilisation and thermal efficiency. It is a policy of the C.E.G.B. that generating plant is loaded preferentially on a cost basis. The cost of generation is closely allied to thermal efficiency, fuel cost etc. Therefore it is clear that plant with higher thermal efficiency will have a higher utilisation. However, high utilisation demands a high maintenance commitment, and the consistent achievement of a high thermal efficiency similarly demands a high maintenance commitment. This situation is also affected by another variable, the age of the plant. Age has an affect on thermal efficiency and manning levels. In addition to improvements in plant design, layout and control over the years, as plant ages the effects of erosion, vibration and corrosion require an increasing maintenance commitment to achieve high thermal efficiency and utilisation levels.

By taking into account the effects of variables, comparisons of actual and calculated thermal efficiency and manpower levels can indicate the relative productivity of one industry or management unit compared with another. This project assesses methods of comparing the relative productivity of electricity supply undertakings, whether nationally or internationally. In conjunction with absolute productivity, in terms of, for example, added value per employee, the relative productivity values could be used to measure the performance of each industry.

When relationships and effects of the variables on manpower or other resource levels have been found, then by fixing values to the variables, forecasts of manning and resource requirements can be made. Fixing values to these variables based on forecasts for the future, by simulation of predicted values, resource requirements can be assessed for the period being considered. Forecasting resource requirements for electricity supply industries can be carried out by simulating the future patterns and values of variables in mathematical models for working out by digital computers. The opportunity to study the application of digital computers, using mathematical models, as an aid to management decision making and control, was another aspect on which the writer desired to gain experience.

2. PLANNING AND FORECASTING IN ELECTRICITY DEMAND AND SUPPLY

2. PLANNING AND FORECASTING IN ELECTRICITY DEMAND AND SUPPLY

An indication of the present extent of planning and forecasting in electricity supply is given by the wide range of titles in the References Section. It will be observed that at the macro level papers have been published by several countries, whereas very little work appears to have been published at micro level. At macro level much of the published work concerns methods of forecasting future demands for electricity.

National energy models using econometric models as a tool for forecasting,and for planning the whole of energy economics, are used by Countries of the European Economic Community, Norway, Canada, Sweden, Australia, Austria, U.S.A., U.S.S.R., Poland, Czechoslovakia etc.. These models are based on growth trends in the economy, investment, population, productivity, industrialisation and urbanisation. Other factors are taken into account, such as market share of various forms of energy and particular needs of the major final consumers e.g. steel, aluminium, transport etc..

As Wood (2) points out, use may be made of economy based techniques demonstrating logical relationships between economic factors in the business environment and energy requirements. They are based on input/output models which are national or regional forecasts of industry by industry requirements (input) to produce goods or services (output). The corporate model concept places the emphasis on planning for future growth and operation of an entire corporate entity, rather than of a specific portion of the system. Corporate models contain economic, engineering, financial and management sub-system models, all simultaneously interacting. Each model includes considerations of expected volumes of business, corporate, revenues, production costs and operating expenses. Forecasts or models are made on the needs and expenditure to provide increased facilities to meet the expected product demand.

A block diagram of what Wood (2) illustrates to be a typical United States utility corporate model is shown in Fig. 1. This form of model is a collection of the major sub-system models. As an example, due to the high degree of investment in plant, the plant requirements sector of the model include considerations of plant growth, plant shut downs, depreciation and construction. The financial model sector incorporates considerations of financial planning, accounting and cash flow, financing and management policies. The model control sector incorporates the logic required to control the use of the model for studying specific problem areas.

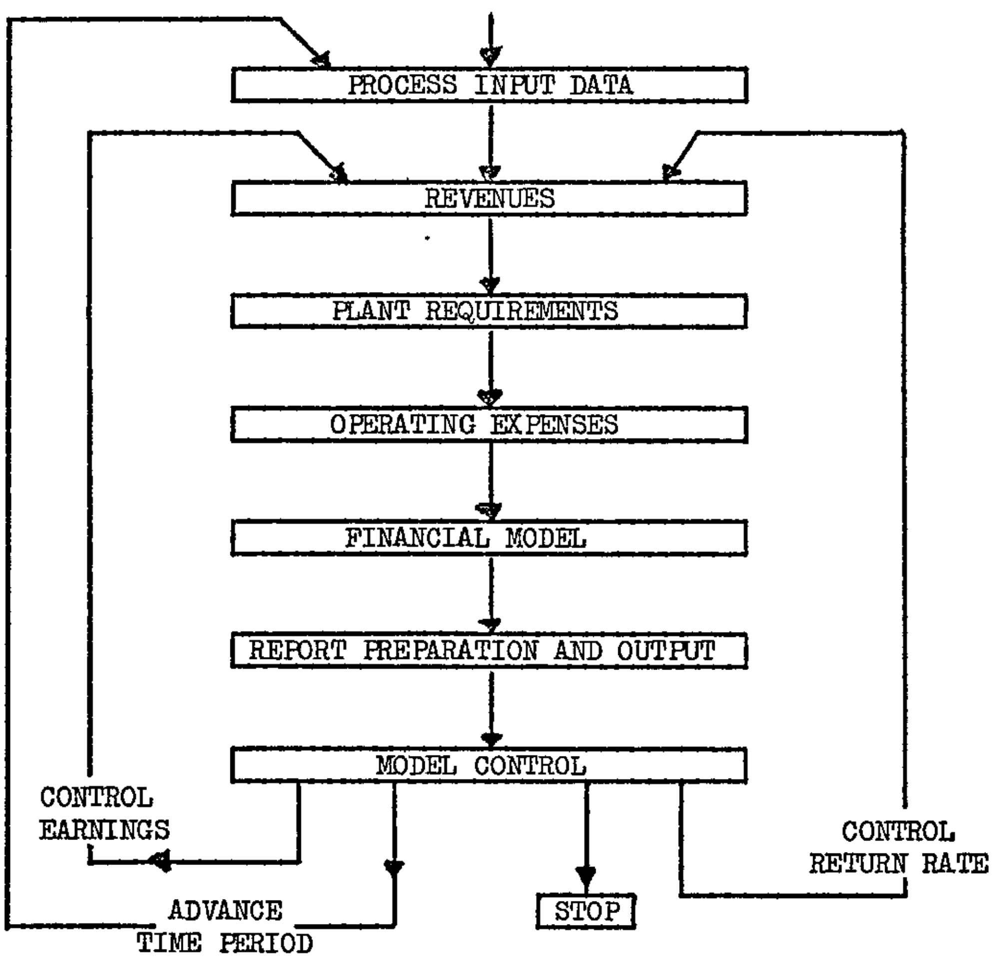


Fig. 1 - General Structure of a Utility Corporate Model

A number of electric utilities have developed corporate or financial models, the current emphasis being on the financial aspects, in some cases the models exclude production costing and models of future construction.

Rydbeck and Figley (10) show that models are used for planning and analysis of the economic and financial effects of alternative physical expansion plans and for studying the effects of possible changes in the technical or business environment in which the utility operates. In some cases the models help studies of the effects of optimisation procedures. In other cases they allow analysis of the potential effects of management policy changes before they are implemented.

In short term or long term planning of system expansion, one of the most important aspects is the selection of appropriate objectives on which to base a decision. Wherever planning is carried out in engineering, systems engineering, business and government, specific value measures have developed the general link for all values at macro-level being economic. One American Electricity supply utility uses measures based on the expected present value of the revenues required to support a given plan, and the annual net income (or net revenue) pattern resulting from the selection of a given plan. The first measure being economic, the second financial.

Wood (2) informs us that a fundamental part of the overall planning problem is the multiplicity of value functions. By using them the corporate model offers in the case of a utility, the chance to analyse and forecast both revenue requirements and the effects on net income of various choices.

When the utility is viewed as a corporate entity in terms of cash flows associated with its operation, see Fig. 2, the revenue required from the utility customers is shown at one end of the pipeline and the disposition of these funds at the other.

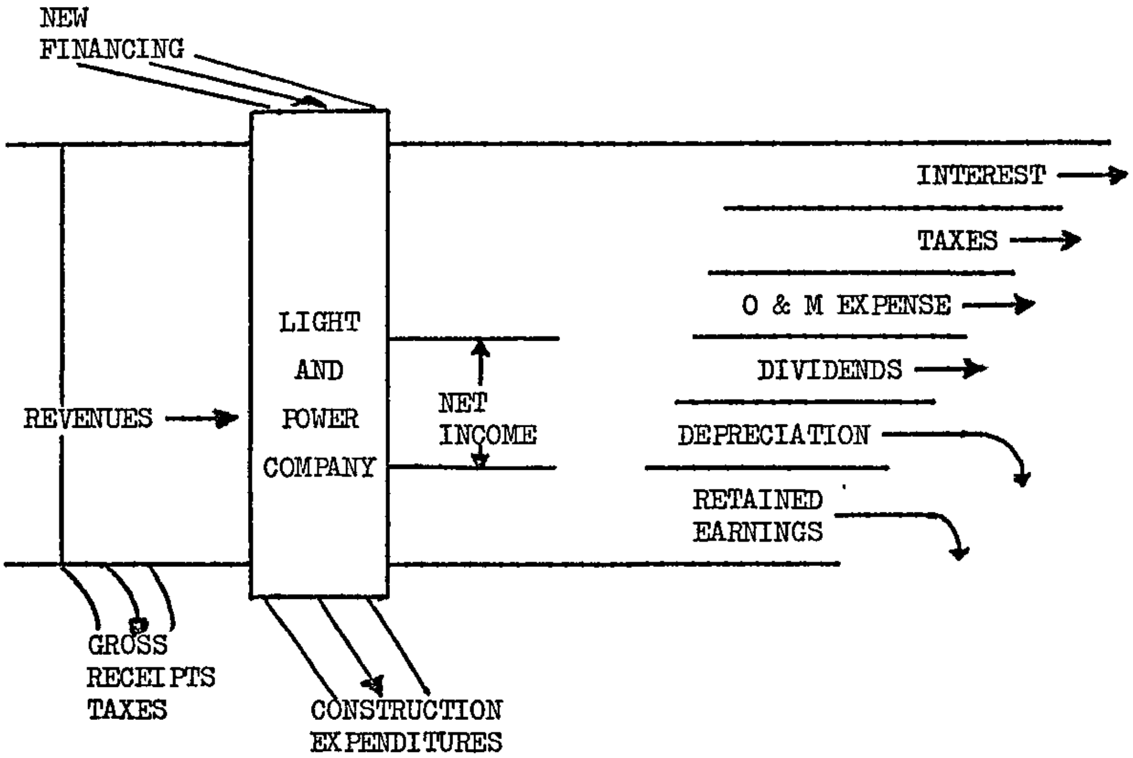


Fig. 2 - Cash Flow for an Electric Utility

The model may be developed to forecast resultant net income for a given set of alternative plans and fixed revenue patterns, or it may be employed to develop the required revenues for a set of plans on the basis of holding a given pattern of net income or percentage return on net investment. It offers the flexibility to incorporate consideration of new measures if they develop and treats the economic and financial aspects together.

Wood (2) also shows another example of a corporate planning model in this case a financial model and programme for comparing results for an American utility. This model produces standard financial statements as output and is based on a yearly interval.

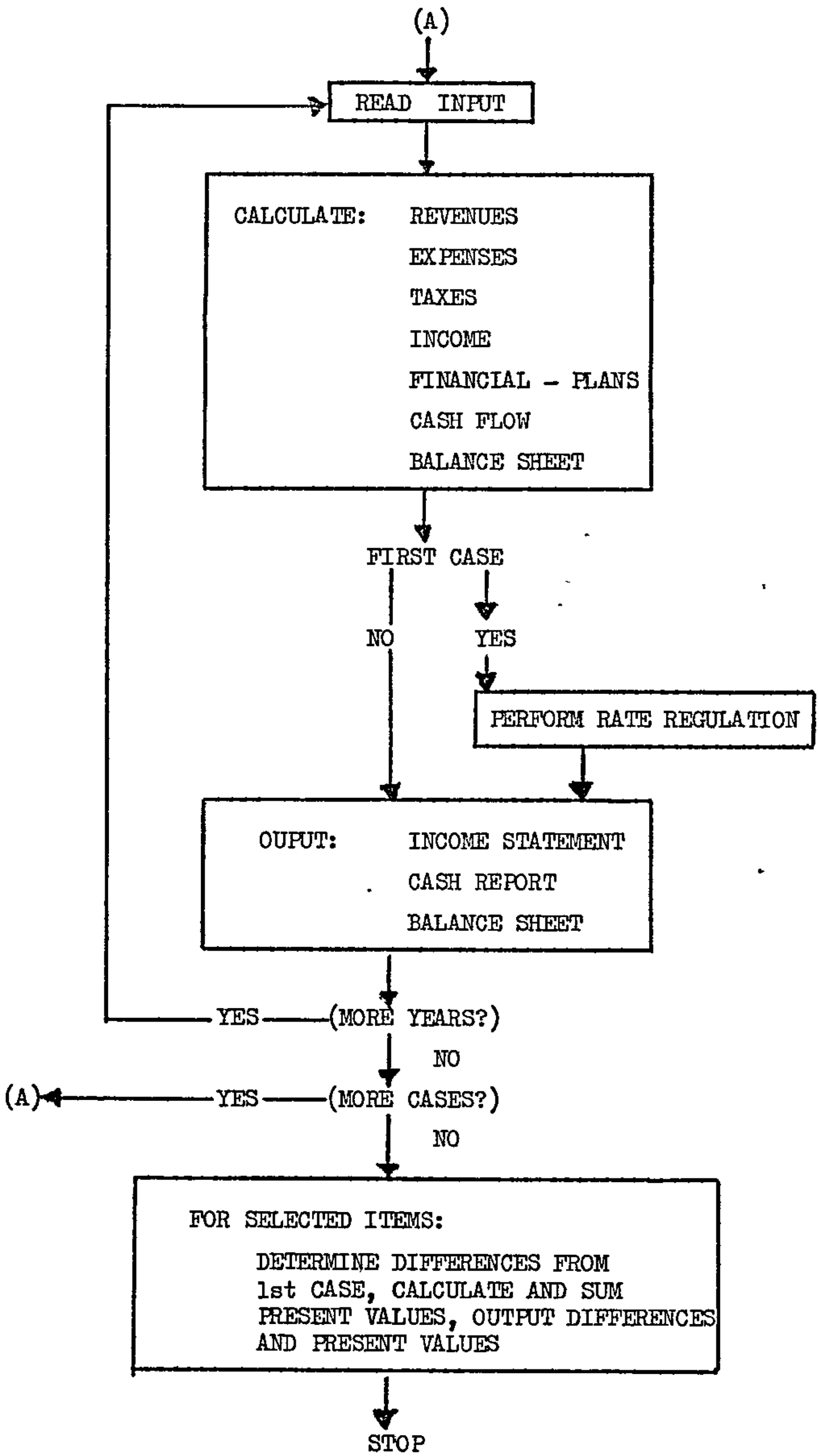


Fig. 3 - U.S. Utility Corporate Model Programme (2)

It may be used to compute financing needs and the resultant net income, or it may be used to find the revenues required for a particular plan with the financial performance of the utility being used as a constraint. When financial value measures are being examined the programme uses the same revenue pattern for all alternatives. Alternatively, when revenue requirements are being evaluated the financial constraint will be used in alternatives. The final output is a sequence of year by year comparisons of income for each alternative, plus a final, present value comparative analysis of the income statement. This model has potential for use in studying corporate policies and in system planning evaluations. One generation planning problem covers the merits, economic and financial, of the retirement of older generating plant. Another example of the use of such a model is to examine the effect of adopting a policy of self-financing of capital expenditure from income. The actual question is what will be the effect on revenues if the utility changes from financing construction expenditure by loans, to a policy where say half the future capital requirements for construction are financed from revenue.

Other utilities used planning models which show the effects on profits, or revenues of energy conservation, or higher interest rates, or higher costs of labour and/or equipment or of excess plant or new antipollution legislation.

Common to many national electricity supply industries (see references.) are models for finding the optimum allocations of generating plant, nationwide, to achieve the maximum overall economy of supply. The basic approach is to forecast, for various future periods, the evolution of the optimum structure of electricity generating plant and its distribution in the main national regions. From these forecasts investment programmes are compiled, including the divisions of energy sources for generation; hydro, coal, oil and nuclear. In itself the field of energy resource allocation and fuel mix is an extremely important aspect of planning. It appears that many countries have strategic models aimed at optimising energy resources. At macro level it has been shown(2) that econometric forecasting and prediction is widely practised, and documented. The implications of industry wide plans result in planning and decision making at lower levels to ensure that resources such as new generating plant, materials, fuel and manpower are available to dovetail into the overall plan. To highlight one aspect, the output of generating units has to be forecast for the foreseeable future.

Depending on the size of units will be the number of new sites required to meet a particular electricity demand. Booth and Dore (12) show that generating unit capacity depends on technical considerations and predicted availabilities, which will be assessed by the manufacturers of such plant. It may be that limitations can be overcome in other ways, for example, the transportation limit of 200 tons may be overcome by prefabrication, on site assembly or new transportation methods e.g. air cushion vehicles.

Forecasting models described so far have been applied at the national or industry level, to optimise output of electricity by considering how factors will affect demand and costs over the medium and long terms.

Within the operations of electricity supply industries, mathematical models and computers are used for optimising economic performance. The C.E.G.B. utilises computer operated models for optimising the use of generating units, to generate at the cheapest unit cost. This system of models operates to the concept that the cheapest fuel is burned by the most efficient generating units to produce the cheapest electricity for a predicted demand.

Tables are arranged so that the generating unit which produces the cheapest electricity heads the table, the next cheapest following and so on, hence the title Order of Merit.

Predictions are very much for the short term. The computer runs are carried out approximately four weeks before the new generating plant order of merit tables come into force and are for one month's duration. An Order of Merit Table then details the costs of heat and fuel and electricity produced by each individual generating unit in part of a Region, similar tables are produced nationally.

Four programmes from the suite find the cheapest combination of power station plant and fuel supply to meet the demand for electricity are shown in Fig. 4.

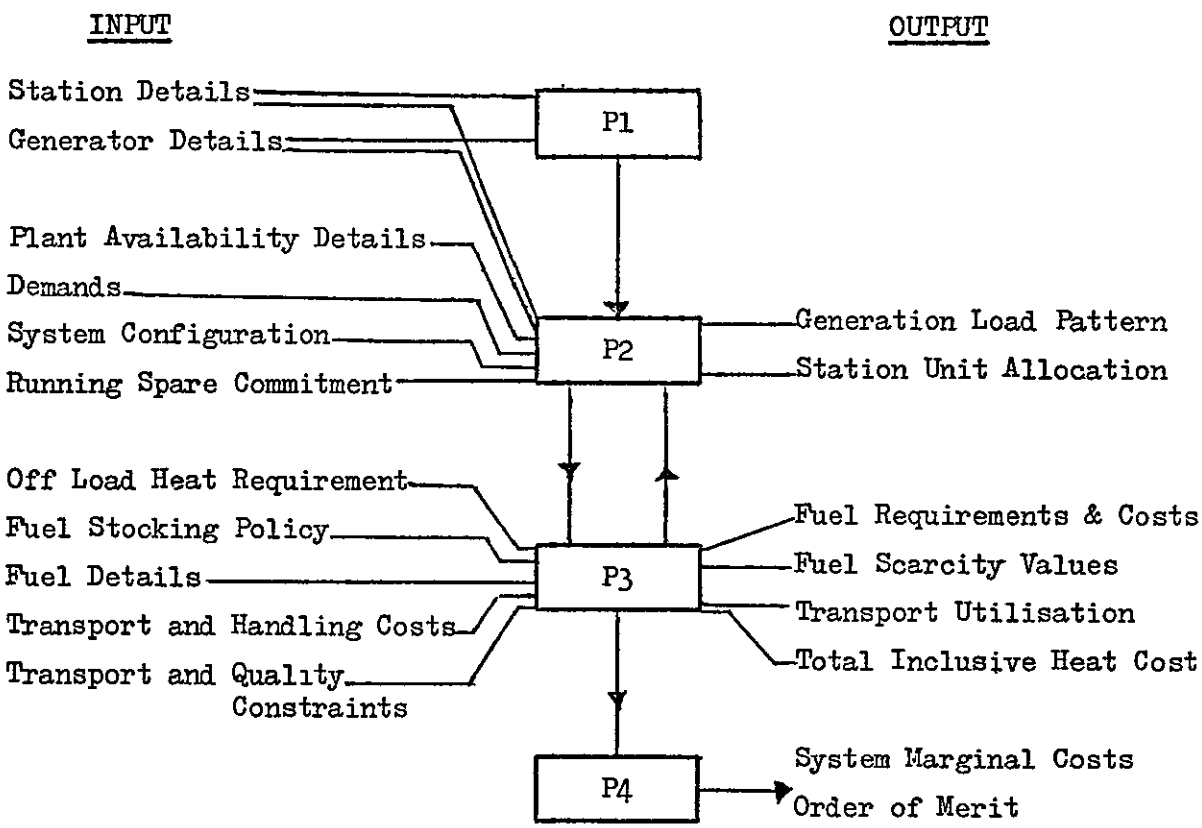


Fig. 4 - System Marginal Cost Suite

The derivation of the system marginal costs of heat for each station requires a number of iterations around the cycle of calculations as seen in Fig. 5.

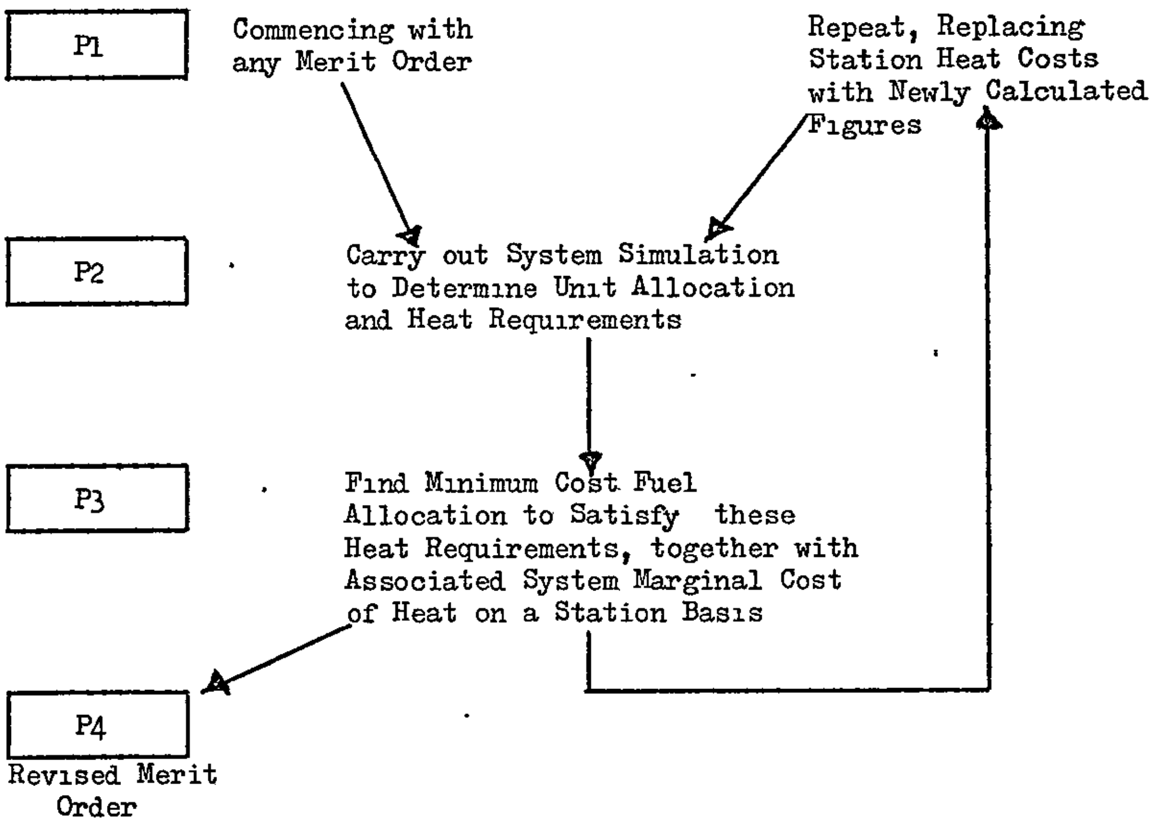


Fig. 5 - Iterative Process

As the number of iterations increases, the solution converges towards the minimum overall cost solution. The product of the station heat costs, when multiplied by the overall heat rates for each set, is then used as the basis for the merit order costs, based on system marginal costing.

