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AN INVESTIGATION INTO THE USE OF MATHEMATICAL MODELS FOR RESOURCE ALLOCATION IN AGRICULTURAL RESEARCH

by

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Abstract

The management of state financed agricultural research have the responsibility of selecting a portfolio of projects which will provide the greatest benefit to society for the resources invested. The purpose of this investigation was to examine the possibility of using mathematical models to aid in the making of resource allocation decisions within agricultural research.

Both the data and criteria on which a quantitative project selection and resource allocation procedure could be based were found to be inadequate. Consequently a formal Resource Allocation System for Agricultural Research (RASAR) was developed as a framework within which mathematical models could be developed and used.

RASAR was conceptualized as in iterative system with the purpose of selecting a portfolio of research projects such that the research outputs would provide society with the potential power to change the agricultural system in ways that are expected to

bring about the greatest improvement in social welfare. The ultimate goal of agricultural research was tentatively identified as having nine dimensions in three broad categories: Consumption category -- (1) quantity, (2) quality, (3) availability; Security category -- (4) human safety, (5) economic defence, (6) food sources security, (7) conservation; Equity category -- (8) distribution, (9) individual rights. Subsystems within RASAR for generating socio-economic data relating to these dimensions were specified and tested with four case study research projects. A mathematical programming model which could provide management with a tool for assimilating the complexity of criteria and data into a form which is readily usable for decision making was developed and evaluated.

A number of conclusions emerged from the research: (a) mathematical models can be effectively used to assist agricultural research management with the complex problem of resource allocation, providing an adequate system for specifying selection criteria and for generating data is utilized; (b) RASAR offers considerable scope for development into an effective system for the more effective and rational allocation of research resources; (c) the multiplicity of objectives or reasons for research and the lack of adequate socio-economic data which tend to make resource allocation decisions difficult can be adequately brought together in a well defined resource allocation system and used to improve the decision making process; (d) projects which appear to have beneficial outputs and be justifiable in terms of their immediate objectives may, in fact, have obscure but substantial social costs that are not apparent without a rigorous socio-economic assessment.

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Contents

APPENDICES

List of Figures

LIST OF TABLES

List of Abbreviations

ARC	Agricultural Research Council (United Kingdom)
ARS	Agricultural Research Service (United Kingdom)
ASULGC	Association of State Universities and Land Grant Colleges (United States)
BISRA	British Iron and Steel Research Association
bu	bushels
Can	Canadian
CAP	Common Agricultural Policy (of the EEC)
CAS	Centre for Administrative Studies (Civil Service Department, United Kingdom)
CCP	Customer/Contractor Principle
cf.	compare
c.i.f.	cost, insurance, freight
Cmnd.	(publication by) Command (of Her Majesty)
CPA	Critical Path Analysis
CPM	Critical Path Method
CSII	Centre for the Study of Industrial Innovation (United Kingdom)
CSO	Central Statistical Office (United Kingdom)
CSP	Council for Scientific Policy (United Kingdom)
CWB	Canadian Wheat Board
DAFS	Department of Agriculture and Fisheries for Scotland
d.m.	dry matter
DP	diastatic power
e.g.	for example
EDC	Economic Development Council (of NEDO)
EEC	European Economic Community
et al.	and others
FAO	Food and Agriculture Organization (United Nations)
f.o.b.	free on board
gal	gallons
GRI	Grassland Research Institute (England)
H.C.	House of Commons (publication, United Kingdom)
HDP	high diastatic power (barley)
HFRO	Hill Farming Research Organisation (Scotland)
H-GCA	Home-Grown Cereals Authority (United Kingdom)
HMSO	Her Majesty's Stationery Office (United Kingdom)
HO	Home Office (United Kingdom)
ibid.	in the same place
i.e.	that is
IMF	International Monetary Fund

k	thousands
kg	kilograms
lb	pounds
M	millions
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
MANI	Ministry of Agriculture, Northern Ireland
MBO	Management by Objectives
m.c.	moisture content
Mcal	megacalories
MMB	Milk Marketing Board (United Kingdom)
NATO	North Atlantic Treat Organization
NEDC	National Economic Development Council (United Kingdom)
NEDO	National Economic Development Office (United Kingdom)
NIAE	National Institute of Agricultural Engineering (United Kingdom)
No.	number
OECD	Organization for Economic Co-operation and Development
PERT	Program Evaluation and Review Technique
PPB	Planning, Programming and Budgeting
PAU	Programmes Analysis Unit
RASAR	A Resource Allocation System for Agricultural Research
RDE	Research and Development Effectiveness
R & D	Research and Development
SPBS	Scottish Plant Breeding Station
SPRU	Science Policy Research Unit (United Kingdom)
SPNA	Shortest Path Network Analysis
UK	United Kingdom
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
USA	United States of America
USDA	United States Department of Agriculture
WO	Welsh Office

1. INTRODUCTION

Decision makers in agricultural research have the responsibility of selecting a portfolio of research activities that will maximize the benefit received from the resources invested. The specialization of agricultural research investigation in increasingly complex areas, and a lack of explicit and specific direction from research sponsors makes the decision maker's task increasingly difficult.

The purpose of this study was to investigate the extent to which mathematical models can effectively be used in agricultural research as aids in making resource-allocation decisions. However, before mathematical models could be evaluated, the criteria for resource allocation decisions had to be established and a system for specifying and generating the information needed for mathematical models had to be developed.

In this thesis the difficulties encountered in establishing a foundation for the effective use of mathematical models are discussed prior to the presentation of a resource allocation system which includes a mathematical model. More specifically, the thesis has five main sections. Firstly, Section 2 reviews the current discussion of issues relevant to the application of quantitative methods in the management of research and development and suggests sources of further information. Section 3 discusses the nature of agricultural research, and its purposes, outputs, inputs, and activities. Section 4 develops a resource allocation system within which both research project generation and evaluation, and allocation decisions can be purposefully and effectively performed.

The section also compares the allocation system to other proposed systems and discusses in more detail closely related research studies and issues. Section 5 presents a mathematical model with several levels of complexity that can provide a considerable amount of useful information to aid in research project portfolio selection. In Section 6, a summary of the assessments of four current agricultural research projects preceeds a demonstration and evaluation of the mathematical model. The detailed project assessments are contained in appendices.

2. BACKGROUND TO THE RESOURCE ALLOCATION PROBLEM

The philosophies, concepts, methodologies, and sources of information that are pertinent to the issues and methodologies dealt with in this investigation are extensive and complex. This section attempts to present some of the topics that are dealt with in the literature.

These topics include (a) the role of agricultural research in the United Kingdom, (b) the increasing socio-economic awareness that is having an increasing impact on agricultural research management, and (c) the use of mathematics models as resource allocation aids in industrial research and development. Brief surveys of sources of further information and data are also included.

Since the topics identified are so diverse and complex, a detailed evaluation of them has not been attempted. However, detailed evaluation of research more closely related to the topic of this investigation is present in Section 4.2.

2.1. Agricultural Research in Britain

Government agency agricultural research which is planned and co-ordinated by the Agricultural Research Council (ARC) and is largely financed by the State represents a very large proportion of agricultural research in the United Kingdom and is the area of agricultural research that is of primary concern in this investigation (see Central Office of Information, 1969, p.37).

The ARC states that its " . . . main functions are to provide facilities for research and to review research in progress, promoting new work where necessary, and ensuring, as far as possible, that manpower and resources are used to the best advantage. The Council must, while avoiding over-organisation and over-direction, be able to guide the work of the institutes along lines that are likely to contribute to the solution of problems of practical importance. The preservation of the right balance between individual freedom in which able research workers may develop their own interests on the one hand, and some central direction of effort on the other is an important consideration in the administration of research to which continuing attention is paid." (ARC, 1969, p.4). The ARC financially supports about 37 stations and units with a budget (in 1971-72) of £18.7 million. In addition the ARC has considerable responsibility for the programs of eight research institutes in Scotland which receive most of their support (£6.5 million in 1971-72) from the Department of Agriculture and Fisheries for Scotland (see Green Paper on R and D, 1971, pp. 8 and 9).

The decision making mechanisms and administrations of the various institutions appear to vary from a more or less democratic process within the established hierarchy of staff to a more authoritarian administrative structure. Each institution appears to be reasonably autonomous within its established field of investigation, and within the pressures of visiting groups (set up by the ARC to review the research program), financial sources and public opinion regarding the relative importance of various sections of the research program.

Changes are currently taking place in the organization and administration of agricultural research in Britain. A system of universal project definition and costing has been implemented (see Section 4.2). The basis for deciding on the importance of various research activities and hence the basis for allocating research resources is being questioned (Select Committee on Science and

Technology, 1972; Green Paper on R and D, 1971; White Paper on R and D, 1972). The Government White Paper on research and development has endorsed " . . . that applied research and development commissioned by the Government should be organised in accordance with a 'customer/contractor' principle." (White Paper on R and D, 1972, p.3). The White Paper defines the 'customer/contractor' principle as Government " . . . Departments, as customers, define their requirements; contractors advise on the feasibility of meeting them and undertake the work; and the arrangements between them must be such as to ensure that the objectives remain attainable within reasonable cost. This is the customer/contractor approach." (White Paper on R and D, 1972, p.4).

By 1975/76, the proposed changes effectively transfer £10 million of the £18.7 million (1971-72 prices) of ARC's budget to the budgets of customer Departments, who then "contract" the various research establishments (White Paper on R and D, 1972, p.12). The effect may well be a major shift in the decision making procedures since under the new system government departments such as MAFF and DAFS should have much more influence on the direction of agricultural research than they have had previously.

There does not appear to be any significant use of mathematical modelling techniques in resource allocation decision making within agricultural research in the United Kingdom. However, a formal system approach to the management of a whole institution is being applied by one research establishment, Hill Farming Research Organisation, and may well be in operation on a smaller scale or in a less formal manner in other places.

Mathematical modelling and operational research techniques are also being used as tools of analysis within current research projects (see NIAE, 1971, p.30; Jones, 1970; GRI, 1971, Page 111; Dent and Anderson, 1971).

2.2. Issues in Research Decision Making

Guides to Other Researchers: Several sources of information provide details for locating individuals and institutions that are investigating decision making in research and development. Rubenstein and Sullivan (1968) have published 'A Directory of Research-on-Research' that lists and briefly describes 324 research-on-research projects largely in North America. The projects cover a wide spectrum of fields including agriculture. A European version of this type of directory containing 123 projects has been published by Rubenstein and Barth (1971).

There are two publications that deal more specifically with the management of agricultural research. One is based largely on papers presented at the Minnesota Symposium on Resource Allocation in Agricultural Research held in Minneapolis on February 23-25, 1969 (see Fishel, 1971). The other is a set of papers presented at the Symposia on Agricultural Research, a series of three one-day seminars held in January and February 1971, at the University of Manitoba (e.g., Puterbaugh, 1971; Hannah, 1971; Gilchrist, 1971).

Increasing Socio-Economic Awareness: There is considerable discussion and debate throughout the world about the role that agricultural research should play in society. The debate appears to intensify whenever there is pressure to modify the established system of organization and administration or modify the programs of the established institutions.

The rate of change in society is increasing not only in changing technology but in the changing values and norms held by society. There is a growing feeling that perpetual increases in scientific knowledge and economic growth in the ways that they have been developed and utilized in the past are not going to lead to utopia (Meadows, et al., 1972; Goldsmith, 1972; Pearl and Pearl, 1971; Marstrand, 1970 and 1971; OECD, 1971; Schaeffer, 1968 and 1970; Rookmaaker, 1970). Some of the indicators of the problems and issues facing society are (a) ecological deterioration, (b) an apparent world shortage of resources, the effects of which may be apparent in the immediate future, (c) exponential growth rates in population and consumption which may not slow without a crisis, and (d) increases in crime and terrorism.

New ways of viewing problems and looking for solutions have appeared in the last decade. The methodologies of operational research, management science, work study, and econometrics have been enveloped by the systems approach (Churchman, 1968; Ackoff, 1973; Nadler, 1967). Systematic approaches to management such as Programming, Planning and Budgeting (PPB) and Management by Objectives (MBO) have recently become popular as means for analysing and clarifying an organization's objectives with the view to improving operational effectiveness (Canada, Treasury Board, 1969; Humble, 1970; Molander, 1972).

Other more traditional techniques such as investment appraisal, dealing largely with monetary returns, have been broadened into cost/benefit or social cost/benefit analysis to include social and ecological considerations (Peters, 1968; Walsh and Williams, 1969; UNIDO, 1972; OECD 1969; Little, 1971). An annotated bibliography by Wood and Campbell (1970) provides abstracts of 389 publications on the subject.

<u>Socio-Economic Research Evaluation</u>: The increasing socio-economic awareness has had an impact on agricultural research. In general, the relation of research to society's goals, and the objectives of the production system have become topics for examination (Evenson, 1967; Glen, 1968; Andarawewa, 1969; Robertson, 1971).

The consideration of agricultural research in the context of welfare economics is an approach to research evaluation which is becoming increasingly important in research management as a supplement to technical evaluation (Tweeten, 1969; Schultz, 1969; Heady, 1969). This approach involves establishing suitable criteria for non-price allocation (Hildreth, 1966; Gilchrist, 1971). The criteria used have tended to be those associated with economic growth, such as monetary benefits and costs, and returns to investment, while criteria associated with security or equity have been largely set aside (Paulsen and Kaldor, 1968). One of the main reasons for this may be that society through its government has not defined a rigorous and operationally useful social objective function (Kaldor, 1969, p.78).

The social evaluation of research is perhaps more complex than evaluation from the point of view of an individual or a firm because the prices and factors relevant to a firm may be inadequate from the point of view of society. The recognition of this fact by investment project appraisal analysts has led to the development of guidelines which advocate the replacement of market prices with shadow or accounting prices that are more accurate estimates of real costs and benefits to society than market prices (OECD, 1969; UNIDO, 1972).

2.3. Mathematical Models as Decision Aids

A brief review of attempts at quantitative management and the application of mathematical models to research management decisions (largely within industrial situations) provides useful insight into the potential for using these techniques in agricultural research management.

A mathematical model may be described as any symbolic representation of a real world system that is used to gain insight into the real system. This description covers a very wide scope of models from the simplest of charts or rating systems to complex simulations. Some models are used to study the system as a whole while others are used to examine a particular segment of the system.

Scoring models have been used in an attempt to provide a quantitative base for comparing alternative research projects (Skolnick, 1969; Moore and Baker, 1969). However, these models have been criticized because they are arbitrary, and model builders often fail to realize the impact which the model structure will have on the scores generated (Moore and Baker, 1969a).

Decisions in research and development are often based on probabilistic estimates. Methods for dealing with this type of datum in decision processes are presented by Raiffa (1968) and Hadley (1967). Some probabilistic estimates can be objective while others are subjective. Hurter and Rubenstein (1969a) advocate the development of models in research management which can use subjective data simply because objective data are not available. Souder has reported that one experiment tended " . . . to support the hypothesis that R & D planning and control models that are based on subjective probability estimates may reliably be used by management to aid in early identification of eventually failing projects, as well as to aid in project selection and project funding." (Souder, 1969, p. 35).

A number of attempts have been made (with varying degrees of success) to apply mathematical programming and network type models to problems of resource allocation: Linear programming models have been used by Bell and Read (1970) and Asher (1962). An integer programming model has been suggested by Beged Dov (1965). A combination of probabilistic networks, simulation and mathematical programming has been used by Lockett and Freeman (1970). A mathematical programming model with probabilistic objective function has been suggested by Freeman and Gear (1971). Numerous other variations have also been suggested (Rosen and Souder, 1965; Rea and Synnott, 1963; Souder, 1967; Wiest, 1967).

The number of different types of models which have been suggested for resource allocation and related decisions in industrial situations is so large that comparative surveys of these models have been undertaken (Baker and Pound, 1964; Cetron et al., 1967). In addition the realism and effectiveness of models is being questioned (Allen and Johnson, 1971; Souder, 1973; Lockett and Gear, 1972). Souder (1972) has even used a scoring methodology for assessing the suitability of management science models for R and D project selection. This scoring methodology included five major criteria: realism, flexibility, capability, ease of use, and cost. Souder concluded that of twenty-six models, " . . . the linear and non-linear models had generally higher flexibility,while the linear, non-linear and zero-one models had generally higher realism than the other model types." (Souder,1972,p. B526). Although there are many models suggested in the literature, Hurter and Rubenstein report that a " . . . formal mathematical analysis of R & D portfolio selection seldom is used by decision makers in industrial settings." (Hurter and Rubenstein, 1969a, p.i). Two reasons are given for this lack of use: (a) lack of suitable data, and (b) formal mathematical models leave out important considerations which are difficult to quantify. Hurter and Rubenstein suggest that these problems be overcome by developing models with a view toward the use of subjective data, and by using models for " . . . the identification of efficient project portfolios without attempting to select the 'best' one." (Hurter and Rubenstein, 1969a. p.i)

2.4. Data Aquisition

The application of any type of mathematical model requires data. Some data are available in statistical publications or annual reports (e.g., DAFS, 1971 and 1971a; NEDO 1969; MAFF, et al., 1971; MAFF, 1964; H-GCA Annual Report, 1971), while some are only available by conducting field experiments or surveys.

Other data must be generated and techniques for generating data must be developed. For example, the DELPHI method is a technique that was developed "to obtain the most reliable consensus of opinion of a group of experts"(Dalkey and Helmer, 1963, p. 458). Technological forecasting and long range forecasting are fields of study which have arisen out of the need to develop methods for identifying trends in technology and estimating their probable future effects in industry and on the economy (Quinn, 1967; Hendry, 1971 and 1971a; Hetrick, 1969).

The accuracy of data is another consideration in the use of mathematical models. A study by Norris (1971) of four industrial research organizations showed that actual project cost ranged from 97% to 151% of the estimated cost, and actual project duration ranged from 139% to 304% of the estimated duration. If these figures are typical of R and D, research personel tend to optimistically underestimate project cost and duration.

2.5. Summary

This brief survey of the concepts, issues, and techniques that are related to the problem of using mathematical models for resource allocation in agricultural research provides some indication of the diversity of topics which are relevant to this investigation.

The literature, reviewed both in this section and in Section 4.2, contains considerable discussion about the problems and inadequacies of existing management systems. However, there appears to be no universally or even substantially accepted base on which a resource allocation system in agricultural research can be built. For this reason, the sections which immediately follow will deal with the problem of establishing a base on which to consider the use of mathematical models for resource allocation decisions in agricultural research.

3. THE NATURE OF AGRICULTURAL RESEARCH

An examination of the nature of agricultural research provides some insight into research that will be useful in the development of a system for the allocation of resources. The purposes of agricultural research are first examined; then the types, nature, and beneficiaries of research outputs are considered. Finally, the inputs and phases of research are discussed.

3.1. Purposes of Research in Agriculture

Management decisions which are related to the allocation of resources should stem from the reasons for, or purposes of, agricultural research. If decisions are not related to purposes there is no justification for doing the research and no logical basis for allocating resources. An examination of the stated purposes of Government financed agricultural research illustrates the degree of direction given to decision makers.

<u>The Stated Purposes of Agricultural Research in the United Kingdom</u>: Since most Government supported agricultural research is both financed and under the direct or indirect control or guidance of the Agricultural Research Council (ARC), the published statements of the Council are presented as representing all Government financed agricultural research. The objectives of the ARC are stated as follows:

> "The Agricultural Research Council is a corporate body established by Royal Charter with the following objectives:
>
> (a) the organisation and development of agricultural and food research;

(b) the establishment or development of institutions or departments of institutions for investigation and research relating to the advancement of agriculture or the production and processing of food; and

(c) the making of grants for such investigation and research.

(References to agriculture in this context include horticulture.)" (ARC, 1969, p. 3).

Note that these objectives give very little indication of either the specific purposes of agricultural research or for whose benefit the research should be pursued. However, some indication of the Council's own concept of the purposes of agricultural research may be gleaned from the following statement:

"THE SCOPE OF AGRICULTURAL RESEARCH

"Agricultural research has no definite boundaries. It embraces all scientific research directed towards the improvement of agriculture and its products, and so covers a wide range of scientific disciplines. . . .
. . . .
The work of the agricultural research service combines applied research with studies of a more basic nature. The ultimate object is to solve practical problems; but the prospects of success depend upon the extent of the background knowledge. The solution of even an apparently simple problem may well demand quite extensive fundamental investigations. The attempt to supply the missing information falls rightly within the field of agricultural research, although it may belong equally to some field of pure science." (ARC, 1969, p. 1).

This statement suggests that the reason for promoting agricultural research is to improve agriculture and its products by solving practical problems, but it does not identify what constitutes an improvement or a practical problem, or whose problems should be solved.

However, in dealing with the policy of one specific area of research, plant breeding, the ARC states that its policy is ". . . to encourage the State-aided institutes to develop improved techniques and to establish their validity by the tests of practical breeding; and to breed new crop plants and new varieties to provide, as far as possible, for needs of farmers, growers and processors that might otherwise not be satisfied from British sources. The Council also has in mind the importance of the State-supported institutes as training grounds for plant breeders." (ARC Annual Report, 1970, p. 4). This statement is more specific than the previous statement in that it does identify beneficiaries of the research (i.e., farmers, growers, and processors). It also gives some general guidance on the boundaries of research activities, and suggests in general terms the reasons for research (i.e., to provide for needs).

In general, the directors of research establishments who were interviewed in the course of this investigation state that they either do not know who should be the beneficiary of agricultural research or that they assume the farmer in most cases is the immediate beneficiary.

A Function Statement for Agricultural Research: An explicit statement for the overall function or purpose of agricultural research within the United Kingdom does not appear to exist. In addition, the recent investigations and debate surrounding the role of all research within the United Kingdom suggests that even an agreed implicit function does not exist, or may soon be changed (see Green Paper on R and D, 1971; Select Committee on Science and Technology, 1972; White Paper on R and D, 1972). Since an acceptable function for agricultural research must be identified before an effective allocation system can be developed, a suggested function based on an examination of the research system is presented as follows:

> Agricultural Research Function: To produce research outputs (knowledge, methods, and products) that provide society with the potential power to change the agricultural system in those ways that are expected to improve the welfare of individuals within society.

This statement is not intended to represent the concepts or opinions of management in agricultural research, or be necessarily defensible as the best function for agricultural research. It is only intended to be a reasonable basis for subsequent discussion. The statement is both explicit and general because it is not intended to specify the goals of research, but rather the general aim of research that encompasses the reasons for research.

Some of the terms used in the statement need elaboration or definition. The terms 'research outputs' and 'potential power to change' are elaborated upon in Section 3.2. What constitutes an improvement in social welfare is defined in Section 4.1, and the choice of society as beneficiary of the research is justified in Section 3.2. The term 'agricultural system' is defined as the production, marketing, and distribution organizations for products and services from farm or farm based enterprises, including the provision of farm inputs.

3.2. Outputs of Agricultural Research

Categories of Research Outputs: The outputs of agricultural research may be grouped into three categories:

I. Knowledge -- ideas, facts and figures, relationships, and the specifications for components comprising a system.

II. Methods or Blueprints -- specific and complex sets of components having relation, order, or sequence, and performing specific functions as units.

III. Products or Commodities -- tangible products of the research work which cannot be replaced if totally destroyed except by repeating the research, at least in part.

An alternative classification for research activity may be a continuum from basic to applied research (and even on into development). However, this type of classification is not as effective for the purposes of this investigation as the classification system given above because it places emphasis on the degree of immediate application of the research output rather than on the nature of the research acitivity and the nature of the actual research output.

Perhaps a more realistic description of the outputs would be a continuum from ideas to commodities, but the distinctions provided by the above three categories are sufficient for the purposes of this investigation.

Research Provides Potential Only: One important aspect of the nature of research output is that the output normally only provides power to bring about change. For example, the ability to predict with less risk or uncertainty, or the knowledge which enables the construction of something new provides the power to bring about changes in a system, but does not bring about the change itself. Whether or not the new power is desirable or undesirable, needs controlling, can be controlled, or can be used in a given situation may not be determined by the research output itself. The change may or may not come about depending on factors not necessarily within the realm of research. In some cases more research may be needed to make use of or control the power made available by previous research. Research output provides the potential for change but does not bring about the change itself.

Beneficiaries of Agricultural Research: The function of agricultural research given in Section 3.1 specified society as the beneficiary of research output. Society normally means the people within a particular nation or political boundary. There are a number of parties within society that may have an interest in, or be directly or indirectly affected by research outputs. Any particular output may have potential effects that have varying degrees of positive or negative benefit for the various parties.

Although ultimately individuals are affected, groups of individuals can be described that have enough in common to provide useful categories for assessing the potential effects of research output. Sometimes these groups correspond to institutions within society while other times they do not.

A list of the groups within society that may need consideration when evaluating research output is shown in Table 3.1. The list is not intended to be exhaustive or necessarily contain the most useful categories. However, it illustrates the diversity of groups (which are by no means mutually exclusive) that have an interest in agricultural research. The list is also a demonstration of the type of check list which could be developed as an aid to project evaluation.

TABLE 3.1 PARTIAL LIST OF AGRICULTURAL RESEARCH BENEFICIARIES

Within the whole of society

1. Consumers (various income levels)

2. Taxpayers (property, income, and consumer taxes)

3. Governments

   (a) National (economic management -- growth, employment, trade, etc.; defence -- internal and external, for socio-economic protection, etc.; social security; etc.)

   (b) Regional

   (c) Local

Within the Agricultural System

4. Producers

   (a) Agricultural Products (cereals, forages, oilseeds, fruit and vegetables, livestock and poultry, etc.)

   (b) Agricultural related products (fertilizers and chemicals; machinery, buildings and equipment; fuels and lubricants, etc.)

   (c) Non-Agricultural Products

5. Processors

6. Distributors/Retailers

Other Special Groups

7. Landlords/Tenants

8. Management/Labour/Unemployed/Retired/Infirm

9. Service providers

   (a) Teachers

   (b) Advisors

   (c) Statistic Collectors/Data Processing Personnel

   (d) Technicians

10. Researchers

PL.

There are two reasons why the function statement of Section 3.1 specifies society as a whole as the beneficiary. The first is because it is society in general that finances the research under consideration and should therefore be the recipient of the benefits, unless society specifies that particular groups should be the recipients. (In such cases, agricultural research would be a form of transfer payment.) However, there is no evidence that State-financed agricultural research is not considered in the United Kingdom as being ultimately for the benefit of society as a whole.

The second reason is because a particular research output may be expected to allow changes which will have a beneficial effect on one group but a detrimental effect on either another group within society or society as a whole. For any system to work effectively the requirements of the system as a whole must take priority over the requirements of the components. Consequently, in this investigation the potential effect on society as a whole has been accepted as the primary basis for considering research. The potential effects on particular groups are also considered, but only as one dimension of the effects of the research.

3.3. Inputs to Agricultural Research

The things that are necessary for agricultural research include (a) tangible housing and provisions such as laboratories, offices, barns, machinery and supplies; (b) other resources such as knowledge, natural resources, finances, and people with skills; and (c) supporting systems such as social and political support, and organizational and administrative structures. The diversity and, in some cases, subjectiveness of these inputs suggests that a universal method for identifying and quantitatively defining a unit of research will not be based on the inherent properties of the inputs. Any universal method of definition will almost certainly have to be based on arbitrary boundaries.

A partial checklist of resources which may be relevant to agricultural research is shown in Table 3.2. These resources affect the research system in two ways: first as elements of the agricultural system (or other systems in society) influencing the purposes of research, and second as inputs to permit research to be carried out. The role of these resources in the agricultural system may also have a significant effect on the relative importance of particular research.

One other important aspect about the inputs to agricultural research is that a proposed unit of research will probably be rooted in previous research. Consequently, some of the inputs to the unit of research will be the outputs of previous units of research. For this reason some research may not directly benefit any group in society but may only be a necessary input to another unit of research.

3.4. Phases of Agricultural Research Activity

Agricultural research activity may be classified into the following four phases:

Phase I. Background Development -- obtaining current factual information (largely from published sources) and an understanding of the subject area under consideration.

TABLE 3.2. PARTIAL LIST OF RESOURCES USED BY OR AFFECTED BY AGRICULTURAL RESEARCH

I. PHYSICAL RESOURCES

A. Primary (Natural or elementary)

1. Non-renewable and depleting: Fuels, Ores, Fertilizers, Arable Land, Non-arable Land.
2. Renewable but scarce: Fresh Water Reserves, Forests.
3. In abundant supply: Sea Water, Natural Air, Solar Radiation, Nitrogen, Carbon Dioxide, etc.

B. Secondary (Generated or improved resources including improvements in their properties)

1. Non-biological: Metals, Energy Sources (refined fossil fuels, hydro-electric power), Machinery/Buildings/Equipment, Land improvements (clearing, breaking), Fertilizers and chemicals.
2. Biological: Crops (Cereals, Oilseeds, Forages, Vegetables, Fruit), Livestock and Poultry, Insects, Bacteria, etc.

II. SOCIAL RESOURCES

A. Human Capital

1. Skilled labour (and crafts).
2. Unskilled labour.
3. Wisdom and knowledge: Scientific/Technical.
4. Intellectual and Reasoning Ability.

B. Social Systems

1. Political/Judicial/Military.
2. Economic: Production/Distribution/Marketing.
3. Income generating/Income redistribution.
4. Education.
5. Social security: Health/Welfare/Protection.
6. Environmental management: Waste disposal/Conservation/Pollution control/Land-plant-wildlife management.
7. Values/Norms/Standards.

Phase II. Feasibility Study -- supplementing background development with opinions, surveys and exploratory calculations to further one's understanding of a subject area and its relation to other areas. This type of research leads to the specification of a hypothesis or experimental procedure and facilitates decision making.

Phase III. Experimentation/Analysis -- carrying out a specific set of activities designed to prove or disprove a hypothesis or generate new knowledge, methods, or products.

Phase IV. Output Presentation -- preparing the output of the research in a form which can be preserved and made available to others.

These categories may not be easily identified in some research projects but they provide useful distinctions for subsequent discussion.

4. A RESOURCE ALLOCATION SYSTEM FOR AGRICULTURAL RESEARCH

A well defined management system providing both the basis for model construction and a framework for model operation is required if mathematical models are to be effective as decision aids. This system is necessary because, without it, data for use in a mathematical model are unavailable and, perhaps more importantly, the criteria for resource allocation are undefined.

This section (a) defines a Resource Allocation System for Agricultural Research (RASAR) which provides the necessary framework, (b) discusses other research closely related to resource allocation in agricultural research and compares the proposed system to other research findings, and (c) discusses a few related issues and their significance in the proposed system. Systems thinking or the systems approach was adopted as a design strategy (see Nadler, 1967; Ackoff, 1973; Churchman, 1968). In particular, the guidelines of the IDEALS concept outlined by Nadler (1967) were used as an aid in developing the proposed system.

Decisions regarding resource allocation are made at every level from the individual experiment level to the national/international organization level. The national level was chosen as the level for primary consideration in the systems design for two reasons. Firstly, systems for allocating resources at lower levels (such as research station and department levels) are sub-systems of the national level system. Any sub-system must be designed to be compatible with the larger system of which it is a part. The purposes of research which are established at the national level will dictate to a large extent the relative importance of various areas of research. The specification of which areas of research are to be promoted or discouraged and why they are to be promoted or discouraged must be established before a sub-system has any reasonable and systematic basis for allocation. Hence, the national level was given priority for design. An international resource allocation system was not considered because most agricultural research in the United Kingdom is primarily directed towards agriculture within the United Kingdom. However, international considerations are included in the evaluation of research benefits.

Secondly, the national level was chosen because station level resource allocation decisions are much more closely related to the technology of a particular discipline than national level decisions. A station level allocation system would require much closer liaison with a particular station, much greater knowledge (on the part of the designer) of the technology in a particular discipline and would ideally be initiated from within the station.

4.1. Toward an Ideal Allocation System

The description of a resource allocation system within which mathematical models can operate requires the consideration of the system's purposes and components. An attempt is made to design an effective allocation system by first examining the system's function and then identifying and specifying the outputs, inputs and other system components required to make the system both workable and effective. This method of design will draw attention to relevant factors which could easily be overlooked if emphasis were placed on an existing system by simply attempting to modify it (see Nadler, 1967, p. 16).

One assumption inherent in the proposed system or any allocation system based on logic is that an informed allocation will lead to a more desirable, just, and/or beneficial use of resources than an uninformed or random allocation.

4.1.1. Allocation System Function

The distinctions among (a) the research system, (b) the research management system, and (c) the resource allocation system, should be noted. The overall function of the research system was discussed in Section 3. Each unit of research within the overall research system will be a sub-system with its own function. The management system may be considered as closely related to the research system but distinct from it and having the overall purpose of giving direction to, stimulating, and constraining research activity. The resource allocation system is a part or level of the overall management system. A function for the allocation system has been adopted as a design guide. This function is given as follows:

> Allocation System Function: To select research projects for a resource allocation from among those proposed.

The term 'project' will be defined in the discussion of output that follows.

The adoption of the terms 'allocation' and 'utilization' to describe the role of management in decision making at two different levels of the management system may be helpful. The term 'allocation' will be used to refer to allocation decisions at the inter-project level. This is largely advance planning. The term 'utilization' will be used to refer to allocation decisions at the project level. Many of these decisions will be dictated by the technology of the project, or day to day circumstances. Decisions on utilization are made largely from a budget scheduling point of view within the constraints of the allocation system. The relationship of the resource allocation system to larger and smaller systems is given in Figure 4.1. The outputs of the allocation system, which are, in fact, some of the inputs to the management system, are discussed in the next section. The inputs to the allocation system (which are actually outputs of the sub-systems indicated in Figure 4.1) are discussed in Section 4.1.3.

