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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 specific application discussed in this paper relates to the administration of research activities within specific public research organizations or resource settings. The primary aim of the system is to generate relative measurements of benefits and costs of proposed research activities which would conceivably lead to a more efficient, as well as to facilitate, allocation of research resources within the organization. The system is primarily concerned with the selection from among proposed research activities and the efficient allocation of resources among these activities, not with the identification of possible research topics.

The principal distinction of MARRAIS lies in the structure of and the procedures for generating the data required by the analysis. The total task is disassembled into information components in a manner which, on the one hand, permits collection from the best possible sources of the individual segments of information independently of other segments and, on the other hand, permits effective separation of the data collection and analysis procedures from the specification and application of desired selection criteria used in determining the relative goodness of alternative research activities. The uncertainty that arises in making estimates about the various pieces of required information are retained throughout the analysis; hence, the resulting benefit-cost estimates are distributed values. MARRAIS also permits evaluation of each research activity for several alternative levels of annual resource expenditures, and it permits including both essentially "basic" and "applied" research activities in a single analytical and comparative process.

In the following, I first present a general description of the methodology of MARRIS. The second part describes the mechanics for generating and analyzing information in MARRIS. The last part presents the results of an experiment in the application of MARRIS.

A General Description

The primary interest in the development of the information system was basically the resource allocation process, regardless of whom is involved or where the activities that are a part of the process might be performed. In addition to an organization's central administration, divisional or departmental managers and even project leaders are frequently involved in resource allocation decisions. However, this model assumes that these activities are either carried out by or the inherent responsibility of a research administrator who can (and does) transfer the performance of as many of these activities as deemed necessary and prudent to others in the research organization. Focusing on the process rather than on an all-encompassing objective (optimization of resource allocation) or on the performance of the organizational structure (optimum allocation of the decision-making processes) permits development of an information system independently of particular organizational structures.

The role of an information system within this frame of reference derives its justification in facilitating the decision-making processes, particularly the functions of information collection and processing. In general, (management) information systems have two primary functions: "filtration" and "condensation". Filtration is concerned with separating the relevant from the irrelevant. Condensation is concerned with the reduction of relevant data through analysis or other useful transformation to a form most meaningful to the research administrator. As applied to this model, filtration is carried out in two steps, in screening of possible alternative research activities, which results in only certain ones being presented to the research administrator for consideration, and in the collection of data or information relevant to the making of decisions about resource allocations.

Condensation is carried out primarily in the basic analysis of collected data and in presenting it to the decision makers in a useful format. In some cases, this may be as far as the information system can go in assisting the research administrator in his decision-making processes. Such would be the case for what is termed "cost-effectiveness" analysis. However, it usually is possible to further condense the information presented to the administrator. If there is one or more commonly-accepted selection criteria or a particular criteria specified by the research administrator to be included in the evaluation, then the information can be further condensed by a "preordering" of the alternative research on the basis of how well each satisfies the specified selection criteria. One such criteria usually is the relative contribution of, say, a technical research project ina livestock area to the economic well-being of the livestock production industry.

In any case in which benefits of a proposed research activity are evaluated, even on the basis of market values, such a preordering process is assumed. In this case, the commonly-held selection criteria are values associated with the market place. Hence, in cost-benefit analysis, there are actually two distinct stages involved in arriving at a research investment strategy: (1) Given all research possibilities, an initial preordering of alternative research investments based on some selection criteria at least partially distinct from that of the research administrator. (2) A selection process of the preordered research alternatives by the research administrator based on evaluation of research alternatives utilizing additional criteria. The distinction between the two steps has been discussed by Williams and Nassar (1966) who consider that a preordering can be carried out using criteria of goodness independent of the second step. The criteria of the second step they consider to be environmental or boundary restrictions bearing on the final selection only. Further, Naslund and Whinston (1962) indicate that such a "division of labor is one which puts the burden of analysis on the model (where it belongs) and the burden of evaluation on the decision makers (where it belongs)", the model being the analytical construct used in the preordering of investment alternatives.

The information system developed at Minnesota is intended to provide this preordering of alternative research activities. However, it excludes the initial screening process as an inherent part of the system for several reasons, including limitations on the relative scope of the experiment. There are currently reasonably effective methods for accomplishing the same ends, notably the basic structure developed at the Iowa Experiment Station. The principal emphasis in this effort was on the development of methods for generating better quality information than is currently available to research administrators.