It has been shown that a great deal of forecasting and planning is carried out at macro level and within the electricity supply industry forecasting energy demands and the cheapest way of meeting them is achieved using computers and models. This forecasting is done throughout the time spectrum, from the following month, to the next five years. No publications or other written documentation has manifested itself showing the use of statistical analysis based mathematical models which can be used to forecast resource requirements for the future within the electricity supply industry, at regional level for example. It is also apparent that mathematical methods for comparing the resource requirements of countries, regions or power stations taking into account the many variables which can have a bearing on the comparison, have not been pursued.

In one case, (17) an international comparison of thermal efficiencies of various European Countries, there is little work done to quantify the effects of various variables e.g. age of generating plant, size of plant, although it is stated that different proportions of these variables will affect the effectiveness of comparison.

No publications, or other written documentation has been found in the current survey of literature, which cover the forecasting of the effects of different variables on future productivity within the industry, or allow accurate comparisons of electricity supply industries productivity internationally, or at macro levels, or for example compare the performance of one region against another, or even whether a particular power station is run by the optimum number of staff or resources compared with other stations.

3. PRODUCTIVITY IN ELECTRICITY GENERATION AND SUPPLY

3. PRODUCTIVITY IN ELECTRICITY GENERATION AND SUPPLY

In recent years several studies have been made of the productivitiy of the U.K. electricity supply industry and international comparisons made.

One such study by Pryke (1) used sales per man-hour as the measure of productivity and compared the record of the U.K. industry with those of six other western industrialised nations. In the study Pryke used the annual percentage increase in sales of electricity per man-hour, over the period 1958 - 1968, as a basis for his comparison of productivity. A synopsis of the results of this study for electricity supply is shown at Appendix 2. Productivity calculations, which take into account the use of capital, confirmed the picture which emerges from the comparisons of growth of output per man-hour.

More recently a "Report by the Group of Experts on the Overall Productivity of the Electricity Supply Industry" (17) commenced with a discussion of different methods for studying productivity in the electricity supply industry. The selected method, the - overall productivity method (i.e. output in relation to input) - was aimed at following the productivity development, within an undertaking, over a sequence of years and four pilot cases (Great Britain, France, Spain, Sweden) were followed. Two different methods were considered, both making use of the two concepts output (results attained), and input (resources used to attain those results), both being expressed in financial terms. Both can describe the performance of the undertaking in a particular year in a relative way by means of the ratio between output and input, and also the productivity growth from one year to the next by comparing the two consecutive ratios.

The "added value method" defines the results attained i.e. the output, as the difference between sales revenue of the utility and the cost of fuel and raw materials used to bring about the production. The difference gives the value which has been added to the raw materials.

The "overall productivity method" defines the results, or output, as the sales revenue without any deductions and similarly defines the use of resources, or input, as the sum total of all annual costs (raw materials, fuel, labour, capital costs, etc.).

The main reasons for the selection of the "overall productivity method" was that one participant had already laid the foundation for it, to some extent it had been tested, and it was a also judged to be the more easily understandable to the participants.

One point which was emphasised was that productivity calculations must be based on a number of technical and economic assumptions e.g. life span of equipment, and if a comparison of utility was being made the assumptions had to be on an agreed common basis. Another example to highlight the problem of finding a common basis for assessing productivity in electricity supply is the weather. Variation of water and weather conditions, even in the same country, will influence production and sales of electricity. Corrections were therefore made for water and weather conditions and incorporated in the calculations.

Iulo (6) carried out investigations into the quantitative relationships that by tradition or logic were believed to affect the unit costs of electricity production. He stated that quantification of relationships should help explain the differences that exist among individual electric utilities with respect to unit cost. Another observation made by Iulo was with regard to grouping of electric utilities for performance evaluation. The group would be based on a limited geographical area, with similar size grouping and having similar market composition. Iulo used statistical as opposed to subjective techniques, his explanation being that in this way personal evaluation was minimised. Multiple regression analysis was chosen by him to establish the average relationships that existed between factors, both individually and in combination. He advocated researchers using multiple regression to analyse a number of factors simultaneously to quantify the relationship between factors and unit costs.

A substantial part of Iulo's study deals with the derivation and reasoning behind each of the factors investigated and with the development of measures to reflect these factors. Factors included electricity produced, size of producing unit, cost of construction and level of technology. Iulo included eleven operating factors to determine their relationship to unit electricity costs. Of these, only three factors were demonstrated to have a significant relationship to unit costs of electro utilities, namely Utilisation, Fuel costs (Steam) and Hydro fuel costs.

Market and historical characteristics were also studied and the final factors found to be significant were the three operating factors mentioned plus size of steam - electric generating plant, the consumption of electricity per residential customer, per commercial and industrial customer and the distribution among consumer classifications.

In his study of productivity measures and performance evaluation of public utilities, Dodge (9) employed the rate of change in total factor productivity as a measure or productivity. To some extent Dodge had added to Iulo's work although he emphasised the long run and assumed far fewer constraints on managements ability to influence results than what he considered to be Iulo's short term emphasis.

Wald (21) in explaining why performance should be measured makes the point that a person may be able to develop performance targets which quantify optimum achievement, reflecting the full potential of the existing electric power technology. However, th s is a different order of difficulty from one which is limited to inter-industry comparisons based on company reports. Statistics in a firms files do not indicate the maximum attainable levels of performance but the actual levels achieved each year by the company producing the report. Wald points out the difficulties when carrying out statistical analysis of factors in that data of different utilities does not achieve precise comparability. The important result of statistical analysis is the signalling of possible out-of-line performance to stimulate detailed analysis, which he contends can be done by persons who are familar with the company's operations. When considering utility costs, Wald identifies the amount of money being spent on environmental protection which alters the structure of mobility costs. Wald also identified a need for utilitiesto launch a series of studies of the most effective means of combining high level analytical talent with the computers capability to process data and solve previously unmanageable computational problems related to the analysis of performance statistics.

Barzel (3) in measuring productivity in the electric power industry examines the appropriateness of the output-per-unit-of-input technique as a measure of productivity change. He starts by saying that this measure is not very appropriate because there is a large bias in estimating productivity change. However the sources of bias are known and their size can be estimated, so that the productivity measure is corrected accordingly. Barzel considers that after corrections have been made, the output-per-unit-of-input measure is superior to the most common alternative, a production function with time trend approach.

In his development of methods for measuring the efficiency in the electric supply industry, Pace (5) set out to evaluate the relative efficiency of each firm in a sample of 113 utilities. His approach was to develop a multiple regression model for estimating unit electric costs in two five year periods. A comparison of actual and predicted costs would evaluate relative efficiency. Although Iulo (6) used a similar method it differed from the Pace method in the cost concept and statistical estimating techniques employed.

Pace points out that before effective performance - orientated regulation can be introduced by a utility there must be the ability to measure relative efficiency. When seemingly inefficient utilites are called upon to explain divergencies he maintains that a combination of public suspicion regarding quality of performance of the efficiency problem would result in an improvement in efficiency.

Smith (4) measures performance variables to examine whether costs are significantly higher or lower than predicted. He calls his method the "red flag" approach because the "red flag" is a warning of actual and predicted costs being divergent. As with all these papers, one of the main aspects which is underlined is that of getting the correctly defined variables.

Publications, regarding pitfalls of statistical analysis by Black (7) and of making comparisions of electric utilities by the Edison Electric Institute (8), highlight the problems of comparing like with like. Selection of variables, their definitions and units of measurement vary widely utility to utility. Streissler (12) also emphasises the problems of ensuring that selected variables have similar definitions when making comparisons.

Mention should be made of an International comparison of Thermal Efficiencies (11) which was carried out for several countries. Thermal efficiency is used throughout the electricity supply industry as a ratio of output/input in heat terms. The output is the heat equivalent of the electricity supplied to the system, the input being the heat value of the fuel used to achieve the electrical output, it is therefore a measure of productivity. Throughout this study the point was made that assessing like with like was extremely difficult. Variables which affected thermal efficiency, such as age of generating plant, type of firing or proportion of hydro generation, all affect thermal efficiency to a differing extent and the study merely pointed out the difficulties of assessing the affect of these variables, without endeavouring to find correlations.

Mention was made in the Introduction to the Report of the Plowden Committee of Inquiry (13) which also commented on the difficulty in making comparisons, although there was a need for them.

When setting out to consider manpower productivity, similar variables have effects on the number of staff required and these effects have to be quantified so that an accurate basis for comparison is achieved. The selection of variables and method used for quantifying their effect on manning levels is dealt with in 6.2.

Between the years 1967 and 1975 the industrial staff levels in the U.K. electricity supply industry have been reduced appreciably.

The industrial labour force has been reduced by nearly 51,000 (19), being accomplished mainly by natural wastage, control of recruitment and voluntary severence schemes. Reduction in the number of industrial staff has been achieved under a Pay and Productivity Agreement based on work measurement. Administrative staff had also been subject to clerical work measurement and only the technical and managerial sections have not reduced numbers.

An appreciable increase in manpower productivity had therefore been achieved, and a method of assessing this increase was felt by the author to be a worthwhile project for research.

4. ELECTRICITY SUPPLY INDUSTRY ORGANISATION

4. ELECTRICITY SUPPLY INDUSTRY ORGANISATION

The present structure of the Electricity Supply Industry was created by The Electricity Act of 1957 (13) which came into force on 1st January 1958.

This structure comprises the Electricity Council, in which both the generating and distributing sides of the industry can resolve their common problems under independant guidance. Together with the Electricity Council the industry consists of the Central Electricity Generating Board and twelve Area Boards . An organisation chart is shown in Appendix 3.

4.1 Electricity Council

The Electricity Council acts as a forum (13) in which, under its independent guidance, both the generating and distributing sides of the industry resolve common problems.

Membership of the Council at present comprises the Chairman, two Deputy Chairmen, one of whom serves part-time, and fifteen members: The fifteen members consist of the Chairman and two other members of the C.E.G.B. and the Chairmen of the twelve Area Boards. In addition, there are specialist advisory members for marketing, industrial relations, finance, public and overseas relations, commerce and legal matters.

The Council has no control over the Boards, it is not responsible for the financial performance or efficiency of the industry. Its functions are "to advise the Secretary of State on questions affecting the electricity supply industry and matters relating thereto" and "to promote and assist the maintenance and development of the Electricity Boards in England and Wales of an efficient, co-ordinated and economical system of electricity supply".

Specifically its statutory duties include responsibility for establishing and maintaining machinery for negotiating wages and conditions of employment, employee consultation, setting a general programme of research for the industry, borrowing on behalf of the Boards and preparation of accounts and annual reports.

4.2 Area Boards

The twelve Area Boards are directly responsible to the Secretary of State and through him to Parliament, they are the retailers of electricity to consumers, both domestic and industrial. They also sell and repair domestic appliances, provide electricity supplies and run electrical contracting business.

Each Board comprises a Chairman, a minimum of five members and a maximum of seven members, all appointed by the Secretary of State.

Area Boards are entitled to install generating plant to keep local system security, although only the South Western Electricity Board has any of its own generating plant at present.

4.3 The Central Electricity Generating Board (C.E.G.B.)

The C.E.G.B. is a statutory body whose members are appointed by the Secretary of State for Energy, who exercises the powers of ministerial control.

The principle duty of the C.E.G.B. is to develop and maintain an efficient, co-ordinated and economical supply of electricity in bulk for England and Wales.

The C.E.G.B. generates and exchanges bulk supplies of electricity and transmits it in bulk to the Area Boards, for distribution to domestic and industrial consumers. It exchanges bulk supplies with the South of Scotland Electricity

Board and Electricité de France and supplies certain large consumers direct, such as the United Kingdom Atomic Energy Authority and British Rail.

The Board, in consultation with the Electricity Council, formulates and publishes a Bulk Supply Tariff which governs the price which the Area Boards pay for their supplies of electricity.

At 31st March 1975 the C.E.G.B. had assets of £3,428m which was 58% of the industry's total (18). It employed 66,099 people, 38% of the industry's staff and in the financial year 1974-75 was responsible for 82% of the industry's total costs on revenue account.

Under the existing organisation the C.E.G.B. comprises a Chairman, Deputy Chairman, three full-time and three part-time members and a secretary/solicitor.

On the next tier below the C.E.G.B. are the five generating Regions, which are; North Eastern, North Western, Midlands, South Western and South Eastern. Each Region is responsible for the generation and bulk 275kV and 400kV transmission systems.

Also at this level of the C.E.G.B. organisation are the specialist divisions which cover the following; Generation Development and Construction, Transmission Development and Construction and Directorates of Engineering, Services, Operations, Research, Planning, Personnel Management, Overseas Consultancy, Nuclear Health and Safety, Computing, Finance and there is a secretary/solicitor.

Production and bulk transmission of electricity is carried out by the five Regional organisations, each operating its own power stations and controlling the parts of the main transmission supply system which fall within its boundaries.

Regional organisations also include services such as fuel supplies, research, planning, efficiency, operation and maintenance.

The power stations of the C.E.G.B. vary widely in their installed capacity,methods of firing boilers, age of their plants, and in their plant layouts. Each Region has a proportion of all types of station.

Each power station is staffed in similar patterns, each has industrial staff for operations and maintenance. There are technical staff for operations and maintenance, and for specialist services, such as efficiency, development and chemistry, and there are a number of administrative staff.

4.4 Scotland

Scotland is served by two Boards, the South of Scotland Electricity Board and the North of Scotland Hydro-Electric Board.

The two Boards operate their generating plant jointly and 23% of their installed capacity is in hydro-electric stations, compared with less than 1% for the C.E.G.B..

4.5 Northern Ireland

The Northern Ireland Electricity Service completes the power industry of the United Kingdom.

4.6 General

4.6.1 The South of Scotland Electricity Board is unique in that it combines the functions of generation, transmission and sales to the consumer.

4.6.2 The North of Scotland Hydro-Electric Board and the Northern Ireland Electricity Service, both operate in geographical conditions considerably different from those in England and Wales. They are small undertakings, each serving between 2.2% and 2.3% of U.K. consumers, their territories are rural with consumers scattered thinly over them.

4.6.3 This project will consider aspects of productivity and forecasting in electricity generation and supply, and specifically in the United Kingdom industry concerns the C.E.G.B. and subordinate organisations.

4.6.4 At the time of writing the report of the Plowden Committee of Inquiry has been published. This Committee was set up by the Secretary of State for Energy, its terms of reference were:-

"To examine the structure of the electricity supply industry in England and Wales and to report to the Secretary of State for Energy".

The report of the Committee has been sent to the Minister for his consideration and therefore is still some time off implementation.

One major recommendation is that a central controlling body be set up, to be named the Central Electricity Board.

In whatever way the electricity industry is reorganised at national level, it is unlikely that manning levels at power station level will be affected by the findings of the Plowden Committee.

5. MANPOWER IN ELECTRICITY GENERATION

5. MANPOWER IN ELECTRICITY GENERATION

Basically staffing is divided into four sections; managerial, technical, administrative and industrial, each section having its conditions of employment agreed separately with the Electricity Boards.

5.1 Managerial

This section comprises managerial and higher executive staff, of whom there were 1695 in 1975 (19).

The National Joint Managerial Agreement specifies conditions of employment in this Section, the signatory Union being the Managerial Section of the Electrical Power Engineers' Association. Under the existing agreement and structure, in a power station, only the Manager is employed under the National Joint Managerial Agreement.

5.2 Technical and Scientific

The heading of technical staff includes engineering and scientific staffs, all being employed to the conditions of the National Joint Board for the Electricity Supply Industry. The signatory Union for this section is the Electrical Power Engineers' Association.

In 1975 there were 26,421 technical, engineering and scientific staff employed in the electricity supply industry(19). In recent years, due to the increasing sophistication of generating plant and transmission equipment, there have been technical problems of increasing complexity and as a result the numbers of employees, within this section, have increased. However, it is expected that, as older power stations are closed down, resulting from the large surplus of generating plant, the number of these employees will stabilise.

Staff within this Section have agreed, in principle, to a Job Evaluation Exercise being carried out in the near future. In the long term this may result in a reduction of the ratio of technical staff to electricity generated.

5.3 <u>Administrative and Clerical Staff</u>

Staff employed on administrative and clerical duties within the industry, work under the National Joint Council Agreement for the Electricity Supply Industry. As the name implies, these staff carry out administrative and clerical duties, and include storekeepers, nursing staff and area board sales staff.

The N.J.C. Agreement is between the Electricity Council on one side and the following signatory Unions; National and Local Government Officers, Clerical and Administrative Workers' Union, National Union of General and Municipal Workers' and the Transport and General Workers' Union.

About three quarters of the industry's clerical staff are already covered by work measurement techniques which have been applied since 1972. The industry employs 47,798 staff within this section (19).

5.4 <u>Industrial Staff</u>

Industrial staff comprise craftsmen, production workers and all manual workers, their conditions of employment are negotiated under the National Joint Industrial Council of the Electricity Supply Industry. The signatory unions to this Agreement are: The Amalgamated Union of Engineering and Foundry Workers, The Plumbing Trades Union, The Electrical, Electronic and Telecommunications Union, The General and Municipal Workers' Union and The Transport and General Workers' Union.

Since 1967 the industrial staff have participated in a Pay and Productivity Scheme, which was based on work measurement and bonus incentives. Nationally, the majority of industrial staff are paid a bonus under this Scheme and the numbers of industrial staff employed is steady.

By the end of March 1975 there were 91,048 industrial staff employed in the electricity supply industry which is approximately 51,000 less than were employed in 1967. The reduction in staff was accomplished through natural wastage, control of recruitment and voluntary severence, under the provisions of the selective payments scheme for industrial staff.

The manning position for the electricity supply industry with effect 31st March 1975 (19)was as follows:-

Section	Number Employed by CEGB	% of Total Employed by CEGB	Total Number Employed	% of Total Employed
Managerial and Higher Executive	798	1.2	1,695	0.98
Technical, Engineering and Scientific	14,913	22.7	26,421	15.32
Administrative, Clerical and Sales	8,170	12.4	47,798	27.71
Industrial	39,904	60.3	91,048	52.79
Technical Trainees and Apprentices	2,314	3.4	5,521	3.20
Totals:	66,099	100.0	172,483	100.0

Table No. 1 - Number of Staff Employed by the C.E.G.B. on 31st March 1975

6. FACTORS WHICH AFFECT POWER STATION MANNING

6. FACTORS WHICH AFFECT POWER STATION MANNING

6.1 Power Station Plant - General

Alternating current electricity is generated in an alternator, in which a rotating magnetic field induces electricity in static windings, from where connections carry the electricity to the grid system. Generally a steam turbine drives the alternator rotor, the steam being raised and superheated in boilers. Boilers may be fired by oil, coal on chain grates, pulverised coal, or by nuclear fission in a reactor. In some countries e.g. Eire, peat is used to fuel boilers.

The C.E.G.B. has a proportion of Gas Turbine Generators installed for peak topping and emergency uses. Gas Turbines in this case act as gas generators, the gases being used to drive a power turbine which in turn drives the alternator rotor. These sets are usually fully automatic and are generally incorporated into power stations which have conventional steam turbines as the main plant.

Older power stations were built on a range system, whereby a number of boilers supplied steam to a common interconnected pipeline, from which turbo-alternators were fed the steam. Generally there were more boilers than turbo-alternators, which allowed maintenance and insurance surveys to be carried out on a boiler whilst there was sufficient boiler capacity available to maintain full electrical output. The next stage was to have an equal number of boilers and turbo-alternators, but an interconnected steam main was retained. Other systems, such as feed water, were on common mains.

Since the mid-nineteen fifties the common policy within the United Kingdom supply industry has been to have one boiler supplying one turbo-alternator, which is called a generating unit, with no interconnection to other units. Although there was a reduction in flexibility the division was an economic one due to the very high cost of alloy steel piping and valves required to interconnect units, to cater for the increasing steam temperature and pressure conditions.

Manning patterns on the operational side also changed. With separate interconnected boilers and turbo-alternators, there would be one stoker for each boiler, one driver to operate two turbo-alternators. For example, if there are twelve boilers and six turbo-alternators there will be a minimum staffing level of twelve stokers and three turbine drivers, to operate the generating plant, on each shift.

A modern generating unit will be controlled centrally by one unit operator and one assistant unit operator, although in some cases there will only be one assistant unit operator between two units. Most recent generating units are operated and controlled by one man, with all auxiliary plant, such as valves, dampers, pumps and fans, being operated by centrally controlled sequence operated controls. As a result of increased automatic remote control and the increasing unit output the productivity of operations staff has risen considerably. The economy of scale means that the same number of men are required to operate one 60MW Unit as there are for one 500MW Unit.

Maintenance staff are divided into mechanical, electrical and instrument departments and within a power station there are also coal and ash plant operators and a varying number of storekeepers, gatekeepers, chemical samplers and coal samplers. In addition to operations and maintenance roles, technical staff are employed for specialist duties such as efficiency, chemistry, planning and development.

The type of firing has a significant effect on manpower levels. Coal firing requires more men than oil firing, due to the additional maintenance required, resulting from the abrasive qualities of coal, which cause wear on conveying plant, and ash handling plant. Pulverised coal firing (pf) generally needs more staff for maintenance duties than chain grate type coal firing. More plant is involved for pf firing,. feeders to deliver the coal at a controlled rate to the mills, the mills themselves and fans to blow the pf into the boiler. This extra plant is subject to severe abrasion and requires a large maintenance effort to ensure that the plant has a high availability.

Nuclear stations carry fewer industrial staff, although due to technical sophistication and the more stringent monitoring of safety standards of plant and personnel, more technical and scientific staff are required than in fossil fuelled stations.

Hydro stations require a small manning level compared with all the other types mentioned previously. By the nature of the fluid driving force, remotely operated valves and controls and simplicity of the plant, fewer people are needed to operate and maintain them.

6.2 Factors Which Affect Manning

The Factors which affect power station manning are defined below, together with explanations as to why each Factor has an affect on the manning level.

6.2.1 Installed Capacity

The installed capacity of a power station is expressed as the total number of megawatts(MW) the station generators will produce, for supply to the transmission system.