The function given above specifies the purpose or aim of the allocation system but does not provide a target for research or give much information about the constraints within which the system is to operate. This is desirable since targets and constraints may rapidly change with circumstances while the function should remain relatively stable and provide a foundation for improving the system through time.

4.1.2. Allocation System Outputs

The outputs required of the resource allocation system are listed in the following paragraphs. See the following sections for the definitions of vague terms.

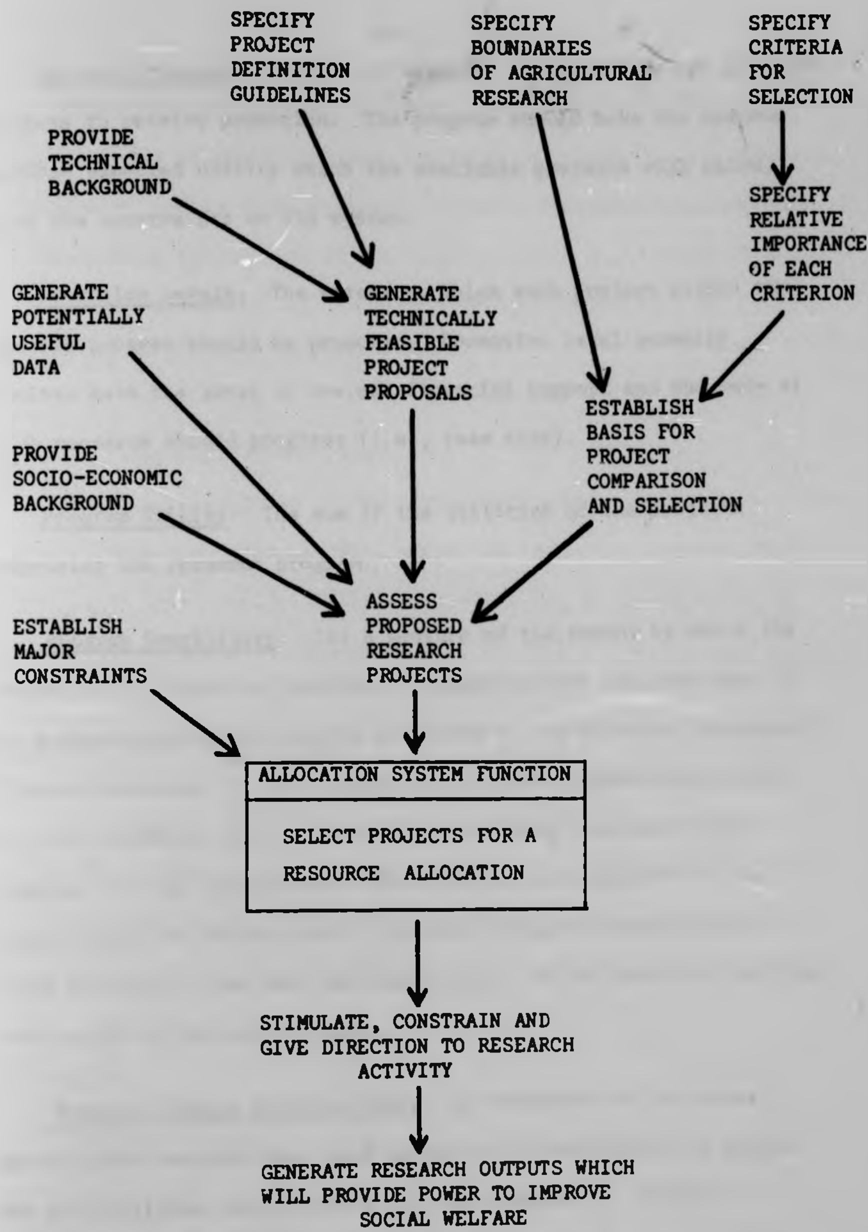

Figure 4.1. Function flow diagram for progressively larger systems in the management of Agricultural Research.

Research Program: The set of projects selected from all proposed projects to receive promotion. The program should have the maximum possible expected utility which the available projects will allow, given the constraints on the system.

Promotion Levels: The extent to which each project within the research program should be promoted. Promotion level normally involves both the level of overall financial support and the rate at which research should progress (i.e., team size).

Program Utility: The sum of the utilities of the projects comprising the research program.

Program Sensitivity: (a) A measure of the amount by which the program will change for reasonable changes in both the data used in the project assessments and the estimates of the relative importance of each criterion; (b) An indication of which projects are barely included and which projects barely missed being included in the program; (c) An indication of how a project not included in the program could be reformulated to provide a higher probability of being included at the next decision point; (d) An indication of the criticality of the weights used.

Research System Modifications: An indication of the areas of agricultural research that need expansion or contraction to improve the possibilities that projects will be proposed at the next decision point which will provide a higher utility to society.

Schedule of Resource Requirements: The resource requirement for each project in the program and the time period in which the resources are required.

These outputs comprise some of the information which is necessary for management to make rational decisions for the effective guidance of agricultural research. Other information necessary for understanding the meaning of the outputs listed above comes from the outputs of sub-systems of the allocation system and will be discussed in the next section.

4.1.3. Allocation System Inputs

The inputs required by the resource allocation system are outputs from sub-systems. Each output is therefore discussed not only as an input to the allocation system, but in relation to the sub-system of which it is a part.

4.1.3.1. Major Constraints

Financing: The availability of financial resources is not normally within the jurisdiction of the agricultural research system and must therefore be treated as a constraint. The resources which are made available may also in some cases be specified for various uses such as capital expenditure, operating expenditure, and salaries.

Staff Availability: Many areas of agricultural research are highly specialized and there can often be a time lag between the recognition of a need for more staff with particular training and the actual availability of the staff. For this reason the availability of staff with particular skills may constrain the selection of research projects.

General Constraints: Other factors such as urgent problems, guaranteed employment, political considerations, social acceptance, and restrictions in nature may from time to time limit the freedom of selection of the allocation system.

4.1.3.2. Project Assessments

The information required of the system for assessing proposed projects is essentially a measure of the contribution which each project makes towards the goal of agricultural research. To permit these assessments to be made, the outputs of several sub-systems are required. These are discussed in turn.

Socio-Economic Background: Management and analysts require a knowledge of the economic and social issues relevant to the proposed research, in addition to the relevant scientific knowledge. The development of a socio-economic background extends Phase I, Background Development, into wider issues related to the particular research and permits Phase II, Feasibility Study, to go beyond scientific and technical factors.

Useful Data Generation: The socio-economic assessment of a project may require the collection and generation of some data which is not required for the technical feasibility study of a particular research project. Much of the necessary source data is collected by conventional statistic generating agencies while other data can be found in the research literature. Occasionally primary data collection using techniques such as market surveys may be necessary.

Project Proposal Generation: Although there does not appear to be any natural or universally applicable criteria for defining a unit of research, some criteria must be adopted as a basis for project evaluation, as well as to facilitate communication. A research project is therefore defined as a package of research activity which is itself a sub-system of the total research system. The project has specified boundaries which attempt to fit natural scientific demarcations, is normally small enough to involve primarily one resource, normally has a single primary objective, and is large enough to require significant amounts of time and expense.

In one respect, the term 'research project' is not unlike the term 'farm.' Neither term is very specific or free from ambiguity, without a corresponding description. Project definitions must therefore contain brief descriptions of the proposed research including such factors as purpose and objective, resources required, time required, and dependence on or association with other research. The definition of a project implies that technical feasibility has been considered as far as it is possible. If nothing is known about technical feasibility the research is essentially speculative or exploratory in nature, and evaluation at this stage is likely impractical. Such research is considered fundamental or basic and decisions regarding sponsorship must be made on the basis of hunches or guesses. These allocation decisions are outside the scope of RASAR.

The most significant parts of the proposal, from the assessment point of view, are the estimations of the outputs of the project and the resources required. Project proposals should be generated with the view to facilitating both resource allocation and resource utilization. In other words they should provide the information needed for project assessment as well as be a general guide in carrying out the research. They should also provide effective communication to others of the intent and expectations of the research.

The systems approach as presented by Nadler (1967) has some useful suggestions for the definition and analysis of a research project. In particular, the function specification methods provide a means of determining and specifying in a useful way the relationships among research projects and the relationship of each project to the purposes of the agricultural system and society as a whole.

The preparation of project proposals may also be facilitated by constructing a model of the project, particularly in the feasibility study phase of research (see Dent and Bravo, 1972).

Project Comparison Basis: The resource allocation system requires a basis for project selection. Two alternative strategies for choosing and applying a selection basis may be recognized.

One strategy is to apply a set of minimum standards which each project must pass. The other is to select the set of projects that provide the greatest attainment of the established objectives, within the constraints on the system. The first method alone would not provide a basis for maximizing the utility derived by society from the research program. Also, if the standard were set high because there were many projects competing for very limited resources, the method could result in a very sub-optimal research program by eliminating projects which did not quite meet one standard but were very favourable by others. However, minimum standards may be necessary as part of the criteria of selection.

The project comparison basis which is needed therefore requires both the specification of minimum standards and a set of criteria for project selection. Each criterion must in some way have a measure so that the relative contributions to the criteria of one research project compared to others may be assessed. Unless all criteria are measured with the same units, a specification of the relative importance of each criterion must be made so that the incommensurate measures of a project's contributions to the criteria may be summed to provide a measure of the total project utility.

The need for project selection rests on the assumption that the sum of the resource requirements of all possible projects is greater than available resources. If this is not the case, a selection system based on competition is not needed and it is highly probable that agricultural research is being over-financed or mis-managed. Finally, the beneficiaries of the research must be specified to establish a point of view for specifying whether or not the research output is beneficial. In keeping with the overall function of agricultural research which was established in Section 3.1, the point of view adopted is primarily that of society. Other points of view are considered as they relate to the set of criteria established by society.

Agricultural Research Boundaries: The first criterion for selecting a project is to establish whether or not the outputs desired can best be obtained through agricultural research. This is a standard which projects must pass before competing in a selection procedure based on merit. If another method of obtaining the same results is preferable, then the project is rejected.

Project Selection Criteria: After it is established that a project is within the boundaries of agricultural research, a set of criteria must be used as a basis for project evaluation and selection.

Each individual research project will have a statement of its immediate objective or goal. Many project goals will have little or no value to society in themselves but may have a value as contributions toward attaining the broad aspirations of society. In order to establish a common basis for comparison the ultimate goal of agricultural research must be established. A single ultimate goal to which all research may be directed and which provides a focal point for the allocation system is given as follows:

> Ultimate Goal of Agricultural Research: To produce outputs within the boundaries of agricultural research which will permit the attainment of an ideal state for social welfare.

This goal, if completely attained at one point in time, would make agricultural research redundant, at least while the outputs necessary to maintain the ideal state of social welfare remain available. In practice, agricultural research may continue to be required because the outputs necessary to attain the ideal state may change.

The outputs required of agricultural research may be recognized as providing power to further a number of dimensions of the ultimate goal. These dimensions fall into the three broad categories of consumption, security, and equity. Some of the dimensions have several aspects which require separate consideration. Also associated with each dimension and aspect is a system or 'yardstick' for rating or measuring the contribution of an individual project to the dimension or aspect. Table 4.1 summarizes the dimensions of the goal, and suggests a rating system for each dimension. The factors summarized in the table are developed and discussed throughout the remainder of this section.

The goal dimensions and rating systems suggested are not intended to be necessarily exhaustive or ultimately ideal. They do, however, provide a basis for demonstrating the fundamentals of the allocation system and how mathematical models can be used within this framework. The responsibility for establishing the set of dimensions for any particular society lies with the agricultural research representatives and government of that society.

Note that by measuring each dimension of the goal separately there is a real danger that any particular effect could be counted more than once. Care should be taken to avoid this by separating a complex effect into its fundamental benefits.

Consumption Category: One of the main aims of agricultural research is to help improve the standard of living. One of the important areas in the concept of standard of living is the consumption of goods and services. Three dimensions of the ultimate goal which are directly related to consumption are identified as

TABLE 4.1. LIST OF GOAL DIMENSIONS AND ASPECTS WITH THEIR CORRESPONDING RATING SYSTEM

Goal Dimension	Aspect	Proposed Rating System
CONSUMPTION CATEGORY		
1. Quantity	- Productivity	- Percentage increase in social profitability per unit of output.
	- Total Production	- Cumulative discounted net social profitability for relevant time period.
2. Quality	- Appeal, Nutritive Value, Reliability, Versatility	- Scoring model from present or low levels to arbitrarily defined ideal levels.
3. Availability	- Growth Cycle Limitations	- Percentage increase in effective season.
	- Supply/demand Imbalance	- Ratio of cost of imbalance to cost with perfect balance.
	- Number of Substitutes	- Percentage increase in number of substitutes.
SECURITY CATEGORY		
4. Human Safety	- Risk of Accident	- Percentage reduction in a particular type, weighted according to the severity of the type of accident.
	- Risk of Disease	- Percentage reduction in contractions, weighted according to the severity of the disease.
5. Economic Defence	- Balance of Payments	- The ratio of the value of the potential reduction in imports to present value of imports.
	- International Dependence	- The ratio of the expected reduction in trade to total trade.
6. Food Sources Security	-	- Reduction in probability of loss,attributable to the research.
7. Conservation	- Utilization Efficiency	- The ratio of the per unit non-renewable resource saving, to per unit requirement before the research.
	- Depletion Rate	- The ratio of the reduction in rate of non-renewable resource depletion to the depletion rate prior to the research.
EQUITY CATEGORY		
8. Distribution	- Consumption, Wealth	- Scoring model based on value of increased income to various groups.
9. Individual Rights	- Opportunity, Discrimination	- Scoring model from present levels to ideal levels.

quantity, quality and availability.

Goal Dimension 1 -- Quantity: Increasing the output of agricultural goods and services is an objective to which much of agricultural research is directed. Two aspects of the quantity dimension are relevant.

The first aspect is the increase in productivity which may be expected as a result of the research. The second is the total increase in production which may be expected. The first aspect disregards the size of the industry and thus provides a measure of per unit increased efficiency. The second provides a measure of the total social profitability society may expect from the research. A selection system based on the total increase in production criterion would favour industries with a large base, while the productivity criterion puts large and small industries on an equal basis. The reason for including both criteria in the selection procedure is because neither criterion is sufficient in itself. One could argue that industries with a large base are more important to society than industries with a small base because a given increase in the efficiency of resource utilization would produce greater economic growth in an industry with a large base than it would in an industry with a small base. On the other hand, a selection procedure which favours large base industries creates a vicious circle where, as a result of improvement through research, large base industries become increasingly more efficient and competitive compared to small base industries. Society must therefore choose a compromise between the two conflicting selection methods. The weighting between the two will depend to some extent on how society would like to have its industries develop.

The rating systems associated with the quantity dimension are based in social cost/benefit analysis (see OECD, 1969; and UNIDO, 1972). The unit of measure is social profitability measured in monetary terms. For the productivity increases criterion the measure is the mean annual social value of the expected output increase, divided by the annual social value of the present production. For the total increases in production criterion the measure is the cumulative discounted net social value of the research throughout the selected time period for consideration.

Research projects which have an effect in the quantity dimension are generally those directed towards more efficient production, and may bring about an increase in output and/or a reduction in price per unit. Rate of adoption of the research output must also be included to put the measure into expected real benefits rather than theoretically possible benefits.

Goal Dimension 2 -- Quality: There are a number of factors in the quality dimension which may be relevant to agricultural research. These include appeal, nutritive value of foods, reliability, and versatility.

Quality is treated as a distinct dimension because even though an improvement in quality may lead to an increase in consumption of a particular item, the change in quality may have quite a distinct value to society compared to increases in consumption of the particular item. If both quantity and quality were being aggregated as a single indicator, the resulting measure could easily become a very distorted indicator of social value. For example,one may consider the ideal quality for peas to be 'garden fresh.' If present technology allows consumers to only have 'canned' peas in winter and consumer preference rates 'canned' peas as lower quality than 'garden fresh,' then a research project producing output which will allow consumers to purchase peas which are nearer to 'garden fresh' than 'canned' would be considered a quality benefit to society. If the 'nearer garden fresh' peas simply replace some or all of 'canned' peas at no increased cost or with no increased pea consumption, society will have an improvement in the standard of living which might not be reflected in the market system as a social benefit.

In other words, the quality of goods and services may have intrinsic value to society which is not reflected in the market system as a measurable social profit but which contributes to a rise in the standard of living.

Since the intrinsic value of quality improvements may not be within normal economic measures, a scoring system for various types of quality improvements must be devised when the range of possible relevant quality improvements has been documented. The rating system could be established as a continuum from the present quality to an ideal quality. Value judgements of knowledgeable assessors would have to be used to place any expected quality effect on the continuum. The continuums for various goods and services may then be compared to each other to derive a master scale as the overall quality dimension rating.

In those areas where the market place does provide a reasonable measure of social value, market indicators can be used in place of value judgements as a means of scoring quality improvements.

This system may be criticized as being arbitrary; but quality is largely an arbitrary parameter and if it is to be used there does not appear to be any alternative to an arbitrary system based on consensus of opinion. Note that the only quality effects which should be considered are those associated with the consumption of goods and services by people. For example, the quality of livestock feed is only relevant tc society if it improves the efficiency or quality of the meat which is to be produced from the feed. Hence, research projects directed toward increasing the quality of feeds should be assessed in terms of their final effects.

Goal Dimension 3 -- Availability: The availability of goods and services may be considered another indicator of standard of living. The relevant aspects of the availability dimension include growth cycle limitations, supply-demand imbalance, and the number of substitutes.

Growth cycle limitations on the availability of goods and services usually occur because plants will only grow and mature at certain times of the year under natural conditions. Research directed toward finding systems for extending the availability of these products through larger parts of the year than is presently technically or economically feasible may be considered as promoting the standard of living. If the extended availability of the product in question does not affect total value of consumption, but only induces a redistribution of consumption, there will be no net social profitability. Hence, the effect will not be reflected in the quantity dimension. Similar cases may be made for increased availability of products through improved matching of supply and demand, and through extending the number of substitutes.

A society with these restrictions diminished could be considered as having a higher standard of living than one with the restrictions undiminished. However, care must be taken that a particular effect is not counted more than once. For example, a new development which will permit a fresh fruit to be available in the off season when previously the fruit was only available in preserved form may be considered as either an improvement in quality or availability, but probably not both. On the other hand a new development which reduces the mis-match between supply and demand may reduce (or increase) the per unit cost of an item as well as reduce the annoyance offluctuating consumption. In such cases there may be justification for crediting the new development in both the quantity and availability dimensions because it has two distinct effects.

A rating system for growth cycle limitations could be based on the percentage lengthening of the season the research is expected to provide. A rating system for supply-demand imbalance could be based in a measure of the cost of the imbalance to society. This cost, although in monetary terms, is an indication of society's unwillingness to replace the product in short supply with substitutes. A rating system for the number of substitutes aspect could be based on the percentage increase in the number of alternative products in predetermined categories.

Security Category: The goal dimensions which fit into the general category of security are concerned with the reduction in threats to society. These include reducing accidents and diseases, protecting society economically, ensuring present supplies needed for survival, and protecting society from short term actions which will have long term detriment.

Goal Dimension 4 -- Human Safety: The environments in which people find themselves often contain the risks of accident or possibly the contraction of a disease. These risks should ideally be eliminated. Since it is unlikely that they will all be eliminated the human safety dimension remains an objective of agricultural research, providing that projects can be proposed which are within the realm of agricultural research and contribute to the promotion of this dimension.

The rating system for this dimension could be a scoring model based on the expected reduction in the number of accidents or diseases contracted, weighted according to the relative importance of the disease or accident.

Goal Dimension 5 -- Economic Defence: Any trading nation must, by equalizing exports and imports, protect itself from the danger of being economically engulfed by other nations. This balancing of payments in the long run can be assisted through research directed toward improving the efficiency of home production relative to production abroad. The improved efficiency at home puts home production at a comparative economic advantage, thus encouraging exports and discouraging imports. Comparative advantage is a power which society seeks and is distinct from any social profit which may acrue from increased exports.

The rating system for this dimension must be a measure of the importance of the power society receives from the output of a particular project relative to the total problem. The ratio of the potential per annum reduction in the value of imports to the total per annum value of imports, under existing or expected policy, would provide such a measure.

Another possible aspect of economic defence is the level of a nation's international dependence. A society may adopt the view that in the interests of increasing security it should reduce either its overall level of trade or some aspect of trade such as food imports. In such a situation the outputs of research projects could be rated on their potential for substituting home produced goods for imports.

Goal Dimension 6 -- Food Sources Security: The reliability of food supplies is a dimension of security which is relevant to many agricultural research projects directed at reducing or eliminating threats to crops and livestock. For many of these projects the reduced threat is in addition to any increase in productivity or total production which may be credited to the research output.

A rating system for this dimension could be a measure of the risk-of-loss reduction which would arise from the use of the research output, suitably weighted for various food sources by the value of the relevant production.

Goal Dimension 7 -- Conservation: Conservation is a dimension of security relating to the trade-off between present and future consumption of resources which are both non-renewable and depleting. There are at least two aspects to this dimension. The first is the consumption of a non-renewable resource per unit of output and is a measure of the efficiency of utilization. The second is the total annual consumption of each non-renewable resource in relation to the total supply of the resource and is a measure of the threat to the existing way of life or standard of living that the rate of depletion of the resource represents.

If society wants to secure the continuing use of non-renewable resources, it should be encouraging the efficient utilization and preservation of non-renewable resources regardless of the economic value society places on these resources at present. The conservation dimension is dissociated from the total production or productivity aspects of the quantity dimension because these aspects do not distinguish between those resources which are non-renewable and depleting, and other resources which can be utilized without any significant security effects.

Another reason for the dissociation is that, although discounted future prices may provide some indication of the value of a resource used today compared to sometime in the future, estimates of future prices may be grossly unrealistic. This is because, with changing technology, (a) accurate real income levels may by very difficult to predict a decade or more in advance, and (b) the value of a given resource may be impossible to estimate because individuals today are not, in many cases, given the option of either buying today or buying sometime in the distant future. Hence, society may wish to select certain resources to receive a conservation bias out of proportion to their expected future economic value as estimated from present forecasts.

A rating system for the efficiency aspect of conservation could be the ratio of the per unit non-renewable resource savings attributable to the research in question, to the per unit non-renewable resource requirement, prior to the research. A rating system for the depletion aspect could be the ratio of expected reduction in the rate of depletion as a result of the research to the rate of depletion before the research, weighted according to the relative importance of the resource.

<u>Equity Category</u>: The third broad category of goal dimensions is equity and is concerned primarily with the sharing of things both tangible and intangible.

<u>Goal Dimension 8 - Distribution</u>: Within society a system must be used to equitably distribute the benefits resulting from productive activity. There are two aspects to the problem of distribution. One is the distribution of wealth or possessions which in some respects corresponds to a possession of power. The other is the distribution of the products of economic activity.

Defining an equitable distribution is complicated by the fact that society attempts to strike a balance between two conflicting philosophical bases. One is that all individuals in society should share equally in wealth and consumption regardless of their contribution to productive activity.

The other is that each individual should share according to merit. In practice, societies normally attempt to follow a position which is somewhere between these two extremes.

The equitable distribution of consumption or wealth may be considered by society to be normally outside the remit of agricultural research. Other systems such as progressive income tax rates and estate death duties might be quite effective, particularly in the more industrialized countries. On the other hand this dimension may be considered relevant to some aspects of agricultural economics and rural sociology (such as research into ways of eliminating uneconomic farm holdings) and therefore part of agricultural research.

Another and perhaps more compelling reason for considering the dimension relevant to all agricultural research is that a given increase in social profit will have different utility to different groups within society, depending on the present levels of consumption and wealth within the groups.

A rating system for this dimension could be comprised of a scoring model for various groups in society based on the wealth and present level of consumption of groups within society selected for special consideration. Individual research projects could be rated on their contribution to aleviating the inequities identified.

Goal Dimension 9 - Individual Rights: Another dimension of equity is the rights of the individual within society. Two important aspects of this dimension are equality of opportunity and freedom from discrimination.

Both of these parameters are relative measures and may in practice only be assessable in terms of the norm for society or as a comparison of one group to another. Society may consider this dimension to be not within the realm of agricultural research. However, if it is considered relevant, a scoring model similar to that for the distribution dimension could be used as a method for rating projects.

Goal Dimension Weighting: The final factor in the project comparison basis is the method for dealing with the incommensurate dimensions of the goal. Since there does not seem to be any suitable common denominator inherent in the goal or its dimensions, the proposed system uses an arbitrary weight for indicating the relative importance of each dimension. The weight indicates the relative utility which society would derive from the attainment of one unit of the particular dimension. The simple summation of the weighted dimensions of the ultimate goal forms a linear social objective function for agricultural research. A more complex and perhaps more realistic social objective function would have the numerical magnitudes of the weights vary as functions of the levels of utility derived by society from the dimensions of the goal for the program as a whole.

Summary and Discussion of the Assessment System: There are four main sub-systems which provide inputs to the assessment system (see Figure 4.1). The first sub-system is one which provides the analyst and decision maker with a socio-economic background. The second provides a data base which can be used for assessing the socio-economic implications of research project outputs.

The third generates project proposals which are technically feasible and contain enough written information to permit socio-economic assessments. The fourth sub-system or chain of sub-systems provides a guide or basis for evaluating the projects. The same guide is also used subsequently as an input to the project selection system.

Assimilating the outputs of these four sub-systems into a project assessment is the responsibility of the analyst under the guidance of management. Identifying the links between the immediate outputs of a research project and their ultimate effects in society can be facilitated by tracing the chain of purposes or functions from the project under consideration to larger and larger systems within society until the dimensions of the ultimate goal are reached (see Nadler, 1967, Chapter 4).

4.1.4. Other Components of the Allocation System

In addition to the inputs already discussed, there are three main components to the proposed allocation system which are necessary to make the system effective in producing the necessary outputs and fulfilling the function. The first is a decision making body. The second is a methodology or model for organizing and manipulating the data from the project assessments. The third is a real time sequence structure for executing the proposed system.

Decision Making Body: The decision making body responsible for selecting projects and allocating resources is part of the agricultural research management team. The body has the responsibility of reflecting the wishes or preferences of society in its decisions.

The decision making body is concerned with the macro-allocation problem while other levels of management are more concerned with making decisions about resource utilization on a day-to-day basis within the guidelines established at the macro-allocation level. The decision making body may have a hierarchy of decision levels, and it may contain people engaged in the actual research. The body will provide a bridge between research personnel providing technical expertise, analysts providing socio-economic expertise, and society specifying preferences.

The detailed specification of the structure of the decision making body is the responsibility of society through its government. A consideration of alternative structures is not within the scope of this investigation.

Project Comparison Model: The decision making body requires a methodology or system for using the information arising from project proposals for project comparison. Such a system may be called a model.

One obvious and very simple model is a simple ranking of the projects by their utility scores produced from applying the weighted social welfare function. Although this method may be better than attempting to judge projects on subjective assessments, particularly where there are a very large number of projects, the method could produce a suboptimal selection (see Bell and Read, 1970).

One other serious drawback to a simple scoring model is the lack of sensitivity information -- one of the outputs required of the allocation system (cf. Section 4.1.2).

A model which would provide both selection by merit and program sensitivity information is a mathematical program. The structure of this model and its outputs are described in Section 5.

The body of information compiled in the project proposals and assessments can be used in association with the goal dimensions and weights to trace back to the types of agricultural research which are likely to contribute most to the ultimate goal. This information would then provide a basis for specifying expansion and contraction in particular areas of agricultural research.

The research program generated by the selection procedure provides a basis for the last output required of the allocation system -- a schedule of resource requirements throughout the planning period. This schedule will be unique to a particular institution. Discussion of scheduling problems is not within the scope of this investigation.

Application Sequence: The sequence of activities from the preparation of project proposals through the decision processes to actual experimentation is outlined in Figure 4.2. Note that the whole system has several feedback loops which encourage improvements to be made in a project as it progresses.

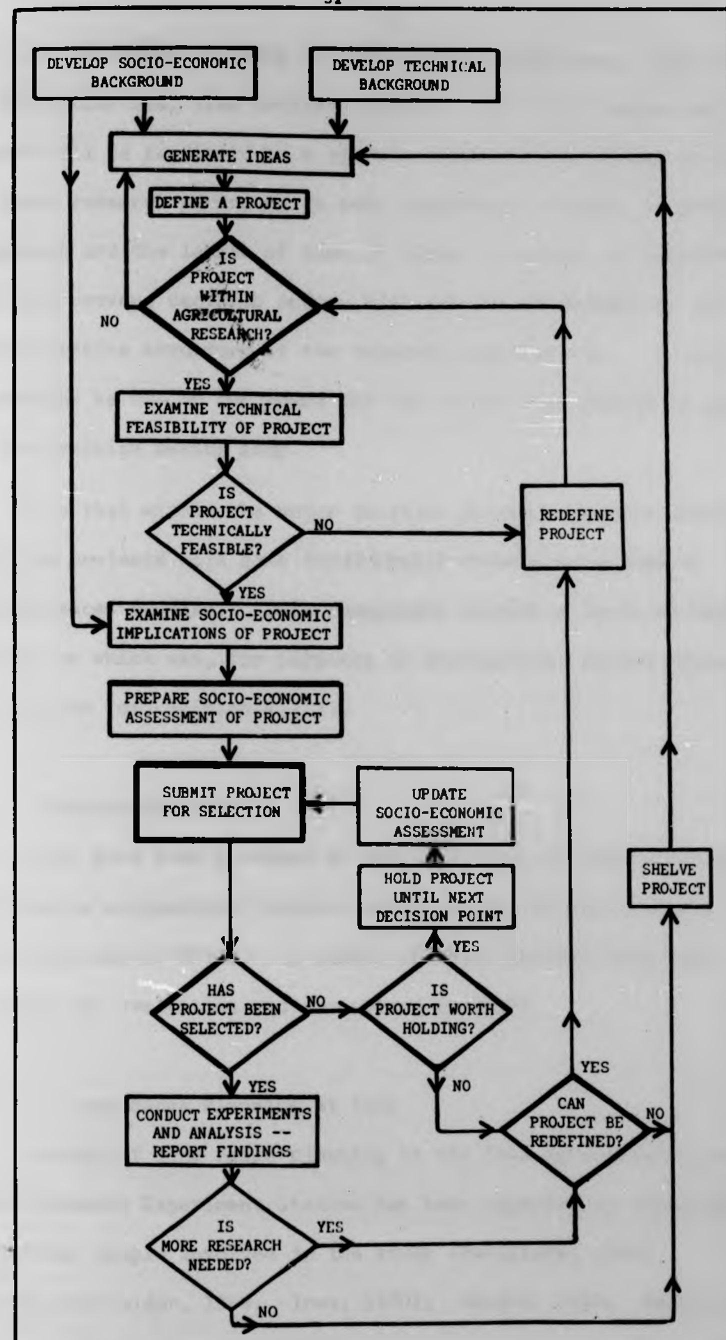

Figure 4.2. Flow diagram showing the integration of experimental work into the proposed resource allocation decision making system.

If the system is going to have project comparison, there must be particular real time decision points. The time between decision points will be regulated to a certain extent by the length of time it takes research personnel to make significant changes in project proposals and the length of time it takes to conduct an experiment. The time between decision points will also be determined by the administrative structure of the research organization. A reasonable time might be one or two years but the actual time should be specified by the decision making body.

Note that within the major decision points, research personnel managing projects will have considerable freedom to manage as circumstances require. This management entails a level of resource allocation which was, for purposes of distinction, called resource utilization (cf. Section 4.1.1).

4.2. Related Research

There have been a number of specific research investigations that are to a greater or lesser extent related to the concepts and specifications of RASAR. A number of these studies have been selected for evaluation and comparison to RASAR.

4.2.1. Long Range Planning at Iowa

A study of long range planning at the Iowa Agricultural and Home Economics Experiment Station has been reported or discussed by several people involved in the study (Mahlstede, 1969; Paulsen and Kaldor, 1968; Iowa, 1970?; Kaldor, 1966; Kaldor and Paulsen, 1970).

In the study, three broad social goals were identified: growth, equity, and security. Also, a system for weighting components of these goals to provide 'contribution to goal' coefficients was conceptualized. The system proposed using these coefficients to determine growth-, equity-, security-, and total goal-cost ratios for each alternative research investment. These ratios were to be used by a decision making body for selecting research activities (Paulsen and Kaldor, 1968). Although the system in theory included these three goals, in practice only the growth goal was used for detailed analysis of alternative investments (Mahlstede, 1969, p. 330).

The Iowa system's definition of a contribution to growth is " . . . a gain in efficiency i.e., reduction of resources required to obtain an output of given value." (Iowa, 1970?, p. 3). In contrast to the quantity dimension of RASAR, no distinction is made in the Iowa system between total savings and per unit savings. Also, the benefit-cost ratios are based on the total savings to both Iowa and the nation, and the calculations of benefits and costs use ordinary market prices rather than the 'accounting' prices suggested by OECD (1969) for social cost-benefit analysis.

Also in contrast to RASAR, the Iowa system includes dimensions of consumption such as quality and availability within their growth goal. For example, quality improvement is " . . . measured by the reduction in resources needed to produce that quantity of the new (improved product) which has a total value just equal to the value of the quantity of the old product which was affected by the improvement." (Iowa, 1970?, p. 4).