An example of the information provided the research administrator by MARRAIS is shown in Table 1. For various levels of average annual expenditure and respective planning periods (equal to the expected value of the time required to complete the project), measures of the expected research effectiveness are provided (for example, a benefit-cost ratio) along with a measure of variability in the estimate and an index indicating the relative feasibility of predicting these measures.

Table 1. Information Provided by Benefit-Cost Estimation Technique for Two Projects Included in the MARRIS Experiment.

Project	Cost Level	Estimated Average Annual Expenditure[a]	Planning Period (Mode-Mean)/(Stand. Dev.)	Maximands: Benefit-Cost (Mode-Mean)/(Stand. Dev.)	Maximands: Benefit-Cost (Mode-Mean)/(Stand. Dev.)	TFP Index[b]
		($1,000)	Years	($1,000)		
A	1	28.7	$\frac{14.0 - 14.9}{2.89}$	$\frac{709 - 964}{560}$	$\frac{1.3 - 5.4}{7.5}$	1.31
	2	58.7	$\frac{9.0 - 8.9}{1.30}$	$\frac{2023 - 2274}{904}$	$\frac{3.5 - 7.5}{5.1}$	1.14
	3	114.9	$\frac{5.8 - 5.8}{.77}$	$\frac{2942 - 3162}{1550}$	$\frac{4.5 - 6.5}{3.3}$	1.09
B	1	15.6	$\frac{5.2 - 5.2}{.65}$	$\frac{388 - 416}{148}$	$\frac{3.2 - 6.5}{3.4}$	1.11
	2	28.2	$\frac{4.7 - 4.8}{.66}$	$\frac{526 - 563}{270}$	$\frac{3.8 - 5.1}{2.8}$	1.07
	3	57.2	$\frac{3.5 - 3.6}{.48}$	$\frac{624 - 657}{279}$	$\frac{3.1 - 3.8}{1.4}$	1.05

[a]Includes the allocated dollar cost of all resources used plus an expected desimination cost of the information generated.

[b]Technological Feasibility Predictability Index. A measure of the variability in the overall estimates of technological feasibility, entirely comparable to the coefficient of variation but based on the variability of the plus and minus 1 standard deviation points of the individual about a concensus subjective benefit/cost distributions. The lower the TFPI, the more predictable the proposed project.

Given the alternative proposed research projects, programs, or other requests for resource commitments, the information in Table 1 is obtained by obtaining solutions to one or more of three equations for each research activity considered.

(1) $$R_1 = B - C > 0$$

(2) $$R_2 = B/C > 1$$

(3) $$R_3 : \frac{B - C}{R_3} = 0$$

where

B = research benefits over time

C = total cost of conducting the research

R_1 = difference maximand

R_2 = ratio maximand

R_3 = internal rate of return

While it is possible to use single values in solving equations (1) to (3), such as the "expected" values, MARRAIS considers these values to be probability distributions based on data that also is expressed as probability distributions. In addition, the "present value" of benefits and costs is used in evaluating the research alternatives, i.e., all benefit and cost values are discounted back to the present regardless of when they are incurred or realized.[1] Prest and Turvey

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[1]Rasmussen (1966, pp. 1-6) has discussed the controversy particularly between Eckstein (1958) and McKean (1959) about the relative appropriateness of these alternative forms. According to Eckstein, the rate of return criteria favors large annual flow projects while benefit-cost analysis favors projects with a high initial investment and component. Eckstein rejects the limited capital implications of the internal rate of return as not being applicable to an advanced industrial economy and accepts only budgetary constraints. McKean argues that cost-benefit analysis will sometimes provide contradictory orderings under varying practices of neting out items from benefits and costs evaluations.

In addition, even the two forms of the cost-benefit analysis can lead to different relative orderings, as indicated in the following:

(1965, p. 70) have indicated that under the conditions of (1) no projects being interdependent, (2) starting dates being given, and (3) no constraints being operative (each of which are or can be circumvented where they do exist), "the present value of total benefits less total costs can be expressed in any of four equivalent ways" (the above three plus a constant annuities form equivalent to equation (1)).