This is a rated, as designed, installed capacity, for example if the total generating capacity of a station is 2100 MW, the assumption may be made that 117 MW will be consumed by the auxiliary plant of the station. Therefore, in this example the installed capacity for supply to the grid system, is 1983 MW.

The point to be stressed is that 1983 MW is the rated output, because in practice the actual power used for auxiliaries varies quite widely from station to station. The percentage of total power used for works auxiliaries can vary from 5.8% at one power station to 10.0% at another station.

There is a wide variation in installed capacities, from say 20 MW at the bottom end, to 1983 MW at the top end. Generally a small station will require fewer personnel to operate and maintain it than a large power station, but not necessarily proportionately.

6.2.2 Age of Generating Plant

As generating plant gets older the accumulative effects of thermal and mechanical stress reversals, abrasion, erosion and corrosion demand an increasing repair and maintenance commitment.

Throughout the industry, planned preventative maintenance systems are in use, which aim at refurbishing or replacing components which have otherwise a limited life, before they fail in service and cause a reduction in availability or efficiency. This system optimises the frequency of maintaining a component against the cost of its failure whilst in service.

However, preventative maintenance has a limited range and as the years pass by components which have eroded over a long period, such as gas ductings, pipework or boiler refractories, need patching or replacing. There is, therefore, a greater need for repair and maintenance for older plant, in order to achieve consistent availabilities and efficiency.

6.2.3 Number of Generating Units

As described in Section 2.3.1, the number of operating staff is determined by the number of boilers, turbo-alternators and generating units. Maintenance staffing will also vary with the numbers of generating units, boilers and turbines, there being proportionally more men for more plant items, even when the capacity of the generating plant is low. This is because there are more plant components with multiples of even small output boilers and turbo-alternators than with fewer larger generating units.

6.2.4 <u>Type of Firing</u>

In Section 2.3.1 brief mention was made of the effect of different boiler fuels on manpower requirements. Included under this heading are oil firing, coal firing, pulverised fuel firing (pf), nuclear reaction and although not a type of firing, hydro-electric plant is also included. Less than 1% of the capacity of C.E.G.B. plant is hydro, whereas many countries have a high proportion of hydro-electric plant. Hydro stations are lightly staffed, compared with all other stations, fossil fired or nuclear.

Oil fired stations are manned by appreciably fewer personnel than pulverised fuel (or pf) stations. For example, an oil fired station having the same number of generating units, of similar age and output as a pulverised fuel station, could have a staff of 386 compared with 630 for the pf station.

Coal fired stations employ fewer staff than pf stations, although a direct comparison is not quite so clear. All post 1955 fossil fired boiler plant built for the C.E.G.B. has been oil or pf fired. Chain grate coal fired boilers are only built to a maximum output of about 550,000 lb steam per hour which is equivalent to an electrical output of 60MW. Pf and oil fired boilers produce steam for all sizes of boilers up to the existing 660MW Unit boilers.

The reasons why more staff are required for pf stations than coal stations is that extra plant is required to feed raw coal to mills, to mill it to powder and to blow the powdered coal into the boiler. By the nature of the coal, this extra plant is subjected to abrasion and hence a high wear rate. Additionally the ash dust from pf boilers needs handling. Approximately 20% of all ash make falls to the bottom of the boiler from where men sluice it to ash disposal plants, the 80% remaining passes in the flue gases to electrostatic precipitators where 99.3% of dust is removed from the gases before they pass via the chimney to the atmosphere.

In comparison coal on chain grates requires very little handling and the majority of ash make falls after quenching onto conveyors, which carry the ash to the disposal plant. Only a small proportion of the ash passes as dust to the chimney and hence to the atmosphere. Pf firing demands more staffing to carry out ash and dust handling and a greater number of maintenance personnel to repair the milling, ash and dust handling plants.

Ranking upwards in manning levels are hydro, oil, nuclear, coal and pf stations.

6.2.5 Thermal Efficiency

The thermal efficiency of a power station is the ratio of the heat output: heat input, expressed as a percentage.

Heat output is the heat equivalent of the electricity actually supplied to the grid system, the heat input is the heat equivalent of the fuel consumed to produce the electricity supplied to the Grid, during the same time scale.

Although thermal efficiency is a technical ratio and is mainly dependant on the heat cycle conditions, it can be influenced by operational and maintenance work.

Thermal efficiency is optimised by station management as part of their general aim of reducing generating costs. When, for example, a station burns one million tons of coal each year, costing £15 per ton a 1%(i.e.0.3% on 30%) improvement in thermal efficiency will result in a saving of £150,000.

The achieving of the optimum rated thermal efficiency for a power station requires a large manpower commitment.

In each boiler all heat exchange surfaces need to be clean, sootblowers must have a high availability, air heaters clean, dampers must seal when shut, fuel must be burned efficiently etc. Turbine glands need to be at minimum clearance, condensers need to be clean etc.. It will be seen that to carry out work on these few examples requires a significant commitment of manual effort. Power station managements find that in many cases the utilisation of manpower to achieve higher plant availability demands the greatest allocation.

Thermal efficiencies vary from a figure of 35.5% for a 500 MW Unit to less than 20.0% for very small old generating plant.

6.2.6 Utilisation

It will be apparent that the achievement of high output, or utilisation, from plant demands a higher manpower commitment than a low output for the same capacity of plant. This holds particularly true for the boiler side of power generation plant. Therefore utilisation was considered an important factor to take into account for this project.

There is an inter-relationship also between utilisation and thermal efficiency. As mentioned in the introduction the power station generating units are loaded according to a merit order position, which is based on the cheapest and most efficient units being put on load and loaded higher than less efficient plant. If, therefore, the national demand is low a station with a high unit cost of production, which is generally correlated with low thermal efficiency, will probably remain shut down. A power station which produces cheaper power, even if installed plant parameters are similar to the previous example, will be called on to generate more and hence have a higher utilisation.

It will be appreciated that if a commitment is made to increase thermal efficiency and reduce generating cost, the resultant increased utilisation will demand more manpower to keep the utilisation higher than was needed previously.

Utilisation is expressed as a percentage of the units actually generated over a period, divided by the maximum number of units which could have been generated during the same period.

6.2.7 Power Generated

Closely allied to the utilisation of plant is the actual power generated. However, as it has an important effect on manpower requirements, in a similar manner to utilisation, it has been included as a variable.

The unit of power generated is kWhr and as the figures are high the variables used in this project are expressed in TWhr which is 10^6 x kWhr.

6.2.8 Generating Unit Capacity (Average Unit Size)

The size of a generating unit has an important bearing on manning levels, the economies of scale result in manpower requirements being much less than pro-rota output for output. We have mentioned earlier that the same number of men will operate a 60 MW Unit as a 500 MW Unit. However the larger units are more complex and use more sophisticated systems than the small units, hence they demand more men to maintain them. The increased requirement is however, far less than the proportional difference in size would suggest.

The average unit size for a given power station is used as a variable and is expressed in Megawatts (MW).

6.2.9 General

Having identified the variables which will be used in the project for assessing manpower levels and explaining why they affect manning levels it should be pointed out that some of these variables are not subject to decisions by operating managements.

The interplay between thermal efficiency, utilisation, units generated is determined to a large extent by the decisions taken by management during the life of the station.

Fixed variables such as installed capacity, age of plant, number of units, type of fuel and average set size are decided initially by management, but cannot in general be changed later on a manning level basis.

When the decisions are taken to design a power station the variables mentioned above will be decided on technical and economical grounds. Manning levels do not affect the decisions, although when it is decided what the physical arrangements of a power station will be, the philosophy of control will be up-to-date having evolved over the years. Plant layout, particularly control arrangements, will be designed to allow operation by the smallest number of operators.

The Board also pursues policies based on terotechnology in that good availability should be designed into the generating plant before installation. The philosophy of the Board is that defects, which, in the past, have caused loss of availability will be designed out of new plant. The power plant design organisation operates to this philosophy.

7. METHODS AND THEIR APPLICATIONS

7. METHODS AND THEIR APPLICATIONS

7.1 Data

The data comprises values of the technical factors and manpower levels for each power station of the Central Electricity Generating Board, with effect the year ending 31st March 1973. This data has been put together in Table No. 43.

Table 43 is arranged so that the thirteen columns, one for each variable, are kept together for each power station. All the power stations of a region are listed together and are unnamed. The regions are listed in order of their allotted number.

The variables, their unit of measurement used in the project and their column number are identified as follows:-

Column 1 - Installed Capacity:- is expressed as $\frac{MW}{10}$

Column 2 - Age of Station:- the age of a power station is calculated by substracting 1926 from the year of completion. The figure 1926 was selected as being the date of completion of the oldest power station, i.e. if completed in 1965 the age factor would be quoted as 1965 - 1926 = 39.

Column 3 - Number of Generating Units:- the number of turbo-alternators installed in the power station.

Column 4 - Type of Firing:- each type of firing is allocated a unique digit as follows:-

1 - Oil fired

2 - Coal fired

3 - Pulverised fuel (coal) fired

4 - Nuclear fission

Column 5 - Thermal Efficiency:- specified as a percentage, being the average thermal efficiency for the power station for the preceding year. It is the thermal efficiency with which fuel was converted into electricity supplied to the grid system.

Column 6 - Power Generated:- the total power supplied to the grid system by the power station during the preceding year, units expressed as $\frac{10^6 \text{ kWhr}}{100}$.

Column 7 - Utilisation:- annual utilisation expressed as a percentage, where utilisation is defined as the ratio of units actually supplied to the grid system, divided by the number of units which the plant could have supplied if run continuously, at continuous maximum rating for the same period.

Column 8 - Average Set Size:- average output capacity of each turbo-alternator in the power station, obtained by dividing the installed capacity by the number of turbo-alternators.

Column 9 - Operating Region:- The C.E.G.B. production and transmission is divided between five operating Regional organisations. Managements of Regions may have different policies regarding manpower levels and patterns which have measurable effects, therefore the operating region becomes a variable to be considered in this project.

In the Table each Region is allotted a digit, 1, 2, 3, 4 and 5, the stations being listed in order of the Regions in which they operate, i.e. all No. 1 Region's power stations are listed, then No. 2 Region's stations, and so on.

Column 10 - <u>Technical and Scientific Staff</u>:- this column shows the number of technical and scientific staff employed in the power station. In order to achieve brevity the staff in this section will be referred to as technical staff.

Column 11 - <u>Administrative Staff</u>:- the number of administrative staff employed in the power station are quoted in this column.

Column 12 - <u>Industrial Staff</u>:- this figure shows the number of industrial staff employed in the power station.

Column 13 - <u>Total Staff</u>:- the total number of technical, administrative and industrial staff employed at the station i.e. sum of columns 10, 11 and 12.

<u>Manpower Ratios</u>

In addition to considering these thirteen variables, two further variables were included. These were 14, Ratio of technical staff to total staff and 15, Ratio of administrative staff to total staff, being derived from the values tabulated.

These ratios were selected to show whether they had any real significance and whether high values would give commensurate higher thermal efficiencies and utilisation. It could be that more technical staff per total would, as a result of more than normal technical knowledge being applied to problems, result in better solutions and hence higher thermal efficiences. Conversely if low ratios had more effect it would show that industrial staff i.e. manual workers and tradesmen, were used more effectively and gave better performance.

Similar reasons were pertinent for including variable 15.

7.2 METHOD OF ASSESSING MANPOWER PRODUCTIVITY

In Section 6 the variables which are assumed to affect, directly or indirectly, power station manning levels are listed and the reason for selecting them explained.

Having decided on these variables it was necessary to test whether the variables do actually have any significance with regards to manning, or whether any relationship is accidental.

On a logical basis, it would be reasonable to assume that if more industrial staff are thought necessary to achieve higher levels of utilisation and thermal efficiency, then an increase in administration staff will be necessary, to administer the higher number of staff, to meet the higher pay and productivity scheme work load etc..

Briefly, the method will be assessing the significance of any relationship between the variables and manning levels, after which the intensity of any such relationships will be determined.

When relationships are validated they will be expressed in mathematic form by determination of equations connecting variables, the data is used with corresponding values of the variables under consideration from Table No.43.

The correlation, or degree of relationship, between the variables was found by multiple rather than by simple regression, there being fifteen variables involved.

Least square regression curve fitting was used. The disadvantages of using the least squares method where many very large value samples have a greater influence than those samples lower down, were mitigated by removing very small stations from the data for calculation purposes (recently the C.E.G.B. has closed down these small obsolete power stations). This ensures that 'least squares' is relevant as the curve fitting method for this type of project. If the values of variables had remained as stated above an alternative method would have been advantageous.

In addition, stations were withdrawn which were not representative of their size. Typical cases were new uncommissioned power stations which had not been staffed to establishment levels, and new stations where particularly onerous problems in commissioning were being encountered. In the latter case, the very large temporary staffing levels were untypical for established power stations and would be reduced when the power station was fully commissioned.

7.2.1. Installed Capacity as Dependant Variable

Overall

$F = 228.07 \quad r^2 = 0.9647$ (96.47%), Approx. $P = 0.100 \times 10^{-74}$

Individual Results

No. of Variable	Variable	'r'	P Approx. Probability by pure chance
2	Age of Station	0.685	0.146×10^{-18}
3	No. of Gen. Units	0.239	0.572×10^{-2}
4	Type of firing	0.390	0.154
5	Thermal Efficiency	0.735	0.108×10^{-22}
6	Units Generated	0.877	0.351×10^{-42}
7	Utilisation	0.133	0.125
8	Unit Capacity	0.933	0.944×10^{-59}
9	Region	0.297	0.531×10^{-3}
10	Technical Staff	0.713	0.896×10^{-21}
11	Administrative Staff	0.750	0.195×10^{-22}
12	Industrial Staff	0.696	0.180×10^{-19}
13	Total Staff	0.715	0.571×10^{-21}
14	Ratio 10 : 13	0.010	0.111×10
15	Ratio 11 : 13	0.164	0.589×10^{-1}

Table No. 2 - Predicting Installed Capacity

The results show that nine of the variables were highly significant when predicting the installed capacity of a power station, one variable was significant and two had no significance, two were affected by auto-correlation.

Overall the F value was high, 96.47% of the variation could be explained away and the approximate probability of these results being by pure chance is extremely low.

In predicting installed capacity, the two variables, type of firing and utilisation had no significance.

That the type of firing has no significance indicated that station capacities were decided irrespective of the type of firing. The choice of fuel would be based on the economics and availability of fuels. Nuclear stations vary from medium size to very large mainly because even the earliest C.E.G.B. nuclear stations are comparatively new, their nuclear reactors being matched to large capacity turbo - alternators.

Utilisation of power station plant depends on functions of thermal efficiency, fuel and other generation costs and plant availability. Poor early performance of very large units and stations probably contributed to the lack of significance of utilisation in predicting installed capacity.

Units generated and unit capacity were affected by their auto-correlation with installed capacity. This occurred because for example when calculating units generated the installed capacity is included in the calculation, i.e. units generated = installed capacity x utilisation x time. Therefore when predicting installed capacity, the dependant variable occurred at each side of the regression.

Thermal efficiency had the greatest significance in this case. Installed capacities have increased over the years, generally as generating unit sizes have grown with developments in materials and design. Larger sizes with attendant higher steam conditions have improved thermal efficiencies.

Similarly the age of the station was highly significant in predicting installed capacity.

All classes of staffing were highly significant in predicting installed capacity, their significances being of a similar order.

This is understandable in that more plant requires more technical and industrial staff to operate and maintain it and in turn these allied increases required more administrative staff.

The ratio of technical staff: total staff had no significance whereas the administrative staff: total staff ratio had some significance.

7.2.2. Age of Station as Dependant Variable

Overall

$F = 23.77$, $r^2 = 0.7398$ (73.98%), Approx. $P = 0.834 \times 10^{-27}$

Individual Results

No. of Variable	Variable	'r'	P Approx. Probability by pure chance
1	Installed Capacity	0.685	0.146×10^{-18}
3	No. of Gen. Units	0.188	0.305×10^{-1}
4	Type of firing	0.326	0.131×10^{-3}
5	Thermal Efficiency	0.774	0.152×10^{-26}
6	Units Generated	0.657	0.128×10^{-16}
7	Utilisation	0.444	0.102×10^{-6}
8	Unit Capacity	0.640	0.154×10^{-15}
9	Region	0.026	0.778
10	Technical Staff	0.685	0.139×10^{-18}
11	Administrative Staff	0.683	0.167×10^{-18}
12	Industrial Staff	0.558	0.390×10^{-11}
13	Total Staff	0.594	0.598×10^{-13}
14	Ratio 10 : 13	0.083	0.328
15	Ratio 11 : 13	0.039	0.637

Table No. 3 – Predicting Age of Station

The overall results were again satisfactory, although they were all of appreciably lower significance than when predicting installed capacity. However they showed that the eleven significant variables were satisfactory for predicting the age of a Power Station.

Thermal efficiency was again the variable with the highest significance. Installed capacity was slightly significant and of similar order of significance were the numbers of technical staff and administrative staff.

Units generated and unit capacity were, not surprisingly, highly significant.

The Region and both manpower ratio variables, showed no significance. Generally speaking each Region has power stations of varying age and when the geographical boundaries of Regions were considered the age of station would not have been a consideration.

Manpower ratios were of no significance and indicate that the ratios do not change whether a power station is old or new, whereas the actual numbers of men employed in these categories vary with the age of station.

7.2.3. Number of Generating Units as Dependant Variable

Overall

F = 21.18, $r^2 = 0.7170$ (71.70%), Approx. $P = 0.9493 \times 10^{-25}$

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.239	0.572×10^{-2}
2	Age of Station	0.188	0.304×10^{-1}
4	Type of firing	0.032	0.71
5	Thermal Efficiency	0.180	0.378×10^{-1}
6	Units Generated	0.259	0.257×10^{-2}
7	Utilisation	0.068	0.416
8	Unit Capacity	0.037	0.658
9	Region	0.407	0.119×10^{-5}
10	Technical Staff	0.392	0.325×10^{-5}
11	Administrative Staff	0.497	0.138×10^{-8}
12	Industrial Staff	0.605	0.156×10^{-13}
13	Total Staff	0.576	0.495×10^{-12}
14	Ratio 10 : 13	0.270	0.171×10^{-2}
15	Ratio 11 : 13	0.210	0.153×10^{-1}

Table No. 4 - Predicting Number of Generating Units.

In predicting the number of generating sets, the results overall show that the eleven individually significant variables had a similar order of significance to those predicting the age of a power station.

The most significant individual variable was the number of industrial staff although the total staff, administrative staff and technical staff were all highly significant.

In this case the Region proved the most significant probably because some Regions include large conurbations within their boundaries, which have a number of old small stations containing a large number of generating sets.

Utilisation had no significance which is logical; utilisation is dependant on physical characteristics of generating plant such as thermal efficiency rather than the number of generating sets installed in a power station. The type of firing also had no significance in predicting the number of generating sets.

Generating set capacity is affected by auto correlation with regard to number of generating sets as it is calculated by dividing the installed capacity by the number of generating sets, the latter being the dependant variable in this instance.

Installed capacity, age of station, thermal efficiency and units generated were also significant variables for predicting number of generating sets.

7.2.4. Type of Firing as Dependant Variable

Overall

$F = 3.76$, $r^2 = 0.3102$ (31.02%), Approx. $P = 0.3268 \times 10^{-4}$

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.123	0.154
2	Age of Station	0.326	0.131×10^{-3}
3	No. of Gen. Units	0.032	0.718
5	Thermal Efficiency	0.212	0.143×10^{-1}
6	Units Generated	0.255	0.304×10^{-2}
7	Utilisation	0.394	0.302×10^{-5}
8	Unit Capacity	0.168	0.534×10^{-1}
9	Region	0.090	0.289
10	Technical Staff	0.359	0.230×10^{-4}
11	Administrative Staff	0.344	0.550×10^{-4}
12	Industrial Staff	0.289	0.740×10^{-3}
13	Total Staff	0.309	0.302×10^{-3}
14	Ratio 10 : 13	-0.000724	0.284
15	Ratio 11 : 13	0.058	0.487

Table No.5 - Predicting Type of Firing.

Nine variables were shown to be individually significant in predicting type of firing. Overall,'F' was satisfactory although at 3.76 appreciably smaller than in previous cases, only 31.02% of the variability could be explained away, although the approximate probability that the results could occur by pure chance was satisfactorily low.

The most significant variable was utilisation and indicated that the higher order fuel (nuclear) was highly utilised. This phenomenum being due to the low cost of generation of nuclear reactors, nuclear fuels being cheap although installation capital costs are high. High nuclear utilisation therefore is due to low generating costs and also inflexibility of magnox nuclear reactors which encourages the maintenance of high loads.

Not surprisingly the manpower variables were significant in predicting the type of firing, whereas the two manpower ratios had no significance. It could have been anticipated that the ratio technical staff : total staff would have been different for nuclear stations than for coal fired stations as the increased safety and health monitoring and sophistication of these stations results in a larger number of technical and scientific staffs proportionally to other staffs, than in conventional fossil fired stations.

The age of the stations, thermal efficiency, units generated and size of generating set were significant in predicting type of firing.

There again all sizes of generating plant have been installed whether for oil, pf firing or in nuclear stations, although chain grate coal boilers were only used in association with generating units of up to 60MW capacity.

Installed capcity, number of generating sets and Region had no significance, all of which can be explained satisfactorily.

7.2.5. Thermal Efficiency as Dependant Variable

Overall

$F = 29.05$, $r^2 = 0.7766$ (77.66%), Approx. $P = 0.1493 \times 10^{-30}$

Individual Results

No. of Variable	Variable	'r'	P Approx. Probability by pure chance
1	Installed Capacity	0.735	0.108×10^{-22}
2	Age of Station	0.774	0.152×10^{-26}
3	No. of Gen. Units	0.180	0.378×10^{-1}
4	Type of Firing	0.212	0.143×10^{-1}
6	Units Generated	0.722	0.141×10^{-21}
7	Utilisation	0.479	0.592×10^{-8}
8	Unit Capacity	0.667	0.256×10^{-17}
9	Region	0.073	0.388
10	Technical Staff	0.638	0.190×10^{-15}
11	Administrative Staff	0.676	0.576×10^{-18}
12	Industrial Staff	0.598	0.360×10^{-13}
13	Total Staff	0.620	0.208×10^{-14}
14	Ratio 10 : 13	0.070	0.398
15	Ratio 11 : 13	0.150	0.831×10^{-1}

Table No.6 - Predicting Thermal Efficiency.

Overall the results were much more satisfactory in this case, the twelve significant variables being very satisfactory overall in predicting thermal efficiency.

The overall results show a much higher significance when predicting Thermal efficiency, than in the previous case where Type of firing was being predicted.

The most significant variable for predicting thermal efficiency was the year of installation, or the age of the station. Thermal efficiency was more a function of the year of installation than of the size of generating unit. The explanation would be that as plant became more advanced technically the thermal cycle became inherently more efficient. Similar cycle conditions were used for 200MW Units as for 500MW Units for example. Installed capacity had a greater significance in predicting thermal efficiency than did the size of generating unit. Units generated was a highly significant variable which was to be expected as the higher the thermal efficiency the more generation it will be called upon to provide.

However, units generated had an appreciably higher significance than utilisation, which is probably due to new large generating units not having a high utilisation as a result of low availability rather than poor thermal efficiency. In other words if the large units could have performed at higher loads they would have done so due to having higher thermal efficiencies, but despite having lower utilisation they generated a large number of units, due to their high individual capacity.