As pointed out in the discussion of the quality dimension (see Section 4.1) there may be products with inelastic demands which can be replaced by improved products without any significant changes in costs and prices. Such improvements have no monetary growth effects but could be viewed by society as improvements in the standard of living. Even if most quality improvements do have an effect which can be measured this way, these effects are an indication of the intrinsic value consumers place on quality rather than an indication of the amount of extra output which will be made available for consumption. The quantity and quality dimensions of the ultimate goal are mixed in an effect which is measured in this way, and a comparison of research projects on the basis of this mixture could be meaningless and misleading. In addition, if the improved quality reduces consumption there is a security effect (conservation dimension) which may not be insignificant.

The overall system of evaluation as illustrated for soybean research (Iowa, 1970?) is comprehensive and could provide useful suggestions for developing project proposals in other areas of research.

4.2.2. Minnesota Study

> "The Minnesota Agricultural Research Resource Allocation Information System (MARRAIS) is a computer-based, generalized structure for collecting and processing information relevant to resource allocation decisions under situations characterized by a high degree of uncertainty. . . . The primary aim of the

system is to generate relative measurements of benefits and costs of proposed research activities which would conceivably facilitate and lead to a more efficient allocation of research resources within the organization." (Fishel, 1969, p. 344).

MARRAIS is basically a system for filtering and condensing information and focuses on the information generating process. For guiding this process, the system relies on either commonly accepted criteria or criteria specified by administrators. "The principal emphasis in this effort was on the development of methods for generating better quality information than is currently available to research administrators." (Fishel, 1969, p. 346).

Three parameters are generated for each research project. They are net benefit (benefit minus cost), the benefit-cost ratio, and the internal rate of return. Monte Carlo procedures are used to generate estimates of the three parameters from probability functions for the following factors: technological feasibility, expected benefits, and project completion time.

In contrast to RASAR, research projects are evaluated in terms of their immediate objectives rather than the dimensions of the ultimate goal for agricultural research. For those projects which are expected to have outputs of direct measurable dollar value, estimation of benefits is made directly. For projects with outputs of indirect value, dollar values are inputed to the project by a system for making subjective comparisons to projects with direct dollar values.

The final selection is made on the basis of the ordering of the projects according to the three parameters. Conventional cost-benefit analysis rather than social cost-benefit analysis was used as the basis for estimating costs and benefits. However, the report does provide a useful discussion of the problems in generating data for project evaluation. Also, some of the techniques presented could be usefully employed in project evaluation.

4.2.3. Research Evaluation at An Foras Taluntais

"An Foras Taluntais has in operation a scheme for <u>ex-ante</u> research evaluation . . . " (Whelan, 1967, p. 290). The scheme uses evaluation panels to assess research proposals in various commodity areas and advise on priority ratings. A set of national objectives and criteria for evaluation are used as a basis for assessment.

Seventeen objectives were identified and grouped into the following five categories: Resources; Production and Marketing; Agricultural Produce -- Supply and Demand; Organization of Farming; and Agricultural Policy. The eight criteria identified include the extent to which the research meets the identified objectives, scope and size of problem, urgency of research, feasibility of implementation and likelihood of success, benefits in relation to costs, likelihood of adoption, contribution to knowledge, and results not available elsewhere.

For each proposed project, the evaluation panels assign marks for each criterion. These marks are then weighted and summed to form the priority ranking. " . . . The aggregate of projects, ranked in order of priority, thus forms the research programme which now reflects the judgements of scientists (both domestic and foreign), economists, and competent personnel drawn from the 'users' of research, and is based upon the requirements of a national programme for agricultural research." (Whelan, 1967, p. 296).

This scheme differs from RASAR in that the objectives are used to identify what research is needed and only form one criterion, while other criteria are used to examine the effectiveness of the research. In RASAR the goal dimensions are the criteria for evaluating research and the criteria identified at An Foras Taluntais form part of the evaluation within these dimensions. Also, the objectives identified at An Foras Taluntais tend to concentrate on either the immediate objectives of the research or intermediate effects in society rather than identifying the ultimate effects of the outputs. However, these objectives, as well as the criteria, provide useful lists of factors relevant to the management of agricultural research.

4.2.4. Activity Planning at Beit-Dagan

A model for selecting research projects has been developed at the Agricultural Engineering Institute, Beit-Dagan, Israel. The model has two linear functions as objectives for project selection: economic value and personal satisfaction. Manpower and budget requirements form linear constraints.

Economic value is defined as " . . . the net present value of the expected returns due to the implementation of the results of a given research project." (Pasternak and Passey, 1972, p. 4). Personal satisfaction is a relative and quantitative assessment made by research staff using a scale in conjunction with indicators such as published papers and increased local prestige. The model determines the set of optimal solutions (sets of selected projects) which maximize one objective function as the value of the other varies.

This method for selecting projects differs from RASAR in several important ways. First, RASAR has many more than two criteria for evaluating projects. Second, the criteria for evaluating projects in RASAR are oriented primarily toward society as a whole. Consequently, criteria such as published papers and local prestige are not included as objectives in project selection (although they may well be included as constraints). Third, the estimation of economic value appears to have been made using ordinary cost/benefit analysis methods rather than social cost/benefit analysis techniques as required for RASAR.

4.2.5. ARC Project Classification

The Agricultural Research Council (ARC) has recently designed and implemented a project classification system (see ARC, 1972). One of the main objectives of the system was to provide a means whereby various types and aspects of agricultural research could be costed.

The system was developed and tested on a pilot study basis in 1971/72 and implemented throughout the ARC in 1972/73.

The system has 19 categories of information in five groups. The first group labelled 'Identification' provides general information on the research station and staff involved, and the project number and title. The second group labelled 'Cost' contains an estimate of the total cost of the project for the current year and a record of the amount spent to date. The third group labelled 'Agricultural Situation' contains information on factors such as the plant or animal involved, primary and secondary inputs and outputs, and qualifiers which distinguish broad aspects of agriculture. The fourth group labelled 'Research Activity' contains information on how the problem involved in the agricultural situation is being attacked. The final group labelled 'Relevance' contains information on the benefit which may be expected from the research and the link between the benefit and the plant, animal, input or output identified in the 'Agricultural Situation' group.

From the point of view of generating information for RASAR, the classification system has several inadequacies. Firstly, little information is provided on the relationships between research outputs and ultimate effects in society. For example the benefits which are to be identified in the classification system tend to be factors that can be associated with the functions or outputs of research projects (such as yield, time effects, and pollution) rather than the ultimate effects of the outputs.

(However, some of the benefits defined, such as quality and safety, are more closely related to both the immediate outputs of the research and the ultimate effects in society). Secondly, the system does not require the identification of a beneficiary, since the benefit identified is usually related back to some aspect of the research project itself rather than to effects in society. Consequently, little information is provided for the distribution dimension of RASAR. Thirdly, the projects defined for the ARC classification may not be of the same size as would be most useful for RASAR. In general they are probably too large and are not related specifically enough to research outputs with associated benefits.

Although the ARC classification system may not prove to be particularly useful for assessing the benefits of projects, the cost information compiled by using the system should be quite useful for RASAR.

4.2.6. United States Report on Agriculture

A long range study of agriculture and forestry in the United States was jointly undertaken in 1965 by the Association of State Universities and Land Grant Colleges, and the United States Department of Agriculture (ASULGC-USDA, 1966; Williamson, 1969). The purposes of the study were to (a) define the goals, purposes and scope of agricultural research, (b) develop an agricultural research classification system, (c) appraise the character and the effectiveness of the current program, (d) project the future needs of people as they relate to agriculture, (e) recommend research needed during the next decade, and (f) specify resources required to achieve the goals (ASULGC-USDA, 1966, p. 5).

The report presented ten goals for agricultural research. In general the goals are much more related to the immediate objectives of research projects than to effects in society at the national consumer level. Also, some goals such as " . . . expand the demand for farm and forest products . . . " (ASULGC-USDA, 1966, p. 6) are primarily oriented to the agricultural industry rather than being oriented toward society as a whole.

The research classification system which was devised has three dimensions -- activity, commodity or resource, and field of science. The activity dimension gives the immediate objective of the project. The commodity or resource dimension indicates the principal commodity or resource benefited, while the field of science dimension shows the scientific discipline employed. The system does not attempt to show the links between the immediate objectives of the research and the ultimate effects of the research outputs in society.

An inventory of research projects provided the basis for assessing the extent that research was directed by various agencies toward each of the goals. Technical review panels assisted the study staff in evaluating research problem areas. Eight criteria were used for judging the relative importance of research problems. These included factors such as urgency, feasibility, size and scope of effects, likelihood of adoption, benefits relative to costs, and the extent to which the research meets the established goals.

Each problem was scored on a scale from 1 to 5, according to the degree to which the assessors thought the problem met each criterion. A statistical analysis of individual paired comparison tests provided weights for relative importance. The score for each criterion was multiplied by the corresponding weight and the resulting products were summed to give a total score for each problem. These scores were used to assist in assessing the needs of future research but were not used as a mathematical or statistical basis for resource allocation. The study staff suggested that " . . . experience in using these criteria demonstrated their usefulness in evaluating the importance of a multitude of broad agricultural and forestry research problems." (ASULGC-USDA, 1966, p. 30).

The areas of research inquiry were classified into 91 problem areas within the goals identified. Then levels of research effort for fiscal years 1972 and 1977 were recommended.

There are two main differences between this classification and evaluation system and that needed for RASAR. First, the emphasis in the ASULGC-USDA system is on the immediate objectives or goals of the research while in RASAR the emphasis is on the potential ultimate effects of the research in society. Second, the ASULGC-USDA system used a more subjective evaluation of broad problem areas rather than the more objective evaluation of relatively precisely defined research projects which is required for RASAR.

4.2.7. Special Studies

Four notable studies have been undertaken to investigate the value of research in particular areas. Griliches (1958) estimated that since 1910 the internal rate of return to hybrid-corn research in the United States has been 35 to 40 per cent. Peterson (1967) estimated that since 1915 the return to poultry research in the United States has been 20 to 30 per cent from the date of investment. Grossfield and Heath (1966) estimated that the net benefit in the United Kingdom from the innovation in 1959 of a potato harvester invented by the National Institute of Agricultural Engineering was £460 thousand by 1965. Schmitz and Seckler (1970) estimated that the net social rate of return from the development of a mechanized tomato harvester in the United States has been between minus 8 and plus 929 per cent, depending on the amount of compensation (which could have been paid to displaced workers) that is included in the calculation.

These studies are not examples of the precise type of assessment needed for RASAR for a number of reasons. First, all of the studies have been historical in nature while RASAR requires ex-ante assessments. Second, the studies tend to aggregate research effort in particular broad areas rather than define reasonably narrow projects with specific outputs as required by RASAR. However, the studies for hybrid-corn and the tomato and potato harvesters are much nearer the type of analysis suggested for RASAR than the poultry study, since the former studies aggregate a number of research projects related to a single development while the latter study aggregates all research in poultry.

Third, the studies tend to concentrate on the effects of the research on growth in the economy. They also tend to lump all effects together by assigning monetary values to each identified effect. This is in contrast to RASAR which rates each ultimate effect separately and may not use monetary assessments if another rating system is a more accurate reflection of utility to society. For example, in the tomato harvester study the displaced labour arising from the innovation of the tomato harvester is assigned a monetary compensation before net social return is calculated. In RASAR the effects on displaced labour would be included in the distribution dimension while the increases in consumption for society as a whole arising from the more efficient harvester would be included in the quantity dimension.

Although these studies do not demonstrate completely the type of analysis needed for RASAR they do contain many ideas on the application of cost benefit analysis to agricultural research which can be useful in project assessment for RASAR.

4.3. Related Issues

There are a number of issues which are associated with but not central to the proposed allocation system. These include centralized versus decentralized control, basic versus applied research, policy considerations, rate of discount, output adoption rate, and standard of research. These topics will be considered particularly as they relate to the proposed allocation system.

4.3.1. Centralized Versus Decentralized Control

There are two important distinctions between centralized (e.g. national level) and decentralized (e.g. station or department level) control of agricultural research. Firstly, centralized control of agricultural research projects will not only permit but could require that the allocation of resources to research activity be based on the extent to which the proposed research is likely to meet a particular set of universal criteria. Decentralized control would permit but could not require research activity to meet a particular set of universal criteria. Secondly, centralized control is much more likely to inhibit the inventiveness of research personnel (which is necessary for effective research) than is decentralized control.

Neither extremely centralized nor extremely decentralized control appear to offer both 'scope for inventiveness' and 'direction toward fulfilling the common purposes of society'. For this reason the proposed system offers a level of control which is somewhere between the two extremes. Research personnel are encouraged to pursue ideas until they can be formulated into reasonable research proposals. The proposals are then evaluated to determine their potential contributions to the aspirations of society and promoted on the basis of merit. The actual analysis and the elucidation of a set of criteria upon which research may focus will in turn tend to give some general direction to research personnel in the generation of research project proposals.

Once the allocation system is operational, research personnel will be generating new proposals and conducting current experiments in parallel. Most of the resource requirement for any research proposal should normally be for the experimental part of the project which comes after the project has been approved by the central decision makers.

4.3.2. Basic Versus Applied Research

If research is labelled basic it normally implies that the outputs are either completely unknown or cannot be predicted with any reasonable degree of accuracy. As such, no type of merit system is applicable to this type of research except in terms of broad areas of investigation. There does not appear to be any alternative to an allocation for basic research on the basis of hunch. Allocation to broad areas of basic research may be vaguely related to applied research, but the allocation will have to be essentially arbitrary.

There may, however, be some research projects which are considered fundamental because their outputs are only useful as inputs to applied research projects. If the research can be reasonably related to one or more applied research projects, the cost of the fundamental research should be allocated to the applied research projects in much the same way that overheads can be allocated.

4.3.3. Policy Considerations

Policy considerations affect agricultural research in a number of ways. On the administrative side, provisions such as security of employment restrict the freedom of an allocation system to select projects on the sole basis of merit. Such policies constitute constraints in an allocation model.

In project evaluation, policies can have a great effect on the actual benefit of a particular project. For example, some of the dimensions of the goal given in Section 4.1.3.2 are dependent upon present or expected future policies. The policies which society chooses regarding future development and conservation will also affect the weights which are chosen for the various dimensions of the ultimate goal.

The choice of beneficiary for the research output is another policy consideration which is of significance in the proposed system. The selection of projects comprising the research program can change substantially by changing the point of view for project evaluation from the nation to some multinational group, or to a group within the nation. For RASAR to be workable and consistent, policies such as these must be established and consistently followed.

4.3.4. Discount Rate

Benefits and costs arising in different periods of time may not be directly comparable. The reason for this is that per capita aggregate consumption is expected to rise in the future decreasing the per unit value or utility of consumption (UNIDO, 1972, p. 154). Discounting is an attempt to weight future benefits and costs to make them comparable to present benefits and costs.

A discount rate of zero implies that society places the same value or utility on a unit of consumption in the future as it does today. A positive discount rate implies that future consumption is of lower value than present consumption.

Another possibility which is not normally considered is that per capita aggregate consumption may decline in the future. This could arise through decreasing productivity of labour brought about by either or both (a) increasing population compared to limited productive capacity in the world, or (b) decreasing efficiency in the procurement of supplies of natural resources. In such a case the per unit value of future consumption may increase making a negative discount rate appropriate. (Future price rises will not rule out the possibility of a negative rate because, although prices help establish the level and pattern of consumption at a given time, they are not normally considered valid for comparison between time periods. If they were, the discount rate, from society's point of view, would not be needed.)

The effect of using a non-zero discount rate is to place a different emphasis on costs and benefits in different time periods than would be obtained using a rate of zero. A positive rate increases the relative magnitude of costs and benefits incurred in the near future compared to those incurred in the far future. A negative rate has the opposite effect. The higher the rate the greater the effect.

The choice of rate is a difficult problem, particularly since the social rate of discount will not likely be the same as the private rate of interest on investment. If the social rate of discount is linked with the level of per capita aggregate consumption, there may be little justification for using a rate which is significantly different from the rate of expected growth in aggregate per capita consumption. One possible reason for deviating from this rate is to deliberately emphasize (for political reasons) costs and benefits out of proportion to the expected aggregate level of consumption in a particular time period.

For more extensive discussions of the problem see UNIDO (1972, p. 154), OECD (1969), and Winch (1971).

4.3.5. Output Adoption Rate

The rate at which the output of research is utilized in the agricultural system to bring about the benefits envisaged will affect the present social profitability of the project. For this reason, the level of adoption of the research output over the period of time that the outputs are expected to be available and of use, must be included in the calculation of net social benefit.

This type of forecast is in addition to the forecasts of technical feasibility, relative usefulness of the outputs compared to other developments, and future economic policy and social changes.

4.3.6. Standard of Research

The standard or quality of research may in part be a function of the rate at which the research progresses. The use of a positive discount rate will encourage research to be completed quickly. However, this should not be done at the expense of lowering the standard of the research. If it is, research errors are likely to increase with a resulting long term detrimental effect.

The onus for maintaining standards is largely on the project proposer and assessor. They must ensure that the proposed projects have time and cost estimates which will allow research standards to be maintained.

Choosing the rate of research is a management problem which is directly related to the problem of resource allocation. Diminishing returns in terms of research quality or accuracy are likely to be encountered as the amount of resources allocated to a particular project increases. There is also probably a minimum allocation below which returns will decrease. Selecting the appropriate allocation is a problem which can be solved by defining and evaluating several variations of each project and restricting the selection procedure to only one of the alternatives. (See also Section 5.3.3.)

5. MATHEMATICAL MODELS FOR RESOURCE ALLOCATION

Mathematical models operating within RASAR provide the means whereby the complex interactions among criteria and data can be examined and reduced to a form which will equip decision makers with the information necessary for improved decisions. There is one particular group of mathematical models which has the necessary basic structure and flexibility to provide much scope for building effective resource allocation models that meet the decision making information requirement of RASAR. Models in this group are known as mathematical programming models.

In this section a particular mathematical model which has been developed specifically for RASAR is presented and discussed in relation to the requirement of RASAR. The basic model is presented first. Then alternative formulations and extensions are discussed. Finally other mathematical models are briefly mentioned.

Model building is more of an art than a science. For this reason, this section specifically discusses many variations to the basic model which could considerably improve the operation of the basic model in particular circumstances.

5.1. A Basic Linear Allocation Model

5.1.1. General Form

The linear model has the following general structure:

(5.1.) Maximize $Z = \sum_{j=1}^{m} W_j G_j$

Subject to:

(5.2) $G_j = \sum_{i=1}^{n} (A_{ji}/R_i)P_i$ for $j = 1,m$

(5.3) $R_T \geqslant \sum_{i=1}^{n} P_i$

(5.4) $R_i \geqslant P_i$ for $i = 1,n$

(5.5) and $P_i \geqslant 0$ for $i = 1,n$

where:

Z = total utility of the program

G_j = number of units of goal dimension G_j supplied by the program

W_j = units of utility derived by society from a unit of goal dimension G_j

m = total number of goal dimensions

n = total number of projects

P_i = level of financial promotion for the i - th project (£)

A_{ji} = expected units of goal dimension G_j supplied by project P_i if promoted as per the project proposal

R_i = level of financial promotion (£) specified in the project proposal for project P_i

In matrix form, the general structure of the model is illustrated in Figure 5.1.

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(5.4) $R_i \geq P_i$ for $i = 1,n$

(5.5) and $P_i \geq 0$ for $i = 1,n$

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R_i = level of financial promotion (£) specified in the project proposal for project P_i

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Equation Number	Row Description			Goal Dimensions G_1	G_2	. . .	G_m	Research Projects P_1	P_2	. . .	P_n
5.1	Program Utility -- Maximize	Z	=	W_1	W_2	. . .	W_m				
		0	=	-1				A_{11}/R_1	A_{12}/R_2	. . .	A_{1n}/R_n
5.2	Equations Linking Goal Dimensions to Projects	0	=		-1			A_{21}/R_1	A_{22}/R_2	. . .	A_{2n}/R_n
		. . .				. . .		. . .	. . .		. . .
		0	=				-1	A_{m1}/R_1	A_{m2}/R_2	. . .	A_{mn}/R_n
5.3	Total Resource Limit	R_T	$\geq$					1	1	. . .	1
		R_1	$\geq$					1			
5.4	Project Resource Limits	R_2	$\geq$						1		
		. . .								. . .	
		R_n	$\geq$								1

Figure 5.1. Matrix structure for the general form of the linear allocation model.

5.1.2. Variables

In the model's simplest form there are two types of variables: goal dimensions (G_j), and projects (P_i). These two sets form the columns in the mathematical program. The units of the goal dimensions are related to the rating system for each goal dimension.

The P_i variables (projects) are measured as units of resource and are limited to the levels which were specified in the project proposals as being necessary to produce the expected outputs. The selection algorithm is therefore free to select a project on the basis of merit and allocate resources up to this level of financing.

The goal dimensions are related to the projects through equation set 5.2, where the coefficient (A_{ji}/R_i) for a given i and j is the contribution project P_i makes to goal dimension G_j per unit of financial promotion R_i.

5.1.3. Objective Function

The mathematical programming algorithm seeks to maximize the objective function. The value of the objective (Z) as defined by equation 5.1 is dependent upon the values of both the W_j coefficients and the G_j variables. The W_j coefficients must be established by society (see Section 4.1). The level for each G_j variable is determined by the coefficients (A_{ji}/R_i)and the selected levels of the P_i variables. The algorithm will therefore select as many projects P_i to a level of financing R_i on the basis of the highest values of A_{ji} as permitted by restraint 5.3 and any other restraints which may be added (see subsequent sections).

The value of the objective function is a measure of the utility of the total research program, and is defined as the weighted sum of the dimension scores. Note that the more goal dimensions that a project contributes toward (i.e. the more non-zero A_{ji} coefficients a project has) the more it will contribute to the objective function and the more likely it is that the project will be selected. Note also that the weights W_j can be used to place relatively more or less emphasis on any particular goal dimension.

5.1.4. Constraints

Restraint 5.3 simply limits the number of projects selected by limiting the availability of financial support. Restraint set 5.4 limits the amount of financial support for each particular project.

Other constraints similar to restraint 5.3 could be added to limit the selection of projects in any broad area of research.

5.1.5. Optimal Solution

The solution generated by the algorithm will be the set of projects which maximizes the expected utility of the program within the limitations imposed by the constraints specified. This set of projects is the desired research program.

There will be three types of projects in the final solution: those that are selected to be financed at their specified level R_i; those that are rejected (set at zero level of financing); and those that are selected to be financed at less than their specified level of financing R_i. Projects in the first groups are definitely included in the research program. Projects in the second group are

PL.

definitely not included while those in the third group are marginal. Since the mathematical programming algorithm will, for a linear model, select the level of each P_i variable at as high a value as is permitted by the constraints, the projects which are at less than their specified R_i values are there because resources are depleted. For this reason these projects are considered to be borderline and the decision making body can choose to either include or reject them by making slight adjustments in the resource limits.

The information which can be provided by a computer algorithm solution to the model is given as follows (see also IBM, 1968):

1. The total utility of the program (Z).
2. The number of units of each goal dimension supplied by the program.
3. The set of projects comprising the program.
4. The level of financial promotion for each project in the program.
5. The level of promotion of each project compared to the upper limit set by equations 5.4.
6. The amount of financial resources required by the program compared to the total available.
7. The marginal utility which could be derived from investing an extra unit of resources (if it were available) in the research program. Also, marginal utility values for investing, in turn, in each project of the program.

Note that the marginal utilities in item number 7 are indications of the relative utility of one project compared to another and suggest which general areas of research or types of projects provide the most benefit to society.

5.1.6. Post-Optimal Information

In addition to the information provided as the solution, much useful management information may be generated using two post-optimal algorithms. One of these procedures may be called coefficient ranging and the other parametric programming. These procedures are used to generate information about the sensitivity of the optimal solution (research program selected) to changes in the coefficients of the problem.

Coefficient Ranging: This procedure provides an indication of the extent to which changes can be made in any one coefficient in either the objective function or the right hand side of the mathematical program, without changing the optimal solution. In terms of the general form of the problem given in Section 5.1.1., the objective function is equation 5.1. and the right hand side is comprised of the coefficients R_T and R_i in restraint 5.3 and restraint set 5.4, respectively. (For convenience these coefficients appear on the left of these restraint inequations but are termed right hand side coefficients in mathematical programming language.)

More specifically the ranging procedures provide the following information:

1. For each project included in the research program:
   (a) The reduction (or increase) in total utility, Z, which would occur per unit reduction in financial promotion if the project were excluded (or if another project with identical coefficients were included).

(b) The extent to which the reduction (or increase) in financial promotion could occur at this rate of utility loss (or increase) without affecting the selection of projects for the research program.

(c) The project or constraint which limits this reduction (or increase).

(d) The amount by which the aggregate utility of the project, per unit of financial promotion, could be reduced (or increased) without affecting the inclusion of this project in the research program.

2. For each project excluded from the research program:

   (a) The reduction in total utility Z which would occur per unit of reduction in financial promotion if the project were included.

   (b) The extent to which this increase in promotion could occur at this rate of utility loss without affecting the selection of projects for the research program.

   (c) The project or constraint which limits this increase in level of promotion.

   (d) The amount by which the aggregate utility of the project would have to be increased per unit of financial promotion before the project would be included in the research program.

3. For each goal dimension:

   (a) The amount by which total utility Z would increase (or decrease) if a change in the research program resulted in a one unit increase (or decrease) in the goal dimension score.

   (b) The extent to which the goal dimension weight W_j may increase (or decrease) without changing the research program.

   (c) The project or constraint that limits the extent to which the goal dimension weight W_j may vary.

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4. For each resource constraint, both binding and not binding in the present solution:

   (a) The increase (or decrease) in total utility Z which would occur for each unit increase (or decrease) in the particular resource (i.e., the values of R_T and R_i).

   (b) The extent to which each resource could be varied without affecting the selection of projects comprising the research program.

   (c) The project or other resource that limits the resource variation.

<u>Parametric Ranging</u>: This procedure provides an indication of the extent to which the optimal research program will change when (a) any one coefficient is moved beyond the range given by the coefficient ranging procedure, or (b) a number of coefficients are changed simultaneously. In any one parametric change the group of coefficients to be changed is limited to a set from either (a) any one row, (b) any one column, or (c) both the objective row and the right hand side of the matrix. The types of changes that are normally permitted by mathematical programming algorithms are discrete increases or decreases in the whole of the selected set of coefficients. At each step in the change, the solution is re-optimized.

This procedure provides a means of obtaining a series of optimal solutions for varying conditions. For example, particular weights (W_j) may be varied to determine which projects in the research program are most sensitive to variations in the weights. Coefficient range information can also be obtained after a parametric change thus providing even more information about the sensitivity of the research program to changes in input parameters.

5.1.7. Linear Model Modifications

The linear model may be modified or extended either initially, to make it more comprehensive, or as part of the sensitivity analyses. Most computer algorithms for solving mathematical programs have facilities for revising a problem by simply adding or removing rows or columns or by modifying coefficients. These facilities provide an efficient means for either revising the basic structure of the model or testing the sensitivity of the optimal research program to changes in the constraint variables.

There are a number of simple modifications which can be made to the basic model which could improve the way in which the model represents a particular situation. For example, if the availability of staff with particular skills is considered a significant constraint on project selection, a series of constraints similar to restraint 5.3 may be added. Rather than limit the availability of financial resources, the new constraints would limit staff resources. If the alternative of re-training staff or hiring more staff at a given cost is considered feasible, the staff constraints and resource constraints could be linked with a new set of variables representing staff re-training and staff hiring.

Another extension to the model is project linking. One project may be dependent upon the output of another project. In such a case a restraint may be added to ensure that the dependent project is not selected until the project upon which it is dependent is selected.

Mathematical programming is a versatile format for a model, allowing much scope for including unique restrictions. However, the greater the number of constraints, the less freedom the algorithm has to select projects on the basis of merit.

5.2. Nonlinear Formulation of the Basic Allocation Model

One limitation inherent in a linear model is the fact that the relationships among variables in the model must always be linear. This approximation to the real world is often, within limits, reasonably accurate. However, there may be situations where a non-linear representation would be preferred to a linear representation.

Separable programming is an extension of linear programming which permits an equation which is a nonlinear function of a single variable to be included as a piecewise linear approximation in a linear programming format. The basic theory of separable programming is explained by Hadley (1964, p. 104 ff) while practical guidelines for a computer application are given by IBM (1968, p. 165 ff).

One aspect of the resource allocation problem which may be more accurately described in nonlinear than linear terms is the relationship between an aggregate dimension score (G_j) and the utility which society derives from progressive increases in the score. In the general model given in Section 5.1.1., the relationship was assumed to be linear; i.e., society obtained a constant amount of utility from a unit of a particular goal dimension no matter how many units the program provided.

A model which includes a nonlinear relationship between each goal dimension and the utility function is presented and discussed.

5.2.1. General Form

An allocation model which includes utility as a nonlinear function of the aggregate dimension scores has the following structure:

(5.6) Maximize $Z = \sum_{j=1}^{m} W_j V_j$

Subject to:

(5.7)	$V_j = f(G_j)$	for $j = 1,m$
(5.8)	$G_j = \sum_{i=1}^{n} (A_{ji}/R_i)P_i$	for $j = 1,m$
(5.9)	$R_T \geq \sum_{i=1}^{n} P_i$	
(5.10)	$R_i \geq P_i$	for $i = 1,n$
(5.11) and	$P_i \geq 0$	for $i = 1,n$

where:

Z = total utility of the research program

V_j = number of standard units of the goal dimension G_j in the program

$f(G_j)$ = function relating V_j with G_j (see Figure 5.2)

G_j = number of units of the j-th goal dimension supplied by the program

W_j = number of units of utility derived by society from a standard unit of goal dimension G_j

m,n,P_i,A_{ji}, and R_i as defined in Section 5.1.1.

The functional relationship between each V_j and $f(G_j)$ is illustrated in Figure 5.2. If the function were the dashed line in this figure, then the relationship would be linear and one unit of G_j would have the same value to society no matter how many units the research program provided.

The function represented by the solid line may be interpreted as follows: The point (g_j^*,v_j^*) is the standard where one unit of G_j is equivalent to one unit of V_j. If the research program provides less than g_j^* units of G_j, then those units which are provided have a higher per unit value than the per unit standard value at g_j^*. If the program provides more than g_j^* units of G_j, then the units which are provided have a lower per unit value than the per unit standard value at g_j^*. The solid line is used as an indirect way of deliberately modifying the extent to which a particular dimension will affect total program utility and is dependent upon the extent to which the research program contributes to the particular goal dimension.

To actually program the functions given in equation set 5.7, piecewise linear approximations to the functions must be specified. For example the solid curve in Figure 5.2 can be approximated as shown in Figure 5.3. A general form for the equations necessary for programming the approximation is given as follows:

(5.12) $$V_j = f(G_j) = \sum_{k=1}^{b} S_{jk}\lambda_{jk} \qquad \text{for } j = 1,m$$

(5.13) $$G_j = \sum_{k=1}^{b} \lambda_{jk} \qquad \text{for } j = 1,m$$

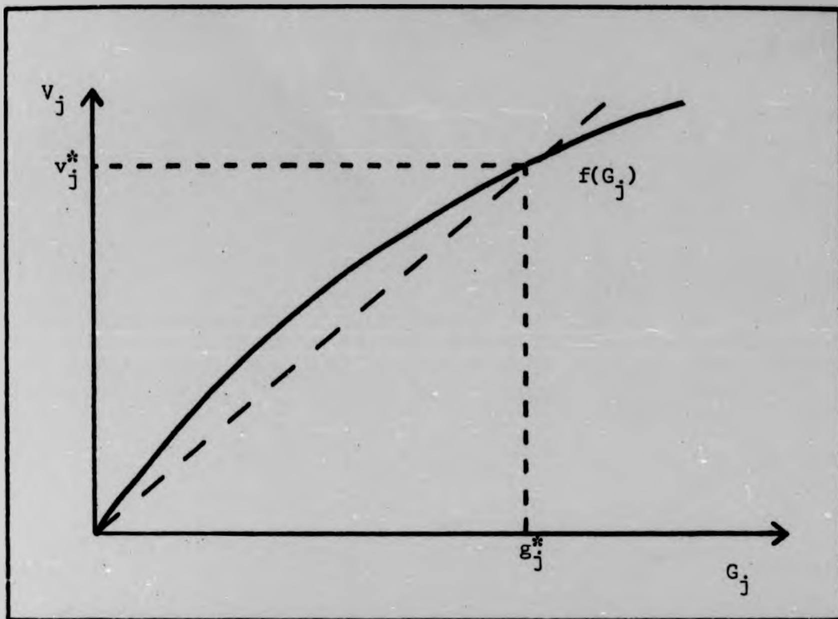

Figure 5.2. A nonlinear function which may be used in a mathematical programming model to represent the relationship between an aggregate dimension score (G_j) and the amount of utility which society derives from progressive increases in the score.

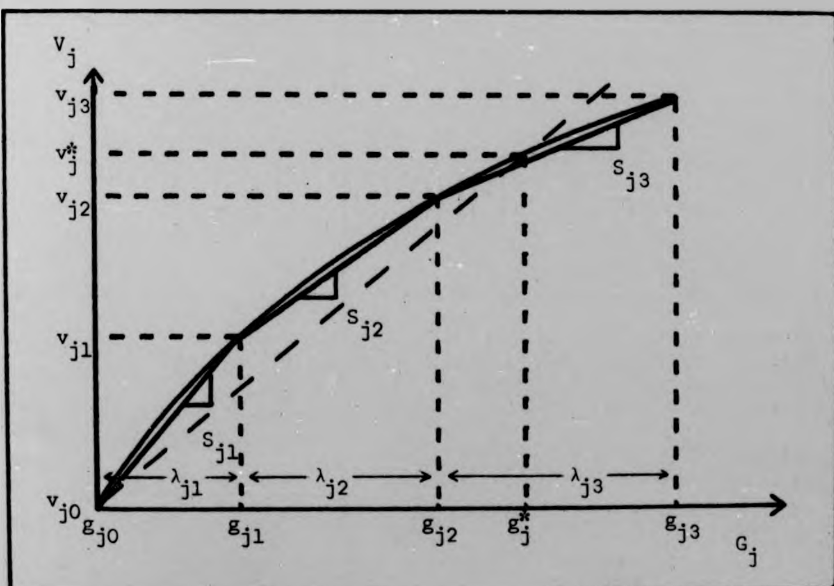

Figure 5.3. Piecewise linear approximation to the function $V_j = f(G_j)$ showing variables for a separable programming matrix.

where:

λ_{jk} = the set of special variables (for k from 1 to b) used to link V_j and G_j in the piecewise linear approximation

$\lambda_{jk} \leq g_{jk} - g_{j(k-1)}$ (upper limit for each λ_k)

λ_{jk} = 0 unless $\lambda_{j(k-1)}$ is at its upper limit

S_{jk} = slope of the piecewise linear approximation over the interval of variable λ_{jk}

b = number of special variables in the piecewise linear approximation

V_j and G_j as defined in Section 5.2.1.

Equation sets 5.12 and 5.13 replace equation set 5.7 in the piecewise linear approximation to the general formulation.

In matrix form, the general structure of the nonlinear allocation model is illustrated in Figure 5.4.

5.2.2. Variables

In addition to the variables specified for the linear model, the nonlinear model contains a set of special variables λ_{jk} for each goal dimension G_j. The sole purpose of these special variables is to permit the nonlinear relationships to be approximated as linear relationships. As indicated in Figure 5.4 and the variable definitions following equation sets 5.12 and 5.13, these special variables must (a) be numerically limited or bounded (Bounds conditions) and, (b) assume non-zero values in sequence as k increases from 1 to b (Ordered Entry condition). These conditions ensure that, as G_j increases, the piecewise linear approximation to the curve $f(G_j)$ is followed, and the relationship between G_j and V_j is maintained as approximated.

Equation Number	Row Description			Goal Dimensions														Research Projects			
				Dimension 1							Dimension m										
				V_1	λ_{11}	λ_{12}	...	λ_{1b}	G_1	...	V_m	λ_{m1}	λ_{m2}	...	λ_{mb}	G_m	P_1	P_2	...	P_n
5.6	Program Utility Maximize Z		=	W_1						...	W_m									
5.12 and 5.13	G_j to V_j Linear Approximation Links	0	=	-1	S_{11}	S_{12}	...	S_{1b}												
		0	=		1	1	...	1	-1											
		⋮								⋱										
		0	=								-1	S_{m1}	S_{m2}	...	S_{mb}					
		0	=									1	1	...	1	-1				
5.8	Goal Dimension Links to Projects	0	=						-1								A_{11}/R_1	A_{12}/R_2	...	A_{1n}/R_n
		⋮								⋱							⋮	⋮		⋮
		0	=													-1	A_{m1}/R_1	A_{m2}/R_2	...	A_{mn}/R_n
5.9	Resource Limit	R_T	≥														1	1	...	1
5.10	Project Resource Limits	R_1	≥														1			
		R_2	≥															1		
		⋮																	⋱	
		R_n	≥																	1
Bounds Ordered Entry					δ_{11}	δ_{12}	...	δ_{1b}		...		δ_{m1}	δ_{m2}	...	δ_{mb}					

Figure 5.4. Matrix for the general form of the nonlinear formulation of the basic allocation model.

5.2.3. Objective Function

The objective function in the nonlinear model is the same as the objective function of the linear model except that the values (V_j) for the goal dimensions are used in place of the aggregate goal dimension scores (G_j). The matrix form of the problem may be simplified by substituting equation sets 5.12 and 5.13 into equation 5.6 and equation set 5.8 respectively.

5.2.4. Constraints

The constraints in the nonlinear model are the same as those in the linear model except for the Bounds and Ordered Entry conditions shown in Figure 5.4 and described in Section 5.2.2.

Note that the Ordered Entry condition need not explicitly be specified in computational instructions if, for all k and j, $S_{jk} \geq S_{j(k+1)}$ and all W_j are positive in a maximizing program. This is because the λ_{jk} will automatically enter the solution in order from k = 1 to b since for each j, λ_{jk} will always be more profitable than $\lambda_{j(k+1)}$.

5.2.5. Optimal Solution

The optimal research program in the nonlinear model will be determined in a way which is very similar to the way it is determined in the linear model. The main difference is that the aggregate score (merit) of a particular project is modified by the functions in equation set 5.7. At any particular point in the selection procedure the relative merit of a project will be determined by both (a) the total contributions projects within the program have made to each goal dimension, and (b) the project's own A_{ji} coefficients. For this reason, the aggregate contribution which a particular project will make to the total utility of the program (relative to other projects which have not yet been selected for the program) will vary as the number of projects in the research program increases.

A project will become relatively more favourable if it has a high score in a dimension with a low aggregate contribution from the research program at the present stage of selection, given a function similar to the one illustrated in Figure 5.2.

Computationally, nonlinear models in general have the disadvantage of being susceptible to local optimums. As the mathematical programming algorithm increases the value of Z by moving from one solution to another within the specified constraints, it can reach an extreme point in the feasible solution space, which, due to the nonlinear functions, will appear to be the maximum value for Z. If it is not in fact the maximum value for Z, the solution is termed a local optimum. Linear programs have only one extreme point and hence the optimum is both local and global. Nonlinear programs may have a number of extreme points, and usually only one is the global optimum.

The nonlinear model suggested above has no local optimums, if, for each j, $S_{jk} \geq S_{j(k+1)}$ for all k from 1 to b.

The information provided with the solution to the nonlinear model will be similar to that provided for the linear model and listed in Section 5.1.5.

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5.2.6. Post-Optimal Information

The post-optimal information available for the nonlinear formulation is the same as that available for the basic linear model except that it is a little more restricted. For example, the numerical range over which a variable may change with a given effect on Z is governed by the extent to which the variable can change (if one constraint is relaxed) without being affected by other constraints in the problem. The substitution of a set of λ_{jk} for each G_j requires a large number of additional constraints (Ordered Entry and Bounds conditions) to ensure that the nonlinear function is followed. These extra logical constraints effectively limit the post-optimal information to a far greater extent than it would be limited in a linear model. The greater the number of special variables that are used for each G_j, the more greatly the post-optimal numeric range will be restricted.

5.3. Extensions to the Basic Allocation Model

5.3.1. Matrix and Report Generators

The mathematical model is itself only part of an overall information system. Using the model can be time consuming because input data must be prepared in matrix form and output data must be tabulated in a form usable by decision makers. However, the amount of time required to use the model can be drastically reduced by developing matrix and report generators. A matrix generator could be a computer program which would generate the required matrix from the data given in the project assessments. A report generator could be a computer program which would prepare the output from the mathematical program in a predetermined standard format containing the information relevant to decisions regarding project selection. An example of the type of information which could be generated by a report generator is shown in Section 6.

Matrix and report generators can be computer programs written in any of a number of computer languages and linked directly with the mathematical programming computer code. With these generators the computer itself could, in a few minutes, generate a set of optimal research programs and tabulate these programs in a manner which is directly usable by decision makers. The data used would be that from the project appraisals, and the set of optimal programs would correspond to predetermined sets of weights on the goal dimensions.

5.3.2. Timeliness of Available Resources

One implicit assumption in the mathematical models described in Sections 5.1 and 5.2 is that all resources available throughout the time period under consideration can be utilized at any time within that period. In practice, resources are probably allocated on an annual basis and probably cannot be spent before they are received. As the model stands, an optimal research program generated by the model may require funds at a time when they are unavailable. If funds could not be redistributed, such a research program would be infeasible. However, this situation is less likely to arise if the number of projects in the program is large than if it is small.

The problem can be overcome easily by separating both total resource availability and the requirements for each alternative project into an appropriate number of time periods. The project scores (A_{ji} coefficients) will also have to be either divided among the various time periods (if benefits arise as the project progresses) or allocated to the final time period (if benefits arise only after completion of the project) and an ordered entry condition will have to be applied to the segments of each project. The ordered entry condition ensures that the parts of a project enter the optimal research program in their logical sequence.

The revised linear model would have the following general form:

(5.14) Maximize $Z = \sum_{j=1}^{m} W_j G_j$

Subject to:

(5.15) $G_j = \sum_{i=1}^{n} \sum_{\alpha=1}^{\theta} (A_{ji}^{\alpha}/R_i^{\alpha})P_i^{\alpha}$ for $j = 1,m$

(5.16) $R_T^{\alpha} \geq \sum_{i=1}^{n} P_i^{\alpha}$ for $\alpha = 1,\theta$

(5.17) $R_i^{\alpha} \geq P_i^{\alpha}$ for $\alpha = 1,\theta$; $i = 1,n$

(5.18) $P_i^{\alpha} \geq 0$ for $\alpha = 1,\theta$; $i = 1,n$

(5.18a) $P_i^{\alpha+1} = 0$ unless P_i^{α} at upper limit

In practical terms the matrix for this form of the model can become large if θ is large. However, a bounds condition can be used in some mathematical programming computer codes to place an upper-limit on each project segment P_i^{α}. The bounds condition can be used to replace restraint set 5.17, thus reducing the matrix to the same number of rows as the basic linear model (if the bounds condition were used in the basic model to eliminate restraint set 5.4). The revised model will have more columns than the basic model but these can be easily added with the matrix generator and are inexpensive to add in terms of computer solution time compared to additional rows.

If projects are divided into a number of time periods and resources are allocated to these time periods, the selection procedure in the model will only consider projects for which there are resources available in the first time period. In practical terms, an optimal research program may exist such that all projects in the program cannot start in the first time period due to limited resources in that period. Also, for some projects successive segments need not necessarily follow in successive time periods. In other words, in some projects gaps in the work may be permitted. A model which does not permit these possibilities could generate an optimal solution which is a local optimum. (Such a local optimum would be due to the lack of alternatives in the model rather than nonlinear characteristics in the objective or constraint functions.) A model which would eliminate this possibility could be constructed by (a) enumerating all possible ways in which the segments of each project could correspond to the time periods, (b) including these possibilities in the model, and (c) restricting the model to the selection of no more than one of the alternatives. However, this type of model would be rather large and cumbersome.

A local optimum generated by the model described by equations 5.14 to 5.18 will probably be near the global optimum if delaying projects reduces net benefit (e.g., future benefits are discounted with a positive rate). However, projects that are more beneficial than the least beneficial in the selected research program could be prevented from entering the selected program simply because resources in a particular time period are depleted. Whether or not this is happening can be discovered either by observing the post-optimal information or by using parametric programming to vary the resource availability in particular time periods.

Alternatively, the model may be revised to include the most likely ways in which projects could match time periods in the global optimum. For example, the model could be modified to permit projects to be started in the first time period or delayed to the next. This version of the model would require a separate set of A^{α}_{ji} coefficients for each project start period (i.e., the first period or the second period), and a corresponding restraint to restrict the optimal program to either the first period start or the second period start, but not both.

The revised linear formulation of this form of the model is shown as follows:

(5.19) $$\text{Maximize } Z = \textstyle\sum_{j=1}^{m} W_j G_j$$

Subject to:

(5.20) $$G_j = \textstyle\sum_{i=1}^{n} \sum_{\beta=1}^{2} \sum_{\alpha=1}^{\theta} (A^{\beta\alpha}_{ji}/R^{\beta\alpha}_{i})P^{\beta\alpha}_{i} \qquad \text{for } j = 1,m$$

(5.21) $$R^{\alpha}_{T} \geq \textstyle\sum_{i=1}^{n} \sum_{\beta=1}^{2} P^{\beta\alpha}_{i} \qquad \text{for } \alpha = 1,\theta$$

(5.22) $$R^{\beta\alpha}_{i} \geq P^{\beta\alpha}_{i} \qquad \text{for } \alpha = 1,\theta;\ \beta = 1,2;\ i = 1,n$$

(5.23) $$1 \geq \textstyle\sum_{\beta=\alpha=1}^{2} P^{\beta\alpha}_{i}/R^{\beta\alpha}_{i} \qquad \text{for } i = 1,n$$

$$(5.24) \qquad P_i^{\beta\alpha} \geq 0 \qquad \text{for } \alpha = 1,\theta;\ \beta = 1,2$$

$$(5.24a) \qquad P_i^{\beta(\alpha+1)} = 0 \quad \text{unless } P_i^{\beta\alpha} \text{ at upper limit, for } \beta = 1,2;\ \alpha = 1,\theta$$

In the revised model, $P_i^{\beta\alpha}$ is the segment of the project P_i which can be selected for financing in time period α if the starting period for the project is β. Clearly, variables $P_i^{\beta\alpha}$ and restraints within sets 5.22 and 5.24 will not be included if $\alpha<\beta$(i.e., $R_i^{\beta\alpha}=0$), since by definition the first time period ($\alpha=1$) for the alternative of the project starting in the second time period ($\alpha=2$) will require no resources and is therefore redundant. Constraint set 5.23 restricts the selection procedure to selecting to its maximum resource requirement the first segment of either of the start now or the start next period alternatives, but not both. This constraint set coupled with the condition in restraint set 5.24a effectively limits the research program to only one of the alternatives for matching time period with projects. (Actually, one could get a linear combination of the first segments of the two alternatives, but this is highly unlikely, particularly if more than the first segments are required to obtain any benefit.)

The model described by equations 5.19 to 5.24 may be generalized to include any number of alternative patterns for varying starting periods or including gaps (delays in the research). Each pattern would require its own set of coefficients.

5.3.3. Variations in Project Definition

The model as described requires each project to be defined in terms of resource requirements, expected duration and expected outputs. There may be cases when there are a number of different ways of defining a project, each of which will have different requirements and benefits. All of the variations can be included in the model as though they were separate projects. If they are, and the project variations are so similar that only one should be included in the selected research program, an additional restraint is required for each set of variations to limit the optimal research program to only one of the variations. Such a constraint may have the following form:

$$1 \geq \sum_{\gamma=1}^{\phi} P_{i\gamma}/R_{i\gamma} \tag{5.25}$$

where there are ϕ alternative forms for project P_i, each with a resource requirement $R_{i\gamma}$ and a set of $A_{ji\gamma}$ coefficients. Restraint 5.25 will not strictly limit the optimal research program to only one variation of each project, but the equation will limit the program to a linear combination of the alternative forms of each project. This linear combination would probably be roughly equivalent to one project. Whether or not a linear combination has any meaning will depend on the physical properties of the particular project. In one case, Bell and Read (1970) report that, in practice, only one form of a project is included in the optimal research program.

5.3.4. Linked Projects

There may be a number of reasons for wanting to link projects in the model. For example, one project may only be possible if another project is completed as a pre-requisite or co-requisite project. In such cases projects may be linked with constraints of the following type:

(5.26) $P_i/R_i \geq P_{i+a}/R_{i+a}$

where P_i and P_{i+a} are any two different projects in the matrix. This constraint requires project P_i to be included in the optimal research program before project P_{i+a} can be considered. If P_{i+a} has a high benefit but P_i does not, the restraint will cause the high benefit of P_{i+a} to be reflected in P_i internally in the model, so that P_i is much more likely to be included in the optimal research program than if P_{i+a} were not in the model. This type of linking restraint has obvious applications to a situation where applied research projects with high benefits require basic type research projects with little or no benefit by themselves.

Another example of a situation in which project linking may be useful is if one or more projects require the same physical resource as a host. For example, if two or more projects require a similar herd of cattle and can be run concurrently on the same herd, there is no need to include the cost of the herd in the coefficients of both projects. The herd (or any other resource) may be defined as a separate activity (column in the matrix). Additional restraints would then be required to link the herd to the appropriate projects. A form for this type of linking is given as follows:

(5.27) $D \geq (d_i/R_i)P_i$

where d_i is the number of units of herd D required by project P_i. Since the resources required to obtain and maintain D are not included in R_i, restraint 5.3 in the basic model will have to be extended as follows:

(5.28) $R_T \geq \sum_{i=1}^{n} P_i + R_d$

where R_d is the resource requirement per unit of herd D. If projects cannot be run concurrently on the same herd, each project requiring the herd can be given the option in the model of being carried out in a number of different time periods. (The form of this type of model is illustrated by equations 5.19 to 5.24.) If constructed in this way the model would require constraints similar to restraints 5.27 and 5.28 to link the alternative time periods to the herd D.

Another extension to the model which may be useful in these situations is to include the alternative of more than one herd, with, of course, the corresponding costs.

5.3.5. Program Changes Through Time

A research program in agriculture is unlikely to be static. New ideas for projects will arise and projects which are on-going will have changing resource requirements, expected durations and expected benefits. However, this fact does not reduce the need to plan research on the basis of the best available information at a given time.

The RASAR system with accompanying mathematical model permits project assessments to be updated and the research program to be re-optimized on the basis of the new information. Projects which are partially completed will probably have a lower resource requirement (from the present time to the end of the project) relative to expected benefits than projects which are just being proposed. Hence a project which is partially completed will tend to be selected by the model in preference to a new project unless the new project is exceptionally favourable, or the partially completed project is becoming increasingly unfavourable. Thus the model will normally allocate to new projects only those resources which are not needed for the current research program. The model also provides a basis for a stopping policy, since any project partially completed and not included in the research program has probably lost much of its benefit as the research progressed.

Decision makers must establish the optimum frequency for re-optimizing the research program. The frequency of re-optimization will depend on the time required to generate new projects and update existing ones, and the extent to which project assessments change through time in a particular field of investigation.

5.4. Other Mathematical Models

There are a number of mathematical models, in addition to those suggested in Sections 5.1 to 5.3, which may have useful applications within RASAR. In particular, there are models which can be used to help plan and co-ordinate a research project or program, or to generate data required for the application of an allocation model.

Flowcharts are models which can be used to identify and examine (a) the inter-relationships among parameters within a project, and (b) a project in relation to external factors. Flowchart models can take on a number of forms to suit the particular situation (see Nadler, 1967; Beattie and Reader, 1971). Examples of one such model are the function flow diagrams shown in Appendices A to D.

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Networks type models, known under names such as Decision Trees, Critical Path Analysis (CPA) or Method (CPM), Program Evaluation and Review Technique (PERT) and Shortest Path Network Analysis (SPNA), are potentially of value in project planning, control and evaluation (see Raiffa, 1968; Wiest and Levy, 1969; Preston, 1967). Decision trees can be used to determine the optimum plan and maximum expected net benefit for a complex project with numerous chance variables and decision points corresponding to various alternative courses of action. Decision tree models can be modified to include continuous stochastic functions in place of discrete estimates for some chance variables (Hespos and Strassmann,1965). CPM and PERT models can be used to aid research activity scheduling as well as estimate the minumum expected duration of a project. These basic models can be adapted to include heuristics and probabilities (Wiest, 1967; Lockett and Freeman, 1970). SPNA is a variation of the CPM type model. This model can be used to find the least cost method of carrying out a research project, for a project which has a number of alternatives for various segments of the project (Preston, 1967).

Simulation models (perhaps incorporating some of the models mentioned above) can be used to identify the relative importance of particular parameters in a research project (see Dent and Bravo, 1972; Jones, 1970). Simulation models also have potential for improving the efficiency of research if simulation can be effectively applied to produce improved project planning and control, or to reduce the amount of experimentation needed to obtain the expected project output.

The mathematical models which have been mentioned here are only a few of the types of models which may have applications in particular situations in agricultural research. A brief survey of other models which have been proposed by other researchers (primarily in the context of industrial research laboratories) is given in Section 2.3.

Most mathematical models which have an application within RASAR will have their application in either project planning and assessment or in resource utilization micro-decisions, rather than in project selection and resource allocation macro-decisions. Since the main emphasis in this investigation is on project selection and resource allocation macro-decisions, a detailed appraisal of all potential models is considered beyond the scope of the investigation.

6. TESTING THE MATHEMATICAL MODEL

Throughout the course of this investigation several specific research projects were examined in some detail as a demonstration of the workability of both the proposed models and the system for generating data for the models. An indepth evaluation of the models was not possible since this would have required the whole or at least a large part of the Agricultural Research Service to implement the project proposal and evaluation parts of the proposed system. However, some evaluation was possible on the basis of the selected projects.

The purposes of this section are to (a) discuss both the methodology used to assess the case study projects and the findings of these assessments, and (b) show in terms of these projects the type of information the proposed models can provide to research management.

Four projects were assessed. These assessments demonstrate the form in which project assessment reports could be presented to decision makers. They also contain considerable detail which is relevant to the particular project but is not central to the theme of this investigation. Consequently, the assessments are included in appendices rather than in the text (see Appendices A through D). Readers interested in the detail of the projects and their socio-economic assessment are advised to refer to the appendices.

Following an explanation of the general form of the reports, Section 6.1 contains a discussion of the findings of each of the assessments as an introduction to the use of the data from the projects in the demonstration of the resource allocation mathematical model. Section 6.2 presents the data preparation methods, the data itself, and the results of the model application.

6.1. Research Project Case Studies

The four current research projects were selected from three research institutions in the East of Scotland. The projects were selected early in the study, and the selection was made on the basis that the projects were toward the applied end of the basic-applied continuum of project types. As applied projects, the outputs were considered to be directly relatable to the production system and would therefore be more readily assessable in quantitative terms than basic projects. The projects were also selected because they were directly related to the economics of production and as such were considered as being easier to quantify than projects which were essentially non-economic.

The dimensions of the ultimate goal of agricultural research were specified and developed subsequent to the selection of research projects for analysis. On hindsight, the selection could have been improved by selecting projects with contributions to more dimensions of the ultimate goal than the selected projects contained. (see Section 4.1.3.2).

Each case study was discussed with personnel at the research institution involved in directing the research. The assessments were criticized by these personnel and were subsequently revised. The final revisions of the project assessments are presented in Appendices A through D.

The technical information contained in the reports is minimal since the purpose of the assessments was to evaluate the socio-economic implications of the research. The projects were assumed to be technically feasible.

The socio-economic assessments were not intended to demonstrate procedures for data collection or forecasting. Consequently, crude data and methods for treating the data were considered sufficient for demonstrating the basic assessment methodolgy and for testing the allocation model. This course of action reduced the amount of contact which would be needed with research personnel at the institutions. The course of action also permitted the author to concentrate this investigation on developing a resource allocation system, rather than simply utilizing existing but time consuming methods for data collection and generation.

General Method of Analysis: The general framework outlined in Section 4.1 was used as a guide for analysing the projects. Each project report contains first a summary and then a detailed analysis. The summary provides the information necessary for decision making while the detailed analysis provides details of the data on which the assessments are based.

The projects themselves were treated as systems with identifiable functions, outputs, and inputs. For each project a flowchart of functions was used to specify the relationships of the particular project to other projects providing inputs to the particular project. The same flowchart was used to help establish and present the relationships of the particular project to the purposes of larger systems within society. This model assisted the analyst in establishing the relationships of the particular project to the dimensions of the ultimate goal of agricultural research. In addition, the model was used to specify alternatives to the proposed research and highlight the

Socio-Economic Appraisal of Research Project

PART I. SUMMARY

A. Project Name and Function

1. Name

2. Function

3. Function Expansion

B. Expected Outputs

C. Expected Total Resource Requirements and Project Duration

D. Ultimate Effects of the Outputs (Listed under the headings 'Goal Dimension and Effect' and 'Rating'.)

PART II. DETAILED ANALYSIS: (Project Name)

A. Introduction

1. Brief Description of Methodology

2. Pre-requisite and Co-requisite Projects

3. List of Major Resources Required (Listed under the headings 'Resource' and 'Amount'.)

4. Requirements for the utilization of the Outputs (Policies required, production system changes envisaged, etc.)

B. Evaluation of the Ultimate Effects of the Outputs (Presentation of the outputs under each goal dimension along with supporting analysis, arguments, and data.)

C. Discussion (Anything of significance such as the effects of the outputs on intermediate systems and institutions within society, which are not detailed in Section B.)

D. List of Abbreviations

E. References

Figure 6.1. Form of the structure for a socio-economic appraisal of an agricultural research project.

effects that the research may have on other systems within society.

As background information, a very brief summary of the technology of the project is included in the introduction to the detailed analysis. An outline of the general form of the project assessments is shown in Figure 6.1.

6.1.1. Project A: High Diastase Barley

The main objective of the High Diastase Barley research is to produce a variety of barley which will have at least the same level of diastatic power as imported Canadian varieties and at the same time be an economically attractive alternative to varieties presently produced in the United Kingdom. The high diastase Canadian varieties are economically competitive in Canada under Canadian growing and market conditions but these same varieties are not competitive in Britain. Commercial plant breeders in Britain are not interested in developing a variety because the potential market for seed is too small. Consequently government financed research has become involved.

The main justification for the research was that, if the imported barley could be replaced by home-grown barley, imports could be reduced. The output was therefore considered to contribute toward the economic defence goal dimension. The potential annual import saving was estimated at £2 million per annum, about 0.02% compared to total imports of £10,000 million per annum.

In addition, the project has significant effects in the quantity dimension. The net social profitability of growing a unit of the barley in the United Kingdom is calculated as the social value of the barley minus the social costs of production. The social value per unit is the price users would have to pay under conditions of free trade since this is the price users would pay if governments were not forcing consumers to subsidize local industries. The social cost per unit is the price at which producers in the United Kingdom are prepared to grow the barley. The social value per unit is therefore approximately the world price, and the social cost per unit is approximately the domestic price. The world price was estimated to be £31 per ton or £6 lower than the home price. The net social benefit of the research output is therefore negative for both the productivity and total production aspects of the quantity dimension. The productivity rating is -19% (-6/31). The total profitability estimates for discount rates of 0%, 5% and 10% are -£7.47 million, -£2.67 million, and -£1.07 million respectively. For simplicity, the total profitability calculation was based on the assumptions that the research would cost £10 thousand per annum for 13 years and thereafter the social profit would be constant at -£0.432 million per annum. (The negative social profit would arise from growing the high diastase barley in the United Kingdom at a higher social cost than the social cost of importing the barley.) This simple approximation to the real world situation was assumed for convenience and not as a demonstration of the methods which, in practice, would normally have sufficient accuracy.

The output of the project is also expected to have effects in the distribution dimension. Farm operators are expected to receive a net income increase of £0.76 million per annum. In addition, farm labourers are expected to receive an increase of £0.36 million per annum. For the realization of these expected increases in income, total agricultural production must rise by the amount of the high diastase barley import saving. Effects in the other dimensions of the ultimate goal are considered either insignificant or non-existent.

An alternative way of achieving a reduction in these imports would be to increase the efficiency of production of home-grown barley. At present, producing whiskey from grain malt (15 parts imported high diastase barley to 85 parts imported maize) is at least as economical as producing whiskey from barley malt (all home-grown barley). If the efficiency of barley production in the United Kingdom could be improved, the price of home-grown barley could drop and production could be expanded. Distilling with home-grown barley malt would become relatively more competitive, reducing demand for barley imports and increasing demand for home-grown barley. This expansion would, of course, be at a negative social profit (if world cereal prices were still lower than domestic prices) but would be offset by the positive social profit arising from reducing the cost of all barley produced in the United Kingdom.

One other effect of eliminating the need for high diastase barley is the elimination of the need for maize for grain malt. This would produce a much larger potential import saving than would be produced by simply replacing imported high diastase barley with home-grown high diastase barley.

The calculation of social profitability was based on the assumption that the import levy for high diastase barley was a transfer payment within the economy and therefore not a social cost (from society's point view) to be applied to high diastase barley imports.

One could argue that, from the point of view of the United Kingdom, the value of high diastase barley is the world c.i.f. price at United Kingdom ports plus any import levy, since (a) the import levy initially goes to the EEC headquarters in Brussels instead of staying within the United Kingdom economy, and (b) little if any of the levy will return to the United Kingdom economy. In the analysis, high diastase barley production costs for the United Kingdom growing conditions were estimated at £37 per ton while the value of the crop to society was estimated at £31 per ton (the world c.i.f. price at United Kingdom ports). The difference between these two figures is the estimated import levy of £6 per ton.

If none of the import levy returns to the United Kingdom, the social cost of growing the barley in the United Kingdom would appear to be zero. However, the £6 per ton import levy presently collected on high diastase barley must be raised in some other way if imports of high diastase barley are reduced. One perhaps not unreasonable assumption under present EEC policy is that the lost revenue would be obtained from each country in proportion to the country's gross national product. Under this assumption the United Kingdom would have to contribute about one fifth of the lost import levy or about £1.2 per ton of reduced barley imports. The total social cost of producing the high diastase barley at home would then be £37 per ton in production costs and £1.2 per ton in increased costs of EEC membership. The net social benefit from the home production would be -£1.2 per ton (£37 per ton social value minus £38.2 per ton total social costs), and the United Kingdom would effectively be paying £38.2 per ton instead of £37 per ton for the barley.

From the point of view of the EEC as a whole, the social value would still be -£6 per ton if high diastase barley grown in the United Kingdom replaced imports from Canada. There would, however, be a change in the source of transfer payments within the EEC.

The suggestion that the United Kingdom should disregard the overall effects on the EEC as a whole and only assess research projects strictly from the point of view of the United Kingdom may be criticized as being contrary to the spirit or good neighbourliness of EEC membership. By growing the high diastase barley at home at a cost of £6 per ton more than the world import price, the United Kingdom would be lowering her contribution to the EEC by £4.8 per ton of high diastase barley produced. This would effectively require other members of the EEC to increase their contributions.

The problem of selecting boundaries for assessing social benefits and costs may, in some cases, be difficult. The high diastase barley study is an example of a situation in which there are some rather curious implications associated with selecting one boundary or another. The high diastase barley assessment was based on the United Kingdom as a whole and the £6 per ton import levy was assumed to effectively not leave the United Kingdom economy.

This project also illustrates that any research which is aimed at permitting expansion in an area of production where Britain has a comparative disadvantage relative to other countries will normally have a negative social benefit.

Details of the analysis are shown in Appendix A.

6.1.2. Project B: Hybrid Swedes

The main objective of the Hybrid Swedes research is to increase swede yield per acre. The increased yield would reduce the cost of this form of animal feed and thereby reduce the cost of meat to the consumer. If the objective of the reasearch is achieved, swede output per acre could be increased by 5 tons (19%) by simply using the new variety.

The social benefit arising from this reasearch was estimated in two ways. One was to estimate the value of an alternative crop which could be produced on the land released from swede production if total annual swede production remained constant and the higher yielding swede variety was used. The other method was to estimate the value of the extra quantity of swedes which could be produced if all of the present swede acreage was converted to the new higher yielding variety. The social value of the extra quantity of swedes could not be estimated directly since there is virtually no market for swedes. A value was established indirectly by determining the value of the amount of barley which would be required to replace a unit of the swedes. Barley was also used in the first method as a reference for establishing social value.

As in the case of High Diastase Barley, the world price of barley was used as a basis for calculating social benefit. Social costs were assumed to be zero since, in both calculation methods, the extra production was expected to be achieved at no change in total inputs.

The two methods produced considerably different estimates for the social value of the extra swede production. The first method placed the value of the extra swedes at 92 thousand tons of barley while the second placed the value at 198 thousand tons. The difference arose because energy content was used as a basis for determining the barley equivalent of swedes. Since the average yield of barley only produces about 60% of the energy per acre which the present average yield of swedes produces, the two methods are bound to give very different results.

The true value of the extra swedes is probably somewhere between these two estimates. The lower estimate is probably too low because if farmers have some way of utilizing the extra swedes, they can probably obtain a higher return per acre by keeping the land in swedes and increasing swede production than by growing a crop like barley.

The upper estimate is probably too high because a unit of energy in swedes is not as valuable as a unit of energy in barley. (Swedes have a much higher moisture content than barley. Consequently,by feeding swedes, a lower rate of gain in livestock will be obtained than would be obtained by feeding barley, thus reducing the economic value of the energy in the swedes.) For the analysis, the value of the extra swede production was assumed to be equivalent to 150 thousand tons of barley.

One other estimation method which could have been used is to value the land and other inputs which would be saved by reducing total swede acreage while maintaining production. This method was not attempted because the inputs and their values would be difficult to estimate.

Another dimension of the ultimate goal that is significantly affected by this research is economic defence. The value of the reduction in animal feed imports which could be expected as a result of the increased yield of swedes was evaluated in terms of the amount of foreign exchange which could be saved by replacing barley imports with home grown barley. The import saving was estimated at £4.2 million per annum, 0.042% when compared to total annual imports of £10,000 million per annum.

There was also a significant effect in the distribution dimension. Farmers would not have to purchase as great an amount of feedstuffs if swede yields were increased. The net value of this feed saving was estimated to be £4.7 million per annum.

The evaluation methods used in this analysis raised a number of problems in forecasting. These included (a) the extent to which the enlarged EEC will in future remain a net importer of barley, and (b) whether or not the increased efficiency of swede production would reverse the trend to lower swede acreage which has been occurring for the past decade. Calculations were made on the assumption that (a) the enlarged EEC will remain a net importer of barley, and (b) future swede acreage will stabilize at the annual average for 1962/63 to 1966/67. This case study is a good example of the type which could, in practice, be improved by using a more elaborate type of assessment.