The number of generating sets and type of firing, although significant, were of a much lower order than those mentioned above.

Highly significant were the four manpower level variables: technical, administrative, industrial and total staffs, whereas once again the manpower ratios were much less significant, in fact the ratio technical staff to total staff had no significance.

The latter could have been expected to have some significance in predicting thermal efficiency. A higher ratio of technical staff should yield improvements in thermal efficiency.

Region showed no significance in predicting thermal efficiency, again no surprise as it is to be expected that each operating Region will place equal emphasis on maintaining optimum thermal efficiency.

7.2.6. Units Generated as Dependant Variable

Overall

F = 75.70, r^2 = 0.9006 (90.06%), Approx. P = 0.9682 x 10^{-51}

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.877	0.351 x 10^{-42}
2	Age of Station	0.657	0.128 x 10^{-16}
3	No. of Gen. Units	0.259	0.257 x 10^{-2}
4	Type of Firing	0.255	0.304 x 10^{-2}
5	Thermal Efficiency	0.722	0.141 x 10^{-21}
7	Utilisation	0.437	0.161 x 10^{-6}
8	Unit Capacity	0.812	0.370 x 10^{-31}
9	Region	0.338	0.731 x 10^{-4}
10	Technical Staff	0.734	0.124 x 10^{-22}
11	Administrative Staff	0.768	0.641 x 10^{-26}
12	Industrial Staff	0.725	0.906 x 10^{-22}
13	Total Staff	0.743	0.192 x 10^{-23}
14	Ratio 10 : 13	0.015	0.983
15	Ratio 11 : 13	0.166	0.560 x 10^{-1}

Table No. 7 – Predicting Units Generated

The overall results showed a high order of significance.

Eleven of the variables proved to be significant in predicting Units generated by power stations.

Two of the fifteen variables, Installed capacity and generating Unit Capacity were affected by auto correlation and would therefore be omitted in future predictions of Units generated.

The ratio of technical staff : total staff had no significance, that of administrative staff : total staff had some significance.

Industrial staff had the greatest significance which is a fair indication of the important contribution industrial staff provide to achieve generated units.

Technical, administrative and total staffs were only slightly less significant in predicting units generated and each staffing variable had a much higher significance than any of the technical variables. Thermal efficiency was the closest in importance to the manning variables and it is acknowledged that highly efficient plant will contribute proportionally more generation. However, the importance of manpower to achieve generation is identified in these results.

Age of plant was highly significant and can be identified relative to thermal efficiency with the realisation that younger plant will contribute more to units generated than old plant.

Utilisation had a higher significance than the type of firing or number of generating sets, no type of fuel contributed more generation than any other unless the utilisation is higher. Utilisation is based on generating costs including thermal efficiency, emphasising that thermal efficiency had the greatest significance of the technical variables, underlining the merit order system of loading generating plant operated by the C.E.G.B..

7.2.7. Utilisation as Dependant Variable

Overall

$F = 25.62$, $r^2 = 0.754$ (75.4%), Approx. $P = 0.3501 \times 10^{-28}$

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.133	0.125
2	Age of Station	0.444	0.102×10^{-6}
3	No. of Gen. Units	0.068	0.416
4	Type of Firing	0.394	0.3025×10^{-5}
5	Thermal Efficiency	0.479	0.592×10^{-8}
6	Units Generated	0.437	0.161×10^{-6}
8	Units Capacity	0.134	0.121
9	Region	0.049	0.546
10	Technical Staff	0.489	0.251×10^{-8}
11	Administrative Staff	0.456	0.375×10^{-7}
12	Industrial Staff	0.356	0.265×10^{-4}
13	Total Staff	0.389	0.373×10^{-5}
14	Ratio 10 : 13	0.052	0.526
15	Ratio 11 : 13	0.068	0.411

Table No. 8 - Predicting Utilisation

The overall results, although not as high as previously, were of satisfactory levels, proving that the eight individually significant variables were acceptable for predicting utilisation of power station plant.

Tehnical staff were highly significant and pointed to utilisation levels depending more on the technical and scientific staff contribution than the administrative and industrial staffs. However, the four staff level variables were all highly significant whereas the two manpower ratio variables had no significance. The proportions of technical and administrative staffs to the total staffing had no significance and no importance in predicting plant utilisation, although each section of manpower had an important role.

The technical variables thermal efficiency, units generated, the age of station and type of firing were highly significant. Understandably thermal efficiency had the highest significance, more so than the age of the station and units generated. It was to be expected that plant with the highest efficiency would be called upon for the highest utilisation. The age of station and thermal efficiency were closely allied as was seen in sections 7.2.2 and 7.2.5.

Installed capacity, number of generating sets, generating unit capacity and the Region also had no significance in predicting utilisation.

The only unusual aspect being that generating unit capacity was not significant. It was to be expected that larger units would have been highly utilised, being more efficient than smaller units, the conclusion to be drawn being that the large units suffered from poor availability and were not runable when required. To a lesser extent installed capacity might well have had some significance in this case, because the larger units tend to result in a station of higher installed capacity. Therefore the explanation is probably that the lower availability of large units was the reason for the lack of significance of installed capacity.

The results show that the Regions adopted a common policy of optimising thermal efficiency, with resultant utilisation levels.

7.2.8. Unit Capacity as Dependant Variable

Overall

F = 114.28, r^2 = 0.9319 (93.19%), Approx. P = 0.298 x 10^{-60}

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.933	0.944 x 10^{-59}
2	Age of Station	0.639	0.154 x 10^{-15}
3	No. of Gen. Units	0.037	0.658
4	Type of Firing	0.167	0.534 x 10^{-1}
5	Thermal Efficiency	0.667	0.256 x 10^{-17}
6	Units Generated	0.812	0.370 x 10^{-31}
7	Utilisation	0.134	0.121
9	Region	0.327	0.123 x 10^{-3}
10	Technical Staff	0.656	0.142 x 10^{-16}
11	Administrative Staff	0.647	0.506 x 10^{-16}
12	Industrial Staff	0.594	0.583 x 10^{-13}
13	Total Staff	0.619	0.258 x 10^{-14}
14	Ratio 10 : 13	0.078	0.360
15	Ratio 11 : 13	0.122	0.158

Table No. 9 – Predicting Unit Capacity

The overall results proved very satisfactory, 'F' was high, 93.19% of the variability could be explained away and the approximate probability that the results could have occurred by pure chance was extremely low.

Thermal efficiency was the variable with the highest significance, the age of the station only slightly less significant. The Region proved to be significant as was the type of firing. It is understandable that Regions may have differing proportions of generating unit capacities. The Midlands Region for example has the largest number of modern large units due to their proximity to cheaper coal, and cooling water from the River Trent, whereas the North Western Region has fewer large units but more small stations containing smaller generating units. The latter result is due to the many urban authority stations which were quite old.

That the type of firing was significant in predicting set size may be explained by the chain grate coal fired boilers only being used in stations having turbo-alternators of up to 60MW capacity. Pulverised fuel and oil are used for similar sizes of generating plant, and nuclear stations use medium to large generating sets, although the largest of 660 MW are not yet commissioned being coupled with the Advanced Gas Cooled Reactors.

Installed capacity and units generated were considered to be affected by auto correlation in the prediction of generating unit capacity.

Not surprisingly the number of generating units was not significant, however it would have been reasonable to expect utilisation to be significant in predicting generating unit capacity. The explanation yet again being that some of the large generating units at this time were not available sufficiently to achieve the utilisation that their efficiency and generating cost would have warranted.

The significance of the various staffing levels and ratios followed a similar pattern to those found in previous cases. Technical, administrative, industrial and total staffing levels were all highly significant in predicting generating unit capacity, whereas the two ratio variables had no significance. Poor availability of the very large generating units where technical staff : total staff ratios are higher than for smaller generating units probably accounts for this lack of significance.

7.2.9. Region as Dependant Variable

Overall

F = 9.49, r^2 = 0.5317 (53.17%), Approx. P = 0.1041×10^{-12}

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.297	0.532×10^{-3}
2	Age of Station	0.026	0.776
3	No. of Gen. Units	0.407	0.119×10^{-5}
4	Type of Firing	0.090	0.289
5	Thermal Efficiency	0.073	0.388
6	Units Generated	0.338	0.731×10^{-4}
7	Utilisation	0.049	0.546
8	Unit Capacity	0.327	0.123×10^{-3}
10	Technical Staff	0.324	0.145×10^{-3}
11	Administrative Staff	0.329	0.120×10^{-3}
12	Industrial Staff	0.437	0.155×10^{-6}
13	Total Staff	0.423	0.443×10^{-6}
14	Ratio 10 : 13	0.131	0.129
15	Ratio 11 : 13	0.159	0.660×10^{-1}

Table No. 10 - Predicting the Region

The overall results were much poorer than in previous cases, although of a satisfactory level with regard to the reliability of the nine individually significant variables in predicting the Region.

Generally the variables show a higher significance in predicting technical factors of power station than in predicting the Region.

Industrial staffing had the highest significance which is interesting in that it indicates that Regions have varying patterns of manning of industrial staff. Total staff is only slightly less significant, including in its number the industrial staff. Technical and administrative staff were highly significant and of a similar order of significance.

The ratio technical staff : total staff had no significance but the ratio of administrative staff : total staff was significant, indicating that Regions vary in their policies regarding the number of administrative staff employed in relation to other staffs.

Installed capacity, number of generating units, units generated and generating unit capacity were significant in this case.

Age of station, type of firing, thermal efficiency and utilisation had no significance in predicting the Region. Thermal efficiency optimisation is common to all Regions' policies and it turned out that utilisations were of a similar order for each Region. This was despite varying patterns of installed capacities, generating unit capacities and number of generating units. With utilisations of similar values higher units generated were therefore a result of larger installed capacities and vice versa.

In brief, Regions had different manning levels and policies, operated stations of differing patterns of plant capacities, but all operated similar policies of optimising thermal efficiencies.

7.2.10. Technical Staff as Dependant Variable

Overall

F = 885.02, r^2 = 0.9906 (99.06%), Approx. P = 0.100×10^{-74}

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.712	0.897×10^{-21}
2	Age of Station	0.685	0.138×10^{-18}
3	No. of Gen. Units	0.392	0.325×10^{-5}
4	Type of Firing	0.359	0.230×10^{-4}
5	Thermal Efficiency	0.638	0.190×10^{-15}
6	Units Generated	0.734	0.124×10^{-22}
7	Utilisation	0.489	0.251×10^{-8}
8	Unit Capacity	0.656	0.142×10^{-16}
9	Region	0.324	0.145×10^{-3}
11	Administrative Staff	0.943	0.786×10^{-63}
12	Industrial Staff	0.871	0.660×10^{-41}
13	Total Staff	0.912	0.378×10^{-51}
14	Ratio 10 : 13	0.103	0.227
15	Ratio 11 : 13	0.205	0.180×10^{-1}

Table No. 11 - Predicting Number of Technical Staff

Overall the results indicated a very high order of significance of the twelve variables which were individually significant in predicting the number of technical staff.

'F' was very high, only 0.94% of the variability could not be explained away and the approximate probability of these results occurring by pure chance was extremely low, as is to be expected as these measurements are directly interrelated.

Interestingly all but two of the variables were significant in this case. The two variables which had no significance were total staff and the ratio of technical staff : total staff both being auto correlated with the dependant variable technical staff.

Administrative staff had more significance in predicting technical staff than any other variable, with industrial staff closely following. The numbers of these staffs were a better measurement than any of the technical variables.

Installed capacity and units generated proved to be highly significant as did the age of station, thermal efficiency and generating unit capacity.

Type of firing whilst being signficant showed to be of less importance than those just mentioned which was interesting in that nuclear stations would be expected to have appreciably higher tehnical staff levels. The conclusion to be made is that technical staff manning patterns are quite similar whatever the type of firing, with small differences only in the number of technical staff between the varying fuels.

The results emphasise that the choice of variables was correct when considering manning levels. These variables being the basis of the method of comparing relative manpower productivity levels.

7.2.11. Administrative Staff as Dependant Variable

Overall

$F = 465.14$, $r^2 = 0.9824$ (98.24%), Approx. $P = 0.100 \times 10^{-74}$

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.732	0.195×10^{-22}
2	Age of Station	0.683	0.167×10^{-18}
3	No. of Gen. Units	0.497	0.138×10^{-8}
4	Type of Firing	0.344	0.550×10^{-4}
5	Thermal Efficiency	0.676	0.576×10^{-18}
6	Units Generated	0.768	0.641×10^{-26}
7	Utilisation	0.456	0.375×10^{-7}
8	Unit Capacity	0.647	0.506×10^{-16}
9	Region	0.329	0.120×10^{-3}
10	Technical Staff	0.943	0.786×10^{-63}
12	Industrial Staff	0.933	0.206×10^{-58}
13	Total Staff	0.956	0.491×10^{-70}
14	Ratio 10 : 13	0.066	0.428
15	Ratio 11 : 13	0.159	0.674×10^{-1}

Table No. 12 – Predicting Number of Adminstrative Staff

Here again the variables, apart from one manpower ratio and two auto-correlated variables, proved to be highly significant in predicting administrative staff levels.

Total staff, which included administrative staff and the ratio administrative staff : total staff were both auto-correlated with administrative staff and were not therefore considered further.

The ratio of technical staff : total staff proved to have no significance in this case, whereas the level of technical staff had the greatest significance of all the variables. This is interesting when compared with the situation in 7.2.10 when the level of administrative staff had the greatest significance in predicting technical staff levels and again industrial staff followed closely after.

Again manning levels had appreciably greater significance in predicting administrative staff than any technical variable.

Of the technical variables the units generated have more effect on administrative staffing levels than installed capacity with the age of the power station and the thermal efficiency also having a great effect.

Type of firing and the Region both had significant effects on administrative staff levels.

7.2.12. Industrial Staff as Dependant Variable

Overall

$F = 14515.24$, $r^2 = 0.9994$ (99.94%), Approx. $P = 0.1000 \times 10^{-74}$

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.696	0.180×10^{-19}
2	Age of Station	0.558	0.390×10^{-11}
3	No. of Gen. Units	0.605	0.156×10^{-13}
4	Type of Firing	0.289	0.740×10^{-3}
5	Thermal Efficiency	0.598	0.360×10^{-13}
6	Units Generated	0.725	0.906×10^{-22}
7	Utilisation	0.356	0.265×10^{-4}
8	Unit Capacity	0.594	0.583×10^{-13}
9	Region	0.437	0.155×10^{-6}
10	Technical Staff	0.871	0.660×10^{-41}
11	Administrative Staff	0.933	0.206×10^{-58}
13	Total Staff	0.995	0.100×10^{-74}
14	Ratio 10 : 13	0.249	0.400×10^{-2}
15	Ratio 11 : 13	0.374	0.959×10^{-5}

Table No. 13 – Predicting Number of Industrial Staff

Overall and individual results and significances bore a close similarity to those of 7.2.10 and 7.2.11.

'F' was extremely high, only 0.06% of the variability could not be explained away and the approximate probability was exceedingly small, being the same value as in the previous two cases.

Total staff was auto-correlated with industrial staff and therefore not considered further.

Administrative staff had the greatest significance in predicting industrial staff levels with technical staff also of a very high order. These two variables were appreciably more significant than the technical or plant variables.

Of the plant variables units generated again had the greatest effect on industrial staff, which showed that producing high generation levels was an important objective of industrial staffs. That utilisation had a lower significance indicates that actual production levels needed more staff than making plant run for longer periods. It is a surprising phenomenon that utilisation is so less important than units generated, they are closely allied and a high utilisation is important to give resultant high generation levels.

All plant variables were significant which again emphasised the satisfactory choice of variables which were to be used for predicting various manning levels. Again the Regions had differing policies with regards to manning patterns and numbers of industrial staffs. One aspect which was not selected in the form of a variable, which does have an affect on manpower levels is the extent of the use of contractors. The use of contractors could well have been significant in predicting industrial staff levels.

7.2.13. Total Staff as Dependant Variable

Overall

$F = 22781.05$, $r^2 = 0.9996$ (99.96%), Approx. $P = 0.1000 \times 10^{-74}$

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.715	0.571×10^{-21}
2	Age of Station	0.594	0.598×10^{-13}
3	No. of Gen. Units	0.576	0.495×10^{-12}
4	Type of Firing	0.309	0.302×10^{-3}
5	Thermal Efficiency	0.620	0.208×10^{-14}
6	Units Generated	0.743	0.192×10^{-23}
7	Utilisation	0.389	0.373×10^{-5}
8	Unit Capacity	0.619	0.258×10^{-14}
9	Region	0.423	0.443×10^{-6}
10	Technical Staff	0.912	0.378×10^{-51}
11	Administrative Staff	0.956	0.491×10^{-70}
12	Industrial Staff	0.995	0.100×10^{-74}
14	Ratio 10 : 13	0.192	0.266×10^{-1}
15	Ratio 11 : 13	0.348	0.438×10^{-4}

Table No. 14 - Predicting Total Staff

In this case the overall results were highly significant, 'F' extremely high, only 0.04% of the variability cannot be explained away and the approximate probability that the results occurred by pure chance was minute and of the same value as in each of the previous cases.

The variables technical staff, administrative staff, industrial staff and the two ratio variables were all auto-correlated with total staff and would not therefore be used in any predictions.

Units generated was the most significant technical variable closely followed by the installed capacity.

The remaining technical variables proved to be highly significant; thermal efficiency, generating unit capacity, age of power station and number of generating units.

As with the prediction of previous staff variables, the Region was significant, pointing to varying manning policies between Regions. The explanation in this case being that although the introduction of pay and productivity schemes was in progress throughout the period, the rate of introduction varied Region to Region, for example in one Region over 90% of the staff were on the scheme whereas in another Region 60% were on it.

7.2.14. Ratio of Technical Staff: Total Staff as Dependant Variable

Overall

F = 33.48, r^2 = 0.8002 (80.02%), Approx. P = 0.2486×10^{-33}

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.0098	0.110 x 10
2	Age of Station	0.083	0.328
3	No. of Gen. Units	0.269	0.171×10^{-2}
4	Type of Firing	0.0019	0.151 x 10
5	Thermal Efficiency	0.070	0.389
6	Units Generated	0.015	0.981
7	Utilisation	0.052	0.526
8	Unit Capacity	0.078	0.360
9	Region	0.132	0.129
10	Technical Staff	0.103	0.227
11	Administrative Staff	0.066	0.428
12	Industrial Staff	0.249	0.400×10^{-2}
13	Total Staff	0.192	0.266×10^{-1}
15	Ratio 11 : 13	0.630	0.604×10^{-15}

Table No. 15 – Predicting the Ratio Technical Staff : Total Staff

Overall results were satisfactory regarding the prediction of this Ratio from the three variables which were individually significant.

'F' was satisfactory, 80.02% of the variability could be explained away and the probability of the results happening by pure chance was low although these overall results are not as good as in the previous case.

However, only three variables showed any significance, the Ratio administrative staff : total staff having the largest significance. The number of industrial staff and number of generating sets being the only other significant variables. The only surprising aspect is that the number of generating units should be significant whereas, for example, thermal efficiency was not. A greater proportion of technical staff would be expected to yield higher utilisation and higher thermal efficiencies. That greater proportions are not used for these purposes indicated a common policy of technical staff patterns,because availability of all stations is not of a high enough order and all stations do not achieve optimum thermal efficiency. All the Regions have a common policy with regard to technical staff manning levels in proportion to total staffs. The extra sophistication of more modern and larger units had not resulted in a greater proportion of technical staff being employed. This points to higher standards of industrial staff being employed in modern large stations, having been trained to operate and maintain larger and more complex machinery.

One factor not covered by this project, which may affect this ratio in the early life of a new power station, is the work carried out by contractors, either those who manufactured the plant, or contractors who are qualified to carry out work on sophisticated systems or plant.

Another factor which may be pertinent is that scientific teams which are usually based at each Region generally carry out more investigations into problems at large new stations, where the pay back is higher, than for smaller well established stations. Similarly other Regionally based services, maintenance workshops for example, carry out more work for large stations than small.

The results bear out earlier observations that proportions of technical staff involved on operation do not differ, whether as a result of variation in station capacity, units generated or for different types of firing.

The variables technical staff and total staff were auto-correlated with the dependant variable and were therefore not considered further.

7.2.15. Ratio Administrative Staff: Total Staff as Dependant Variable

Overall

F =30.97, r^2 = 0.7875 (78.75%), Approx. P = 0.8513×10^{-32}

Individual Results

No. of Variable	Variable	'r'	P, Approx. Probability by pure chance
1	Installed Capacity	0.194	0.589×10^{-1}
2	Age of Station	0.039	0.635
3	No. of Gen. Units	0.210	0.153×10^{-1}
4	Type of Firing	0.057	0.487
5	Thermal Efficiency	0.150	0.831×10^{-1}
6	Units Generated	0.166	0.560×10^{-1}
7	Utilisation	0.068	0.411
8	Unit Capacity	0.122	0.158
9	Region	0.159	0.660×10^{-1}
10	Technical Staff	0.205	0.180×10^{-1}
11	Administrative Staff	0.159	0.674×10^{-1}
12	Industrial Staff	0.374	0.959×10^{-5}
13	Total Staff	0.348	0.438×10^{-4}
14	Ratio 10 : 13	0.630	0.605×10^{-15}

Table No.16 - Predicting the Ratio Administrative Staff : TotalStaff.

Overall results were of a similar order to those in the previous case although nine of the independant variables proved to be significant, compared with three significant variables predicting the previous ratio.

The variables administrative staff and total staff were auto-correlated with the dependant variables.

Variables showing no significance in the prediction of this Ratio were age of station, type of firing, utilisation and generating unit capacity.

The most significant variable was the Ratio technical staff : total staff, being appreciably more significant than any other. Technical staff and industrial staff also proved to be significant.

Regions had differing policies regarding the proportion of administrative staff to total staff.

Of lesser significance were the Installed Capacity, number of generating units, thermal efficiency and units generated. It was surprising that thermal efficiency was significant whereas the age of the station was not, there being a strong inter-relationship between these variables.

Similarly utilisation did not have any bearing on this Ratio whereas the units generated did. More units generated would affect the ratio of administrative staff : total staff , whereas the increased utilisation necessary to achieve more units generated does not affect this ratio at all.

A major feature of administrative staff work is that of administering personnel matters, monitoring expenditure and compiling statistics and returns. These activities increase as a result of increased activity by technical staff. The significance of the technical staff : total staff Ratio is explainable in this context.

7.2.16. General Comments on Significance of the Variables

The overall results for the prediction of the dependant variables were as follows:-

Dependant Variable	F	r^2 (% variability explained away)	P, Approx. Probability by pure chance
1. Installed Capacity	228.07	0.9647(96.47%)	0.100×10^{-74}
2. Age of Station	23.77	0.7398(73.98%)	0.834×10^{-27}
3. No. of Gen. Units	21.18	0.7170(71.70%)	0.9493×10^{-25}
4. Type of Firing	3.76	0.3120(31.20%)	0.3268×10^{-4}
5. Thermal Efficiency	29.05	0.7766(77.66%)	0.1493×10^{-30}
6. Units Generated	75.70	0.9006(90.06%)	0.9682×10^{-51}
7. Utilisation	25.62	0.754 (75.4%)	0.3501×10^{-28}
8. Unit Capacity	114.28	0.9319(93.19%)	0.298×10^{-60}
9. Region	9.49	0.5317(53.17%)	0.1041×10^{-12}
10. Technical Staff	885.02	0.9906(99.06%)	0.1000×10^{-74}
11. Administrative Staff	465.14	0.9824(98.24%)	0.1000×10^{-74}
12. Industrial Staff	14515.24	0.9994(99.94%)	0.1000×10^{-74}
13. Total Staff	22781.05	0.9996(99.96%)	0.1000×10^{-74}
14. Ratio 10 : 13	33.48	0.8002(80.02%)	0.2486×10^{-33}
15. Ratio 11 : 13	30.97	0.7875(78.75%)	0.8513×10^{-32}

Table No. 17 - Overall Results for Predictions of Dependant Variables

In all cases the values of 'F', r^2 and the approximate probability showed that when predicting each dependant variable some of the independant variables were highly significant.