One other effect worth noting is that international trade relations may be affected by the feedstuff supply changes which could arise as a result of this project. A reduction in imports caused by the increased production of non-imported feedstuffs could easily be more acceptable in international trade negotiations than reduced imports from increased production of a commodity which requires protective tariffs to maintain home production levels. If this is the case, there may be a political advantage in using the increased acreage for increased swede production, rather than increased barley production.

Details of the assessment are shown on Appendix B.

6.1.3. Project C: Triticale for Energy in Poultry Rations

This project was initially defined as the assessment of new energy sources as alternative ingredients in poultry rations. Three new feeds were being considered: triticale, potatoes (which are high yielding but unfit for human consumption) and naked barley. However, the project was more specifically defined to consider only triticale because it was found that each new ingredient was requiring a largely separate assessment.

The main objective of the redefined project is to assess the effect of substituting triticale for other energy ingredients (such as wheat) in poultry rations. The hope is that triticale will be an acceptable substitute. If it is, poultry will not in the future be competing with humans for this source of energy, since the feed is unlikely to be used as a human food. However, the production of triticale requires land which is also required by many crops which are used for human food. Therefore, triticale will not have any benefit to society or even the poultry industry unless the production of poultry feed per acre is higher for triticale than for conventional ration ingredients such as wheat.

PL.

Triticale was compared to wheat and in terms of energy production per acre, is almost identical to wheat. Therefore, triticale was not expected to provide any benefit as an alternative source of energy. The crop may have other advantages, such as being a better source of protein, but these other potential benefits were outside the scope of this project as it is presently defined.

This project demonstrates the importance of a careful project definition. If the project had been defined to include an appraisal of aspects which may make triticale advantageous compared to other cereals, the project may well have had benefits in some of the dimensions. The project also illustrates that a careful socio-economic appraisal of the expected outputs of the research could be useful as an aid in selecting those aspects of the research which will produce the most useful results.

The quantity dimension is the only goal dimension significantly affected by this project. There were no expected benefits but the research costs were estimated at £5 thousand, all occurring in the first year. The net social profitability was therefore -£5 thousand for any rate of discount.

One other possible justification for assessing triticale as a poultry food source is to help assess the cereal as a possible human food source. There may be parts of the world where triticale will out-produce wheat, rice or maize. If it will, and if triticale were being considered as part of a human diet, then the nutritional qualities and possible side effects of the cereal would need to be determined. One way of assessing these qualities is to experiment with poultry. However, this justification is outside the objective of the project as presently defined.

If the project were re-defined to include the assessment of triticale as a human food, there could be social benefits in the quality or availability dimensions. These benefits could arise if triticale were being considered as a cereal to make a new food such as a new breakfast cereal. If no uses within the United Kingdom were contemplated, there would be no benefit to society within the United Kingdom and the research would be a form of foreign aid to those areas of the world using the information.

6.1.4. Project D: Dairy Female Replacement Systems

The main objective of the study into dairy female replacement systems is to improve the efficiency of dairy production by improving the systems for selecting herd replacements.

This case study is an example of a project which has not been explicitly described in terms which permit adequate assessment. In other words, the project is still in the feasibility study phase. Since the project has not been specifically defined, the outputs could not be evaluated in detail. Consequently the project is treated as a pilot project and can be considered as an illustration of how a speculative socio-economic assessment can be used to examine the potential implications of more specific research projects in a particular area.

A basis for assessment was provided by assuming that a new female replacement system would make possible a 10% increase in annual milk yield per cow, thus permitting the size of the national dairy herd to decline while holding total milk production constant. The reduction in herd size would bring about a saving in feed, which would have effects in the quantity and economic defence dimensions.

In the quantity dimension, the savings were estimated to result in a reduction in the average price of milk by about 1.8%. This price reduction is much less than the 10% increase in gross production efficiency because (a) adoption of the new system was assumed to be 50% (b) higher yielding cows do not produce more milk without higher per cow feed costs, and (c) savings, other than feed, which are associated with the reduced dairy herd are ignored. Total profitability estimates for discount rates of 0%, 5% and 10% were £180 million, £69 million, and £30 million respectively.

For the economic defence dimension, the reduced feed requirement was estimated to provide a feedstuffs imports saving of £11 million or 0.11% compared to total annual imports of £10,000 million.

Another possible reason for conducting this research is that an attempt should be made to maintain the competitive position of dairy products compared to substitute foods, particularly synthesized foods. If society in general concurs that research should be sponsored to restrict the substitution of synthetic foods for natural foods, then this 'naturalness maintenance' factor could be considered as another of the dimensions of the ultimate goal. Alternatively, the factor could be considered one aspect of the quality dimension. From society's point of view, the objective may be counter-productive. This would be true if the standard of living could be raised more by increasing the utilization of milk substitutes than by maintaining or increasing the utilization of natural milk products. In any case, the objective is probably unnecessary because society, through consumer preference (and the legal system if necessary) can select the levels of consumables utilization.

From the point of view of the dairy industry, the main threat is that once substitutes for milk products capture a signigicant amount of the market, it may become increasingly difficult for natural dairy products to maintain a competitive position. The result could be a continuing reduction in the size of all aspects of the dairy industry relative to the size of the market, including the amount of research into dairying. Consequently, from the point of view of the dairy industry the objective may be valid.

In RASAR, the assessment is made from society's point of view and effects such as lost markets are included in the distribution dimension. Once a specific system has been defined, the expected market gain (or reduction in market loss) can be estimated and included in the distribution dimension.

Details of the assessment are given in Appendix D.

6.2. Model Application

6.2.1. Data Preparation Techniques

Data relating to the dimensions of the ultimate goal are given for each of the four case studies in the corresponding project appraisals (see Appendices A through D). However, these data are unsuitable for direct application in the mathematical model for two reasons.

First, only one measure for each dimension should be used in the model. This is because (a) each dimension is an independent effect while aspects within dimensions are either inter-dependent or are different measures of the same effect, and (b) the rational assignment of weights following from the subjective assessment of the relative importance of the dimensions can be facilitated if each dimension has only one measure.

The second reason for the data being unsuitable in its present form is that the units of measure for the dimensions and aspects within dimensions are often incommensurate, and the ranges of acceptable numerical values vary considerably from one dimension to another.

For these reasons the numerical ratings given in the project summaries must be translated into scores which have a common range of values. Also the systems for translating the ratings to scores must be compatible with the numerical weights assigned to the dimensions. Scoring systems for those dimensions and aspects which are relevant to the case studies are discussed in the following paragraphs.

<u>Quantity Dimension Coefficients</u>: The quantity dimension has two aspects. The measures for these aspects are incompatible because one is in percentage terms and the other is in monetary terms. The two aspects are also two different ways of measuring the same effect. The ratings for the two aspects must therefore be translated into a common scale and then combined in a single score.

Arbitrarily defined systems for translating the productivity and total production aspects of the quantity dimension into a common scale are shown in Table 6.1. A function for aggregating the ratings is defined as follows:

$$A_{ji} = h_p X_{1p} + h_t X_{1t} \tag{6.1}$$

where the two coefficients, h_p and h_t, are the relative weights assigned to the two aspects and must sum to unity. For purposes of the model demonstration, the relative weights are arbitrarily defined as $h_p = h_t = 0.5$.

<u>Economic Defence Dimension Coefficients</u>: The only aspect of economic defence considered in this analysis is the balance of payments aspect. The potential annual import saving made possible by the research output is used as a measure of the effect. This measure can be compared to annual total imports and annual agricultural imports. These ratios give an indication of the relative importance of the import saving.

Both ratios are given in the summaries of the projects and may give the decision maker a more adequate impression of the importance of the import saving than could be obtained from either ratio by itself. However, if the ratio of agricultural imports to

TABLE 6.1. SYSTEMS FOR TRANSLATING THE INCOMMENSURATE RATINGS OF THE GOAL DIMENSIONS INTO A COMMON SCALE COEFFICIENT

Common Scale Coefficient[a]	Dimension Ratings			
	1. Quantity		5. Economic Defence	8. Distribution
	Productivity	Total Production		
(X_j)	(B_{1p})(%)	(B_{1t})(£M)	(B_5)(%)	(B_8)(£M)
10	50. ≤ B	50. ≤ B	5. ≤ B	20. ≤ B
9	30. ≤ B < 50.	30. ≤ B < 50.	2. ≤ B < 5.	10. ≤ B < 20.
8	18. ≤ B < 30.	18. ≤ B < 30.	1. ≤ B < 2.	5. ≤ B < 10.
7	10. ≤ B < 18.	10. ≤ B < 18.	0.5 ≤ B < 1.	2. ≤ B < 5.
6	6. ≤ B < 10.	5. ≤ B < 10.	0.25 ≤ B < 0.5	1. ≤ B < 2.
5	4. ≤ B < 6.	3. ≤ B < 5.	0.12 ≤ B < 0.25	0.5 ≤ B < 1.
4	3. ≤ B < 4.	1.5 ≤ B < 3.	0.06 ≤ B < 0.12	0.2 ≤ B < 0.5
3	2. ≤ B < 3.	0.5 ≤ B < 1.5	0.03 ≤ B < 0.06	0.05 ≤ B < 0.2
2	1. ≤ B < 2.	0.1 ≤ B < 0.5	0.01 ≤ B < 0.03	0.01 ≤ B < 0.05
1	0.1 ≤ B < 1.	0.01 ≤ B < 0.1	0.001 ≤ B < 0.01	0.001 ≤ B < 0.01
0	-0.1 ≤ B < 0.1	0.0 ≤ B < 0.01	0.0 ≤ B < 0.001	0.0 ≤ B < 0.001
-1	-1. ≤ B < -0.1	-0.01 ≤ B < 0.0	-0.001 ≤ B < 0.0	
-2	-2. ≤ B < -1.	-0.1 ≤ B < -0.01	-0.01 ≤ B < -0.001	
-3	-3. ≤ B < -2.	-0.5 ≤ B < -0.1	-0.03 ≤ B < -0.01	
-4	-4. ≤ B < -3.	-1.5 ≤ B < -0.5	-0.06 ≤ B < -0.03	
-5	-6. ≤ B < -4.	-3. ≤ B < -1.5	-0.12 ≤ B < -0.06	
-6	-10. ≤ B < -6.	-5. ≤ B < -3.	-0.25 ≤ B < -0.12	
-7	-18. ≤ B < -10.	-10. ≤ B < -5.	-0.5 ≤ B < -0.25	
-8	-30. ≤ B < -18.	-18. ≤ B < -10.	-1. ≤ B < -0.5	
-9	-50. ≤ B < -30.	-30. ≤ B < -18.	-2. ≤ B < -1.	
-10	B < -50.	B < -30.	B < -2.	

a See text for methods of deriving project scores from the common scale coefficients.

total imports does not change significantly from year to year, there is no reason for using both measures in a quantitative model. Since the balance of payments may be more closely related to changes in total imports than agricultural imports, the ratio of potential import saving to total imports has been selected for this demonstration.

One other possible indicator is the ratio of import saving to payments deficit. However, the indicator is unsuitable because the deficit in payments is highly variable which makes the indicator unstable over time.

An arbitrarily defined system for translating the selected ratio to a scale is shown in Table 6.1. The dimension score is set equal to the scale value.

<u>Distribution Dimension Coefficients</u>: The distribution of potential increases in consumption is the only aspect of the distribution dimension considered in the project assessments. There may be many groups within society which are potentially affected by agricultural research outputs. However, there may be very few groups that are significantly affected by or are considered relevant to agricultural research outputs.

In the project appraisals only two groups are identified as being significantly affected. These are farm operators and farm labourers. A formula for combining the estimated increases in real net income for the various groups was arbitrarily defined as follows:

$$(6.2) \qquad B_8 = \rho(\textstyle\sum_{i=1}^{p} e_i Y_i)/\sum_{i=1}^{p} e_i$$

where:

B_8 = weighed aggregate income from all relevant groups (ℓ)

Y_i = potential increase in income for group i arising from the research output (ℓ)

e_i = relative value to group i of an extra unit of income

ρ = total number of relevant groups

The application of the formula generates a weighted aggregate of the estimated potential increases in income to the groups considered. The formula provides a figure that may be higher or lower than the figure which would be obtained by simply summing the estimates for the individual groups.

For this analysis the group designated 'farm operators' is given a weight $e_1 = 1$ and the group designated 'farm labourers' is given a weight $e_2 = 2$. Using these coefficients and the data from the appendices, values for B_8 for each project may be readily determined. An arbitrary system for translating the weighted aggregate income estimate to a common scale coefficient is shown in Table 6.1. The dimension score is set equal to the scale value.

6.2.2. Model Test Data

Dimension Weighting Coefficients: Since no information was available on the relative importance dècision makers may assign to the dimensions of the ultimate goal, each dimension in the model was assigned a weighting of unity.

Resource Limits: The estimated total resource requirement for the four projects was £315 thousand. However, the model was limited to £200 thousand to force it to make a selection. Each project was, of course, limited to the resource requirement specified in the corresponding project assessment.

Data Summary: The systems for generating dimension scores described in Section 6.2.1 were used to generate the coefficients necessary for applying the mathematical model. These data are shown in Table 6.2.

TABLE 6.2. DATA USED FOR TESTING THE LINEAR ALLOCATION MODEL

	Goal Dimension[e]					Total Resource Requirement (R_i)(£k)
	1. Quantity		5. Economic Defence	8. Distribution		
	Productivity	Total Production		Farm Operators	Farm Labourers	
A. High Diastase Barley						130
Rating[a]	-19%	-£2.67M	0.02%	£0.76M	£0.36M	
Common Scale Coefficient[b]	-8.	-5.	2.	5.		
Score[c]	-6.5		2.	5.		
Model Coefficient[d]	-5.0		1.54	3.84		
B. Hybrid Swedes						80
Rating[a]	14.7%	£34.M	0.04%	£4.7M	--	
Common Scale Coefficient[b]	7.	9.	3.	7.		
Score[c]	8.		3.	7.		
Model Coefficient[d]	10.0		3.75	8.75		
C. Triticale for Energy in Poultry Rations						5
Rating[a]	0.0%	-£0.005M	--	--	--	
Common Scale Coefficient[b]	0.	-1.				
Score[c]	-0.5					
Model Coefficient[d]	-10.0					
D. Dairy Female Replacement Systems						100
Rating[a]	1.8%	£69.M	0.11%	--	--	
Common Scale Coefficient[b]	2.	10.	4.			
Score[c]	6.		4.			
Model Coefficient[d]	6.0		4.			

a B_j coefficients (except for distribution dimension--see Section 6.2) from Appendices A to D.
b X_j coefficients--see Table 6.1.
c A_{ji} coefficients--see Section 6.2.
d A_{ji}/R_i coefficients scaled up by a factor of 100.
e Goal dimensions not listed have no rating and therefore a model coefficient of zero.

Data Scaling: The resource requirement data used in the model were scaled by a factor of 100 before being included in the model. This scaling has not been removed from the tables of results. Consequently, resource requirements are given in £100,000 units and the utility values are 100 times larger than they would be without scaling. Scaling was not removed from the results because the scaled utility values are of a convenient order of magnitude, and the utility values are not absolute values but relative values. The term 'unit of investment' in the discussion of the results refers to £100,000 and not £1,000 of investment.

Matrix for the Basic Model: Since there were only four case studies, the solution to the problem could be obtained by inspection. However this small amount of data was sufficient for demonstrating the mathematical model. The matrix for the basic model is shown in Figure 6.2,

No attempt has been made to demonstrate the nonlinear model or the other extensions to the basic model. The attempt was not made because the small sample of data (a) would seriously restrict the usefulness of such an extended demonstration, and (b) would not permit the more complex model to provide information which could be used to make general observations about agricultural research.

6.2.3. Optimal Solution and Post-Optimal Information

The mathematical model shown in Figure 6.2 was solved using the IBM linear and separable programming computer package (IBM, 1968). The optimal solution and accompanying post-optimal information are summarized in Tables 6.3 and 6.4.

In the optimal solution, Projects B and D (Hybrid Swedes and Dairy Female Replacement Systems) are allocated resources at the levels specified in their corresponding project appraisals. Project C,

Equation Number	Row Description				Goal Dimension									Project			
					Quantity G_1	Quality G_2	Availability G_3	Human Safety G_4	Economic Defence G_5	Food Sources Security G_6	Conservation G_7	Distribution G_8	Individual Rights G_9	High Diastase Barley P_1	Hybrid Swedes P_2	Triticale for Energy in Poultry Rations P_3	Dairy Female Replacement Systems P_4
5.1	Utility	Maximize	Z	=	1	1	1	1	1	1	1	1	1				
5.2	Equations for Linking Goal Dimensions to Projects		0	=	-1									-5.0	10.0	-10.0	6.0
			0	=		-1											
			0	=			-1										
			0	=				-1									
			0	=					-1					1.54	3.75		4.0
			0	=						-1							
			0	=							-1						
			0	=								-1		3.84	8.75		
			0	=									-1				
5.3	Resource Limit	Total Resources	2.0	≥										1	1	1	1
5.4		High Diastase Barley	1.3	≥										1			
		Hybrid Swedes	0.8	≥											1		
		Triticale for Poultry	0.05	≥												1	
		Dairy Systems	1.0	≥													1

Figure 6.2. Matrix for the basic resource allocation model using test data from four case studies.

TABLE 6.3. OPTIMAL SOLUTION AND POST-OPTIMAL INFORMATION USING THE MODEL TEST DATA--INFORMATION RELATING TO PROJECT INVESTMENT

	Change in Z for a Unit Change from the Optimal Activity Level (and Limit within which the Marginal Value is Valid)					Limits on Change in Project Utility without Changing the Optimal Research Program		
	Lower Limit on Activity	ΔZ_{LL} [a]	Optimal Solution Activity Level	ΔZ_{UL} [a]	Upper Limit on Activity	Lower Limit	Input Value	Upper Limit
	(£100k)	(Utility/ £100k)	(£100k)	(Utility/ £100k)	(£100k)	(Project Utility/£100k)		
Resource Allocation to:								
A. High Diastase Barley	0.0	-0.38	0.20	-9.62	1.20	0.0	0.38	10.00
B. Hybrid Swedes	0.0	-22.12	0.80	+22.12	1.00	0.38	22.50	∞
C. Triticale for Energy in Poultry Rations	0.0	-- [b]	0.0	-10.38	0.05	-∞	-10.00	0.38
D. Dairy Female Replacement Systems	0.0	-9.62	1.00	+9.62	1.20	0.38	10.00	∞
Total Resource Allocation	1.80	-0.38	2.00	+0.38	3.10			

a Marginal change in aggregate utility (ΔZ) for a unit change in the activity level toward the lower limit (LL) and upper limit (UL) respectively.

b The optimal solution activity level is already at the lower limit.

TABLE 6.4. OPTIMAL SOLUTION AND POST-OPTIMAL INFORMATION USING THE MODEL TEST DATA--INFORMATION RELATING TO GOAL DIMENSIONS

Goal Dimension	Change in Z for a Unit Change from the Optimal Program Score (and Limit within which the Marginal Value is Valid)					Limits on Change in the Goal Dimension Weight without Changing the Optimal Program		
	Lower Score	ΔZ_{LL} [a]	Optimal Solution Score	ΔZ_{UL} [a]	Upper Score	Lower Limit	Input Value	Upper Limit
Consumption Category								
1. Quantity	2.000	-0.875	13.000	-0.760	14.000	0.125	1.0	1.076
2. Quality	0.0	$-\infty$	0.0	$-\infty$	0.0	$-\infty$	1.0	∞
3. Availability	0.0	$-\infty$	0.0	$-\infty$	0.0	$-\infty$	1.0	∞
Security Category								
4. Human Safety	0.0	$-\infty$	0.0	$-\infty$	0.0	$-\infty$	1.0	∞
5. Economic Defence	7.000	-0.247	7.308	$-\infty$	7.308	0.753	1.0	∞
6. Food Sources Security	0.0	$-\infty$	0.0	$-\infty$	0.0	$-\infty$	1.0	∞
7. Conservation	0.0	$-\infty$	0.0	$-\infty$	0.0	$-\infty$	1.0	∞
Equity Category								
8. Distribution	7.000	-0.098	7.768	-2.505	11.608	0.901	1.0	3.505
9. Individual Rights	0.0	$-\infty$	0.0	$-\infty$	0.0	$-\infty$	1.0	∞

a Marginal change in aggregate utility (ΔZ) for a unit change in the dimension score toward the lower limit (LL) and upper limit (UL) respectively.

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Triticale for Energy in Poultry Rations, is allocated no resources. Project A, High Diastase Barley, is a marginal project and is therefore allocated the resources remaining after Projects B and D have been allocated their full requirements.

The research program makes contributions toward three of the goal dimensions: quantity, 13.000 units; economic defence, 7.308 units; and distribution, 7.768 units. Since in this case all dimension weights are unity, the aggregate weighted utility of the program (Z) is the sum of the individual dimension scores or 28.076 units.

Optimal Research Program Ranging Sensitivity Analysis: The model provides marginal cost data as well as the ranges over which the marginal cost data are valid. The cost data and ranges relate to both increases and decreases in investment in the research projects. These cost figures are not simply the aggregate weighted utilities of the particular projects but are the differences between these amounts and the aggregate weighted utility of the marginal project which could increase or decrease by one unit if the particular project decreased or increased by one unit. For example, a unit of Hybrid Swedes research contributes 22.50 units to Z but the marginal cost of reducing investment in Hybrid Swedes research is 22.12 units. This is because High Diastase Barley research could increase by one unit and increase Z by 0.38 units if Hybrid Swedes research were reduced by one unit.

The changes in Z for increases in investment in Hybrid Swedes or Dairy Female Replacement Systems are positive rather than negative. Each of these figures gives the net increase in Z which would result from a one unit increase in the corresponding project. (This would require the relaxation in the corresponding resource constraint since these projects are fully financed). The marginal value is the increase in Z which could arise from a one unit increase in the corresponding project and may be interpreted as the per unit value to the program of a similar project if it were included as an alternative project. These figures are not the marginal values of more investment in the same projects.

Some of these data were obtained from the post-optimal information for the particular project and some were obtained from the post-optimal information for the associated resource limit restraint.

The aggregate utility for each project and the extent to which the utility of each project would have to change before any change in the research program would occur are also given in Table 6.3. In most cases substantial changes in project utility are required before any change in the program would occur. Note that these marginal cost and range figures are only valid for changes in one project at a time and only if all other coefficients in the model are held constant at their input values. However, a more extensive sensitivity analysis can be carried out with parametric programming methods.

<u>Goal Dimensions and Weights Ranging Sensitivity Analysis</u>: The model gives the cost of a modification in the research program which would result in a one unit change in the contribution of a particular goal dimension to Z. (The marginal cost for a given dimension is not unity--as may at first be expected since the weights are all unity--because a change in the program causing a one unit change in one particular dimension will probably cause changes in other dimensions.) The ranges over which these marginal cost coefficients are valid are also given (see Table 6.4). The marginal analysis on the goal dimensions gives an indication of how the total aggregate utility of the program (Z) would change if the program were modified to change the relative contribution in a particular dimension.

In addition to information on the goal dimensions themselves, the model provides an indication of the sensitivity of the research program to changes in the weights assigned to the goal dimensions. For example, the optimal research program would not change if the weight on the quantity dimension varied between 0.125 and 1.076 (see Table 6.4). The value of Z would, of course, change with the weight change, but the selection of projects for the optimal research program would remain the same. These ranges give some indication of the stability of the present optimal solution. A narrow range would indicate that the optimal program could be changed by changing the weight assigned beyond this range. How extensive a change would occur cannot be determined from the post-optimal information but could be determined using parametric programming.

6.2.4. Research Program Sensitivity to Resource Availability

The significance of total resource availability to the optimal research program was examined. This was done by parametrically changing total resource availability from zero to £350,000 in £50,000 increments. The optimal solutions at these increments are shown in Tables 6.5 and 6.6. The development of the optimal research program and the changes in utility which accompany the increase in resource availability are illustrated in Figures 6.3 and 6.4.

The analysis demonstrates that as resources become available the model allocates these resources to a project which has not received its full requirement before allocating any resources to another project. The analysis also demonstrates that the model allocates resources to projects in decreasing order of total project utility. Hence there are decreasing returns to increasing investment, even though total utility is rising (see Figure 6.4).

TABLE 6.5. OPTIMAL SOLUTIONS (USING THE MODEL TEST DATA) FOR CHANGING RESOURCE AVAILABILITY--INFORMATION RELATING TO PROJECT INVESTMENT

	Resource Requirement (£100k)	Resource Availability (£100k)							
		0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5
Resource Allocation to:		(£100k units)							
A. High Diastase Barley	1.30	0.0	0.0	0.0	0.0	0.2	0.7	1.2	1.3
B. Hybrid Swedes	0.80	0.0	0.5	0.8	0.8	0.8	0.8	0.8	0.8
C. Triticale for Energy in Poultry Rations	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D. Dairy Female Replacement Systems	1.00	0.0	0.0	0.2	0.7	1.0	1.0	1.0	1.0
Total Investment	3.15	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.1
Marginal Value (Change in Z) of Investment in:		(Utility units)							
A. High Diastase Barley		-22.12	-22.12	-9.62	-9.62	--	--	--	0.38
B. Hybrid Swedes		--	--	12.5	12.5	22.12	22.12	22.12	22.5
C. Triticale for Energy in Poultry Rations		-32.5	-32.5	-20.0	-20.0	-10.38	-10.38	-10.38	-10.0
D. Dairy Female Replacement Systems		-12.5	-12.5	--	--	9.62	9.62	9.62	10.0
Total Program		22.5	22.5	10.0	10.0	0.38	0.38	0.38	-10.0

TABLE 6.6. OPTIMAL SOLUTIONS (USING THE MODEL TEST DATA) FOR CHANGING RESOURCE AVAILABILITY--INFORMATION RELATING TO GOAL DIMENSIONS

	Weight	Resource Availability (£100k)							
	Assigned	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5
Aggregate Utility[a] (Z)		0.0	11.25	20.00	25.00	28.076	28.266	28.456	28.494
Aggregate Goal Dimension Scores (Unweighted):		(Unweighted Dimension Scores)							
Consumption Category:									
1. Quantity	1.0	0.0	5.0	9.2	12.2	13.0	10.5	8.0	7.5
2. Quality	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3. Availability	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Security Category:									
4. Human Safety	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5. Economic Defence	1.0	0.0	1.875	3.80	5.80	7.308	8.078	8.848	9.002
6. Food Sources Security	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7. Conservation	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Equity Category:									
8. Distribution	1.0	0.0	4.375	7.00	7.00	7.768	9.688	11.608	11.992
9. Individual Rights	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a Sum of weighted dimension scores.

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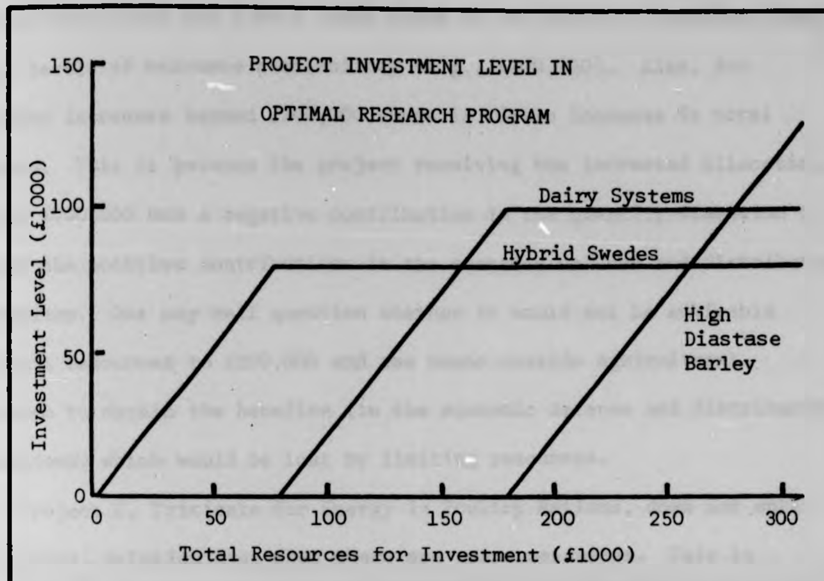

Figure 6.3. Changes in the levels of investment in research program projects as total resource availability increases.

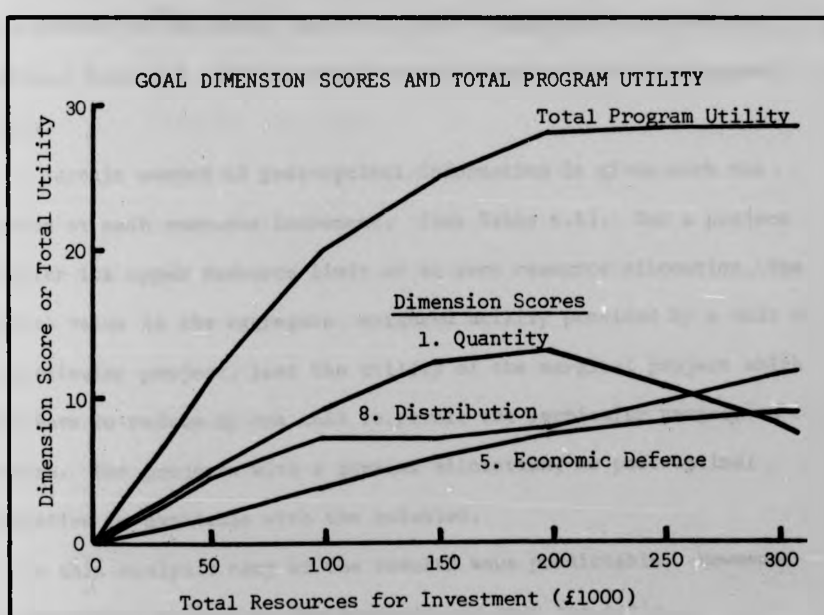

Figure 6.4. Changes in total program utility and aggregate goal dimension scores as total resource availability increases.

From Figure 6.4 it may be observed that the point of maximum utility (£310,000) has a much lower score in the quantity dimension than lower levels of resource availability (e.g., £200,000). Also, for resource increases beyond £200,000 there is little increase in total utility. This is because the project receiving the increased allocation beyond £200,000 has a negative contribution in the quantity dimension to offset the positive contributions in the economic defence and distribution dimensions. One may well question whether it would not be advisable to limit resources to £200,000 and use means outside agricultural research to obtain the benefits (in the economic defence and distribution dimensions) which would be lost by limiting resources.

Project C, Triticale for Energy in Poultry Rations, does not enter the optimal solution even when there are spare resources. This is because the project would only reduce Z. In practical terms, a project which has negative or zero contributions in all dimensions should never be considered in the model (unless it was a requirement for another beneficial project) since it would never be selected for the research program.

A certain amount of post-optimal information is given with the solution at each resource increment. (See Table 6.5). For a project at either its upper resource limit or at zero resource allocation, the marginal value is the aggregate weighted utility provided by a unit of the particular project, less the utility of the marginal project which would have to reduce by one unit to permit the particular project to increase. For projects with a partial allocation, no post-optimal information is available with the solution.

In this analysis many of the results were predictable. However this is because there were few projects and only the basic allocation model was used. If a more complex (and more realistic) model were used and the number of projects was larger, the results would not be as easily predicted.

6.2.5. Research Program Sensitivity to the Quantity Dimension Weight

The changes in the optimal research program which would take place if the weight on the quantity dimension was changed were determined by parametric variation. The optimal solutions for weights ranging from 0 to 1.2 in 0.2 unit increments are shown in Tables 6.7 and 6.8 and in Figures 6.5 and 6.6.

As would be expected by observing the post-optimal information in Table 6.4, there was no change in the research program for weight changes from 0.2 to 1.0. At a weight of zero, Project A (High Diastase Barley) is more beneficial than Project D, (Dairy Female Replacement Systems). At a weight of 1.2, the net utility for High Diastase Barley becomes negative and the project leaves the optimal research program even though all resources are not allocated.

The post-optimal information shown in Table 6.7 indicates that projects which are fully financed throughout most of the weight variations (e.g. Projects B and D) become increasingly profitable as the weight increases. Those which are unprofitable (e.g. Project C) become increasingly unprofitable.

Figures 6.5 and 6.6 show the information obtained from the model for incremental changes in the quantity dimension weight. If the size of the increments were to approach zero the functions shown in these figures (except for the quantity score and total utility functions) would become step functions.

TABLE 6.7. OPTIMAL SOLUTIONS (USING THE MODEL TEST DATA) FOR CHANGING WEIGHT ON THE QUANTITY DIMENSION--INFORMATION RELATING TO PROJECT INVESTMENT

	Resource Requirement (£100k)	Quantity Dimension Weight						
		0.0	0.2	0.4	0.6	0.8	1.0	1.2
Resource Allocation to:				(£100k units)				
A. High Diastase Barley	1.30	1.20	0.20	0.20	0.20	0.20	0.20	0.0
B. Hybrid Swedes	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
C. Triticale for Energy in Poultry Rations	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D. Dairy Female Replacement Systems	1.00	0.0	1.00	1.00	1.00	1.00	1.00	1.00
Total Investment (2.0 available)		2.0	2.0	2.0	2.0	2.0	2.0	1.80
Marginal Value (Change in Z) of Investment in:				(Utility units)				
A. High Diastase Barley		--	--	--	--	--	--	-0.62
B. Hybrid Swedes		7.12	10.12	13.12	16.12	19.12	22.12	24.50
C. Triticale for Energy in Poultry Rations		-5.38	-6.38	-7.38	-8.38	-9.38	-10.38	-12.00
D. Dairy Female Replacement Systems		-1.38	0.82	3.02	5.22	7.42	9.62	11.20
Total Program		5.38	4.38	3.38	2.38	1.38	0.38	0.0

TABLE 6.8. OPTIMAL SOLUTIONS (USING THE MODEL TEST DATA) FOR CHANGING WEIGHT ON THE QUANTITY DIMENSION--INFORMATION RELATING TO GOAL DIMENSIONS

	Weight Assigned	Quantity Dimension Weight						
		0.0	0.2	0.4	0.6	0.8	1.0	1.2
Aggregate Utility[a] (Z)		16.456	17.676	20.276	22.876	25.476	28.076	30.800
Aggregate Goal Dimension Scores (Unweighted):		(Unweighted Dimension Scores)						
Consumption Category:								
1. Quantity	varying	2.000	13.000	13.000	13.000	13.000	13.000	14.000
2. Quality	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3. Availability	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Security Category:								
4. Human Safety	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5. Economic Defence	1.0	4.848	7.308	7.308	7.308	7.308	7.308	7.000
6. Food Sources Security	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7. Conservation	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Equity Category:								
8. Distribution	1.0	11.608	7.768	7.768	7.768	7.768	7.768	7.000
9. Individual Rights	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a Sum of weighted dimension scores.

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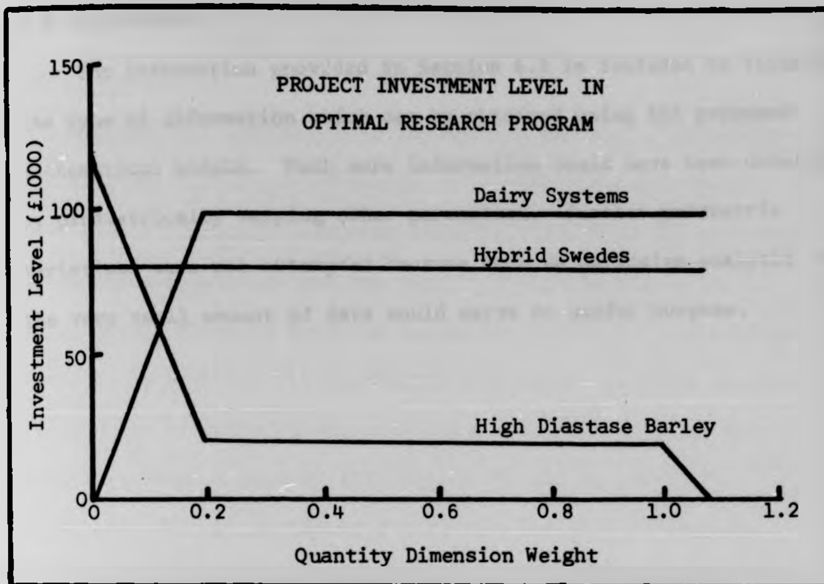

Figure 6.5. Changes in the levels of investment in research program projects as the quantity dimension weight varies.

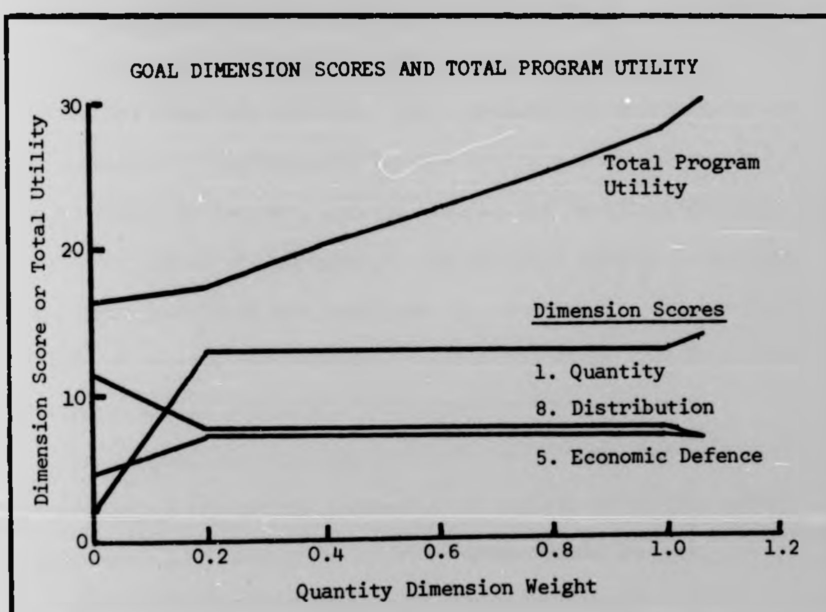

Figure 6.6. Changes in total program utility and aggregate goal dimension scores as the quantity dimension weight varies.

6.3 Discussion

The information provided in Section 6.2 is included to illustrate the type of information which can be obtained using the proposed mathematical models. Much more information could have been obtained by parametrically varying other parameters. Further parametric variations were not attempted because such an extensive analysis on the very small amount of data would serve no useful purpose.

7. CONCLUSIONS AND DISCUSSION

Mathematical models can be useful aids for making decisions regarding the allocation of resources in agricultural research. These models require a framework which provides both the criteria for resource allocation and the data on which the allocation is to be based. RASAR (a Resource Allocation System for Agricultural Research) is a system which provides a framework for both specifying a usable set of criteria for resource allocation decisions and processing data to provide information for making effective decisions. The system has been effective for both guiding the assessment of four case study projects and demonstrating the usefulness of mathematical models in processing information to provide a basis for effective decisions.

Criteria for Resource Allocation: The criteria for making resource allocation decisions within agricultural research are complex and often ill defined. The complexity of the criteria can be considerably simplified by (a) evaluating research from the point of view of society, and (b) tracing the immediate effects of the outputs of the research to the ultimate effects in society. Using this procedure, the multitude of inter-related and intermediate effects or reasons for research in different areas tend to converge on a small set of relatively independent ultimate effects.

In general, the ultimate goal of state-financed agricultural research appears to be the production of outputs which will permit improvements in the welfare of individuals within society. Agricultural research projects have objectives directed toward producing outputs, the effects of which will lead to one or more relatively independent dimensions of this ultimate goal. Nine dimensions in three categories have been tentatively identified: Consumption category-- (1) quantity, (2) quality, (3) availability; Security category -- (4) human safety, (5) economic defence, (6) food sources security, (7) conservation; Equity category -- (8) distribution, (9) individual rights.

The consumption category is concerned with the generation of consumables which can be used to maintain or increase the general standard of living in society. This category includes not only increases in the amount of consumables but also increases in quality and the increased availability of a wider range of products. The security category is concerned with things like farm safety, import saving, plant and animal disease threats, and the destruction of non-renewable resources. The equity category is concerned with changes in the pattern of consumption, discrimination and equality of opportunity arising from the adoption of research outputs. The four research projects were found to have significant potential ultimate effects in the quantity, economic defence and distribution dimensions.

An extensive development project would undoubtedly improve on the definitions of the dimensions, but this was beyond the scope of the present investigation.

Data Generation: The data on which decision makers are expected to make effective resource allocation decisions are inadequate for several reasons. First, research projects are not, in some cases, defined in such a way that the outputs can be either readily recognized by someone uninvolved in the project, or communicated to decision makers. Second, the ultimate socio-economic effects of research outputs are not obvious, particularly to the scientist who has a very limited socio-economic background. Third, even if some more obvious ultimate effects have been identified, others which radically change the comparative value of a project remain obscure. Fourth, data relating to a wide range of research projects have not been available in a form which is conducive to inter-project comparison.

RASAR provided a framework within which much useful socio-economic information for the four case studies could be generated. This systems approach was effective in isolating the outputs and identifying many of the relationships of the outputs to ultimate effects in society.

The four case study assessments showed that quite crude methods for forecasting and generating socio-economic data provided a considerable amount of quite useful information. Although more elaborate techniques would improve the data, these crude assessments were found to be much better than no data and sufficient for demonstrating the use of mathematical models. A sensitivity analysis on the crude data can sometimes show that more accurate data would have little value.

The market place is often used as a basis for establishing social value. However, some of the dimensions of the ultimate goal are not suitably measured by market indicators. For these dimensions, scoring models appear to offer a reasonable alternative as a means of placing a quantitative rating on effects within the dimensions. In dimensions where market indicators are suitable, the market place sometimes provides a distorted measure of social value. The methods of social cost/benefit analysis can be used to reduce this distortion.

Project Assessments: The four project assessments provide some useful insight into both (a) the relationships among agricultural research outputs and their effects in society, and (b) the ways in which project assessments can be used to guide research and generate data for making decisions.

In the case of the High Diastase Barley project, the main objective of saving imports (a benefit in the economic defence dimension) is of questionable value because it can only be done at a net social cost (quantity dimension). Other systems within society may be equally effective in saving imports and not have the disbenefit of the social cost. An additional benefit for this project (which is probably implicitly recognized as being a result of the import saving) is that farmers at home would have a larger cereal market and hence a potential increase in income (distribution dimension).

In the case of the Hybrid Swedes project, the main objective of increasing yield appears to have favourable effects in the quantity, economic defence and distribution dimensions. No unfavourable effects were identified.

The Triticale for Energy in Poultry Rations project did not appear to have any effects at all because triticale does not appear to have any advantages or disadvantages over wheat as a source of energy in poultry rations. The objective of finding a source of energy for poultry which is not used by humans (on the assumption that competition between human beings and poultry in the future will increase and poultry food will become scarcer) will not be met by using triticale in poultry rations because triticale competes for land with other cereal used as human foods. This project is one which could perhaps become beneficial if redefined, since triticale may provide protein in poultry rations more efficiently than does wheat.

The Dairy Female Replacement Systems project is an example of how a preliminary assessment in a broad area can be used to examine the potential effects in society of the possible outputs. The assessment showed that new replacement systems could have beneficial effects in the quantity and economic defence dimensions. The benefits arose because the replacement systems have the potential for reducing the size of the national dairy herd (for a given milk output) which in turn reduces feed requirements and saves feed imports.

Mathematical Model Applications: Two main categories of uses were found for mathematical models within RASAR. The first use is in project definition (helping to specify expected research outputs and methods for obtaining them) and execution (assisting in the management of experimental work and analysis of results). The second use is in the selection of research projects to comprise a program which has the maximum expected social benefit for the resources available. This investigation has been primarily concerned with the latter use.

Mathematical programming methods are sufficiently versatile to provide a model that can be effectively adapted to resource allocation decision problems at any level of the hierarchy of decision levels.

The demonstration of a mathematical programming model showed that models can be used to (a) generate additional useful data from the basic data provided by project assessments, and (b) facilitate a comparative analysis for generating a research program. The information which is provided includes the identification of (a) the most profitable areas of research for further analysis, (b) the set of research projects (from among all projects included for selection) which has the greatest potential benefit to society, within specified constraints such as capital and labour, and (c) the sensitivity of the program to changes in input estimates.

There does not appear to be any way to combine the incommensurate measures in the goal dimensions to provide a total project utility rating except to use an arbitrary weighting function. The reduction of aspects within dimensions into a single score also requires arbitrary scoring models with arbitrary weights.

Scoring models may be criticized because they are arbitrary. However, if the volume of data which a decision maker is expected to assimilate becomes very large, scoring models that are understood by decision makers probably provide a more rational basis for making decisions than highly subjective opinion.

The proposed system is at a stage where it can be implemented as a development project.

Most of the procedure suggested in RASAR is amenable to automation so that little effort would be required on the part of decision makers to use the mathematical models. The development of the proposed system to the point where it could be implemented on a large scale would require a team of analysts and decision makers to (a) establish an improved set of dimensions from the tentative set suggested, and (b) develop both a data bank and systems for quickly assessing a project. Research staff would also have to become at least familiar with the system in order to effectively participate in suggesting technical modifications in research projects to improve the net benefit of the project.

The implementation of the proposed system requires individuals with a systems background and preferably strong backgrounds in both agricultural economics and one or more agricultural science.

The model can probably be most effective if particular decision points are established. The optimum frequency for these decision points is probably the same as the frequency of major budget allocations. Once the system has been implemented, research staff with the assistance of analysts can prepare new project proposals at any time which would then be used with current project assessments as the basic data for the selection model. The amount of time required to prepare a new project porposal including a socio-economic assessment may be several man-weeks, but much of this time would be spent in any case just collecting the technical data and defining the project. Updating each project assessment at each decision point should not take more than a few man-days.

The operation of RASAR, once both a basic understanding of possible socio-economic effects from various types of research and efficient systems for data generation and processing have been fully developed, should require little additional administrative effort. The system will require a greater orientation of the agricultural research system to the needs of society and for this reason will require either (or both) an increasing interest on the part of scientists in socio-economics or a larger proportion of systems economists working in agricultural research.

Discussion: The relation of the agricultural research system to other systems within society has not been clearly established. Some problems being attacked by agricultural research are also soluble by other means. This is one area where further development is needed to identify which aspects of the dimensions of the ultimate goal of agricultural research should be the responsibility of agricultural research and which the responsibility of other systems within society.

Research personnel are often primarily concerned with the immediate effects of the research outputs, usually in the farming community. However, the effects that are beneficial to the farming community may have no benefit or a negative benefit to society as a whole. In other words there may be a positive benefit in the distribution dimension (to the farmer), which may be implicitly assumed a positive benefit to society as a whole when there is, in fact, no benefit or a negative benefit.

Basic type research projects appear to defy a socio-economic analysis if the outputs are unknown or unpredictable. Such projects cannot be included within RASAR. For some basic projects the outputs can be specified but they have no beneficial effects because they are simply inputs into other research projects. In such cases the basic projects can be linked to applied projects in the model and in this way become competitive for selection.

RASAR has been demonstrated to be a practical framework within which the socio-economic evaluation of agricultural research can be used to improve decisions regarding resource allocation.

The criteria for project selection are much broader than economic cost/benefit criteria. This fact is recognized but little has been done in the past to generate an explicit system for resource allocation which is based on a wider range of criteria. RASAR provides some hope that such a system will be fully developed. The system would provide government, decision makers, and research staff with much more precise knowledge of the direction in which research is going and the probable impact of research on the economy and society.

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APPENDICES

Appendix A

SCOTTISH PLANT BREEDING STATION

SOCIO-ECONOMIC APPRAISAL OF RESEARCH PROJECT

HIGH DIASTASE BARLEY

by: D.G. Russell
Department of Industrial Science
University of Stirling
April, 1973.

CONTENTS

PART I. SUMMARY

A. Project Name and Function

1. Name: High Diastase Barley.

2. Function (aim or purpose of the project): To develop a high diastatic-power enzyme barley variety for United Kingdom growing conditions.

3. Function Expansion: See attached sheet (p. 5) showing the relationship of this project to (a) component projects (both necessary and alternative), (b) alternative projects fulfilling the same or similar functions, and (c) higher (larger) system functions.

B. Expected Outputs (knowledge, methods, products)

1. Genetic analysis of the complex character high diastatic-power enzyme and its component enzyme system.

2. Control systems for amalyse genes.

3. Possible alternative methods for producing high diastatic-power enzymes.

4. Barley varieties with varying levels of diastatic-power enzymes and other favourable agronomic characteristics.

C. Expected Resource Requirements and Project Duration

1. Expected total resource requirement (£1000 units): 130 units.

2. Expected project duration: 13 years.

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2. Control systems for analyse genes.

3. Possible alternative methods for producing high diastatic-power enzymes.

4. Barley varieties with varying levels of diastatic-power enzymes and other favourable agronomic characteristics.

C. Expected Resource Requirements and Project Duration

1. Expected total resource requirement (£1000 units): 130 units.

2. Expected project duration: 13 years.

D. Expected Ultimate Effects of the Outputs (For details of calculations and data see corresponding sections in Part II, B, Detailed Analysis.)

Goal Dimension and Effect	Rating
Consumption Category:	
1. Quantity:	
(a) Productivity: social profit is -£6 for each ton of high diastase barley compared to a social value of £31.	-19%
(b) Total Production: research costs of £0.01M per annum for 13 years followed by 17 years with a net social profit of -£0.432M per annum -- varying discount rates.	@ 0%: -£7.47M @ 5%: -£2.67M @10%: -£1.07M
2. Quality: no significant effects.	
3. Availability: no significant effects.	
Security Category:	
4. Human Safety: no effects.	
5. Economic Defence: potential import saving of £2M per annum compared to:	
(a) Total imports of £10,000M per annum	0.02%
(b) Agricultural imports of £1,8000M per annum	0.11%
6. Food Sources Security: no effects.	
7. Conservation: no significant effects.	
Equity Category:	
8. Distribution:	
(a) Farm operators receive £0.76M per annum (£1.81 per capita).	£0.76M
(b) Farm labourers receive £0.36M per annum (£1.04 per capita).	£0.36M
(c) Grain distillers: no effects	
9. Individual Rights: no effects.	

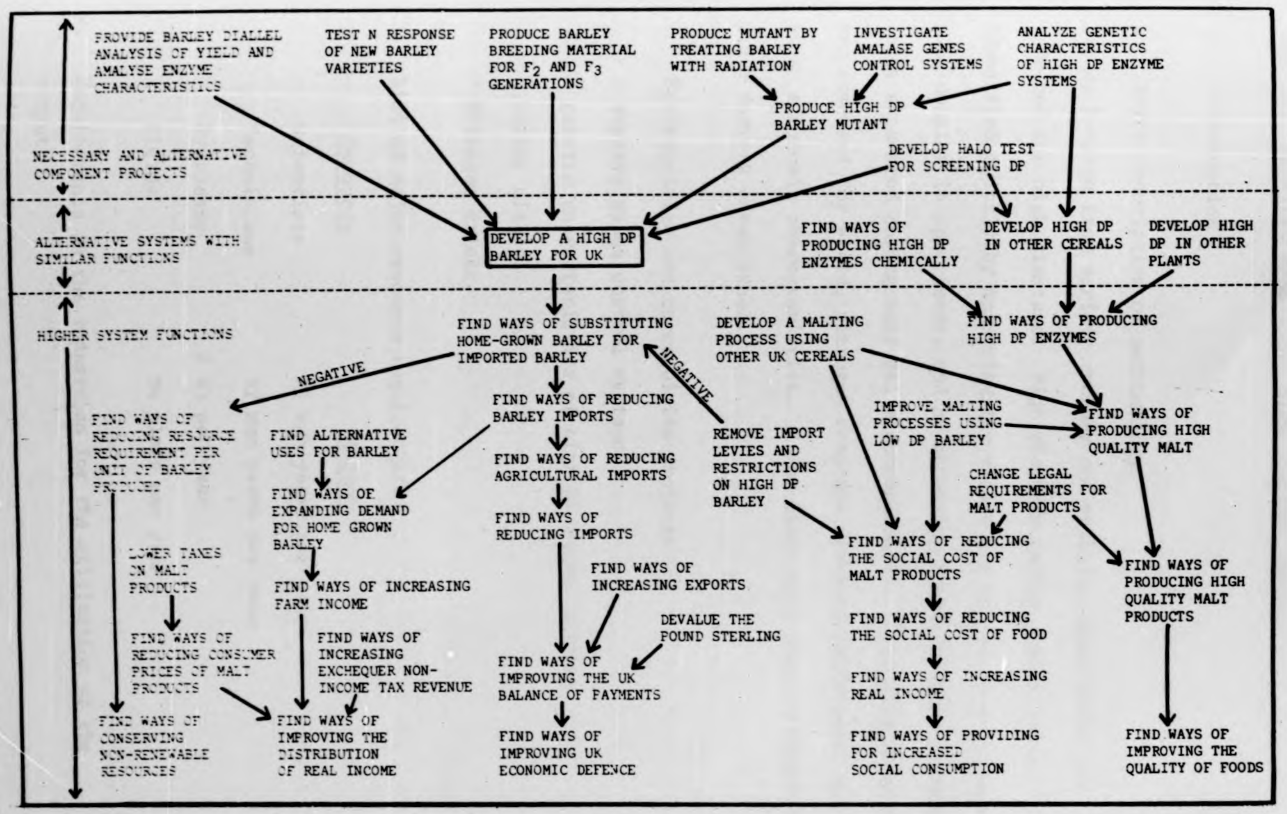

Figure A1. Function expansion for the High Diastase Barley project showing the relationships of this project to (a) both necessary and alternative sub-projects, (b) alternative projects directed toward the same or similar functions, and (c) the functions of higher systems.

PART II. DETAILED ANALYSIS: High Diastase Barley

A. Introduction

1. Brief description of methodology

Barley samples from variety crosses and mutation experiments are screened for high diastase. High diastase barley grains can be identified quickly by measuring the extinction of the starch-iodine blue complex in spot tests, and by observing characteristic isoenzyme bands separated during agar gel electrophoresis. Promising mutants are assessed for yield, nitrogen response, disease resistance, and other agronomic characteristics. A few lines will then be selected and a variety established.

2. Pre-requisite and co-requisite projects

- amylase genes control systems
- genetic characteristics of high DP enzyme systems
- barley diallel
- Nitrogen trials

3. List of major resource requirements

Resource	Amount
Scientists	X1 man years per year
Technicians	X2 man years per year
Overheads	£ X3 per year
Fields	X4 plots per year

4. Requirements in the industries for the utilization of the output

(a) The continuation of existing subsidies and guranteed prices for barley production. Otherwise imported barley is too competitive.

(b) The expansion of home-grown cereal production must continue to remain a possibility.

B. Evaluation of the Ultimate Effects of the Outputs

Research project outputs are evaluated in terms of their contribution to the dimensions of society's social welfare function or ultimate goal. Since the primary purpose of this project is to produce a high diastase barley variety, the output of major concern is the barley variety itself. The primary point of view for the analysis is that of society (United Kingdom as a whole) although the potential effects of the outputs on particular groups within society are noted where these are significant.

The fact that the United Kingdom is entering the EEC created difficulties in collecting suitable data for analysis. These difficulties were overcome by projecting stable EEC and world political and market conditions from recent conditions in the United Kingdom, the EEC, and the world.

The potential contributions of the research output to the goal dimensions are considered in turn.

Consumption Category:

1. Quantity Dimension

All high diastase barley used in grain distilling is at present imported from Canada because a high diastase barley variety suitable for United Kingdom production and market conditions is not available. The social benefit from eliminating this import by developing and growing a high diastase barley in the United Kingdom is measured as the difference between the value of the product to the nation and the costs of producing the product. Since statistical data relating to high diastase barley was not obtainable, a number of assumptions were made before calculating net social profitability.

Grades Imported: Canadian 3 CW six-row barley was reported by one maltster as the only grade of barley which they used for grain distilling. The maltster reported that this grade is guaranteed 95% germination while lower grades such as Canadian feed barley are not consistent in germination and are therefore unacceptable. In 1969, Britton (1969, p. 504) suggested that a grade called 'Canadian No. 2 Feed' had been used but that it was unduly variable and was therefore being replaced by more expensive grades. For these reasons, and since price information is available for the 3 CW six-row grade, it is assumed that all imported high diastase barley is the 3 CW six-row grade or a grade of approximately the same price.

Amount utilized: High diastase barley is not listed as such in statistical sources. However, an approximate figure for the utilization of high diastase barley may be established in several ways. First, the Home-Grown Cereals Authority report that the amount of barley imported for human food in recent years has averaged approximately 72 thousand tons per annum (see Table A1). This barley is probably all high distase barley (cf. NEDO, 1968, p. 35). Second, the amount of high diastase barley required for grain distilling may be derived from the amount of maize used in distilling. Grain distilling requires 15 parts by weight of high diastase barley for every 85 parts of maize (see Britton, 1969, p. 495). Using this ratio and the maize utilization (for brewing and distilling) statistics reported by the Home-Grown Cereals Authority, the annual average barley requirement would be 81 thousand tons in recent years (see Table A1). A third estimate reported by Britton (1969, p. 498) is that high diastase barley utilization from 1956 to 1967 has ranged from 63 to 173 thousand tons per annum, and that this barley has been mainly imported from Canada. A fourth estimate by the Canadian Wheat Board (through direct correspondence with their London office) is that the United Kingdom annually imports about 60 thousand tons of Canadian barley for distilling purposes.

The estimates vary somewhat but are of the same order of magnitude. For purposes of analysis the amount of imported high diastase barley which could be eliminated was assumed to be 72 thousand tons per annum.

The relationship of the potential production of high diastase barley to present production of barley and other crops in the United Kingdom is shown in Table A2. The amount of land required for the annual production of 72 thousand tons of high diastase barley is estimated at about 51 thousand acres -- less than 1% of present barley acreage and about one quarter of one percent of all arable land.

Price: The value of the high diastase barley to the United Kingdom is the price which consumers would pay for the product

TABLE A1. UTILIZATION OF BARLEY AND MAIZE IN GRAIN DISTILLING, AND SELECTED MALTING AND FEED BARLEY PRICES

Year	Utilization of		Derived High Diastase Barley Utilization[c] (long tons)	Barley Prices			
	Imported Barley[a] (long tons)	Maize[b] (long tons)		Canadian Malting[d] (£/long ton)	UK Feed[e] (£/long ton)	EEC basic Intervention[f] (£/long ton)	World Feed[g] (£/long ton)
1961/62 to 1965/66 average	-	-	-	25.95	-	-	22.20
1966/67	64	445	79	26.50	-	-	24.45
1967/68	58	407	72	25.40	25.00	37.26	23.35
1968/69	67	451	80	23.30	24.67	38.52	21.45
1969/70	98	539	95	21.80	25.91	38.73	18.70
1970/71	-	-	-	25.40	28.24	38.73	-
Average	72	460	81	25.21	25.95	38.31	22.10

a H-GCA Annual Report, 1971, p. 81: Barley imported for human food including malting and distilling (July/June years).

b Ibid., p. 82: UK usage of imported maize for brewing and distilling (July/June years).

c Calculated as 15/85 times maize utilization. Ratio obtained from Britton (1969, p. 495).

d CWB Annual Report, 1972, Table XXIV, Appendix p. 20: Annual average Canadian Wheat Board selling quotations, basis in store at Thunder Bay, for 3 CW six-row barley (August/July years). Can$0.05 was added to the CWB quotation. The CWB state (through direct correspondence) that this premium is added to barley which is set aside for malting purposes. 1 bu = 48 lb. Can$1.00/bu = Can$46.67/long ton. Can$2.50 = £1.00.

e NEDO, 1972, p. 18: Producer or nearest cereal prices including deficiency payment (calendar years 1967-1970).

f H-GCA Annual Report, 1971, p. 108: Basic intervention prices for the month of January.

g FAO, 1970, p. 538: Canada No. 1 feed, basis in store at Thunder Bay, domestic wholesale and export price (calander years 1961-1969). Can$1.00/bu = Can$46.67/long ton. Can$2.50 = £1.00.

TABLE A2. HIGH DIASTASE BARLEY UTILIZATION IN RELATION TO CROP PRODUCTION AND UTILIZATION IN THE UNITED KINGDOM

Factor	Units	Mean	Range	Ratio of High Diastase Barley Acreage To Other Cropland (%)
BARLEY				
Home Production[a]	k tons	8580	8140-9069	
Imports[a]	k tons	400	107-941	
Total Supply[a]	k tons	8980	8506-9468	
Exports and Re-Exports[b]	k tons	490	12-1091	
HDP Barley Imports[c]	k tons	72	58-98	
Average Yield[d]	tons/acre	1.4	1.3-1.5	
Acreage Required for High Diastase Barley[e]	k acres	51	48-55	
CROPLAND				
Arable Land[f]	M acres	18.1	17.5-18.5	0.28
Arable Grasses[f]	M acres	6.6	5.9-7.0	0.77
Permanent Grasses[f]	M acres	12.6	12.1-13.4	0.40
Cereals[g]	M acres	8.8	7.5-9.4	0.58
Barley[g]	M acres	5.3	3.8-6.1	0.96

a H-GCA Annual Report, 1971, p. 79: 1966/67 to 1969/70 (July/June years).

b Ibid., p. 80: 1966/67 to 1969/70 (July/June years).

c Ibid., p. 81: 1966/67 to 1969/70 (July/June years).

d Ibid., p. 77: 1961/62 to 1970/71 (July/June years).

e Calculated as high diastase barley imports divided by average yield.

f MAFF et al., 1971, p. 13: 1958 to 1967.

g H-GCA Annual Report, 1971, p. 77: 1961/62 to 1970/71 (July/June years).

under free market conditions, since any price fixed by import levies and price guarantees is a form of transfer payment within the economy. A reasonable approximation to the free market price is the world c.i.f. price at United Kingdom ports (see OECD, 1969, p. 107).

The price of high diastase imported barley (Canadian 3 CW six-row) in recent years has been about £25 per ton basis in store at Thunder Bay, Ontario. This price includes a five cent per bushel premium which the Canadian Wheat Board add to the quoted price for barley which is set aside as selected for malting purposes, but does not include freight to British ports.

Several statistical sources provide an indication of recent freight rates. The FAO (1970, p. 617) give maritime freight rates from St. Lawrence to the United Kingdom for 1961 to 1969 ranging from £1.75 to £2.35 per long ton. The Canadian Grain Commission (1972a, p. 6) report shipping rates for wheat from Thunder Bay to Western Europe for 1970/71 as 44.6 cents per bushel (£6.65 per long ton at $2.50 per pound sterling). The freight rates for wheat from St. Lawrence to the United Kingdom given by the Commonwealth Secretariat (1973, pp. 19 and 20) for December 1970 to December 1972 ranged from £2.00 to £3.40. These rates range widely, but the low rates are only from the St. Lawrence and the rate required is from Thunder Bay. Consequently the high rate for wheat from Thunder Bay is assumed to be more realistic.

For purposes of analysis the rate was assumed to be £6.00 per long ton which would make the c.i.f. price of high diastase

Canadian barley at United Kingdom ports approximately £31 per long ton.

<u>Home Production Costs</u>: The domestic price of barley averaged over a number of years is a reasonable estimate of production costs. (Barley production would expand and, in the long run, force down the price if production costs were less than the domestic price). Wholesale prices in the EEC may range from the intervention price to about £3 above this price. Intervention prices range from the basic intervention price to about £4 below this price depending on the relative cereal deficiency of the area. Producer prices are about £2 below the wholesale price (see NEDO, 1972, p. 13). Assuming (a) that when a British high diastase barley variety is available for production the price of barley in the United Kingdom will be in line with the price in the EEC, (b) Britain will be essentially not a cereal deficient area, and (c) EEC prices will be approximately the same as they have been in the recent past, the wholesale price of feed barley will be at least £34 per ton (£38 - £4: see Table A1). The producer price would be at least £32 per ton (£34 - £2).

Since the wholesale price and hence presumably production and marketing costs are about £3 per ton higher in Canada for high diastase barley than feed barley (see Table A1: £25 - £22 per ton), there is a good possibility that the costs of producing a new high diastase barley in British growing conditions would also be higher than the cost of producing feed barley. For this reason £3 is added to the £32 producer price to arrive at a high diastase barley producer price of about £35 per long ton and a wholesale price of about £37 per long ton.

Reasearch Costs: The estimated expenditure for barley research at SPBS for 1971/72 was £39 thousand (Simmonds, 1972, p. 3). Of this amount, approximately one quarter was spent on high diastase barley research.

This analysis is based on the assumption that the high diastase barley research will cost about £10 thousand annually for the expected life of the project (13 years) for a total of £130 thousand.

Quantity Dimension Rating: The high diastase barley research project affects both the productivity and total production aspects of the quantity dimension. The productivity aspect is a measure of the average per unit benefit society is expected to derive from the research once the research output has been adopted. This rating is designed to give a measure which is free from the effects of the size of the industry and the costs of the research in relation to the size of the industry. The net social profit from producing a unit of high diastase barley in the United Kingdom is the social value of the output (£31 per ton) minus the social costs of production (the wholesale price of £37 per ton). The net social profit is therefore minus £6 per ton. Expressed as the ratio net social profit to social value, the productivity rating is -6/31 or -19%.

The total production aspect of the quantity dimension is a measure of the total net benefit society would derive from investing in the research at present and reaping the benefit in the future. The net benefits for discount rates of 0%, 5% and 10% are -£7.47 million, -£2.67 million and -£1.07 million respectively (see Table A3).

TABLE A3. AGGREGATE NET SOCIAL PROFITABILITY OF INTRODUCING HIGH DIASTASE BARLEY PRODUCTION INTO THE UNITED KINGDOM

Year	Description	Amount Per Annum (£M)	Total Amount at Discount Rate of 0% (£M)	5% (£M)	10% (£M)
1-13	Research Costs[b]	-0.010	-0.13	-0.09	-0.07
14-30	Value of Output[a,c]	-0.432	-7.34	-2.58	-1.00
		Totals	-7.47	-2.67	-1.07

a Adoption of new barley assumed to be immediate, and substitute for 100% of imports.

b Cost of adoption assumed to be negligible

c 72,000 tons per annum at -£6 per ton.

These calculations are based on the assumptions that (a) the adoption of the new variety is immediate and completely eliminates the imports, (b) the cost of adoption is negligible, (c) benefits beyond thirty years are not required for decisions today, and (d) the probability of success of the project is 100%.

2. Quality Dimension

The research project is expected to produce a variety of barley which is similar in quality to the imported varieties. The project is therefore not expected to have any significant quality effects.

3. Availability Dimension

The research project will probably not have any significant effects on the availability of products for human consumption, since there is a lag of several years between the production of high diastase barley malt and the consumption of grain whiskey. Any reduction in supply uncertainty may tend to reduce production costs but this is an effect in the quantity dimension and is probably not significant.