There was a considerable difference between the results when predicting Type of Firing, which showed lowest significance of all, and those variables with the highest significance i.e. Installed Capacity and the staffing variables.

The staffing level variables were highly significant in every case, whether the dependant variable was of a technical nature or number of staff. However, when predicting the Ratio technical staff : total staff the administrative staff had no significance, although industrial staff and total staff were both significant and the Ratio administrative staff : total staff was highly significant.

Similarly when predicting the Ratio administrative staff : total staff the staffing variables were significant and the Ratio technical staff : total staff was highly significant.

Generally the two Ratio variables were not very successful in predicting the other variables. The Ratio technical staff : total staff was only significant when predicting the number of Generating Units and the number of industrial staff. The technical staff numbers variable was also highly significant when predicting the number of Generating Units and the number of industrial staff.

Therefore the higher proportion of technical staff : total staff is only likely when there are more generating units, not when there is more installed capacity, and a greater proportion of technical staff will not result in higher thermal efficiencies or utilisation. The actual numbers of staff in each section is more important than different proportions of technical staff, although more technical staff proportionally will indicate more industrial staff.

In contrast the Ratio administrative staff : total staff was significant in predicting all but four variables, these were Age of Station, Type of Firing, Utilisation and Unit Capacity.

To complete the picture regarding staffing sections, a further variable may have proved to be useful, that being the Ratio industrial staff : total staff.

By testing this Ratio it may be confirmed that, for example, a higher thermal efficiency is achieved by having a larger proportion of industrial staff, or that a higher utilisation and more units may have been generated.

As the variables stand, without this further ratio, the importance of having sufficient staffing levels in each section is seen to be very important. For some variables the Ratio of administrative staff : total staff is significant but in no case is this Ratio as high in significance as each of the staff level variables.

Despite the varying results from the two Ratio variables it has been shown that when predicting the technical variables the levels of technical, administrative and industrial staff are highly significant. Equally it has been shown that when predicting individual staff levels; technical, administrative or industrial, the technical variables are all significant, many being highly significant.

Even though the interaction between technical and staffing variables varies, in other words the cause and effect vary from one side to the other, the technical variables are satisfactory for predicting staffing levels.

A large Installed Capacity for example is the cause of a large number of technical staff, whereas an increase in industrial staff may be a cause, the effect of which is that thermal efficiency increases or more units are generated.

It has also been shown that when predicting staffing variables the remaining staffing section variables are highly significant. For example, when predicting the technical staff, the administrative and industrial staffs appeared to be highly significant.

The Region also proved to be significant when predicting all the individual staffing sections, which indicates that each Region has different policies for their staffing levels, or that progress in implementing the Pay and Productivity Schemes has been slower in some Regions than in others.

There was no significance in the variables Age of Station, Type of Firing, Thermal Efficiency and Utilisation in predicting the Region and equally when predicting each of these technical variables, the Region had no significance.

This shows that each Region had plant of similar age groups, with similar proportions of fuel firing and aimed for optimising thermal efficiency with the same priority and produced similar results in terms of thermal efficiency and utilisation. If thermal efficiencies and utilisation are similar from Region to Region, it follows that Regional performances do not vary very much and it also follows that overall plant availability must be similar.

The requirement for optimum thermal efficiency and its achievement is a measure of productivity, it has already been highlighted as being very important and a major objective of power station and Regional managements, and has been the subject of international comparisons.

In every case where it is used in predicting technical variables, thermal efficiency is highly significant and when thermal efficiency is being predicted all the technical variables proved to be significant. Similarly when predicting thermal efficiency the staffing levels were shown to be highly significant, being higher in significance than some of the technical variables.

When predicting each section of staffing, thermal efficiency proved to be highly significant, there is, therefore, an inter-relationship between thermal efficiency and the different staff sections.

The dependant variable which the independant variables predicted the least satisfactorily was Type of Firing. It appears that there are similarities between the types of firing, in technical performance and manpower levels.

The explanation is probably that type of firing is concerned with the boilers in each power station, or steam raising reactors, in the case of nuclear plant. Boilers only form part, albeit a large part,of plant installed in a power station. However the remaining plant is similar, size for size, from one station to another. Type of Firing would have had a much higher significance if the C.E.G.B. had a large capacity of hydro plant. When international comparisons are made,Type of Firing will have much more significance for industries with a large proportion of hydro-electric plant.

In Section 7.2.5 it was noted that low availability of large modern generating units had resulted in the number of units generated having a much higher significance than utilisation. When these generating units are contributing more generation the results will be somewhat different to those obtained in this project. However, if annual comparisons of relative performance were to be carried out the reactions and significances of the variables would vary but the principles and variables used should still have proved to be soundly based.

7.3 Predicting Values of Variables

In the previous section it was shown that certain of the independant variables were significant when predicting them individually as dependant variables.

Predictions will be made, in this section, of values of dependant variables, for different size power stations, using the coefficients of the significant independant variables as follows:-

$$\text{Predicted value} = a_0 + a_1 v_1 + a_2 v_2 + \ldots\ldots a_n v_n$$

where a = coefficient

v = value of significant independant variable for the power station.

The dependant variables to be predicted are those which may be expected to vary, from station to station, as a result of different operating management policies or decisions. There is no point in predicting installed capacity or age of station for example, these two variables will affect staffing levels but staffing levels will not affect them.

Therefore, of the technical variables only Thermal Efficiency will be predicted . This is affected by management policies and efficient use of resources as are the staffing and staffing ratio variables which will also be predicted.

7.3.1. Predicting Thermal Efficiency

No. of Indep't Variable	Independent Variable	Coefficient	Probability by Chance
		Constant= 16.336	
1	Installed Capacity	0.09247	10^{-22}
2	Age of Station	0.20076	10^{-26}
3	No. of Gen. Units	- 0.21134	10^{-1}
4	Type of firing	- 0.30461	10^{-1}
6	Units Generated	- 0.08026	10^{-21}
7	Utilisation	0.10766	10^{-8}
8	Unit Capacity	- 0.00784	10^{-17}
10	Technical Staff	- 0.06863	10^{-15}
11	Administrative Staff	0.20924	10^{-18}
12	Industrial Staff	0.00646	10^{-13}
13	Total Staff	- 0.00633	10^{-14}
15	Ratio Admin. : Total Staff	-30.657	10^{-1}

Table No. 18 - Coefficients for Predicting Thermal Efficiency. (Overall probability= 10^{-32})

In predicting thermal efficiency the signs of the coefficients of the significant independent variables show that thermal efficiencies improve as stations increase in installed capacity and as they get younger in age.

Stations with fewer generating units have higher thermal efficiencies, which is a reflection of recent policies of installing fewer large units of say 500 MW output, than the many stations having six or more 60 MW units.

One surprising coefficient is that for generating unit capacity which indicates that as generating unit capacity increases, thermal efficiency decreases, albeit to a very small degree. Over the years as generating unit sizes increased higher steam temperatures and pressures and the incorporation of reheat resulted in higher thermal efficiencies. Additionally larger generating units have proportionally lower losses which again should result in improved thermal efficiencies. The contrary result indicates the poor early performance of the new large generating units which up to March 1973 did not achieve designed thermal efficiencies.

The staffing level coefficients show that an increase in administrative and industrial staff levels produce an improved thermal efficiency, whereas increasing technical and total staff levels are associated with reductions in thermal efficiency. That the total staff is negative was due to the negative sense of technical staff just overcoming the positive senses of administrative and industrial staffs.

The negative sense of technical staff is interesting, in that when predicting thermal efficiency the expectation is that if more technical and scientific knowledge and expertise is applied then thermal efficiency should increase. It could be deduced that rather than increasing technical staff to achieve an improved thermal efficiency, an improvement would be achieved by increasing the number of administrative and industrial staff, decreasing the number of technical staff. However, the Ratio Administrative Staff: Total Staff also takes the negative sign of Total Staff.

Applying the variables and their coefficients to a selection of power stations, results were obtained and are shown in the table.

Power Station		Installed Capacity $\frac{MW}{10}$	Predicted Thermal Efficiency %	Actual Thermal Efficiency
Class	No.			
Small	16	3.90	20.401	23.580
	66	5.70	17.905	14.240
Medium	23	39.0	31.180	25.100
	53	42.0	29.404	25.880
Large	44	198.0	35.253	34.760
	88	198.3	34.256	33.940

Table No.19 - Comparison of Predicted and Actual Thermal Efficiencies for a sample of Power Stations.

These power stations were selected to show examples for small stations of up to 200 MW capacity, medium capacity of 201 MW to 1000 MW and large stations of greater than 1001 MW installed capacity.

In this case Nos. 16 and 66 being small, 23 and 53 medium, 44 and 88 being large capacity stations.

Table No. 20 - Net Effect of Variables when Predicting Thermal Efficiency. (Constant = 16.336).

Power Station		Predicted Thermal Efficiency %	Net Effect of Plant Variables	Net Effect of Staffing Variables
Class	No.			
Small	16	20.401	5.8340	- 1.7685
	66	17.905	4.3370	- 2.7677
Medium	23	31.180	16.5901	- 3.7459
	53	29.404	16.2035	- 3.1358
Large	44	35.253	21.7749	- 2.8584
	88	34.256	19.6547	- 1.7343

Table No.20 shows the net effect of plant variables which are positive, compared with the negative net effect of staffing variables when prediciting thermal efficiency. Staffing variables have a small effect compared with the value of thermal efficiency and yet as seen from Table 18 they are highly significant.

The constant is quite high at 16.336 and has a large effect on predicted thermal efficiency.

In the case of Power Station No. 16 (P.S.16) the actual thermal efficiency is appreciably higher than that predicted. The result for the station is a utilisation of 32.85%, which will be seen from Table No.43 to be high for a station of this very small installed capacity. It can be compared with P.S.66 which had a utilisation of 6.26% and a low actual thermal efficiency of 14.240%.

The high utilisation of P.S. 16 had an appreciable affect in predicting thermal efficiency and when comparing the performance of power stations it would be realised that this station is returning an excellent thermal efficiency.

P.S.66 has particularly poor plant performance variable results and the predicted thermal efficiency is appreciably higher than was actually achieved. It will be seen that (compared with P.S.16) the number of industrial staff is particularly low at 22 (P.S.16 having 109) and administrative staff low at 3 (P.S.16 having 8)

The medium size stations P.S.23 and P.S.53 both returned lower thermal efficiencies than were predicted, particularly P.S.23 which has quite large sized generating units at 97.5 MW. It also is quite a modern station so that the designed thermal efficiency could well be of the order of 32%. Both stations have 100% utilisation which, considering their low thermal efficiencies, is a reflection of the low availability of the newer larger stations, which return much lower utilisations. In this prediction the effects of high utilisation are a major contribution to the high predicted values of thermal efficiencies for P.S.23 and P.S.53.

P.S.44 and P.S.88, the large stations, have actual thermal efficiencies which fall short of designed values, again a result of poor availability. If one considers a situation where the large units achieved a utilisation of 90% then the results of the multiple regression would appear completely different. In the existing exercise, for P.S.44 and P.S.88 the Installed capacity factors are particularly high, whereas Utilisations (V7) are very low. Under the postulated situation the relative values of Installed capacity and Utilisation factors would be reversed.

In general it may be stated that the significant independant variables can be used to predict the thermal efficiency of a power station. Having predicted a value for a station, the reason for any deviation from the actual value can be assessed by studying the weighting of the various factors as shown for example in Table No. 20, and as explained above.

It is necessary when using variables in the way they have been used in this exercise, to present results in such a way that reasons for deviations from actual values can be identified together with the cause of the deviation.

7.3.2. Predicting the Number of Technical and Scientific Staff

No. of Indep't Variable	Independant Variable	Coefficient	Probability by Chance
		Constant = 24.688	
1	Installed Capacity	0.23218	10^{-21}
2	Age of Station	0.31362	10^{-18}
3	No. of Gen. units	- 1.29860	10^{-5}
4	Type of firing	0.04732	10^{-4}
5	Thermal efficiency	- 1.22370	10^{-15}
6	Units generated	- 0.43650	10^{-22}
7	Utilisation	0.32682	10^{-8}
8	Unit Capacity	- 0.00810	10^{-16}
9	Region	0.92400	10^{-3}
11	Administrative Staff	3.06860	10^{-63}
12	Industrial Staff	- 0.02434	10^{-41}
15	Ratio: Admin: Total Staff	-254.490	10^{-1}

Table No. 21 - Coefficients for Predicting the Numbers of Technical and Scientific Staff. (Overall probability = 10^{-58})

When considering the coefficients of independant variables for predicting numbers of technical staff the negative coefficient of number of generating units calls for some explanation. Generally, in most stations, generating units are similar in manufacture, design and construction but on the face of it more units would seem to require more technical staff. But the patterns of operational staffing are similar whether there are two generating units or four. In many stations the patterns of technical staff for maintenance and services are the same, independant of the number of generating units but dependant on the installed capacity.

When predicting technical staff, thermal efficiency has a negative coefficient. This is similar to predicting thermal efficiency, as was seen in the previous section when fewer technical staff were associated with a higher thermal efficiency.

In conjunction with the negative coefficient of thermal efficiency it will be seen that units generated also has a negative coefficient, whereas utilisation has a positive coefficient.

Thermal efficiency and utilisation are inter-related in that a higher thermal efficiency would result in the power station being instructed to produce more electricity hence returning a higher utilisation.

Poor performance of large new generating plant in its early life often prevents this. From the data in Table No. 43. the average utilisation of 500 MW generating units was 32.2%. This is very low when one considers that even though several of these stations did not reach optimum thermal efficiency, their efficiency is appreciably higher than most of the remaining generating plant, hence they would have been required to be generating for a much longer period than this. From general observation it will be seen than the highest utilisations occurred in the stations with medium sized generating units.

These results also appear to have affected unit capacity which has a negative coefficient. Increased complexity and technical sophistication have called for more technical staff on new power stations with large generating plant. The coefficient is of a small order but it is highly significant.

The negative coefficient of industrial staff is also interesting showing that more industrial staff will be associated with fewer technical staff. This is surprising when it is realised that the technical staff provide the supervisory and management function and shows that the same number of technical staff are managing more industrial staff. First line supervision, at foremen level, is provided by industrial staff.

The explanation is probably that increased manual industrial staff requires an increased number of foremen. These foremen are recruited and administered as industrial staff, whereas the number of management staff remains the same.

The positive coefficient of administrative staff was to be expected, the greater clerical committment being to provide the greater numbers of reports, statistics, etc., required when more technical staff are employed.

Applying the variables and their coefficients to a selection of power stations, of varying sizes, as explained in 3.3.1., results are shown in Table No. 22.

Power Station Class	Power Station No.	Installed Capacity MW/10	Predicted No. of Technical Staff	Actual No. of Technical Staff	Diff. Pred. -Actual
Small	4	7.5	20	25	-5
	24	8.6	21	24	-3
Medium	59	62.1	74	72	2
	77	67.8	80	77	3
Large	63	198.3	84	119	-35
	123	198.3	103	81	22

Table No. 22 - Comparison of Predicted and Actual Numbers of Technical Staff for a Sample Number of Power Stations

Results for the two small stations P.S.4 and P.S. 24 are quite similar. P.S.24 had a higher thermal efficiency than P.S.4 and had twice the utilisation. P.S.4 was four years older, these differences in the three variable were the main cause of the one extra technical staff being predicted for P.S.24.

Both medium sized stations were actually staffed by fewer technical staff than were predicted. P.S.77 is not as old as P.S.59, it is more efficient, but has a poorer utilisation. Both stations produced very nearly the same units of electricity. P.S.77 employs twice the number of industrial staff with nine generating units as against the seven of PS.59. Some differences can be explained by some power stations being quoted as an entity, whereas they are multi stations on a single site.

Multi-Station sites differ in manning patterns to single station sites, this feature being discussed in more detail in the General Section 3.3.

It is seen from Table 22 that the predictions for the two large stations are different. In the case of P.S. 63 the predicted level is lower than the actual, but vice versa for P.S.123. There is a large difference in the actual numbers of technical staff employed at each station. As both sites have the same number of generating units, the same installed capacity and are of similar ages, the difference in numbers of men of 38, compared with actual number of 81 at P.S.123 and 119 at P.S.63 is high. Being in different Regions, accounted for two more men being employed at P.S.123 which had the lowest actual staffing.

The major difference in predicted values was due to there being more administrative staff in P.S.123 which resulted in a higher factor contributing to the predicted value. P.S.123 employed 6 more administrative staff than P.S.63, the coefficient of 3.0686 giving a factor of 107.5759 for P.S.123, compared with 89.1735 for P.S.63.

An interesting comparison is the net effect which technical variables have against the net effect staffing variables (and Region) have when predicting numbers of technical staff.

Power Stn. Class	No.	Predicted No. of Technical Staff	Net effect of Plant variables	Net effect of Staffing variables
Small	4	20.4	- 15.1	+ 10.8
	24	21.1	- 14.2	+ 10.6
Medium	59	74.3	- 6.0	+ 55.6
	77	79.5	- 18.0	+ 72.8
Large	63	83.6	- 9.6	+ 68.5
	123	103.3	- 7.0	+ 85.5

Table No.23-Net effect of variables when predicting Technical Staff. (Constant = 24.7)

Table No.23. shows that the plant variables have a net negative effect when predicting technical staff whereas the staffing variables make a heavy positive contribution.

7.3.3. Predicting Administrative Staff

No. of Indep't Variable	Independant Variable	Coefficient	Probability by Chance (rounded)
		Constant = - 1.7646	
1	Installed Capacity	- 0.02569	10^{-22}
2	Age of Station	0.06766	10^{-18}
3	No. of Gen. Units	0.29792	10^{-8}
4	Type of firing	0.22253	10^{-4}
5	Thermal efficiency	0.11490	10^{-18}
6	Units generated	0.06456	10^{-26}
7	Utilisation	- 0.01114	10^{-7}
8	Unit Capacity	0.00507	10^{-16}
9	Region	- 0.30995	10^{-3}
10	Technical Staff	0.15396	10^{-63}
12	Industrial Staff	0.02702	10^{-58}

Table No.24- Coefficients for Prediciting Number of Administrative Staff (Overall Prob. = 10^{-74})

From the coefficients it will be seen that the number of administrative staff tend to reduce with increasing installed capacity. However this staffing tends to increase with higher thermal efficiency, where more electricity is generated and at stations where there are multiples of large generating units.

Increases in the numbers of technical and industrial staff tend towards higher levels of administrative staff. This tendancy is to be expected because personnel administration is an important aspect of the clerical function.

The Region has a coefficient with a negative sense when predicting administrative staff, whereas the Region has a positive sense when predicting technical staff. These could indicate varying manning policies adopted by different Regions.

Applying these variables and coefficients to a selection of small, medium and large capacity power stations, gave results shown in Table No.25.

Power Stn. Class	Power Stn. No. from Table	Installed Capacity MW/10	Predicted No. of Admin. Staff	Actual No. of Admin. Staff	Diff Predicted – Actual
Small	21	6.6	6.7	6.0	0.7
	75	3.0	4.1	4.0	0.1
Medium	87	4.7	27.7	29.0	-1.3
	104	59.1	23.9	22.0	1.9
Large	56	118.0	28.5	29.0	-0.5
	102	105.7	30.3	30.0	0.3

Table-No.25-Comparison of Predicted and Actual Numbers of Administrative Staff for a Sample of Power Stations.

The predicted values in this case were quite close to the actual numbers although the percentage variation between predicted and actual values for P.S.21 was high at 17.5%.

The two small stations vary considerably in industrial staff levels, there being 77 employed at P.S.21 and only 12 at P.S.75, these factors therefore being much higher for P.S.21.

The staffing variables were by far the most significant when predicting administrative staff, the contributions made by technical factors and staffing factors excluding the Region being shown in Table No.26.

Power Station Class	Power Station No.	Predicted No. of Admin. Staff	Net Contribution of Plant Variables	Net Contribution of Staffing Variables
Small	21 75	6.7 4.1	4.3 4.8	4.2 1.1
Medium	87 104	27.7 23.9	7.6 8.0	21.9 17.8
Large	56 102	28.5 30.3	8.7 9.6	21.6 22.5

Table No. 26–Net Contribution of Variables when Predicting Number of Administrative Staff. (Constant = -1.76)

In general terms the net contributions of plant variables are very similar to thoseof staffing variables for the small power stations. For P.S.75 the plant variable contribution is more than double the staffing variable contibution. When the medium and large stations are considered there is a similarity between the plant variables contribution for each station and for staffing variables contribution.

The ratios of these for the medium and large stations is of a similar order.

The tendancy shown is that for small station plant the staffing variables have a similar contribution when predicting administrative staff. However the contributions for medium and larger stations from the plant variables is approximately 0.3 to 0.4 times the contribution of staffing variables.

7.3.4. Predicting Industrial Staff

No. of Indep't Variable	Independant Variable	Coefficient	Probability by Chance
		Constant = 152.20	
1	Installed Capacity	0.10660	10^{-19}
2	Age of Station	- 1.68940	10^{-11}
3	No. of Gen. Units	8.66780	10^{-13}
4	Type of firing	4.05450	10^{-3}
5	Thermal efficiency	0.27799	10^{-13}
6	Units Generated	0.21819	10^{-22}
7	Utilisation	- 0.32465	10^{-4}
8	Unit Capacity	0.00636	10^{-13}
9	Region	5.07430	10^{-6}
10	Technical Staff	- 0.25221	10^{-41}
11	Administrative Staff	13.7410	10^{-58}
14	Ratio Technical: Total Staff	-65.0590	10^{-2}
15	Ratio Admin: Total Staff	-2528.90	10^{-5}

Table No.27 - Coefficients for Predicting the Number of Industrial Staff. (Overall probability = 10^{-69})

Considering the coefficients of the significant independant variables for predicting the numbers of industrial staff, the first explanation which is required is the negative coefficient for age of station. This is saying that, as stations get older, they require more industrial staff, which is reasonable when one considers that more wear in plant items necessitates more breakdown repair work. In older stations too, operational staffing patterns resulted in more men being required to operate boiler and turbines locally, whereas in modern stations many fewer men operate a boiler/turbo-alternator unit centrally by remote control.

The negative coefficient for utilisation is interesting because the more plant is being utilised the more wear, vibration, fatigue, etc., is taking place which calls for more industrial staff to carry out repair and maintenance. However if utilisation is extremely high, (some stations have 100% quoted) then there is no opportunity to carry out substantial repairs and preventative maintenance unless standby plant is available. Also if plant is achieving this level of utilisation, the repairs (etc) are not necessary at that time, but will become necessary later, as a result of the high utilisation.

It is interesting that the Region has a substantial effect, indicating that Regions have differing policies with regard to number of industrial staff employed in power stations.