Security Category:

4. Human Safety Dimension

The project is not expected to have any effect on human safety.

5. Economic Defence Dimension

The main objective of this research project is to provide a high diastase barley variety which can be grown in the United Kingdom and thereby save imports. The value of all United Kingdom imports is currently about £10,000 million per annum (IMF, 1973, p. 360). The value of total agricultural imports is about £1800 million per annum (CSO, 1971, p. 12).

The potential gross import saving through the elimination of high diastase barley imports is about £2.23 million per annum (72 thousand tons at £31 per ton). The potential net import saving is the gross saving minus the cost of any imported inputs to the high diastase barley home production.

NEDO (1968, p. 39) estimated that a gross import saving of £85 million resulting from an increase in home production of cereals would be reduced by £6.5 million (7.7%) because imported inputs would be needed for the increased home production. Using this ratio, the potential net import saving is estimated at about £2 million per annum (£2.23 million minus £0.17 million).

The potential net import saving compared to total imports is therefore about 0.02% (2/10,000). Compared to all agricultural imports the saving is 0.111% (2/1800).

6. Food Sources Security Dimension

The only security effect associated with the possible loss of high diastase barley imports is a possible reduction in the availability of grain whiskey. The risk of losing the high diastase barley imports does not appear to be great. In any case society would probably not consider the loss a significant security risk since there are malt whiskeys which can and are being produced from home-grown barley.

7. Conservation Dimension

The production of high diastase barley at home would produce small negative effects in the conservation dimension since the resource requirements for home production are higher than the resource requirements for importing high diastase barley produced in Canada. (The resource requirement is reflected in the market prices for imported versus home-grown barley.)

The effect is considered too small to be significant.

Equity Category:

8. Distribution Dimension

There are a number of groups within society which would be significantly affected by the production of high diastase barley in the United Kingdom.

Producers: The research project is expected to permit British farmers to produce the 72 thousand tons of high diastase barley presently imported. At a price of £37 per ton, the 72 thousand tons of production represents an increase in gross income to farmers of £2.66 million. Part of this amount currently goes to foreign suppliers (£2.23 million) and part is the import levy (£0.43 million).

In 1972, NEDO (1972, p. 19) estimated that if United Kingdom farmers were operating under EEC conditions the margin (return to management) for cereal production would range from £14 to £25 per acre on average to good farms. Labour costs would be about £7 per acre. NEDO estimated that the then current margins on average and good farms in the United Kingdom were £6 and £11 per acre respectively, while in Germany the margins were £19 and £26 per acre respectively.

Assuming future margins to be about £15 per acre, the increase in net income to farm operators which this project could provide is £0.76 million per annum (£15 per acre for 51 thousand acres: see

Table A2). In addition to this increased net income, farm labourers would receive an additional £0.36 million per annum (£7 per acre for 51 thousand acres).

Since there are about 420 thousand farm operators and about 345 thousand farm labourers (MAFF et al., 1971, Tables 20 and 21, pp. 25 and 26), the annual per capita increase in net income for farm operators and farm labourers is estimated at about £1.81 and £1.04 respectively.

Note that for these increases in income to be fully realized, other production must not be reduced. Consequently, either more intensive production methods must be utilized to produce this extra output or land which is not in production must be used. In either case production costs will probably rise. However, these should be small since the increase in acreage which is required is small compared to present production (see Table A2). The increased income estimates given are therefore probably slight over-estimates.

Grain Distillers: The processors of high diastase barley will not likely be greatly affected. There may be a quality differential between a new variety and the imported varieties, and the processor will not be dependent on foreign suppliers. Under EEC conditions, the price of barley to users should decrease by the amount of the differential between the fixed import price and the home market price However this could be overshadowed by any diseconomies resulting from an unfavourable quality differential.

9. Individual Rights Dimension

The research project is not expected to have any significant effects in either the equality of opportunity or freedom from discrimination aspects of the individual rights dimension.

C. Discussion

1. Future Changes

The effects on the foregoing assessment of possible changes in production and marketing systems are worth noting.

The Common Agricultural Policy (CAP): The assessment is based on the assumption that the CAP will be maintained to permit the expansion of barley production at home. Since Britain is just entering the EEC and cereal prices are expected to rise sharply, there is a possibility that a barley surplus in the enlarged EEC will force the price of barley down. If the price does drop, it is unlikely that it would go below the world price or even as low as the world price since the EEC cannot produce cereals as cheaply as other areas of the world.

If the price of barley did drop to the world price, the negative social profitability in the quantity dimension would tend toward zero but would not become positive unless EEC production costs dropped below the world price.

The Common Agricultural Policy encourages as much production at home as possible. If production is to expand, production costs and hence prices will tend to rise since either marginal land or more intensive farming methods will have to be utilized. In the short run feed producers should have increased margins if the cost of inputs does not rise immediately.

Land Owners Capital Gain: In the long run, increased margins from any tendency for barley prices to rise will cause increasing competition for land. This will tend to increase land prices and provide a capital gain to land-owners. The increased margins of cereal producers should disappear in the long run as input costs increase.

World Demand for Cereals: If world demand for cereals rose and remained high the world price of barley could be maintained at the present EEC price or higher. If this were to happen and if input prices did not rise correspondingly, the project could have a positive social profitability. However, the world price is unlikely to remain high for very long because there is a large capacity for increased production at little increased cost in other areas of the world.

Feed Grain Imports: If British farmers do grow the proposed high diastase barley and cereal prices do not rise to cause an expansion in production, the high diastase barley production may simply replace home-grown feed barley production. In this case, feed cereal imports are likely to increase which would tend to reduce or eliminate the balance of payments benefit in the economic defence dimension. In other words, it may not be possible to obtain the import saving without increasing barley prices.

If barley prices were increased there would be a very large additional negative effect in the quantity dimension. For example, a £1 per ton increase in barley price would increase the social cost of home produced barley by £7.4 million (see Table A2: £1 per ton for 5.3 million acres at 1.4 tons per acre yield). The actual increase which may be expected would depend on the elasticity of supply but will probably be small since the required acreage expansion is small.

If the EEC were to have a surplus of feed barley in the next decade through the continuation of the present CAP, the alternative type of barley production would tend to reduce the surplus.

Maize Imports: High diastase barley is only used for grain distilling. If imports of the barley were stopped and a variety suitable for growing in the United Kingdom was not available, maize which is used with the barley and is also imported would not be needed.

2. National Revenue loss

The import levy of £0.43 million (see distribution dimension) which is presently collected on high diastase barley imports would no longer be available if the barley were produced in the United Kingdom.

The intervention authority may also tend to have less intervention buying in the barley market if some feed barley acreage is diverted to producing high diastase barley.

3. Multiplier Effect on the Economy

The £2.23 million transfer from importers to domestic producers should have a multiplier effect on the growth in the agricultural sector of the economy.

4. Trade Negotions

The attempt by the United Kingdom to reduce cereal imports by producing a variety of high diastase barley (which can only be competitive with imported barley if home production is protected by import levies) may cause adverse reactions in international trade negotiations.

5. Brewers Grain

Brewers grain is a byproduct of barley malting which is high in protein but very low in starch. The substitution of home-grown high diastase barley for imported barley should have no effect on the production of brewers grain and hence no change in social profitability.

6. Commercial Development of a Variety

Commercial plant breeders are not interested in producing a high diastase barley variety because the potential market for seed is small.

7. Other Outputs

The other outputs of this project listed in Part I, B, may be useful as contributions to general knowledge but do not have any use in applied projects in the foreseeable future.

D. List of Abbreviations

bu	bushel
Can	Canadian
CAP	Common Agricultural Policy (of the EEC)
cf.	compare
c.i.f.	cost, insurance, freight
CSO	Central Statistical Office (United Kingdom)
CWB	Canadian Wheat Board
DP	diastatic power
DAFS	Department of Agriculture and Fisheries for Scotland
EDC	Economic Development Committee (of NEDO)
EEC	European Economic Community
et al.	and others
FAO	Food and Agriculture Organization (United Nations)
H.C.	House of Commons (publication: United Kingdom)
HDP	high diastatic power (barley)
H-GCA	Home-Grown Cereals Authority (United Kingdom)
HMSO	Her Majesty's Stationery Office (United Kingdom)
ibid.	in the same place
IMF	International Monetary Fund
k	thousands
lb	pounds
M	millions
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
MANI	Ministry of Agriculture for Northern Ireland
NEDO	National Economic Development Office (United Kingdom)
OECD	Organization for Economic Co-operation and Development
SPBS	Scottish Plant Breeding Station
UK	United Kingdom

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Appendix B

SCOTTISH PLANT BREEDING STATION

SOCIO-ECONOMIC APPRAISAL OF RESEARCH PROJECT

HYBRID SWEDES

by: D.G. Russell
Department of Industrial Science
University of Stirling.

April, 1973.

CONTENTS

PART I. SUMMARY

A. Project Name and Function

1. Name: Hybrid Swedes.

2. Function (aim or purpose of the project):

   To develop a 100% hybrid swede (to replace the 1/3 hybrid).

3. Function Expansion: See attached sheet (p. 5) showing the relationships of this project to (a) component projects (both necessary and alternative), (b) alternative projects fulfilling the same or similar functions, and (c) higher (larger) system functions.

B. Expected Outputs (knowledge, methods, products)

1. Genetic properties of swedes.
2. One or more samples of 100% hybrid swede seed yielding 5 tons per acre more than present varieties.
3. Other samples of swede seed with varying genetic properties.

C. Expected Resource Requirements and Project Duration

1. Expected total resource requirements (£1,000 units):

   80 units.

2. Expected project duration: 8 years.

D. Expected Ultimate Effects of Outputs (For details of calculations and data see corresponding sections in Part II, B, Detailed Analysis).

Goal Dimension and Effect	Rating
Consumption Category:	
1. Quantity:	
(a) Productivity: social profit of £12 per acre on a per acre social value of £82.	14.7%
(b) Total Production: research costs of £0.01M per annum for eight years followed by 22 years with a net social profitability of £3.77M per annum -- varying discount rates.	@ 0%: £83M @ 5%: £34M @ 10%: £15M
2. Quality: no significant effects.	
3. Availability: no significant effects.	
Security Category:	
4. Human Safety: no effects.	
5. Economic Defence: potential import saving of £4.2M per annum compared to:	
(a) Total imports of £10,000M per annum:	0.042%
(b) Agricultural imports of £1800M per annum:	0.233%
6. Food Sources Security: no significant effects.	
7. Conservation: no significant effects.	
Equity Category:	
8. Distribution:	
(a) Farm operators receive £4.7M (from reduced feed costs) or £11.2 per capita.	£4.7M
9. Individual Rights: no effects.	

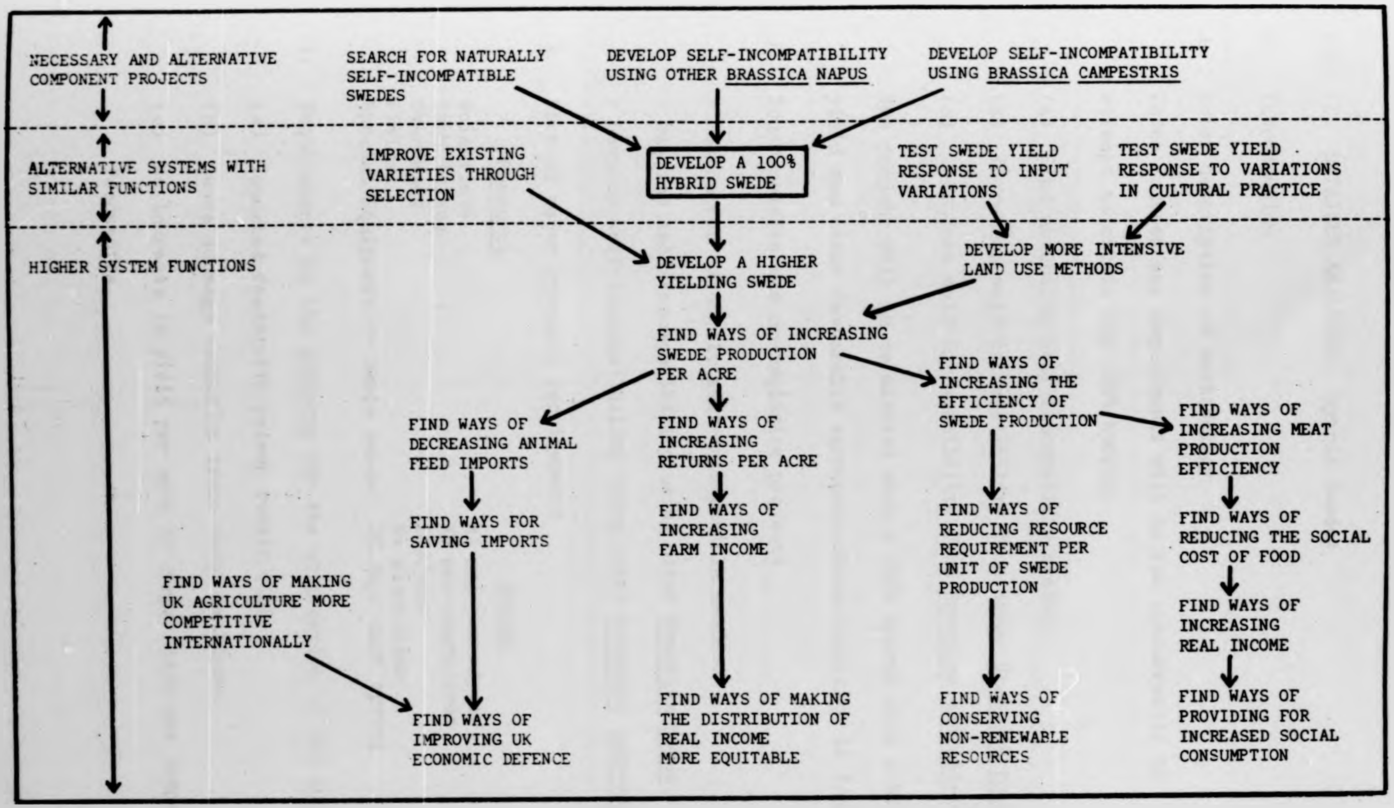

Figure B1. Function expansion for the Hybrid Swedes project showing the relationships of this project to (a) both necessary and alternative sub-projects, (b) alternative projects directed toward the same or similar functions, and (c) the functions of higher systems.

PART II. DETAILED ANALYSIS: Hybrid Swedes

A. Introduction

1. Brief description of methodology

Three independent experiments will be run concurrently to attempt to obtain the 100% hybrid:

(a) Find naturally self-incompatible swedes.

(b) Introduce self-incompatibility from other Brassica napus.

(c) Introduce self-incompatibility from Brassica campestris.

The project will be terminated when a 100% hybrid with a high yield and other favourable agronomic characteristics is found.

2. Pre-requisite and co-requisite projects

- Search for naturally self-incompatible swedes.
- Develop self-incompatibility using other Brassica napus.
- Develop self-incompatibility using other Brassica campestris.

3. List of major resource requirements

Resource	Amount
Scientists	X1 man-years/year
Technicians	X2 man-years/year
Overheads	£X3/year
Fields	X4 plots/year
Special Equipment -- Swede Seeder	X5 days each spring

4. Requirements in the industry for the utilization of the outputs

(a) Imported feedstuffs prices remain high.

(b) Swede acreage reduction trend stops or slows.

(c) No increase in yield per acre of crops which are competitive feedstuffs.

B. Evaluation of the Ultimate Effects of the Outputs

Research project outputs are evaluated in terms of their contributions to the dimensions of society's social welfare function or ultimate goal. Since the primary purpose of this project is to produce a high yielding 100% hybrid swede, the output of major concern for evaluation is the new swede variety itself. The primary point of view for the analysis is that of society (United Kingdom as a whole) although the potential effects of the outputs on particular groups within society are noted where these are significant.

The fact that the United Kingdom is entering the EEC created difficulties in collecting suitable data for analysis. Consequently the data are based on stable EEC and world political and market conditions as projected from recent conditions in the United Kingdom, the EEC, and the world.

The potential contributions of the research output to the goal dimensions are considered in turn.

Consumption Category:

1. Quantity Dimension

The objective of this research project is to increase the average yield of swedes by 5 tons per acre. One estimate of the social benefit arising from such an increase is the difference between the social value of the increased yield and the social costs of producing the increase. The following assumptions regarding production parameters, costs, and benefits form a basis for calculating net social profitibility.

Acreage Produced: The annual swede acreage in the United Kingdom as recorded by statistical sources is given in combination with acreages for turnips and fodder beet for stockfeeding (MAFF, et al., 1971, Table 15, p. 20). Research staff suggest that probably 90% of this combined acreage is swedes. Using this assumption, the annual acreage of swedes for the period 1962/63 to 1966/67 has averaged 314 thousand and the trend from 1957/58 to 1967/68 has been for a continuous decline from 474 thousand acres to 260 thousand acres (see Table B1).

The decline has probably been caused by swedes being uncompetitive with other crops used for animal feedstuffs. Research staff suggest that both recent developments in production technology and the new swede variety may reverse the decline. Since no forecast is available, swede acreage, for purposes of analysis, is assumed to remain constant at the 1962/63 to 1966/67 average of 314 thousand acres.

Product Value: The value of a unit of swedes cannot be established directly since there is no market for this product. However, a value can be determined in terms of a traded feed such as barley which swedes can replace.

There are two ways of determining the value of the extra yield of swedes which would arise as a result of the new variety. One is to value an alternative crop which could be produced on the acreage not required for swedes, given the higher yield and a constant total annual swede production. The other is to value the extra yield in terms of the amount of other feed which it could replace, given the higher yield and a constant acreage. The acreage which would not be required for swede production (given constant total swede production) is estimated at 65 thousand acres. (See Table B1:

TABLE B1. ANNUAL ACREAGE, YIELD AND TOTAL PRODUCTION OF SWEDES IN THE UNITED KINGDOM

Crop Year	Acreage[a] (thousands)	Yield (tons/acre)	Total Production (million tons)
1957/58	474	16.7	7.92
1958/59	458	17.4	7.96
1959/60	434	15.0	6.51
1960/61	408	19.3	7.88
1961/62	377	18.4	6.94
1962/63	354	19.4	6.87
1963/64	329	18.5	6.09
1964/65	319	19.1	6.09
1965/66	297	19.7	5.85
1966/67	270	19.2	5.19
average 1962/63 to 1966/67	314	19.2	6.02
1967/68	260	19.9	5.18

a MAFF, et al., 1971, Table 15, p. 20: Assuming 90% of the acreage reported as "turnips, swedes and fodder beet for stockfeeding" is swedes.

Present production of 6.02 million tons per annum could be produced on 249 thousand acres at 24 tons per acre compared to the present 314 thousand acres at 19 tons per acre.) The 65 thousand acres could produce 92 thousand tons of barley at a yield of 1.41 tons per acre (see Table B2).

The second method of estimation suggests that the extra swedes which could be produced, given the present swede acreage, are equivalent to 198 thousand tons of barley (see Tables B2 and B3: 314 thousand acres at 0.63 tons per acre).

The two estimates differ considerably because swedes normally produce 3630 Mcal of energy per acre (1.88 Mcal per kg for 19 tons at 10% dry matter), while barley produces 2160 Mcal per acre (1.75 Mcal per kg for 1.41 tons at 14% moisture content). For purposes of analysis the value of the extra swedes is assumed to be equivalent to 150 thousand tons of barley in total or 0.48 tons per acre.

The social value of the barley equivalent is approximately the world c.i.f. price of barley at United Kingdom ports. Any other price maintained by import levies or intervention buying is a form of transfer payment within society (see OECD, 1969, p. 107). The world c.i.f. price at United Kingdom ports is assumed to be £22 per ton (see Table B2) plus £6 per ton freight (see Canadian Grain Commission, 1972, p. 6) or a total price of £28 per ton. Using these estimates the gross social value of the potential extra swede production is estimated at £4.2 million per annum (£28 per ton for 150 thousand tons).

Production Costs: The cost of producing this extra output is assumed to be small since the increased yield is expected to arise with no increase in inputs. However, the increased yield will increase harvesting and storage costs. These costs are, for want of a more precise estimate, assumed to be 10% of the gross social value of the extra product.

TABLE B2. ACREAGE AND YIELD OF BARLEY IN THE UNITED KINGDOM, AND WORLD BARLEY PRICE

Year	Acreage[a] (millions)	Yield[b] (tons/acre)	World Price[c] (£/ton)	Domestic Price[d] (£/ton)
1961/62 to 1965/66 average	4.6	1.42	22.20	-
1966/67	6.1	1.40	24.45	-
1967/68	6.0	1.51	23.35	37.26
1968/69	5.9	1.37	21.45	38.52
1969/70	6.0	1.43	18.70	38.73
1970/71	5.5	1.33	-	38.73
1966/67 to 1970/71 average	5.9	1.41	21.99	38.31

a H-GCA Annual Report, 1971, p. 77: July/June years.

b Ibid.: long tons per acre.

c FAO, 1970, p. 538: Canada No. 1 feed, basis in store at Thunder Bay, domestic wholesale and export price (calendar years 1961-1969). Can$1.00/bu = Can$46.67/long ton. Can$2.50 = £1.00.

d H-GCA Annual Report, 1971, p. 108: basic intervention prices for the month of January.

The average cost of producing a unit of swedes is assumed to be the domestic value of the average yield. If, in the long run, costs were higher farmers would stop producing. If costs were lower farmers would increase production until the marginal cost was equal to the marginal value of the increased production.

Research Costs: Research costs are estimated at about £10 thousand per annum for eight years.

TABLE B3. BARLEY EQUIVALENT OF THE POTENTIAL EXTRA SWEDE PRODUCTION ARISING FROM THE NEW SWEDE VARIETY

Factor	Units	Estimate	Range
Present Swede Yield[a]	tons d.m./acre	1.92	1.5 -2.3
Swede Yield Increase[b]	tons d.m./acre	0.50	0.40-0.60
Barley Equivalent of Swedes[c]	tons/ton swede d.m.	1.25	-
Barley Equivalent of Present Swede Yield[d]	tons/acre	2.4	1.9 -2.9
Barley Equivalent of Swede Yield Increase[d]	tons/acre	0.63	0.50-0.75

a Kay, 1971, p. 49: dry matter estimate 10% (range 8 to 12%); also see Table B1: average yield 19.2 tons per acre.

b Expected yield increase of 5 tons per acre due to the new variety; dry matter content as in note (a).

c Kay, 1971, p. 49: 1.88 Mcal net energy value per kg of swedes compared to 1.75 Mcal net energy value of barley; barley moisture content 14%.

d Barley (14% moisture content) equivalent to a ton of swede dry matter (1.88/1.75 x 100/86) for the present yield and the expected yield increase.

Quantity Dimension Rating: The hybrid swedes research has potential effects in both the productivity and total production aspects of the quantity dimension.

The productivity aspect is a measure of the average per unit benefit society is expected to derive from the research once the research output has been adopted. This aspect is designed to give a measure which is free from the effects of the size of the industry and the cost of the research in relation to the size of the industry. The net social profit from replacing an existing acre of swedes with the new variety is estimated as £13.4 (see Table B3: 0.48 tons of barley equivalent per acre at £28 per ton), minus £1.34 per acre extra production costs (10% of the value of the extra 5 tons per acre yield), or about £12 per acre. This represents a per unit social profitability of 14.7% above production costs of £82 per acre. (Production costs are assumed to be £34 per ton for the present average yield of 2.4 tons of barley equivalent per acre--see Table B3. This price is based on the assumption that Britain will not be a cereal deficient area and will therefore have a wholesale price of about £4 below the basic intervention price of £38 per ton--see Table B2 and NEDO, 1972, p. 13.)

The total production aspect of the quantity dimension is a measure of the total net benefit society would derive from investing in the research at present and reaping the benefit in the future. The net benefits for discount rates of 0%, 5%, and 10% are £83 million, £34 million, and £15 million respectively (see Table B4). The calculations are based on the following assumptions: (a) adoption of the new variety is immediate and completely replaces existing varieties, (b) the cost of adoption is negligible (possible increased seed costs are ignored), (c) the probability of success of the project is 100%, and (d) benefits beyond thirty years are ignored for decisions taken today.

2. Quality Dimension

The new swede variety is not expected to have any significant effects on meat produced from this feed.

TABLE B4. AGGREGATE NET SOCIAL PROFITABILITY OF INTRODUCING HIGH YIELDING HYBRID SWEDES INTO THE UNITED KINGDOM

Year	Factor	Amount per Annum (£M)	Total Amount at Discount Rate of 0% (£M)	5% (£M)	10% (£M)
1 - 8	Research Costs[b]	-0.010	-0.08	-0.06	-0.05
9 - 30	Value of Product[a,c]	3.77	83.	34.	15.
	Totals		83.	34.	15.

a Adoption of new variety assumed to be immediate and be used for all present swede production.

b Cost of adoption assumed to be zero (possible increased seed costs are ignored).

c £12 per acre (see text) for 314 thousand acres per annum.

3. Availability Dimension

The new swede variety is not expected to have any effects on the availability of human foods produced from the swedes.

Security Category:

4. Human Safety Dimension

The project is not expected to have any effect on human safety.

5. Economic Defence Dimension

The increase in yield resulting in an increase in feedstuff supplies will tend to reduce demand for imported feeds such as barley.

In recent years, annual barley imports have averaged about 304 thousand tons. (H-GCA Annual Report, 1971, p. 81: The amount of barley imported for feed ranged from 68 thousand to 837 thousand tons per annum for 1966/67 to 1970/71 with the average at 304 thousand tons.)

The value of all imports to the United Kingdom is currently about £10 thousand million (IMF, 1973, p. 360). The value of agricultural imports is about £1.8 thousand million (CSO, 1971, p. 12). The amount of imported barley which the new swede variety could potentially replace is 150 thousand tons per annum (see quantity dimension), providing a potential annual import saving of £4.2 million (150 thousand tons at £28 per ton). This potential import saving represents 0.042% of the value of all imports and 0.233% of the value of agricultural imports.

6. Food Sources Security Dimension

The new variety is not expected to have any less variation in yield than existing varieties and hence should not affect the security of food sources. There may, however, be a marginal security effect from the reduction in dependence on imported feedstuffs, but this is considered insignificant.

7. Conservation Dimension

The increased yield of swedes with little increase in inputs represents a reduction in resource requirements per unit of swede production. This is a positive effect in the conservation dimension but is considered tobe too small to be significant.

Equity Category:

8. Distribution Dimension

The only group within society which would be significantly affected by the availability of the new swede variety is comprised of farmers. The gross saving to farm operators is estimated as £5.1 million, assuming that (a) the saving is equivalent to the value of the barley which the increased swede yield would replace, (b) the wholesale price in the United Kingdom for barley under EEC market conditions is £34 per ton, £4 per ton lower than the basic intervention price (see NEDO, 1972, p. 13 and Table B2), and (c) the barley equivalent of the increased swede yield is 150 thousand tons per annum (see quantity dimension). The net saving to farmers is the gross saving less the extra production costs. Extra production costs were estimated at £1.34 per acre or £0.42 million for 314 thousand acres (see quantity dimension). The net saving is therefore estimated at £4.7 million.

On a per capita basis the net saving is £11.2 per annum (£4.7 million divided by 420 thousand farm operators: see MAFF, et al., 1971, p. 26).

The producer price used above includes both the world barley price and the import levy. In other words farmers receive both the import saving and the import levy as a result of replacing imported barley with home-grown swedes. The reduction in barley imports and hence reduction in import levy revenue represents a loss to treasury or a reduction in transfer payment from feedstuffs users to general revenue.

C. Discussion

1. Future Changes

The effects on the foregoing assessments of possible changes in production and marketing systems are worth noting.

Swede Production: The acreage of swedes grown in the United Kingdom has been continuously declining since 1958 in spite of the fact that the average swede yield produces much more energy per acre than does the average barley yield (see quantity dimension). The decline may arise because swedes are not as convenient or easy to produce as cereals or other forages. This trend may be reversed if production of the crop can be more fully mechanized. The introduction of a higher yielding swede may also help to reverse the trend.

Another possible reason for the declining acreage is the low dry matter content of swedes which makes the crop comparatively unfavourable to drier forms of feed for high energy rations. If this is the case, the decline in acreage may continue unless the new swede has a higher dry matter content than present varieties. If the decline does continue the estimates in this assessment are over-estimates.

Food Prices: The increased efficiency in swede production should tend to reduce consumer prices in the long run.

<u>Alternative Land Uses</u>: The new higher yielding variety of swedes may be used to release land from swede production while maintaining total production. This land can be used to increase feedstuffs production and thereby reduce feedstuffs imports. Alternatively the land may be made available for non-agricultural uses.

The reduced land requirement for a given output should tend to reduce the demand for land and hence land prices. On the other hand, since the return per acre of swedes will increase with the introduction of the higher yielding swedes, the price of land usable for swede production should increase. However, land is unlikely to be taken out of production so, with the new variety, swede production and hence the total supply of feedstuffs will tend to rise. This would, in the long run and under free market conditions, tend to depress feedstuff prices and therefore the per acre value of the high yield swede crop. Under conditions of high fixed prices (as presently occur in the EEC), there would be resistance to declines in the prices of other feedstuffs. Hence, the supply of home produced feedstuffs would rise causing a reduction in feedstuff imports and, when imports were eventually eliminated, force reductions in the high fixed prices for feedstuffs. Consequently, under present EEC policy, which holds feedstuff prices high, the increased per acre returns arising from the new swede variety would tend to increase land prices until increased home production of feedstuffs eliminated feedstuff imports. This tendency for an increase in land prices would counteract the tendency for a reduction arising from the decreased demand for land.

One other effect of the new variety is that farmers not using the new swede variety will find their per acre returns dropping below production costs and will tend to be forced into using the new swede variety.

Cereal Intervention Buying: Increased home production of feedstuffs will tend to reduce the cereal deficiency or perhaps create a cereal surplus and thereby tend to increase cereal intervention buying.

Feed Processors: Any reduced imports of cereals or reduced utilization of cereals as a feedstuff will tend to reduce the demand for off-farm feed processing.

2. International Relations

Reduced cereal imports arising from the increased home production of a competitive feed is probably more acceptable in international trade negotiations than reduced cereal imports arising from increased import levies. In other words, increasing the efficiency of home production relative to production abroad is probably more acceptable in international trade relations than encouraging uneconomical home production with protective tarrifs.

D. List of Abbreviations

Can	Canadian
cf.	compare
c.i.f.	cost, insurance, freight
CSO	Central Statistical Office (United Kingdom)
DAFS	Department of Agriculture and Fisheries for Scotland
d.m.	dry matter
EEC	European Economic Community
et al.	and others
FAO	Food and Agriculture Organization (United Nations)
H-GCA	Home-Grown Cereals Authority (United Kingdom)
HMSO	Her Majesty's Stationery Office (United Kingdom)
ibid.	in the same place
i.e.	that is
IMF	International Monetary Fund
k	thousands
kg	kilograms
M	millions
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
MANI	Ministry of Agriculture for Northern Ireland
m.c.	moisture content
Mcal	megacalories
NEDO	National Economic Development Office (United Kingdom)
OECD	Organization for Economic Co-operation and Development
SPBS	Scottish Plant Breeding Station
UK	United Kingdom

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Appendix C

POULTRY RESEARCH CENTRE

SOCIO-ECONOMIC APPRAISAL OF RESEARCH PROJECT

TRITICALE FOR ENERGY IN POULTRY RATIONS

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May, 1973.

CONTENTS

PART I. SUMMARY

A. Project Name and Function

1. Name: Triticale for Energy in Poultry Rations.

2. Function (aim or purpose in the project): To examine triticale for its potential as an energy substitute in poultry rations.

3. Function Expansion: See attached sheet (p. 5) showing the relationships of this project to (a) component projects (both necessary and alternative), (b) alternative projects fulfilling the same or similar functions, and (c) higher (larger) system functions.

B. Expected Outputs (knowledge, methods, products)

1. The extent to which poultry can utilize triticale as a new energy source.

2. The extent to which triticale can be substituted for conventional energy sources without affecting performance.

3. Technological requirements for the utilization of the substitute.

4. Price requirements for the substitute to be economically viable.

C. Expected Resource Requirements and Project Duration

1. Expected total Resource Requirements (£1000 units): 5 units.

2. Expected Project Duration: 1 year.

D. Expected Ultimate Effects of Outputs (For details of calculations and data see corresponding sections in Part II, B, Detailed Analysis.)

Goal Dimension and Effect	Rating
Consumption Category.	
1. Quantity:	
(a) Productivity: social profitability of zero per unit since triticale no better than wheat.	0%
(b) Total Production: Research costs of £5 thousand in one year for a net social profitability of -£5 thousand -- any discount rate.	@ 0%: -£5k @ 5%: -£5k @ 10%: -£5k
2. Quality: no significant effects.	
3. Availability: no effects.	
Security Category:	
4. Human Safety: no effects.	
5. Economic Defence: no significant effects.	
6. Food Sources Security: no effects.	
7. Conservation: no significant effects.	
Equity Category:	
8. Distribution: no significant effects.	
9. Individual Rights: no effects.	