These variables and their coefficients were applied to a selection of small, medium and large power stations to predict the numbers of industrial staff for each station, results are shown in Table No.28.

P.S.6 has 4 generating units whereas P.S.22 has 2, the contributing factors, from the product of value of variable and its coefficient, result in 34.67 for P.S.6 and 17.34 for P.S.22. P.S.26 is younger than P.S.34 and has 3 generating units compared with 8 for P.S.34, the differencies in these factors causing the difference in values of plant variables between these two power stations.

In the case of staffing variables, the major contribution to the change from negative for small stations to positive for the other stations is the large coefficient of 13.741 for Administrative Staff, and the affect of Region. The factors from the two ratio variables are of the same order for all six power stations, irrespective of size.

Power Station Class	Power Station No.	Installed Capacity $\frac{MW}{10}$	Predicted No. of Industrial Staff	Actual No. of Industrial Staff	Diff. Predicted - Actual
Small	6	6.70	108.9	98.0	10.9
	22	5.90	74.0	80.0	-6.0
Medium	26	64.50	341.9	381.0	-39.1
	34	39.00	365.1	414.0	-48.9
Large	55	133.80	503.4	537.0	-33.6
	107	183.10	774.7	933.0	-158.3

Table No. 28 - Comparison of Predicted and Actual Numbers of Industrial Staff for a Sample of Power Stations.

In the case of P.S.6 there were 10 more industrial staff predicted than were actually employed, but in the other examples the predicted values exceeded the actual.

Where comparisons were being made on a formal basis the discrepancies would be investigated to find reasons.

There are two factors which have not been taken into account which particularly affect the industrial staff and total staff levels.

The first factor is that, where a power station site includes more than one power station, more industrial staff will be employed. Plant varies from station to station so that it is not just a matter of number of generating units which determines manpower requirements.

A difficulty arises when trying to account for the variables on a multi station site, this remains to be resolved. The other factor, not included in this project, is the amount of contractual work carried out on a station. On many of the new stations there is a high utilisation of contractors: even general engineering firms who meet peak maintenance work loads. If no contractors were employed, more industrial staff would be required than at present. This aspect also needs clarifying for inclusion in the calculations regarding relative productivity. Within an industry much of this information could be obtained and used, but in international companies this area of comparison would be more difficult to take account of.

Power Station		Predicted No. of Industrial Staff	Net effect of Plant Variables	Net effect of Staffing Variables
Class	No.			
Small	6	108.9	13.07	- 56.40
	22	74.0	-11.57	- 66.60
Medium	26	341.9	-26.35	216.01
	34	365.1	27.64	185.28
Large	55	503.4	38.74	312.43
	107	774.7	90.13	532.33

Table No. 29 - Net Effect of Variables when Predicting Number of Industrial Staff. (Constant = 152.20)

From Table No. 29 it will be observed that the net effect of plant variables changes sense from positive to negative and then to positive as station sizes increase.

7.3.5. Predicting Total Staff

No. of Indep't Variable	Independant Variable	Coefficient	Probability by chance
		Constant = -156.330	
1	Installed Capacity	1.75840	10^{-21}
2	Age of Station	-1.39130	10^{-13}
3	No. of Gen. Units	41.964	10^{-12}
4	Type of firing	43.458	10^{-3}
5	Thermal efficiency	0.45483	10^{-14}
6	Units Generated	-0.41763	10^{-23}
7	Utilisation	2.6383	10^{-5}
8	Unit Capacity	0.30099	10^{-14}
9	Region	3.0743	10^{-6}

Table No. 30 - Coefficients for Predicting the Number of Total Staff (Overall Probability = 10^{-37})

The significant independant variables in this case are the plant and technical variables plus the Region. All the staffing and staff ratio variables being auto - correlated with total staff.

As was the case in the previous section, the coefficient for age of station is negative: the explanation for this being similar to that given earlier.

One interesting feature is that in predicting industrial staff utilisation is positive, whereas Units generated is negative, it having the highest significance of the variables.

The number of generating units has a high coefficient, showing that a large work load is entailed for each generating unit, which is quite logical in the context of total staffing. Type of firing also has a high coefficient, showing that a typical coal fired power station would have 43 more staff than a comparable oil fired station.

Comments made in the Section predicting Industrial Staff regarding the use of contractors and multi-station sites are again relevant to this section.

Power Station Class	Power Station No.	Installed Capacity MW/10	Predicted Total Staff	Actual Total Staff	Diff. Predicted - Actual
Small	16	3.9	105.0	139.0	-34.0
	82	5.7	142.3	143.0	-0.7
Medium	23	39.0	492.9	512.0	-19.1
	65	46.6	453.7	340.0	113.7
Large	44	198.0	552.6	386.0	166.6
	85	198.3	695.3	707.0	-11.7

Table No. 31 - Comparison of Predicted and Actual Total Staff for a Sample of Power Stations.

Comparing predicted and actual total staffing levels of the six power stations, differences are low in the case of P.S.82, P.S.23 and P.S. 85. Two of the stations P.S.65 and P.S.44 have predicted values appreciably higher than the actual levels.

In the case of P.S.65, a major contribution to this is from the number of generating units, there being 8 at this power station.

The actual value of 340 for this power station is quite low for its installed capacity. Even P.S.23 which is quoted in this section, has a lower installed capacity and yet the total staff of 512 is 172 higher.

P.S.44 also has an actual value of 386, which is very low for a power station containing four 500 MW generating units. As comparisons P.S.85 and P.S.88 (both having four 500 MW generating units installed) each employs over 700 staff.

When predicting total staff, other than the Region, all variables are plant variables. The factors for Region vary from about 3 to 12; so that in the final predicted values, the Region has only a very small contribution, the largest influences on total staff being technical and plant features.

7.3.6 Predicting the Ratio Technical Staff : Total Staff

No. of Indep't Variable	Independent Variable	Coefficient	Probability by Chance (rounded)
		Constant = 0.06331	
3	No. of Gen. Units	-0.00327	10^{-2}
12	Industrial Staff	0.000024	10^{-2}
15	Ratio Admin : Total Staff	1.7800	10^{-15}

Table No. 32 Coefficients for Predicting the Ratio Technical Staff : Total Staff (Overall probability = 10^{-14})

Only three independent variables, of the fourteen tested, proved to be significant when predicting the ratio of technical staff : total staff. Of those three variables only the number of generating units was a plant variable, its coefficient being in a negative sense, showing the tendancy for a lower ratio of technical to total staff with more generating units . From section 7.3.2 it will be observed that the number of generating units had a negative sense when predicting technical staff, whereas this variable has a positive sense when predicting total staff.

Of the significant staffing variables the ratio of administrative staff : total staff had a high significance, the variables industrial staff and number of generating units having a much lower significance, much less than the overall significance.

Predictions were made for a sample of six power stations, the results being shown in Table No.33 .

Power Station Class	Power Station No.	Installed Capacity MW/10	Predicted Value of Tech Staff/ Total Staff	Actual Value of Tech Staff/ Total Staff	Difference Predicted - Actual
Small	82	5.7	0.159	0.157	0.002
	100	3.4	0.161	0.157	0.004
Medium	40	41.0	0.208	0.269	-0.061
	65	46.6	0.133	0.183	-0.050
Large	69	198.3	0.177	0.255	-0.078
	85	198.3	0.167	0.157	0.010

Table No.33 - Comparison of Predicted and Actual Ratios of Technical Staff :Total Staff for a Sample of Power Stations.

The predicted values for P.S.82, P.S.100 and P.S.85 are quite close, the small stations having predicted figures 1.2% and 2.5% higher than actual. P.S. 85 predicted figure is 6.7% higher than actual.

In the case of P.S. 40, P.S.65 and P.S.69, the actual ratio exceeds the predicted ratio by considerable amounts, by 22.7%, 27.3% and 30.6% of the actual values respectively.

Power Station Class	Power Station No.	Predicted Value of Ratio Tech /Total	Net Contribution of plant Variables	Net Contribution of staffing variables
Small	82	0.159	-0.0098	0.1059
	100	0.161	-0.0066	0.1044
Medium	40	0.208	-0.0131	0.1580
	65	0.133	-0.0262	0.0955
Large	69	0.177	-0.0131	0.1268
	85	0.167	-0.0131	0.11644

Table No. 34 - Net Contributions of Variables when Predicting the Ratio of Technical Staff : Total Staff (Constant = 0.0633)

There is a large difference in the actual ratios in the examples selected. For example, in the medium size stations P.S. 40 has a ratio of 0.269, the P.S.65 ratio is 0.183. In the case of the large stations, P.S.69 has an actual ratio of 0.255, whereas the P.S.85 ratio is 0.157.

Nine stations having 4 x 500 MW installed generating units and an installed capacity of 1983MW (ie 2000MW minus works power) show the following actual technical : total staffing ratios.

Power Station No.	Technical/ Total Staff	Power Station No.	Technical/ Total Staff
11	0.157	88	0.157
44	0.216	105	0.150
63	0.245	117	0.135
69	0.255	123	0.132
85	0.157		

Table No. 35 - Actual Technical : Total Staff Ratios for a Sample of Large Power Stations.

As has been shown by the regressions, the type of firing has no significance in explaining the ratio in question and yet there is a large variation in actual ratios in the large stations, from 0.132 to 0.255.

7.3.7 Predicting the Ratio Administrative Staff : Total Staff

No. of Indep't Variable	Independent Variable	Coefficient	Probability by Chance (rounded)
		Constant = 0.01349	
1	Installed Capacity	-0.00003	10^{-1}
3	No. of Gen. Units	0.00057	10^{-1}
5	Thermal Efficiency	0.00041	10^{-1}
6	Units Generated	0.00007	10^{-1}
9	Region	0.00003	10^{-1}
10	Technical Staff	-0.00019	10^{-1}
12	Industrial Staff	0.00001	10^{-15}
14	Ratio Technical : Total Staff	0.26302	10^{-15}

Table No.36 - Coefficients for Predicting the Ratio of Administrative Staff : Total Staff (Overall probability = 10^{-14})

As in the previous prediction the Ratio variable was by far the most highly significant. The next in order of significance was the number of Industrial staff, the remainder having a lower significance.

Larger power stations tend to require a lower ratio of administrative staff : total staff. Higher thermal efficiency, more generating units and more units generated all tend to require larger ratios of this staffing. It is interesting that the coefficient for technical staff has a negative sense whereas that for the technical staff : total staff ratio is positive.

Table No.37 shows predictions of the ratio of Admin. : Total staffs for a sample of power stations.

Power Station Class	Power Station No.	Installed Capacity $\frac{MW}{10}$	Predicted Value of technical : total staff	Actual Value of ratio technical : total staff	Difference Predicted - Actual
Small	67	3.5	0.066	0.039	0.027
	81	7.0	0.060	0.058	0.002
Medium	97	78.4	0.053	0.058	-0.005
	120	67.2	0.056	0.050	0.006
Large	11	198.3	0.051	0.058	-0.007
	107	183.1	0.045	0.043	0.002

Table No.37 - Comparison of Predicted and Actual Ratios of Administrative : Total Staff for a Sample of Power Stations.

Comparisons of predicted to actual ratios show that differences occur negatively and positively independently of power station size.

P.S.67 has the greatest discrepancy between prediction and actual values; it is of course a very small power station which is not representative of small stations. It has remained in the data table due to more than ten technical staff being employed, however, in the last twelve months stations of this size have been closed down.

Power Station Class	Power Station No.	Predicted ratio Admin : Total Staff	Net Contribution of plant Variables	Net Contribution of staffing Variables
Small	67	0.066	0.00985	0.04289
	81	0.060	0.00872	0.03764
Medium	97	0.053	0.01725	0.02178
	120	0.056	0.01905	0.02306
Large	11	0.051	0.01215	0.02504
	107	0.045	0.01870	0.01248

Table No.38 - Net Contributions of Variables when Predicting the Ratio of Administrative Staff : Total Staff (Constant = 0.01349)

Net contributions of plant variables are considerably less than staffing variables for small power stations, however for medium and large stations there is closer to a balance between the contributions.

In the case of both staffing ratios, the medium and large stations are more compatible with each other, the small stations giving different results.

7.4 Procedure to Test Quality of Variables in Predictions

Having predicted the dependant variables in the seven previous sections, one further test was carried out, using the prediction of administrative staff as an example.

The test was to ensure that the independant variables were significant in predicting Administrative staff and not because, as in this case with Technical staff, another variable was so highly significant that the other variables were showing significance towards it. Therefore a test was carried out to show that the other independent variables were not predicting administrative staff biased by the dominantly high significance of technical staff.

The test programme carried out was based on the results of the prediction of administrative staff in section 3.3.3.

Stage I was to remove the independent variable having the least significance, in this case the Type of firing, with approximate p(rounded) of 10^{-4}.

A prediction of administrative staff followed which resulted in a higher overall probability from 10^{-72} to 10^{-74}.

This procedure was repeated, removing variables Utilisation, Number of generating units and Units generated respectively, each time the overall probability of the results occurring by pure chance remaining extremely significant at 10^{-74}.

The next stage was to predict the Number of technical staff which was the most significant independent variable for predicting administrative staff, using the independent variables left after those mentioned above had been removed.

The remaining independent variables were Installed capacity, Age of station, Thermal efficiency, Units generated and Number of Industrial Staff. Overall probability by chance (rounded) was 10^{-44} which was considerably lower than when predicting Administrative staff using the discarded independant variables.

Finally, Administrative staff was predicted using the variables Installed capacity, Age of station, Thermal efficiency, Units generated and Technical staff. Overall probability (rounded) was 10^{-61}, i.e. higher than predicting Technical staff.

This showed that in the original regressions predicting Administrative staff, the independent variables were truly significant in predicting Administrative staff and were not themselves affected by Technical staff.

Step No.	Dependent Variable being Predicted	Independent Variables Nos.	r^2	Approx. Prob. by Chance (rounded)	Overall Approx Prob. by Chance (rounded)
1	Administrative Staff (11)	1,2,3,4,5,6, 7,8,10,12	0.9491	Variable No. 4, lowest at 10^{-4}	10^{-72}
2	Administrative Staff (11)	1,2,3,5,6, 7,8,10,12	0.9490	Variable No.7, lowest at 10^{-7}	10^{-74}
3	Administrative Staff (11)	1,2,3,5,6, 8,10,12	0.9489	Variable No. 3, lowest at 10^{-8}	10^{-74}
4	Administrative Staff (11)	1,2,5,6, 8,10,12	0.9486	Variable No. 8 lowest at 10^{-16}	10^{-74}
5	Adminstrative Staff (11)	1,2,5,6, 10,12	0.9484	Most Significant Variable Technical Staff at 10^{-63}	10^{-74}
6	Technical Staff (10)	1,2,5, 6,12	0.8197		10^{-44}
7	Administrative Staff (11)	1,2,5,6, 10	0.9037		10^{-61}

Table No.39 - Test Procedure for Assessing Independant Variables when Predicting Administrative Staff.

7.5 Examples of Predictions for a Region

To show examples of the use of the predictions, the number of technical and industrial staff were predicted for the power stations of two Regions. The Regions selected were No. 3 and No. 5, the results are shown on Table Number 40 including the actual values. Differences between actual and predicted staff numbers are included together with percentages.

In both cases the total number of technical staff predicted, exceeded the actual total number of technical staff; whereas the total number of industrial staff predicted were less than the actual numbers. Similar exercises would be necessary for the remaining Regions to ascertain where the total actual technical staff exceeded predicted numbers and vice versa for industrial staff.

The value of this type of exercise is in explaining the major differences between predicted and actual values, whether for a power station, or totals for a Region.

Queries regarding use of contractors and allowances for multi-station sites still remain to be answered.

Power Station No. from Table	No. of Technical Staff				No. of Industrial Staff			
	Actual	Predicted	Actual – Predicted	% Age Act.-Pred. / Actual	Actual	Predicted	Actual – Predicted	% Age Act.-Pred. / Actual
58	123	155.5	-32.5	-26.4	635	587.2	47.8	7.5
59	72	70.2	1.8	2.6	263	264.9	-1.9	-0.7
60	50	83.0	-33.0	-66.0	351	313.5	37.5	10.7
61	11	13.4	-2.4	-22.2	53	50.8	2.2	4.2
62	30	41.1	-11.1	-37.1	169	155.3	13.7	8.1
63	119	94.5	24.5	20.6	337	356.9	-19.9	-5.9
64	193	149.3	43.7	22.7	531	563.6	-32.6	-6.1
65	62	66.1	-4.1	-6.6	260	249.4	10.6	4.1
66	11	7.0	4.0	36.2	22	26.5	-4.5	-20.4
67	13	14.8	-1.8	-13.9	60	55.9	4.1	6.8
68	89	75.6	13.4	15.0	272	285.5	-13.5	-5.0
69	110	84.0	26.0	23.6	292	317.1	-25.1	-8.6
70	45	48.5	-3.5	-7.8	182	183.2	-1.2	-0.7
71	66	108.0	-42.0	-63.6	461	407.6	53.4	11.6
72	41	48.5	-7.5	-18.4	192	183.2	8.8	4.6
73	27	37.8	-10.8	-40.0	155	142.8	12.2	7.3
74	21	26.3	-5.3	-25.3	104	99.3	4.7	4.5
75	11	5.3	5.7	52.2	12	19.9	-7.9	-65.6
76	23	22.0	1.0	4.3	83	83.1	-0.1	-0.2
77	77	122.8	-45.8	-59.4	522	463.6	58.4	11.2
78	33	38.0	-5.0	-15.2	149	143.5	5.5	3.7
Total:	1227	1311.7	-84.7		5105	4952.8	152.2	

Table No. 40 - Predictions of Number of Technical Staff and Industrial Staff for Power Stations in Region No. 3.

Power Station No. from Table	No. of Technical Staff				No. of Industrial Staff			
	Actual	Predicted	Actual - Predicted	% Age Act.-Pred. / Actual	Actual	Predicted	Actual - Predicted	% Age Act.-Pred. / Actual
104	63	64.9	-1.9	-3.1	352	346.5	5.5	1.6
105	91	90.4	0.6	0.7	486	482.1	4.9	0.8
106	24	22.4	1.6	6.5	119	119.7	-0.7	-0.6
107	147	167.6	-20.6	-14.0	933	894.4	38.6	4.1
108	99	122.2	-23.2	-23.4	687	651.8	35.2	5.1
109	69	72.5	-3.5	-5.1	392	387.0	5.0	1.3
110	95	88.0	7.0	7.4	466	469.4	-3.4	-0.7
111	29	23.8	5.2	18.0	119	126.9	-7.9	-6.6
112	25	17.5	7.5	29.9	82	93.6	-11.6	-14.1
113	73	67.3	5.7	7.8	359	359.2	-0.2	-0.1
114	33	27.3	5.7	17.1	139	145.9	-6.9	-5.0
115	51	56.8	-5.8	-11.3	310	302.9	7.1	2.3
116	28	31.5	-3.5	-12.5	170	168.1	1.9	1.1
117	87	96.0	-9.0	-10.3	522	512.2	9.8	1.9
118	123	114.4	8.6	7.0	605	610.6	-5.6	-0.9
119	49	53.6	-4.6	-9.5	292	286.3	5.7	2.0
120	71	82.5	-11.5	-16.2	456	440.1	15.9	3.5
121	48	47.1	0.9	1.9	255	251.4	3.6	1.4
122	35	42.4	-7.4	-21.0	234	226.0	8.0	3.4
123	81	91.1	-10.1	-12.5	497	486.1	10.9	2.2
124	83	82.0	1.0	1.2	440	437.7	2.3	0.5
125	10	9.8	0.2	1.9	52	52.3	-0.3	-0.6
Total:	1414	1471.1	-57.1	-4.04	7967	7850.2	116.8	1.47

Table No. 40 - Predictions of Numbers of Technical Staff and Industrial Staff for Power Stations of Region No. 5.

7.6 Forecasting of Resource Requirements

In the previous sections, variables and their relationships were identified and tested, to find whether they were significant in predicting power station manning levels. One application for the significant variables would be in forecasting manpower requirements in future years: for example as part of an electricity supply industry's corporate plan.

Basically the method for this forecasting would be to find values of the significant variables for the periods to be considered.

Many of the variables would be forecast, as they are now, as part of the electricity supply industry corporate plan, which is divided between the generating and distribution activites, each of which is divided between lower operating organisations.

The most difficult to forecast accurately for a long future period would be the part electricity has to play in the demand for energy and the level of demand. Central planning by econometric means is carried out which would give a forecast of the level of generation, from which the allocation to regions and power stations would be assessed. Such allocation, which becomes utilisation, would be based on unit costs of the power stations production, together with the assumptions of plant availability.

Plant availability and thermal efficiency for a power station would be forecast, based on results of work planned for the future, which is concerned with the improvement or maintenance of these parameters. Where work is not to be carried out in a short period, for example on a large turbo-alternator, a'deteriorating' factor could be used to forecast thermal efficiency.

Decisions will be made about which power stations will be closed and which new stations will be commissioned within the time scale of the plan. The variables installed capacity, age of station, number and capacity of generating units and type of firing of the available power stations will be known.

Utilising the forecast values of these variables, by simulating the generating plant mix and performance, predictions of staffing levels could be made. The curve fitting from which predictions were made in earlier sections was based on data from previous results and staffing patterns. It is envisaged that annual predictions would be made on data available from each previous year. The curve fit would then be based on a different number of power stations, with plant mix and type of firing varying as a result of commissioning new plant, shutting down uneconomic power stations and performances varying from the previous years. As annual results were obtained, trends would be observed which could be used to bias future forecasts. If there are only a few power stations, this forecasting for each station could be a practical method, easily and quickly carried out.

A variation of this method would be to forecast for one Region the manning levels for different installed capacities, varying unit sizes, different types of firing, assuming a particular overall thermal efficiency and utilisation level.

Example of Forecasting Technical Staff

Assumptions were made that the example was for Region No. 1 in 1976, when the overall thermal efficiency was 30% and utilisation 70%.

The expression for predicting number of technical staff was compiled from a constant, plus the product of each coefficient times its variable (the variables being installed capacity, age of station, number of generating units, type of firing, thermal efficiency, units generated, utilisation, average generating unit capacity and region).

After inserting the values of the variables the expression for predicting the numbers of technical staff became:

Technical Staff = 32.103 + (0.04565 x Total Installed capacity of power station) + (3.5102 x Installed capacity ÷ Average generating unit capacity) + (6.3758 x Type of firing).

The computer programme was compiled so that the columns were, from left to right, number code of power station, number of technical staff, installed capacity of power station, average generating unit capacity, type of firing and as a final column the number of technical staff per MW of installed capacity.

The programme was designed to list installed capacities in the ranges 100 MW, 250 MW, 400 MW,

500 MW, 750 MW, 1000 MW, 1500 MW, 3000 MW and 5000 MW. Generating unit capacities started at 30 MW and progressed upwards via 60 MW, 120 MW, 200 MW, 350 MW, 500 MW and 660 MW to 1300 MW.

Each combination of installed capacity and generating unit size were predicted for three different types of firing, oil, p.f. and nuclear.

The programme is shown on page number 126. Results of computer print out are shown in Table No.41. In the table some editing has been carried out. When generating unit capacity was greater than installed capacity of the power station, the example was ignored. Similarly where small generating units were installed in very large capacity power stations they were left out (for example 30 MW generating units in 1500 MW capacity power stations).

It will be seen from the results that the lowest staffing for each power station occurs when it is oil fired and the variation from the smallest generating unit and oil fired power stations which employs 0.558 technical staff per MW falls to 0.063 technical staff per MW in an oil fired power station of 5000 MW capacity, containing generating units of 660 MW capacity. Incidentally a 5000 MW capacity power station comprising 1300 MW generating units has a higher number of technical staff predicted than when the generating units are of 660 MW capacity.

This example uses technical staff as the resource being forecast, other sections of staffing or total staffing could be forecast in a similar manner.

```
      DIMENSION WM(11),US(8),F(3)
      WM(1)=100
      WM(2)=250
      WM(3)=400
      WM(4)=500
      WM(5)=750
      WM(6)=1000
      WM(7)=1500
      WM(8)=2000
      WM(9)=3000
      WM(10)=4000
      WM(11)=5000
      US(1)=30
      US(2)=60
      US(3)=120
      US(4)=200
      US(5)=350
      US(6)=500
      US(7)=660
      US(8)=1300
      F(1)=1
      F(2)=3
      F(3)=4
      NUM=0
      DO 2 N1=1,11
      DO 2 N2=1,8
      DO 2 N3=1,3
      NUM=NUM+1
      C6=-.25393*WM(N1)
      TM=32.103+.04565*WM(N1)X                                  -see below
                         +3.5102*WM(N1)/US(N2)+6.3758*F(N3)
      TM=TM+.03391*US(N2)
      E=TM/WM(N1)
      TM1=TM+C6
  2   WRITE(1,17)NUM,TM,TM1,WM(N1),US(N2),F(N3),E
 17   FORMAT(I5,2F6.1,3F7.0,E13.5)
      END



      TM=32.103+.04565*WM(N1)+3.5102*WM(N1)/US(N2)+6.3758*F(N3)
```

Item No.	No. of Technical Staff	Installed Capacity of Power Station MW	Generating Unit Capacity MW	Type of Firing	Ratio No. of Tech. Staff : Installed Capacity MW
1	55.8	100	30	1	0.558
2	68.5	100	30	3	0.685
3	74.9	100	30	4	0.749
4	50.9	100	60	1	0 509
5	63.7	100	60	3	0.637
6	70.1	100	60	4	0.701
7	80.2	250	30	1	0.321
8	92.9	250	30	3	0.372
9	99.3	250	30	4	0.397
10	66.6	250	60	1	0.266
11	79.3	250	60	3	0.317
12	85.7	250	60	4	0.343
13	61.3	250	120	1	0.245
14	74.0	250	120	3	0.296
15	80.4	250	120	4	0.322
16	61.1	250	200	1	0.244
17	73.8	250	200	3	0.295
18	80.2	250	200	4	0.321
19	104.6	400	30	1	0.261
20	117.3	400	30	3	0.293
21	123.7	400	30	4	0.309
22	82.2	400	60	1	0.205
23	94.9	400	60	3	0.237
24	101.3	400	60	4	0.253
25	72.5	400	120	1	0.181
26	85.3	400	120	3	0.213
27	91.6	400	120	4	0.229
28	70.5	400	200	1	0.176
29	83.3	400	200	3	0.208
30	89.7	400	200	4	0.224
31	72.6	400	350	1	0.182
32	85.4	400	350	3	0.213
33	91.7	400	350	4	0.229
34	92.6	500	60	1	0.185
35	105.3	500	60	3	0.211
36	111.7	500	60	4	0.223
37	80.0	500	120	1	0.160
38	92.8	500	120	3	0.186
39	99.1	500	120	4	0.198
40	76.9	500	200	1	0.154
41	89.6	500	200	3	0.179
42	96.0	500	200	4	0.192
43	78.2	500	350	1	0.156
44	90.9	500	350	3	0.182
45	97.3	500	350	4	0.195
46	81.8	500	500	1	0.164
47	94.5	500	500	3	0.189
48	100.9	500	500	4	0.202
49	98.7	750	120	1	0.132
50	111.5	750	120	3	0.149

Table No. 41 - Forecasting Technical Staff for Varying Generating Unit and Power Station Capacities.

Item No.	No. of Technical Staff	Installed Capacity of Power Station MW	Generating Unit Capacity MW	Type of Firing	Ratio No. of Tech. Staff : Installed Capacity MW
51	117.9	750	120	4	0.157
52	92.7	750	200	1	0.124
53	105.4	750	200	3	0.141
54	111.8	750	200	4	0.149
55	92.1	750	350	1	0.123
56	104.9	750	350	3	0.139
57	11.2	750	350	4	0.148
58	94.9	750	500	1	0.127
59	107.7	750	500	3	0.144
60	114.1	750	500	4	0.152
61	99.1	750	660	1	0.132
62	111.8	750	660	3	0.149
63	118.2	750	660	4	0.158
64	117.4	1000	120	1	0.117
65	130.2	1000	120	3	0.130
66	136.6	1000	120	4	0.137
67	108.5	1000	200	1	0.108
68	121.2	1000	200	3	0.121
69	127.6	1000	200	4	0.128
70	106.0	1000	350	1	0.106
71	118.8	1000	350	3	0.119
72	125.2	1000	350	4	0.125
73	108.1	1000	500	1	0.108
74	120.9	1000	500	3	0.121
75	127.2	1000	500	4	0.127
76	111.8	1000	660	1	0.112
77	124.6	1000	660	3	0.125
78	141.0	1000	660	4	0.131
79	154.9	1500	120	1	0.103
80	167.7	1500	120	3	0.112
81	174.0	1500	120	4	0.116
82	140.1	1500	200	1	0.0934
83	152.8	1500	200	3	0.102
84	159.2	1500	200	4	0.106
85	133.9	1500	350	1	0.089
86	146.6	1500	350	3	0.098
87	153.0	1500	350	4	0.102
88	134.4	1500	500	1	0.0896
89	147.2	1500	500	3	0.0981
90	153.6	1500	500	4	0.102
91	137.3	1500	660	1	0.0915
92	150.1	1500	660	3	0.100
93	156.4	1500	660	4	0.104
94	161.7	2000	350	1	0.0809
95	174.5	2000	350	3	0.0872
96	180.8	2000	350	4	0.0904
97	160.8	2000	500	1	0.0804
98	173.5	2000	500	3	0.0868
99	179.9	2000	500	4	0.0899
100	162.8	2000	660	1	0.0814

Table No. 41 Continued

Item No.	No. of Technical Staff	Installed Capacity of Power Station MW	Generating Unit Capacity MW	Type of Firing	Ration No. of Tech. Staff : Installed Capacity MW
101	175.5	2000	660	3	0.0878
102	181.9	2000	660	4	0.0909
103	179.3	2000	1300	1	0.0896
104	192.0	2000	1300	3	0.0960
105	198.4	2000	1300	4	0.0992
106	213.4	3000	500	1	0.0711
107	226.2	3000	500	3	0.0754
108	232.6	3000	500	4	0.0754
109	213.8	3000	660	1	0.0713
110	226.5	3000	660	3	0.0755
111	232.9	3000	660	4	0.0776
112	227.6	3000	1300	1	0.0759
113	240.4	3000	1300	3	0.0801
114	246.7	3000	1300	4	0.0822
115	226.1	4000	500	1	0.0665
116	278.9	4000	500	3	0.0697
117	285.2	4000	500	4	0.0713
118	264.7	4000	660	1	0.0662
119	277.5	4000	660	3	0.0694
120	283.9	4000	660	4	0.0710
121	276.0	4000	1300	1	0.0690
122	188.7	4000	1300	3	0.0722
123	295.1	4000	1300	4	0.0738
124	318.8	5000	500	1	0.0638
125	33.15	5000	500	3	0.0663
126	337.9	5000	500	4	0.0676
127	315.7	5000	660	1	0.0631
128	328.5	5000	660	3	0.0657
129	334.8	5000	660	4	0.0670
130	324.3	5000	1300	1	0.0649
131	337.1	5000	1300	3	0.0674
132	343.4	5000	1300	4	0.0687

Table No. 41 Continued.

8. ALTERNATIVE METHODS

8. ALTERNATIVE METHODS

A major disadvantage of using least squares curve fitting, occurs when variables have a very wide range of values, from very small to very large. When there is this wide range of values, the large values have an overlarge influence on the results. In effect the larger values overshadow the small.

To obviate this disadvantage in this project, when finding the relationships between variables, very small power stations were omitted and least squares curve fitting used for the remainder.

Since the data was collected for this project the C.E.G.B. has closed down these very small power stations. As a result the data used, is representative of the industry at the present time and least squares regression can be used with some confidence.

However there may be electricity supply industries which retain a mixture of very small and very large power stations, in which case alternative methods to least squares may be desirable.

In the least squares method the error squared which is minimised is often in dimensional form, in terms of power generated for example, the values can vary from hundreds of kilowatt - hours to millions of kilowatt - hours.

When the variable being considered has several high values and a few of very low values, the errors at the high end, when squared can be extremely large compared with the errors squared at the low end. Thus the effect is that combinations of very high squares overshadow the very small squares at the low end.

An alternative approach for finding relationships between variables , when the variables have extreme values, could be to find the association between them.

Instead of finding the significance of a variable when using it to predict another variable by regression, the alternative approach would be to find the association of the variable with another.

As an example, to find the relationship between thermal efficiency and number of men using the regression method, the points are plotted and curve fitting using least squares carried out on a curve. In the alternative method the association between number of staff and thermal efficiency is found. Put another way we should find the level of thermal efficiency more frequently in power stations having a certain number of staff.

It could happen that levels of, say, thermal efficiency could occur when certain numbers of staff are employed but where no real association exists. Therefore even in this method a significance test is necessary to test the reality of the association. Having proved that the association is real, measurement of the intensity of the association will be necessary.

When speaking of association,the implication is that a comparison is made, and that when,say,the values of two variables are found frequently higher it can be said that they are associated.

The X^2 ("Chi-square") distribution could possibly be used to test the reality of association as an alternative method to least squares regression. The basis of the X^2 test is expected and observed frequencies.When comparing results of variables the widely differing dimensions will not affect results as mentioned for least squares regression.

The goodness of fit of the data could be determined by the X^2 test,which could form the basis of an alternative method.

9. CONCLUSIONS

9. CONCLUSIONS

Methods have been developed and tested in this project, for measuring the relative productivity of manpower and forecasting future manpower requirements in power generation. The methods were similarly developed and tested to enable comparison of thermal efficiencies achieved by power stations.

9.1 Methods

Variables, both technical and manpower, were selected because they had some influence on thermal efficiency and on manning levels.

These were Installed capacity, Age of power station, Number of generating units, Type of firing, Units generated, Utilisation, Generating unit capacity, Region, Numbers of Technical staff, Administrative staff, Industrial staff, Total staff and the Ratios of Technical : Total staff and Administrative : Total staffs.

Multiple regression curve fitting (by computer, incorporating values of these variables) was used to show whether the selected variables were significant.

Not all the independant variables were shown to be significant in predicting the thermal efficiency and manning levels when each was the dependant variable.

Table 42 shows the best predictive variables and the number and identification number of the significant independant variables for each prediction.

Dependant Variable	Best Predictive Variable	Number of Significant Independant Variable	Identifying Number of the Significant Independant Variable
Thermal Efficiency	Age of Power Station	12	1,2,3,4,6,7,8,10, 11,12,13,15
Technical Staff	Administrative Staff	12	1,2,3,4,5,6,7,8,9, 11,12,15
Administrative Staff	Technical Staff	11	1,2,3,4,5,6,7,8,9, 10,12
Industrial Staff	Administrative Staff	13	1,2,3,4,5,6,7,8,9, 10,11,14,15
Total Staff	Units Generated	9	1,2,3,4,5,6,7,8,9,
Ratio Tech Staff : Total Staff	Ratio Admin Staff : Total Staff	3	3,12,15
Ratio Admin Staff: Total Staff	Ratio Tech Staff : Total Staff	8	1,3,5,6,9,10,12,14

Table No. 42 – Best Predictive Variables and Number of Significant Variables in Predictions.

Identification of Variables for use with Table No 42.

1	Installed Capacity
2	Age of power station
3	Number of generating units
4	Type of firing
5	Thermal efficiency
6	Power generated
7	Utilisation
8	Average unit capacity
9	Region
10	Number of Technical and Scientific staff
11	Number of Administrative staff
12	Number of Industrial staff
13	Total Staff
14	Ratio Technical staff : Total staff
15	Ratio Administrative staff : Total staff

The next stage in the method was to predict values of the dependant variables for a selection of small, medium and large power stations. Comparison of the predicted and actual values followed and deviations explained, giving a measure of relative productivity.

Briefly then the method shows that for a power station or generating organisation comprising several power stations, predictions based on plant characteristics, levels of performance and manning levels, may be made of thermal efficiency and manpower productivity.

A derivation of the method was tested, by which forecasts of future manpower requirements could be made. Having found the relationships of variables, then by simulating how the industry will develop and thus assigning values to the independant variables, forecasts of the level of manpower for some future period was made.

9.2 Alternative Methods

Where the method is to be applied to industries having power stations of widely different characteristics, the use of multiple regression curve fitting may possibly be replaced by alternative methods. One such method could be to use X^2 to test the association of the variables.

9.3 Observations and the Use of Methods

9.3.1 These methods would seem to be adaptable to making comparisons of thermal efficiency and manpower levels for generating industries internationally or nationally.

When comparing different utilities or industries, major problems can occur when selecting variables and ensuring that their definitions are the same.

9.3.2 The methods measure relative productivity, although thermal efficiency is one measure of absolute productivity.

Thermal efficiency has limitations as a measure of management performance in power stations and an alternative such as the C.E.G.B. Station Thermal Efficiency Performance Factor would be an improvement. However, this may introduce problems of similar definitions internationally or even nationally, as thermal efficiency is the most commonly quoted performance indicator.

9.3.3 The methods have been applied for the results of power stations over a period of one year. However management policies and plans are for longer term and therefore it would be preferable to apply the method annually, assessing deviations year by year and observing trends. Another reason for monitoring annual performance would be to give a more complete picture of the early years of modern large power stations operation. New plant, or modifications, take a long period to engineer, manufacture, install and commission. As years pass one would expect to see the gap between prediction and actual value reducing each year.

As large stations performance improves over the year the pattern of the generating load changes and affects results appreciably. This is another reason for monitoring performances annually.

9.3.4 The method as applied for forecasting manpower requirements could be adopted for use in forecasting other particular resources, finance for example.

9.4 Future Work

9.4.1 Application of the methods to later years performance of power stations, to show up deviations and the differences in performance patterns resulting from the large new power stations increasing their production levels.

9.4.2 Assessing the effect of using contractors, on manpower levels in power stations. When carrying out measurement of manpower productivity the use of contractors needs incorporating in some way which needs clarifying.

When used internationally, the use of contractors compared with internal manpower levels is important, in some countries power station maintenance is let out in bulk on contract.

9.4.3 To investigate whether increasing staff levels would improve the performance of large new power stations and if so how to measure the improvement.

9.4.4 Hydro-electric power generation was treated as a type of firing in this project. However hydro-electric power is produced from stored pressure energy which is released merely by opening a valve. Hydro power needs fewer people and resources for operation and maintenance, and is a completely different form of energy to heat energy released from fuel. Types of firing whether oil, coal, pf, or nuclear, all transform heat energy into steam and the main features of these power stations are similar whatever the type of firing.

Investigation into how to incorporate hydro-electric power into this method is required, as in many countries, unlike England and Wales, a large proportion of power is hydro-generated.

9.4.5 In assessing the performance of a power industry a "package" would be needed which measured absolute productivity and relative productivity.

Absolute productivity is not easily measured internationally due to definitions of variables differing widely.

Work is required to draw up a "package" performance measuring system, incorporating absolute and relative productivity factors.

9.4.6 The methods have been applied, in this project, to the power generation side of the industry. Methods need developing and testing for measuring the relative performance of the distribution side of the electricity supply industry.

APPENDICES

APPENDIX 1

Table No.43 - Data for Power Stations of the C.E.G.B. with effect March 1973.

Power Stn. No.	Inst'd Cap. MW/10	Age of Plant Year -1926	No. of Gen. Units	Type of Firing	Thermal Effy.	Power Generated in one yr. 10^6 KWhr/100	Utili-sation %	Average Unit Cap. MW	Region No.	No. of Tech. Staff	No. of Admin. Staff	No. of Indust Staff	Total Staff
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
1	33.60	34	4	3	27.00	12.562	42.20	84.00	1	57	21	282	360
2	14.30	28	4	2	19.97	2.013	15.89	35.75	1	29	11	144	184
3	28.80	35	7	3	24.30	8.430	33.04	41.14	1	49	18	243	310
4	7.50	22	4	2	16.98	0.525	7.91	18.75	1	25	8	122	155
5	19.70	26	4	1	29.21	14.998	85.93	49.25	1	36	13	176	225
6	6.70	18	4	2	20.07	1.086	18.29	16.75	1	20	8	98	126
7	24.00	30	4	3	25.70	11.286	53.08	60.00	1	43	16	213	272
8	23.60	31	4	3	25.47	9.618	46.00	59.00	1	43	16	211	270
9	25.60	27	5	1	23.60	11.629	51.27	51.20	1	59	22	293	374
10	18.00	31	6	3	24.97	5.949	37.30	30.00	1	42	16	210	268
11	198.30	46	4	3	33.08	21.189	12.06	495.75	1	103	38	512	655
12	12.50	23	6	1	18.70	2.723	24.59	20.83	1	28	11	143	182
13	15.00	31	5	3	24.73	4.468	33.62	30.00	1	31	11	150	192
14	24.00	30	4	1	19.74	3.209	15.09	60.00	1	31	11	152	194
15	25.00	23	6	2	17.10	3.235	14.61	41.67	1	49	18	246	313
16	3.90	16	2	2	23.58	1.135	32.85	19.50	1	22	8	109	139
17	15.90	23	5	2	20.00	1.511	10.73	31.80	1	29	11	146	186
18	22.40	36	2	3	31.10	6.729	33.91	112.00	1	33	12	163	208
19	12.00	22	4	2	18.90	1.342	12.62	30.00	1	29	11	144	184
20	12.00	28	4	3	25.20	3.535	33.25	30.00	1	26	10	132	168
21	6.60	17	3	2	17.00	0.321	5.49	22.00	1	15	6	77	98
22	5.90	21	2	2	21.10	1.372	26.25	29.50	1	16	6	80	102
23	39.00	39	4	4	25.10	34.681	100.00	97.50	1	81	30	402	512
24	8.60	26	4	2	19.26	1.175	15.42	21.50	1	24	9	121	154
25	12.00	27	4	3	22.00	2.395	22.53	30.00	1	28	10	139	177
26	64.50	46	3	4	27.78	19.490	34.11	215.00	1	77	28	381	486
27	14.80	32	5	2	23.21	4.722	36.01	29.60	2	33	16	182	231

APPENDIX 1

Table No.43 - Data for Power Stations of the C.E.G.B. with effect March 1973.

Power Stn. No.	Inst'd Cap. MW/10	Age of Plant Year -1926	No. of Gen. Units	Type of Firing	Thermal Effy.	Power Generated in one yr. 10^6 KWhr/100	Utilisation %	Average Unit Cap. MW	Region No.	No. of Tech. Staff	No. of Admin. Staff	No. of Indust Staff	Total Staff
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
28	28.40	37	4	1	27.70	9.846	39.13	71.00	2	40	14	197	252
29	51.00	28	8	1	26.70	12.671	28.04	63.75	2	72	40	776	889
30	47.30	27	11	2	23.50	12.340	29.45	43.00	2	70	29	599	699
31	46.00	35	6	1	31.00	31.556	77.43	76.67	2	44	27	245	317
32	9.50	26	3	3	24.36	2.428	28.85	31.67	2	27	14	111	153
33	25.00	36	9	4	24.64	18.086	81.65	27.78	2	76	31	305	413
34	39.00	32	8	3	25.23	15.638	45.26	48.75	2	71	23	414	509
35	9.60	29	2	2	25.40	2.645	31.10	48.00	2	42	15	253	311
36	33.00	30	6	1	26.91	17.886	61.17	55.00	2	45	16	325	387
37	25.80	26	6	3	25.92	11.230	49.13	43.00	2	49	22	327	399
38	22.70	25	5	2	22.50	5.624	27.96	45.40	2	49	20	216	286
39	27.20	31	6	2	24.75	5.029	20.87	45.33	2	45	24	241	311
40	41.00	39	4	4	28.87	34.487	94.94	102.50	2	144	45	346	536
41	33.60	25	6	1	24.29	11.875	39.89	56.00	2	52	27	379	459
42	16.80	32	6	3	24.58	6.015	40.41	28.00	2	42	16	193	252
43	9.20	31	3	3	23.64	1.932	23.70	30.67	2	25	14	106	146
44	198.00	46	4	1	34.76	39.078	22.28	495.00	2	83	27	275	386
45	11.70	24	4	2	16.33	1.587	15.31	29.25	2	39	17	163	220
46	23.80	33	6	3	24.59	7.023	33.31	39.67	2	43	18	192	254
47	44.00	24	9	2	27.00	20.096	51.55	48.89	2	67	26	355	449
48	68.40	36	6	1	30.59	15.049	24.83	114.00	2	58	27	251	337
49	3.00	11	1	2	20.55	0.424	15.95	30.00	2	17	3	60	80
50	3.80	25	2	3	22.27	1.456	43.25	19.00	2	20	8	77	106
51	34.20	37	3	1	32.31	13.869	45.77	114.00	2	42	15	151	209
52	12.00	27	4	3	22.89	3.286	30.91	30.00	2	37	15	146	199
53	42.00	40	2	4	25.88	39.731	100.00	210.00	2	96	30	319	446
54	24.80	34	4	1	29.97	13.840	62.99	62.00	2	41	15	166	223

APPENDIX 1

Table No.43 - Data for Power Stations of the C.E.G.B. with effect March 1973.

Power Stn. No.	Inst'd Cap. MW/10	Age of Plant Year -1926	No. of Gen. Units	Type of Firing	Thermal Effy.	Power Generated in one yr. 10^6 KWhr/100	Utili-sation %	Average Unit Cap. MW	Region No.	No. of Tech. Staff	No. of Admin. Staff	No. of Indust Staff	Total Staff
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
55	133.80	46	10	2	31.67	40.545	34.20	133.80	2	117	34	537	689
56	118.00	40	5	3	33.30	33.656	32.19	236.0	2	76	29	336	492
57	16.80	29	6	2	17.70	1.562	10.49	28.00	2	26	9	167	203
58	60.00	37	6	3	31.60	24.064	45.27	100.00	3	123	40	635	799
59	62.10	40	7	3	23.13	28.414	55.17	184.00	3	72	25	263	361
60	34.20	30	6	3	21.68	6.520	21.52	57.00	3	50	25	351	426
61	3.50	29	6	2	18.74	0.382	12.32	5.83	3	11	5	53	70
62	19.40	31	6	2	23.85	5.429	31.59	32.33	3	30	12	169	212
63	198.30	45	4	1	34.38	74.037	42.14	495.75	3	119	29	337	486
64	8.50	39	1	4	22.20	7.709	100.00	85.00	3	193	42	531	767
65	46.60	33	8	1	29.33	25.911	62.76	58.25	3	62	17	260	340
66	5.70	22	2	2	14.24	0.316	6.26	28.50	3	11	3	22	36
67	3.50	22	4	2	18.56	0.306	9.87	8.75	3	13	3	60	76
68	40.00	42	2	4	28.30	31.858	89.89	200.00	3	89	27	272	389
69	198.30	46	4	1	34.35	18.498	10.53	495.75	3	110	29	292	432
70	24.80	34	8	1	27.40	0.699	3.18	31.00	3	45	22	182	250
71	52.70	28	9	1	24.71	22.815	40.91	113.50	3	66	27	461	555
72	32.50	32	6	1	27.95	17.847	61.98	54.17	3	41	16	192	250
73	11.20	26	6	1	22.40	2.104	21.20	18.67	3	27	13	154	196
74	12.00	31	2	3	27.55	5.348	50.30	60.00	3	21	10	104	136
75	3.00	17	6	1	14.44	0.231	8.69	5.00	3	11	4	12	27
76	6.40	18	2	1	19.43	2.247	39.63	32.00	3	23	7	83	114
77	67.80	31	9	3	27.46	28.282	47.21	169.00	3	77	31	522	631
78	11.40	20	3	3	23.82	3.077	30.46	38.00	3	33	13	149	196
79	15.10	15	5	2	19.97	2.013	15.05	30.20	4	43	16	214	273
80	149.30	40	8	3	32.75	74.912	56.63	186.63	4	128	47	639	814
81	7.00	23	3	2	17.30	0.901	14.53	23.33	4	24	9	118	151

APPENDIX 1

Table No.43 - Data for Power Stations of the C.E.G.B. with effect March 1973.