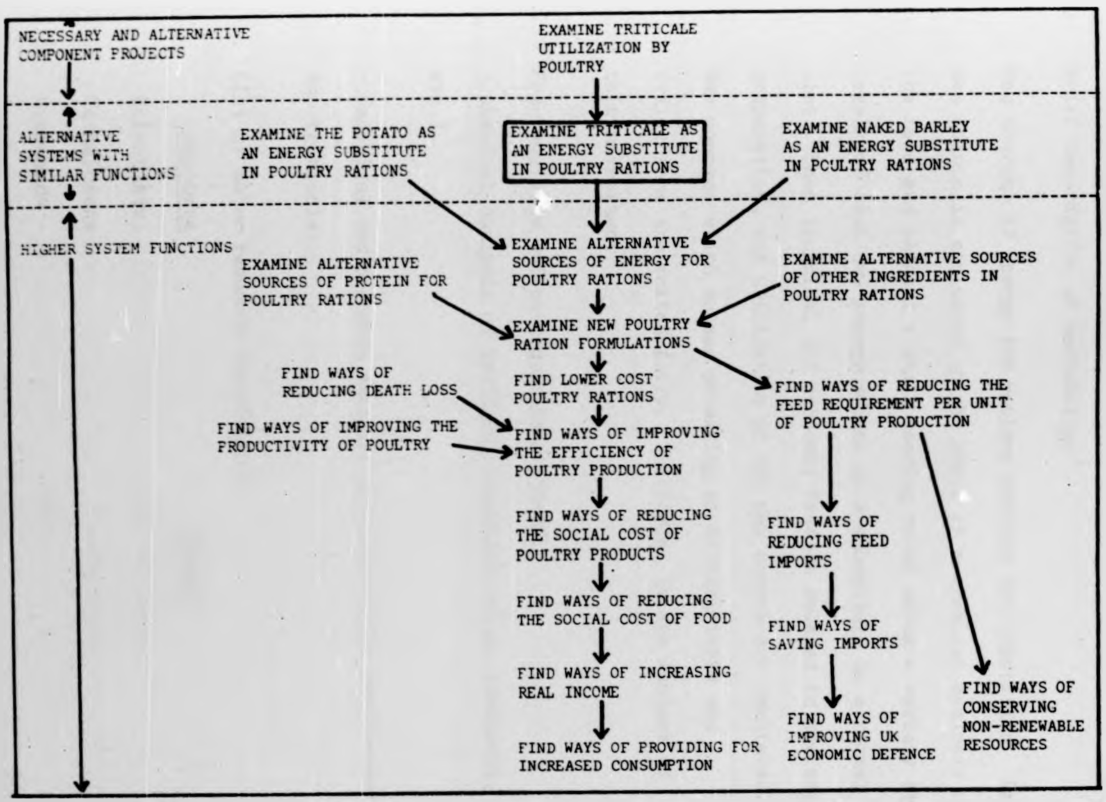

Figure C1. Function expansion for the Triticale for Energy in Poultry Rations project showing the relationships of this project to (a) both necessary and alternative sub-projects, (b) alternative projects directed toward the same or similar functions, and (c) the functions of higher systems.

PART II. DETAILED ANALYSIS: Triticale for Energy in Poultry Rations

A. Introduction

1. Brief description of methodology

New sources of energy for poultry rations are identified. Each new source is evaluated on the basis of a chemical analysis of the feed and perhaps a small feeding trial using a variety of levels of each new energy source as a substitute in a normal diet. Then technical and economic factors related to the supply, preparation, and utilization of the new source are evaluated. New sources which appear promising on ititial tests and evaluations are tested fully. Triticale, is the subject of this assessment.

2. Pre-requisite and co-requisite projects

- chemical analysis of triticale (nutrient value, toxicants, etc.).

- technical and economic analysis and preparation requirements for triticale.

3. List of major resource requirements

Resource	Amount
Scientists	X1 man-years
Technicians	X2 man-years
Overheads	£X3
Chickens	X4
Triticale	X5 tons

4. Requirements in the industry for the utilization of the outputs

(a) Feed processors incorporate triticale into their rations.

(b) Triticale is or becomes an economically viable alternative for cereal producers.

B. Evaluation of the Ultimate Effects of the Outputs

Research project outputs are evaluated in terms of their contributions to the dimensions of society's social welfare function or ultimate goal. Since the primary purpose of this project is to assess the substitutability of triticale as an energy source in poultry rations, the knowledge that triticale is a good substitute is the output of major concern. A substitution rate of 25% was suggested by research staff as a maximum and is used as a basis for evaluation.

The primary point of view for the analysis is that of society (United Kingdom as a whole), although the potential effects of the outputs on particular groups within society are noted where these are significant.

The fact that the United Kingdom is entering the EEC created difficulties in collecting suitable data for analysis. Consequently, the data are based on stable EEC and world political and market conditions as projected from recent conditions in the United Kingdom, the EEC and the world.

The potential contributions of the research outputs to the goal dimensions are considered in turn.

Consumption Category:

1. Quantity Dimension

The main objective of this project is to assess the effect of substituting triticale for other energy ingredients (such as wheat) in poultry rations. The hope is that triticale will be an acceptable substitute. If it is, poultry will not in future be competeing with humans for this source of energy since the food is unlikely to be used as human food. However, the production of triticale requires land which is also required by many crops which are used for human food. Therefore, triticale will not have any benefit to society or even the poultry industry unless the production of poultry feed per acre is higher for triticale than for conventional ration ingredients such as wheat.

The following assumptions regarding production parameters, costs, and benefits form a basis for calculating the potential net profitability from substituting triticale for wheat as a source of energy in poultry rations.

Potential Utilization: The amount of triticale which can be utilized in poultry rations may be derived from estimates of the total energy requirement for poultry rations and the level of substitutability. The annual output of compounded feeds for the poultry industry in the United Kingdom has been estimated at about 4 million tons (CAFMNA, 1971, p. 3). Some of these compounds are concentrates which are mixed with cereals on the farm. Hence the amount of feed utilized may be greater than 4 million tons.

Poultry feed formulations given by the National Institute of Poultry Husbandry (Bolton, 1967, p. 94) contain between 50 and 86% wheat, maize and barley. Most of the rations contain 70 to 80% of these cereals. Assuming (a) compounded feeds contain on average 75% cereals and, (b) the annual utilization of compounded feeds is approximately 4 million tons as estimated by CAFMNA, then the annual consumption of cereals in poultry rations in the United Kingdom is about 3 million tons. The level of substitutability of triticale for other cereals is estimated by research staff to be no more than 25%. On the basis of these estimates the potential utilization of triticale in poultry rations each year is 0.75 million tons.

Comparative Value of Triticale: The value of triticale as a source of energy is unlikely to be significantly different than the value of wheat since (a) research staff suggest that both per acre yield and production costs for triticale are about the same as those for wheat (except for a slightly higher seed cost, since the rate of germination is lower for triticale than for wheat), and (b) the energy content of triticale is about the same as wheat (Bolton, 1973, p. 392: 3090 kcal/kg for triticale compared to 3060 kcal/kg for wheat).

Research Costs: Research costs for this project are estimated at £5 thousand for a one year experiment.

Quantity Dimension Rating: The quantity dimension has both productivity and total production aspects. The productivity aspect is a measure of the average per unit benefit society is expected to derive from the research once the research output has been adopted. This aspect is designed to give a measure which is free from the effects of the size of the industry and the cost of the research in relation to the size of the industry.

The net social profit from replacing an existing acre of wheat with triticale is estimated as zero. This estimate is based on the assumption that triticale has about the same value and production costs as wheat. The total production aspect of the quantity dimension is a measure of the total net benefit society would derive from investing in the research at present and reaping the benefit in the future. Costs are estimated at £5 thousand, all occurring in the first year. The benefit per unit is zero. Hence, the total benefit is zero and the net benefit is -£5 thousand for any rate of discount.

2. Quality Dimension

The replacement of cereals presently used in poultry rations with triticale is not expected to have any significant effects on the quality of poultry products.

3. Availability Dimension

The replacement of cereals presently used in poultry rations with triticale is not expected to have any significant effects on the availability of energy for human food.

Security Category:

4. Human Safety Dimension

The project is not expected to have any effects on human safety.

5. Economic Defence Dimension

Since the project is not expected to have any effect on feedstuff imports, there will be no significant effects in this dimension.

6. Food Sources Security Dimension

The yield of triticale is unlikely to be any less variable than the yields of other cereals. The project should therefore have no effects on the security of food sources.

7. Conservation Dimension

The resource requirement per unit of energy output is not expected to be significantly different for triticale than for other cereals. The project is therefore not expected to have any significant effects on the conservation of resources.

Equity Category:

8. Distribution Dimension

The project is aimed at determining the extent to which triticale can replace other cereals as an energy source in poultry rations. As discussed earlier (see quantity dimension) triticale is not expected to produce any more energy per acre than wheat, or produce any more poultry meat per acre than wheat.

Farmers will neither gain nor lose from replacing some of their wheat acreage with triticale. Therefore no significant effects in the distribution dimension are expected.

9. Individual Rights Dimension

No significant effects are expected.

C. Discussion

1. Triticale Production Possibility

The Common Agricultural Policy (CAP) of the EEC has no support price for triticale. Consequently, the price for this cereal will tend to follow world cereal prices which are normally lower than EEC prices for cereals of equivalent nutritional value. However, the price of triticale in the EEC is unlikely to be much below the EEC price for an equivalent amount of cereal because, if it were, feed users would tend to increase their demand for this cereal.

Under conditions of a marginally depressed price for triticale, farmers are unlikely to grow triticale because they could realize a higher return by growing other cereals which have support prices.

The only condition under which farmers may grow triticale is if they intend to market the crop through livestock.

2. Triticale Imports

An alternative source of triticale supply is the world market. At present there are no import restrictions on triticale so this feed may be imported at a price which is generally lower than the EEC price for the equivalent value of another cereal. However, the lack of import restrictions is unlikely to remain for long if significant quantities of triticale are imported.

3. Ration Balance

The foregoing analysis has been based on the assumption that, since triticale has approximately the same metabolizable energy content as wheat, the one feed ingredient could be simply substituted for the other with no effect on poultry performance. In reality, the higher protein content of triticale may require adjustments in the amount of other ingredients required to form a balanced ration.

Triticale has a crude protein content of 14.1% compared to 10.5% for wheat (see Bolton, 1973, p. 392). The substitution of triticale for wheat in a ration could potentially reduce the requirement for protein supplement. This could give rise to a social profit in the quantity dimension and perhaps save imports. However, the benefit would only arise if triticale proved to be a more efficient converter of cereal inputs (seed, fertilizer, land, etc.) into energy and protein for poultry rations, than the cereals it replaced.

The difference in protein content is small. Consequently, any adjustments in other ingredients required to form a balanced ration are unlikely to have very significant effects on the conclusions in this report. In any case, the assessment of triticale as a source of protein is not within the objective of the project as presently defined.

4. Project Aim

As an energy substitute for wheat or other cereals, triticale does not appear to offer any prospect of providing a social benefit of any kind. However, if the project were redefined with a different objective, social benefits may be possible. One alternative which has already been mentioned is to assess triticale as a source of protein in poultry rations. Another alternative objective is to look for a new source of energy which has a higher yield of energy per acre than wheat, or will give rise to more efficient conversion of the energy in the feed into meat. In both cases there are potential benefits in both the quantity and economic defence dimensions.

D. List of Abbreviations

CAFMNA	Compound Animal Feeding Stuffs Manufacturers National Association Limited (United Kingdom)
CAP	Common Agricultural Policy (of the EEC)
EEC	European Economic Community
HMSO	Her Majesty's Stationery Office (United Kingdom)
k	thousands
UK	United Kingdom

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Appendix D

ANIMAL BREEDING RESEARCH ORGANISATION

SOCIO-ECONOMIC APPRAISAL OF RESEARCH PROJECT

<u>DAIRY FEMALE REPLACEMENT SYSTEMS</u>

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May, 1973.

CONTENTS

PART I. SUMMARY

A. Project Name and Function

1. Name: Dairy Female Replacement Systems.

2. Function (aim or purpose of the project):

   To produce dairy female replacement systems which will promote improved efficiency in milk production.

3. Function Expansion: See attached sheet (p. 5) showing the relationships of this project to (a) component projects (both necessary and alternative), (b) alternative projects fulfilling the same or similar functions, and (c) higher (larger) system functions.

B. Expected Outputs (knowledge, methods, products)

1. Identification of physiological and economic restrictions associated with dairy herd replacement.

2. Information on the genetic control of milk yield and quality.

3. Specification of alternative systems for female replacement.

C. Expected Resource Requirements and Project Duration

1. Expected total resource requirements (£1000 units): 100 units.

2. Expected project duration: 10 years.

D. Expected Ultimate Effects of the Outputs (For details of calculations and data see corresponding sections in Part II, B, Detailed Analysis.)

Assumption: A new system will allow a 10% increase in annual milk yield per cow while holding total milk production constant, thus permitting a decrease in the size of the national dairy herd.

Goal Dimension and Effect	Rating
Consumption Category:	
1. Quantity	
(a) Productivity: £9 million cost saving permitting a 1.8% decrease in the price of milk (£0.0033 per gallon).	1.8%
(b) Total production: research costs of £0.01M per annum for 10 years followed by 20 years with a net social profit of £9M per annum -- varying discount rates.	@ 0%: £180M @ 5%: £69M @ 10%: £30M
2. Quality: no effects.	
3. Availability: no effects	
Security Category:	
4. Human Safety: no effects.	
5. Economic Defence: feedstuff import saving of £11M per annum compared to:	
(a) total imports of £10,000M per annum:	0.11%
(b) agricultural imports of £1800M per annum:	0.61%
6. Food Sources Security: no significant effects.	
7. Conservation: no significant effects.	
Equity Category:	
8. Distribution: no significant effects.	
9. Individual Rights: no significant effects	

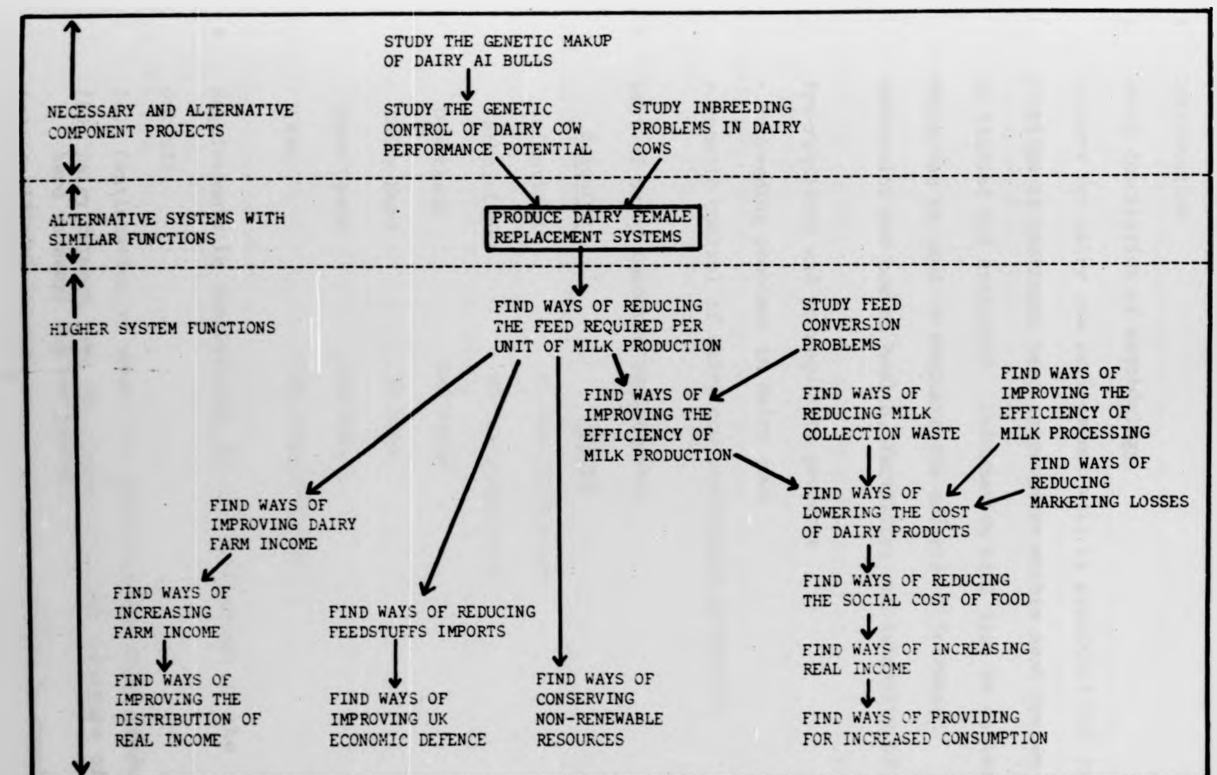

Figure D1. Function expansion for the Dairy Female Replacement Systems project showing the relationships of this project to (a) both necessary and alternative sub-projects, (b) alternative projects directed toward the same or similar functions, and (c) the functions of higher systems.

PART II. DETAILED ANALYSIS: Dairy Female Replacement Systems

A. Introduction

1. Brief description of methodology

Systems for dairy cow replacement will be generated and examined. Problems of continual herd improvement within each system will be studied and evaluated. Information will also be collected which can be used to evaluate the effects of increased production per cow on health, fertility, and longevity of a cow.

2. Pre-requisite and co-requisite projects

- inbreeding problems in dairy cows
- genetic control of dairy cow performance potential.

3. List of major resource requirements

Resource	Amount
Scientists	X1 man-years/year
Technicians	X2 man-years/year
Overheads	£X3 /year
Dairy Herd	X4 cows
Barn Space	X5 stalls
Feed	X6 tons/cow/year

4. Requirements in the industry for the utilization of the outputs

(a) Continuation of demand for home produced dairy products.

(b) Dairy farmers have the correct size and structure of herd to adopt the new system.

(c) Artificial insemination facilities continue to develop.

B. Evaluation of the Ultimate Effects of the Outputs

Research project outputs are evaluated in terms of their contributions to the dimensions of society's social welfare function or ultimate goal. Since the primary purpose of this project is to specify dairy herd replacements systems, the outputs of major concern are the new systems and their potential effect in society.

The new systems have not been specified in detail, making difficult the estimation of effects. For this reason, an assumed increase of 10% in the output of milk from a given herd is used as a basis for assessing the potential effects of a new system. Each new system, when projected, can be evaluated in terms of this standard assessment and the coefficients for each dimension of the social welfare function adjusted accordingly.

The primary point of view for the analysis is that of society (United Kingdom as a whole) although the potential effects of the outputs on particular groups within society are noted when these are significant.

The fact that the United Kingdom is entering the EEC created difficulties in collecting suitable data for the analysis. These difficulties were overcome by projecting stable EEC and world political and market conditions from recent conditions in the United Kingdom, the EEC, and the world.

The potential contributions of the research output to the goal dimensions are considered in turn.

Consumption Category:

1. Quantity Dimension

For purposes of analysis the new dairy female replacement systems are assumed to permit a potential increase of 10% in milk output from the national herd. The social benefit of this output is measured as the value of the extra output minus the costs of producing the output. A number of assumptions relating to future production and market factors must be made before social benefit may be calculated.

Reduced Dairy Herd Requirement: The increased production of 10% will permit the national dairy herd to be reduced by 0.32 million cows (MAFF, et al., 1971, p. 5: 10% of 2.79 million plus 0.42 million dairy cows). This reduction could take place while maintaining production of dairy products at present levels.

Feed Cost Savings: The reduced dairy herd size would permit a reduction in feed requirement. However, since increased milk yield through genetic improvement does not occur without an increase in feed requirement, the feed requirement of the dairy herd will not be reduced in proportion to the reduction in the number of cows. Research staff suggest that each extra gallon of milk obtained through genetic improvement of the herd requires about 40% as much feed as the feed requirement per gallon of milk prior to the improvement.

The net feed savings are estimated at approximately one million tons annually (see Table D1). Assuming a ratio of 5:4:1 for cereals, preserved forages, and green forage in the average annual dairy ration, the annual reduced requirements for cereals and forages are approximately 0.5 million tons each.

Assuming the surplus cereals to be barley or barley equivalent, the social value of the cereal is approximately the world c.i.f. price of the barley at United Kingdom ports. The world price is a reasonable approximation to the social value of barley because any other price maintained by import levies or intervention buying is a form of transfer payment within society (see OECD, 1969, p. 107). The world c.i.f. price at United Kingdom ports is estimated to be £22 per ton (FAO, 1970, p. 538: Canada No. 1 feed) plus £6 per ton freight (Canadian Grain Commission, 1972, p. 6) for a total price of £28 per ton. Using this estimate the social value of the surplus barley is £14 million per annum (£28 per ton for 0.5 million tons per annum).

Assuming that forages have on average 60% of the nutrient value of barley, the 0.5 million tons of surplus forage is equivalent to about 0.3 million tons of barley. The social value of the surplus forage is therefore approximately £8 million per annum (£28 per ton for 0.3 million tons per annum).

The estimated total social value of the surplus feed arising from a reduction in the national dairy herd is estimated at £22 million per annum (£14 million plus £8 million).

TABLE D1. POTENTIAL NATIONAL FEED SAVING PERMITTED BY A SMALLER HERD WITH 10% HIGHER MILK YIELD PER COW

Factor	Units	Estimate
Feed Requirement per Cow[a]		
- Maintenance	lb/day	10.
- Production	lb/day	25.
Total Annual Feed Requirement per Cow[b]	tons	4.1
Annual Milk Yield per Cow[c]	gal	850.
Feed Required per Gallon of Milk[d]	lb/gal	6.4
National Dairy Herd Size[e]	millions	3.2
Potential Herd Size Reduction[f]	millions	0.3
Gross Feed Savings[g]	M tons	1.22
Extra Milk Required of Smaller Herd[h]	M gal	250.
Extra Feed Required for Extra Milk[i]	M tons	0.28
Net Feed Savings[j]	M tons	0.94

a ARC, 1965, p. 31. The feed requirement for maintenance of dry non-pregnant cows ranged from 7.5 to 14.3 lb per day, while the feed requirement for a cow producing 10 to 20 kg of milk per day ranged from 12 to 35 lb per day (including maintenance requirement). The range depended on the energy content of the feed.

b Assumes cows fed at 25 lb per day throughout the year.

c MMB, 1971, p. 17: Estimated yield in 1971 was 850 gal per cow.

d Assumes 60% of the 4.1 tons annual feed was required for milk production.

e MAFF, et al., 1971, p. 5: 2.79 million plus 0.42 million cows kept for milk production in 1967/68.

Table D1 continued:

f Calculated as present national herd size less new herd size required if producing 10% more milk (or 3.21 million minus 0.909 times 3.21 million).

g Annual total feed requirement at 4.1 tons per cow for 0.3 million cows.

h Smaller herd size (0.909 times 3.21 million cows) at 10% higher milk production (935 gal per cow per year).

i Calculated as 40% of the feed which would be required if the milk were produced by extra cows (or 40% of 6.4 lb per gal for 250 million gallons).

j Calculated as the difference between gross feed savings and extra feed required for the extra milk.

Reduced Calf Crop: The reduction in national dairy herd size will reduce the number of calves being produced. Researchers estimate that all male calves and about one third of the female calves produced by a dairy herd are used for beef. The calf crop is normally at least 80%, one half males, and the value of a dairy calf used for beef is about £25 at birth. Using these estimates, the value of the calf crop lost by reducing the national dairy herd by 0.3 million cows is £4 million per annum (0.533 calves per cow at £25 per calf). This estimate assumes that the new replacement system will require the same ratio of herd replacements as the old replacement system.

Other Savings: A new dairy female replacement system which permits a reduction in the national dairy herd size may or may not provide a saving in labour, buildings and equipment, AI service, and management costs. Since no estimates may be made without reference to a particular proposed system, these potential savings have been ignored in this assessment.

Research Costs: Until a specific new replacement system is envisaged and the necessary experiments specified, costs cannot be estimated. However, it is unlikely that a system could be tested in less than ten years at a cost of £10 thousand per year. For purposes of assessment this cost and time period have been assumed.

Quantity Dimension Rating: The dairy female replacement systems research has potential effects in both the productivity and total production aspects of the quantity dimension.

The productivity aspect is a measure of the average per unit benefit society is expected to derive from the research once the research output has been adopted. This aspect is designed to give a measure which is free from the effects of the size of the industry and the cost of the research in relation to the size of the industry.

The net social profit from adopting a dairy female replacement system producing a 10% increase in milk is estimated at £18 million per annum (£22 million saving in feed less £4 million loss in calf crop). This estimate is based on the assumption that the new system will be adopted by all dairy farmers. A more realistic estimate may be 50% adoption, giving a corresponding net social profit of £9 million per annum.

The saving of £9 million to farmers should, in the long run, reduce the cost of milk production and hence the price of milk. The present producer price for milk is about £0.18 per gallon (MMB, 1971, p. 17: 2257 million gallons having a value of £405 million). The £9 million cost saving represents a saving of £0.0033 per gallon (Table D1: 3.2 million cows yielding 850 gallons per year produce 2720 million gallons). Expressed as a ratio the saving represents a reduction in the cost of milk of 1.8%. The percentage reduction in price is much smaller than may be expected from a 10% increase in milk output because (a) the increase cannot be obtained without increased feed costs, (b) adoption level was assumed 50%, and (c) other potential savings such as the cost of labour and buildings have not been included in the calculations.

The total production aspect of the quantity dimension is a measure of the total net benefit society would derive from investing in the research at present and reaping the benefits in the future. The net social benefit for discount rates of 0%, 5%, and 10% are £180 million, £69 million, and £30 million respectively (see Table D2).

2. Quality Dimension

A new dairy female replacement system is not expected to have any effect on the quality of milk or milk products.

3. Availability Dimension

A new dairy female replacement system is not expected to have any effects on the availability of milk throughout the year or to reduce variation in the supply.

Security Category:

4. Human Safety Dimension

A new dairy female replacement system is not expected to have any effect on human safety.

5. Economic Defence Dimension

The reduction in feed requirement for the national dairy herd while maintaining production will permit the reduction of feedstuff imports. The barley equivalent of the potential feed saving, assuming 100% adoption of the new replacement system, was estimated above at 0.8 million tons per annum. The value of this amount of barley at the import c.i.f. price was estimated at £22 million. Using the 50% adoption rate suggested above, the net annual import saving is estimated at £11 million per annum.

In recent years the United Kingdom has annually imported for feed about 707 thousand tons of wheat, 304 thousand tons of barley, 7 thousand tons of oats, and 3387 thousand tons of maize (H-GCA Annual Report, 1971, pp. 81 and 82: annual average for the period 1966/67 to 1969/70). The importation of barley in the future is not likely to increase if price supports are maintained, so it is unlikely that barley imports could be reduced by 0.8 million tons per annum. However, since the total present importation of cereals is over 4 million tons, the assumption that the cereals equivalent

TABLE D2. AGGREGATE NET SOCIAL PROFIT[a] FROM A DAIRY FEMALE REPLACEMENT SYSTEM PERMITTING MILK YIELD TO INCREASE BY 10%

Year	Factor	Amount per Annum (£M)	Total Amount at Discount Rate of 0% (£M)	5% (£M)	10% (£M)
1 - 10	Research Costs	-0.01	-0.1	-0.08	-0.06
11 - 30	Social Profit[b]	9.	180.	69.	30.
		Total	180.	69.	30.

a Assuming constant demand for milk and a reduced national dairy herd size.

b Assuming 50% adoption immediately follows release of the new system and remains constant, and there is no time lag between the adoption of the new system and the realization of its benefits.

to 0.8 million tons could be eliminated is not unreasonable.

The value of all imports to the United Kingdom is currently about £10,000 million (IMF, 1973, p. 360). The value of agricultural imports is about £1,800 million (CSO, 1971, p. 12). The potential cereal import reduction equivalent to £11 million of barley represents 0.11% of the value of all imports and 0.61% of the value of agricultural imports.

6. Food Sources Security Dimension

No reduction in risk in the production of milk is expected with a new replacement system. There may, however, be a marginal security effect from the reduction in dependence on imported feedstuffs but this is considered insignificant.

7. Conservation Dimension

The reduction in feed required per unit of milk represents a reduction in resources required per unit of milk. This is a positive benefit in the conservation dimension but is considered to be too small to be significant.

Equity Category:

8. Distribution Dimension

Farm Operators: In the short run innovating farmers may expect increased profits from adopting a new replacement system. However, as production tends to expand in response to the increased profits, prices will tend to fall. In the long run, farmers will have no change in their income position. The total cost of milk production will be lower but so will total revenue.

Farm Labourers: The decrease in feed requirements for milk production is not expected to decrease the demand for home-grown feedstuffs. Hence no decrease in labour demand for feedstuffs production is expected.

There may, however, be a reduction in the amount of labour required for the smaller national dairy herd. This possibility has not been considered in this analysis since a specific new system has not been defined.

No reduction in labour arising from the loss of calves for beef may be expected since the beef cow herd is expected to expand to make up for the loss of dairy calves.

9. Individual Rights Dimension

The adoption of a new dairy female replacement system is not expected to have any effects on either the equality of opportunity or freedom from discrimination aspects of the individual rights dimension.

C. Discussion

1. Future Changes

The demand for milk may increase in the future rather than remain constant. If the project were assessed on this basis, the benefits in the quantity dimension would be higher since there is a larger national herd which would benefit from the research. The assessment could take the form of determining the costs of expansion with and without the new dairy female replacement system. Increased production with the new system would be at a lower feed cost than it would be without the new system. However, there would be no increase in calves with the new system while there would be without the new system.

If the project were assessed on the basis of a constant national herd size and increasing demand for milk, no reduction in the present demand for feedstuffs would be expected. However, there would still be reductions in imports relative to what would be needed if the dairy herd size were expanded to meet the projected increased milk demand. The import saving would be larger than estimated in the economic defence dimension above, because of the larger national herd size and because all extra feed would have to be imported.

There is also the possibility that in the future the present national dairy herd may be about to degenerate because present herd replacement methods are unsatisfactory. If this is the case, the benefit from this project may be larger than estimated.

2. Benefit in Relation to Selection Intensity

The foregoing analysis has been developed on the assumption that a new replacement system will be able to increase milk yield by 10%. How realistic this assumption is will depend on the present average level of intensity of selection in dairy herds.

The rate of increase in potential benefit (e.g., genetic improvement increasing milk yield) from intensified selection decreases as the intensity of selection increases. Therefore, if herds are already selected very intensely, the benefit which may be expected from a given increase in selection intensity will not be as great as it would be if herds were presently being selected at a low level of intensity. This nonlinear relationship should be taken into account in the analysis of a replacement system, once it has been specifically defined.

3. Cost of Using a Replacement System

The cost of obtaining increased benefits probably increases as the level of intensity of selection increases. These costs include the cost of culling more animals as well as increased management costs associated with more intensive selection. Since no particular system has been specified, these costs have not been included in the foregoing analysis.

4. Time Lag in Benefits

The analysis has been based on the assumption that once a new system has been adopted, the benefits will be realized immediately. In practice, there may be a time lag of several years. This factor should be taken into account when assessing a particular system, once a new system has been specifically defined.

5. Market Value of Calves

The social value of a beef calf generated as a byproduct of the dairy industry was estimated as the market value of the calf at birth. This may be an underestimate of the social value of the calf. The beef herd would have to expand to replace the calf and the cost of replacing the calf in this way may be higher than the market value of the calf as a byproduct to the dairy industry. In other words, part of the actual value of a dairy calf may be hidden in the price of milk.

6. Import Levy Loss

The potential reduction in imports resulting from the adoption of a new dairy female replacement system would reduce the import levy income of treasury. The current EEC minimum import price for barley is about £41 per ton (see NEDO, 1972, p. 13) while the duty free import c.i.f. price at United Kingdom ports is estimated at £28 per ton (see quantity dimension). Under the EEC support system, the import levy is assessed as the difference between the minimum import price (threshold price) and the lowest import price. On this basis, the levy is currently estimated as £13 per ton. The potential reduction of imports was estimated above at 0.8 million tons of barley equivalent. On the basis of these estimates, the potential loss in import levy is £10.4 million per annum for the 100% adoption rate, and £5.2 million per annum for the 50% adoption rate.

7. Shipping Loss

If British ships are used to transport feedstuffs to the United Kingdom, the potential reduction in feedstuffs imports could affect the British shipping industry. This effect is another consideration for the distribution dimension which has been ignored in the assessment.

8. Trade Relations

Eliminating imports by making home production more efficient is probably internationally more acceptable than raising import levies to increase inefficient home production.

9. Project Justification

Attempting to keep milk products competitive to substitutes and thereby maintain their share of the market may be one objective of research projects of this nature. From the point of view of the dairy industry the objective may be valid. However, from society's point of view the objective could be counter-productive if the standard of living can be raised more by increasing the utilization of milk substitutes than by maintaining or increasing the utilization of natural milk products.

From society's point of view this objective for agricultural research is not needed because society, through consumer preference (and the legal system if necessary) can select the levels of utilization for consumables. This assessment has been made from society's point of view.

D. List of Abbreviations

AI	artificial insemination
ARC	Agricultural Research Council (United Kingdom)
c.i.f.	cost, insurance, freight
CSO	Central Statistical Office (United Kingdom)
DAFS	Department of Agriculture and Fisheries for Scotland
EEC	European Economic Community
FAO	Food and Agriculture Organization (United Nations)
gal	gallons
H.C.	House of Commons (publication: United Kingdom)
H-GCA	Home-Grown Cereals Authority (United Kingdom)
HMSO	Her Majesty's Stationery Office (United Kingdom)
IMF	International Monetary Fund
kg	kilogram
lb	pounds
M	millions
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
MANI	Ministry of Agriculture for Northern Ireland
MMB	Milk Marketing Board (England and Wales)
NEDO	National Economic Development Office (United Kingdom)
No.	number
OECD	Organization for Economic Co-operation and Development
UK	United Kingdom

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