Power Stn. No.	Inst'd Cap. MW/10	Age of Plant Year -1926	No. of Gen. Units	Type of Firing	Thermal Effy.	Power Generated in one yr. 10^6 KWhr/100	Utilisation %	Average Unit Cap. MW	Region No.	No. of Tech. Staff	No. of Admin. Staff	No. of Indust Staff	Total Staff
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
82	5.70	17	3	2	18.40	1.409	27.90	19.00	4	23	8	112	143
83	12.20	42	4	2	22.59	5.152	47.66	30.50	4	30	11	150	191
84	24.44	18	6	2	22.63	5.593	28.93	85.60	4	64	23	316	403
85	198.30	43	4	3	33.64	80.940	46.07	495.75	4	111	41	555	707
86	16.80	34	3	3	27.11	7.842	52.68	56.00	4	28	10	138	176
87	40.70	33	6	2	25.80	21.701	60.18	67.83	4	80	29	398	508
88	198.30	42	4	3	33.94	77.319	44.01	495.75	4	111	41	553	705
89	9.40	29	4	2	21.19	2.701	32.43	23.50	4	29	11	144	184
90	33.60	29	6	3	23.92	12.893	43.31	56.00	4	55	20	272	347
91	18.96	22	7	1	19.40	3.664	21.81	27.09	4	37	14	185	236
92	11.28	31	4	2	21.02	3.404	34.06	28.20	4	28	10	141	179
93	15.14	24	4	2	18.99	5.199	38.76	37.85	4	32	12	160	204
94	23.60	27	4	3	26.24	11.687	55.89	59.00	4	35	13	177	225
95	15.04	24	5	2	19.37	4.167	31.27	30.08	4	36	13	179	228
96	8.08	20	3	3	20.59	1.969	27.50	26.93	4	19	7	97	123
97	78.40	36	10	3	27.60	33.819	48.69	78.40	4	123	46	615	784
98	23.60	30	4	3	27.38	10.568	50.54	59.00	4	35	13	175	223
99	30.00	30	5	3	28.20	14.526	54.65	60.00	4	39	14	195	248
100	3.40	16	2	2	20.23	0.757	25.13	17.00	4	10	4	51	65
101	15.76	28	4	2	19.56	4.593	32.89	39.40	4	37	14	185	236
102	105.70	39	2	3	32.30	39.367	42.04	528.50	4	82	30	409	521
103	23.40	31	4	3	27.49	12.619	60.87	58.50	4	34	13	173	220
104	59.10	33	6	3	29.59	20.697	39.53	98.50	5	63	22	352	438
105	198.30	44	4	3	31.61	53.674	30.55	495.75	5	91	31	486	609
106	8.40	15	3	2	16.33	0.913	12.27	28.00	5	24	8	119	152
107	183.10	34	12	3	29.69	66.750	42.69	457.75	5	147	48	933	1129
108	82.30	22	15	2	20.82	36.845	40.54	162.33	5	99	36	687	823

Table No.43 - Data for Power Stations of the C.E.G.B. with effect March 1973.

Power Stn. No.	Inst'd Cap. MW/10	Age of Plant Year -1926	No. of Gen. Units	Type of Firing	Thermal Effy.	Power Generated in one yr. 10^6 KWhr/100	Utili-sation %	Average Unit Cap. MW	Region No.	No. of Tech. Staff	No. of Admin. Staff	No. of Indust Staff	Total Staff
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
109	93.00	36	5	3	30.51	46.091	55.94	186.00	5	69	27	392	489
110	98.40	28	6	2	25.39	32.347	30.03	442.00	5	95	31	466	593
111	9.00	24	3	2	23.11	2.003	25.18	30.00	5	29	12	119	161
112	7.60	31	4	2	19.42	1.601	23.78	19.00	5	25	11	82	119
113	33.60	31	8	3	27.17	13.371	44.92	42.00	5	73	21	359	454
114	11.00	26	5	1	19.72	1.902	19.52	22.00	5	33	12	139	185
115	28.80	31	10	3	25.74	6.906	27.06	28.80	5	51	21	310	383
116	12.00	30	4	2	22.59	4.334	40.76	30.00	5	28	14	170	213
117	198.30	43	4	3	33.27	101.874	57.98	495.75	5	87	37	522	647
118	105.00	39	6	3	28.87	32.125	33.05	385.00	5	123	42	605	771
119	17.00	34	9	2	17.70	4.096	27.19	18.89	5	49	20	292	362
120	67.20	35	9	2	32.85	32.563	54.69	74.67	5	71	28	456	556
121	23.10	28	5	2	27.03	6.017	29.40	46.20	5	48	14	255	318
122	19.10	28	6	2	22.94	5.827	34.43	31.83	5	35	16	234	286
123	198.30	42	4	3	32.93	67.187	38.24	495.75	5	81	35	497	614
124	76.80	37	6	3	30.98	32.041	47.09	128.00	5	83	29	440	553
125	3.50	18	3	2	20.22	1.121	36.15	11.67	5	10	4	52	67

In January 1971 R. Pryke published a paper entitled "Productivity, Performance and Public Ownership (1).

As part of this paper Pryke quoted sales per man-hour as a measure of productivity for the U.K. electricity supply industry, compared with those for six other western industrialised nations.

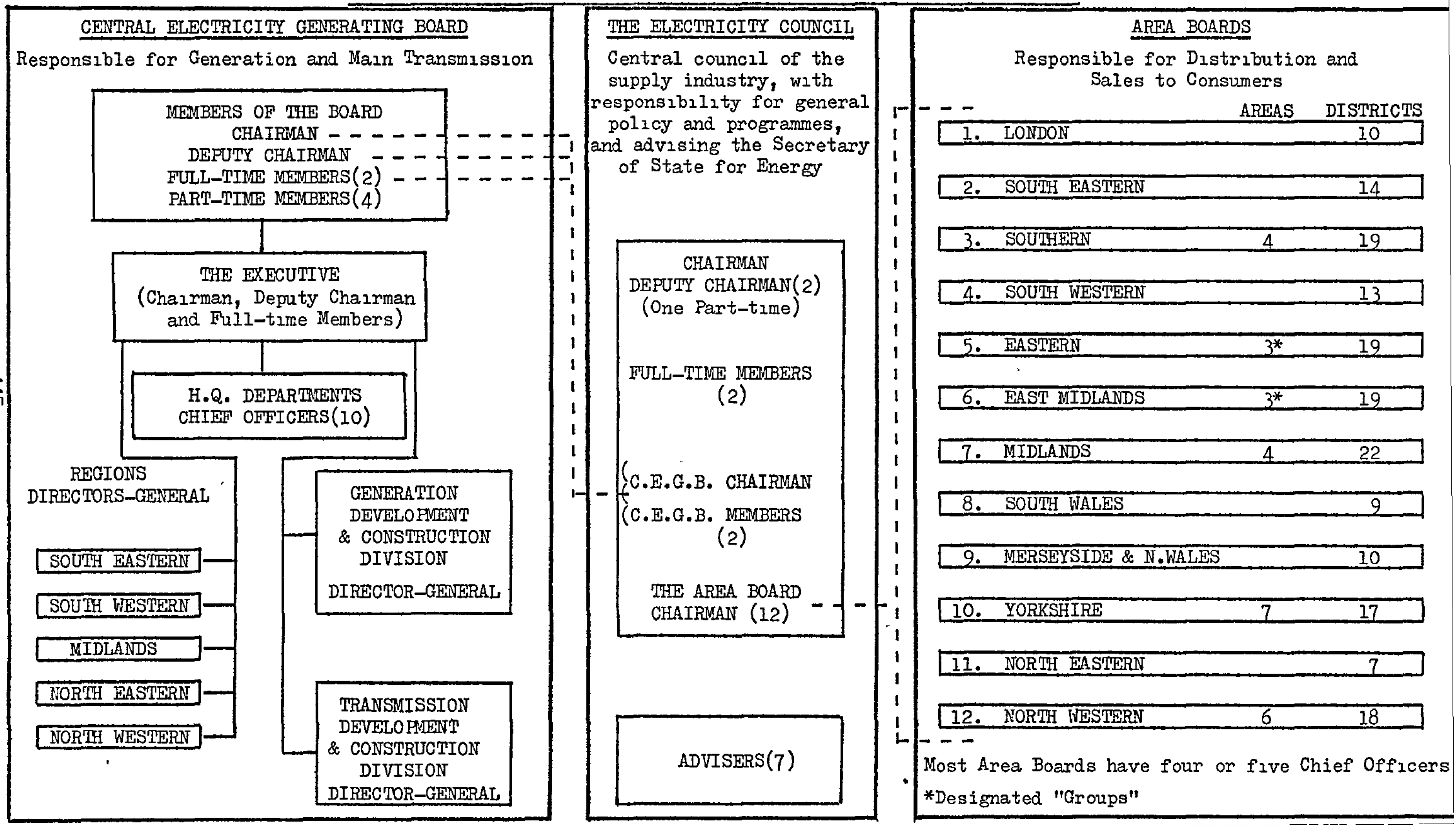
He showed that the British electricity industry's sales per man-hour have risen as fast or faster than all but one of the six major foreign suppliers. During the decade up to 1971, only Belgium, with a productivity growth of 10.4% per annum, advanced more rapidly than the British industry whose rate was 7.7%.

The German industry was just lower at 7.6%, Electricite de France showed 7.3% and the American investor owned utilities returned 7.1%.

The annual percentage increase in sales of electricity per man hour 1958-1968 were as follows:-

Belgium	10.4
Great Britain	7.7
Germany	7.6
France	7.3
United States	7.1
Norway	5.4
Italy	5.1

ORGANISATION OF THE ELECTRICITY SUPPLY INDUSTRY IN ENGLAND AND WALES



REFERENCES

REFERENCES

A - Referred to in the Text

1. R. Pryke. "Productivity Performance and Public Ownerships". Electrical Power Engineer, Jan. 1971.
2. A. J. Wood. "Corporate Models for Electricity Supply Utility Planning". Electrical Review Vol. 189, July 1971, pp 11-14.
3. Y. Barzel. "Productivity in the Electric Power Industry 1929-1955". Ph.D. dissertation, University of Chicago 1961.
4. J. E. Smith Nr. "The Measurement of Electric Utility Efficiency". National Association of Regulatory Utility Commissioners, Washington D.C, 1975.
5. J. D. Pace. "Relative Efficiency in the Electric Utility Industry". Ph.D. dissertation, University of Michigan, 1970.
6. N. Iulo. "Electric Utilities - Costs and Performance". Bureau of Economic and Business Reserarch, Washington State University Press, 1961.
7. W. A. Black. "Pitfalls of Statistical Analysis". Ohio Power Co., American Electric Power System, 1976.
8. Edison Electric Institue. "Problems and Limitations of Inter-Company Comparisons of Investor - Owned Electric Utilities". Edison Electric Institute, 1976.
9. W. H. Dodge. "Productivity Measures and Performance Evaluation". Michigan State University, 1968.
10. V. A. Rydbeck & R. M. Sigley. "Planning to Improve Utility Profitability". The American Power Conference, Chicago, April 1975.
11. C.E.G.B. "International Comparison of Generating Costs and Thermal Efficiencies". Electricity Consultion Council, February 1973.

12. E. W. Strassler. "Pitfalls in Econometric Forecasting". Published by The Institute of Economic Affairs Research Monograph No. 23, 1970.

13. Department of Energy. "The Structure of the Electricity Supply Industry in England and Wales". Report of Committee of Inquiry, Jan. 1976.

14 E. S. Booth & J.W.H. Dore. "The Development of Large Electricity Generating Units". Proc. Institution of Electrical Engineers, 1960 p.1451.

15 Electricity Council. "Electricity Council Annual Report 1973-1974". Published by Electricity Council, 1974

16. C.E.G.B. "C.E.G.B. Statistical Yearbook 1973-1974". Published by C.E.G.B., August 1974.

17. C.E.G.B. "C.E.G.B. Annual Report and Accounts 1974-1975". Published by C.E.G.B., 1975.

18. C.E.G.B. "C.E.G.B. Statistical Yearbook 1974-1975". Published by C.E.G.B., 1975.

19. Electricity Council. "Annual Report 1974-1975". Published by Electricity Council, 1975.

20 Group of Experts on Overall Productivity. "The Overall Productivity of the Electricity Supply Industry". Tariffs Study Committee - Special Report 60, U.N.I.P.E.D.E. Congress, 1973.

21. H.P. Wald. "Potential Uses of Analytical Statistics for Electric Utilities". Federal Power Commission, U.S.A.

B - Additional References

22. E. R. Petersen. "A Dynamic Programming Model for the Expansion of Electric Power Systems". Publication "Management Science", December 1973, pp 656-664.

23. H. Troscher. "General Models of Electricity Supply Undertakings". UNIPEDE Congress 1973, Use of Computers in Electricity Supply Undertakings, Working Group Study Document Ref. 120.2.

24. E. Spumberg. "Load Forecasting Techniques for Power System Planning". Presented at the IEEE Power Eng. Society Winter Meeting, New York, 27 January - 1 February 1974.

25. D. R. Limaye & J. R.Sharko. "U.S. Energy Policy Evaluation : Some Analytical Approaches". Pub. Energy Policy, March 1974 pp 3-17.

26. D. Clark. "Some Aspects of Generation Planning Philosophy Exaplained". Electrical Review Vol. 189, 27 August 1971, pp. 292-294.

27. J. L. Latham. "Probability Approach to Electric Utility Load Forecasting". IEEE Trans. Power Apparatus Supt. (USA), February 1968, pp. 496-504.

28. K. N. Stanton & P. C. Gupta. "Long Range Forecasting of Electrical Demand by Probabilistic Methods". Proceedings of the 31st Meeting of the American Power Conference, Chicago 1968, pp. 964-969.

29. L. F. Robson & D. A. Davies. "Electricity Forecasting". Energy Forecasting for the U.K., a conference organised by the Institute of Petroleum and Institute of Fuel, April 1972 pp. 19-24.

30. R. Jensen. "Forecasting Demand and Consumption in the Electricity Supply Industry". Conference by Society for Long Range Planning and Forecasting, a Study Group of the Operational Research Society, 1971.

31. L. G. Brookes. "A Forecasting Model of the Electricity System". Publication "Atom", July 1970. pp 153-161.

32. R. S. Edwards & D. Clark. "Planning for Expansion in Electricity Supply". Electricity Council, CEGB Publication, 1962.

33. T. W. Berrie & P. E. Betts. "Assessment of Costs of Alternative Plant Proposals on the CEGB System". I.A.E.A. Symposium on International Extrapolation and Comparison of Nuclear Power Costs, London 1967.

34. J. L. Bethune. "Use of the Computer for Dynamic Analysis of a Power Plant's Performance". I.S.A. Transactions Vol.14 1975.

35. J. Kreuzberg. "Load Diagrams and their Development Trends - An Indicator for Supply Undertaking Management". Elektrizitats wirtschaft, Vol. 70, No. 25, 6 December 1971, pp. 709-718.

36. G. F. Ray. "Energy : Medium Term Forecasts Re-assessed". National Institute Economic Review, November 1972, pp 61-68.

37. C. I. K. Forster. Statistical Basis to National Fuel Policy". Paper submitted to the Institute of Actuaries, 27 January 1969.

38. Economic Commission for Europe. "Factors Affecting the Accuracy of Energy Planning and Forecasting". Prepared by the Secretariat, Economic Commission for Europe, Energy-Working Paper No.4, 9 April 1968.

39. A. Kroms. "Energy Forecasts". from Bulletin de L'Association Suisse des Electriciens, 15 May 1971, pp 508-515.

40. R. Stone et al. "A Programme for Growth. Part 8 : The Demand for Fuel 1948 - 1975 - A Sub Model for the British Fuel Economy". London : Chapman and Hall Limited for the Department of Applied Economics, University of Cambridge, December 1968.

41. A. J. Middelhoek. "A Sector Model of Energy Consumption". The Hague - van Stolkwet, 14, Central Planning Bureau 1969.

42. R. J. Ball & L. R.Klein. "An Econometric Model of the United Kingdom". Blackwell 1961.

43. F. M. Fisher. "The Choice of Instrumental Variables in the Estimation of Economy-wide Econometric Models". Institute Economic Review, September 1965, pp 245-274.

44. L. G. Brookes. "Energy Resources and World Economic Growth". Long Range Planning, September 1973, pp 39-43.

45. M. H. Rothkopf. "An Economic Model of World Energy 1900-2000". Long Range Planning, June 1973, pp 43-51.

46. C. I. K. Forster. "New Developments in the Statistical Framework for Reviewing Fuel Policy in the U.K.". World Power Conference, Moscow, Section B, Paper No. 135, August 1968.

47. Economist Intelligence Unit. "Britains Energy Supply". Produced by the Economist Intelligence Unit for the National Coal Board, May 1968.

48. Institution of Mechanical Engineers. "Energy Statistics". I.Mech.E. Convention, 23-25 April 1969.

C - FURTHER READING ON SUBJECTS RELEVANT TO THIS PROJECT

49. C. G. Paradine & B. H. P. Rivett. "Statistical Methods for Technologists". English Universities Press 1960.

50. E. C. Bryant. Statistical Analysis". McGraw Hill, 1960 (2nd Edition 1966).

51. P. G. Moore. "Principles of Statistical Techniques". Cambridge University Press, 1958 (Reprinted 1964).

52. A. Merrett & G. Bannock. "Business Economics and Statistics". Hutchinson 1962.

53. R. Schlaifer. "Introduction to Statistics for Business Decisions". McGraw Hill 1961.

54. L. T. Simister & J. Turner. "Systematic Forecasting in British Industry". Journal of Business Policy, Winter 1972, pp. 43-55.

55. A. H. Q. M. Merkies. "The Reliability of Economic Models". The Hague, Central Planning Bureau, 1968.

56. H. F. Lande. "How to Use the Computer in Business Planning". Englewood Cliffs N.J., Prentice Hall, 1969.

57. R. V. Arnfield. "Technological Forecasting". Edinburgh University Press, 1969.

58. D. R. C. Halford. "Business Planning - a Practical Guide for Management". David & Charles, Newton Abbot.

59. S. Reutlinger. "Analysis of a Dynamic Model with Particular Emphasis on Long-Run Projections". Journal : Farm Economy Vol. 48 No. 1, Feb. 1966, pp 88-106.

60. M. K. Evans. "Multiplier Analysis of a Postwar Quarterly U.S. Model and a Comparison with Several other models". Rev. Economic Studies Vol. 23 , Oct. 1966, pp 4-96.

61. G. D. N. Worswick & F. T. Blackaby. "The Medium Term (Models of the British Economy)". National Institute of Economic and Social Research and The Social Science Research Council. Heinemann Educational Book, 1974.

62. G. Wills, D. Ashton and B. Taylor (Editors). "Technological Forecasting and Corporate Strategy". Bradford University Press 1969.

63. United Nations. "Macro-Economic Models for Planning and Policy - Making". United Nations, Geneva, 1967.

64. M. Young. "Forecasting and the Social Sciences". Heinemann 1968.

65. D. Ashton & L. Simister. "The Role of Forecasting in Corporate Planning". Staples Press.

66. M. R. Spiegel. "Theory and Problems of Statistics". Schauns Outline Series, McGraw Hill Book Co., 1972.

67. P. G. Moore. "Statistics and the Manager". Macdonald, London 1966.

68. J. Woodward. "Management and Technology". HMSO 1958.

69. E. Mumford. "Living with a Computer". Institute of Personnel Management 1964.

70. A. J. Burton & A. G. Mills. "Electronic Computers and their Business Applications". Ernest Benn 1960.

71. F. L. Westwater. "Teach Yourself Electronic Computers". English Universities Press, 1962.

72. T. W. Berrie. "Eonomics of System Planning". Electrical Review, September 1967.

73. K. D. Tocher "The Art of Simulation". Van Nostrand, 1963.

74. H. I. Ansoff. "Corporate Strategy". McGraw Hill 1965.

75. P. Drucker. "Managing for Results". Heinemann, 1964.

76. H. D. Wolfe. "Business Forecasting Methods". Holt, Rinehart and Winston Inc., 1966.

77. Statistical Office of the European Communities. "Energy Statistics Year Book 1970 - 1974". 1975 updated to Jan. 1976.

78. T. A. Boley (Electricity Council). "Load Forecasting Methods and Procedures in the Electricity Supply Industry in England and Wales". Proceedings of French-American Conference, University of Wisconison, Institute of Environmental Studies, Feb. 1976 pp 83-95.

79. R. F. Vancil. "The Accuracy of Long-Range Planning". "Harvard Business Review" (USA), Sept./Oct. 1970 pp 98-101.

80. J. Argenti. "Corporate Planning : A Practical Guide". London, Allen and Unwin, 1968.

81. J. Argenti. "The Job of Corporate Planner". "Personnel", March 1969, pp 33-34.

82. G. F. Ray. "Energy : Medium Term Forecasts Re-assessed". National Institute Economic Review", Nov. 1972 pp 61-68.

83. UKAEA. "Future Prospects for Energy Supply and Demand". "Atom" (UKAEA), Feb. 1973, pp 38-40. (Based on a presentation of the New Systems Forum of the UKAEA).

84. E. Grugesser. "Guidelines for Finding Internationally Valid Factors Determing Electricity Demand". "Brennst - Warme - Kraft" (Germany) March 1973, pp 102-104.

85. T. H. Burbank. "A Critique of Projections in the Electric Power Industry". "Edison Electric Institute Bulletin" (USA) March/April 1973, pp 64-70.

86. H van der Shiys. "The Effect of Weather Conditions on the Demand for Electricity". "Electrotechniek", Vol. 48, 19 Feb. 1970 pp 173-176.

87. P. D. Matthewman & H. Nicholson. "Techniques for Load Prediction in the Electricity Supply Industry". "Proc. IEE". Oct. 1968 pp 1451-1458.

88. R. E. Clayton et al. "Load Model Sensitive to Weather Data" "Electrical World" (USA) 15 March 1973, pp 96-98.