Hence,

(4) $$B = \sum_{t=1}^{\infty} \frac{B_t}{(1+I)^t} \text{ and } C = \sum_{t=1}^{\hat{t}} \frac{C_t}{(1+I)^t}$$

where

B_t = benefits derived in year t

C_t = costs incurred in year t

I = a discount rate expressing the social time preference of consumption

$\hat{t}$ = number of years to complete the proposed research project or program

For the internal rate of return maximand, equation (3), the above has a slightly different form, namely

(5) $$\frac{B-C}{R_3} = \sum_{t=1}^{\infty} \frac{(B-C)_t}{(1+R_3)^t} = 0 \quad .$$

The model of the flow of benefits and costs of research used in MARRAIS requires several kinds of information, some of which are to be estimated and some assumed given, some are fixed-point estimates and some distributed estimates. Where "b" is a single value of the distribution "B" and "c" is a single value of the distribution "C", then "b" and "c" are calculated by the following:

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[1](continued)

	Research Projects A1	A2
Benefits	10	15
Costs	4	7
B/C	2.50	2.14
B-C	6	8

In general, the B-C form tends to favor the larger project as compared to the B/C form, assuming the same time periods.

(5) $$b = fv \sum_{t=\hat{t}+1}^{\infty} a(t)k^t + Sk^{\hat{t}} + P_v(t,\overline{C})$$

(6) $$c = \overline{C} \sum_{t=1}^{\hat{t}} k^t + E \sum_{t=\hat{t}+1}^{\infty} d(t)k^t$$

Where

$k = \frac{1}{1+I}$

f = randomly selected value from P(F), the estimate of technological feasibility

v = randomly selected value from P(V), the estimate of average annual benefits at 100 percent level of adoption of new knowledge generated

$\hat{t}$ = randomly selected value from P(T), the estimate of time required to complete the research activity

$\overline{C}$ = the average annual expenditure on the research activity

The technological feasibility estimate P(F) reflects scientists' impressions regarding the relative success expected in achieving the objectives of the research activity being evaluated.

The "product" value of the research is assumed to be adopted over time according to

$$a(t) = 1-\emptyset^{t-\hat{t}}, \ t > \hat{t}, \ 0 \leq \emptyset < 1$$

where

$a(t)$ = the time rate of adoption of new knowledge

$\emptyset$ = an estimated shape parameter specifying the rate.

It may be that certain facilities, equipment, or supplies purchased for a specific research activity will still have useful value to subsequent research activities at the termination of the research activity for which they were acquired. If so, the "scrap" value is estimated by "S" in equation (5).

Also included in benefits estimates are the value of certain "process" values, i.e., the value that arises from doing the research. In MARRAIS the process values are limited to the increased value of the scientists and to graduate student training. Process values are calculated by

$$P_v(t,\overline{C}) = w_s\overline{C}\ \{\sum_{t=1}^{\hat{t}+1} Atk^t + \sum_{t=\hat{t}+2}^{\alpha} A\hat{t}k^t\} + w_g\overline{C} \sum_{t=4}^{\alpha} Dk^t$$

where

$P_v(t,\overline{C})$ = process value of project

$w_s\overline{C}$ = estimated number of scientists per project

$w_g\overline{C}$ = estimated number of graduate students per project

A = marginal increase in scientist value per year

D = average difference in income attributable to graduate training

In addition to direct and overhead costs of conducting research, costs include an estimate of dissemination costs, including anciliary development costs. Dissemination cost was estimated by

$$d(t) = \sum_{t=\hat{t}+1}^{t'} (1-\theta^{t-t}) + \sum_{t=t'+1}^{\alpha} 1-b(t-\hat{t}) \qquad 0\leq\theta,b<1$$

where

d(t) = time path of annual dissemination costs as a function of the maximum annual outlay expected

E = maximum annual dissemination expenditure

θ,b = shape parameters

t' = epigy of dissemination expenditure function (year)

Once the required variables have been estimated, by procedures described in the next section, solutions for "b" and "c" according to equations (5) and (6) are obtained by Monte Carlo procedures. Repeated random selection of values from cumulative density functions derived from P(E), P(V), and P(T), along with single-valued estimates of the other variables, provide repeated solutions for single values of the maximands r_i indicated by equations (1) to (3). With large numbers of such solutions (20,000 to 25,000), r_i tends to R_i. Parameters of the resulting distributions are then tabulated from R_i

and presented in a form comparable to Table 1 (c.f., Fishel, 1970, for a more detailed discussion of the numerical techniques).

Before discussing the estimation procedures used in MARRAIS, I would like to indicate briefly the basis for using subjective probability distributions rather than single-point estimates for the required information. In this information system considerable significance is attached to the quality of the information used to make allocation decisions. Quality of information refers to (1) the proper identification of specific data elements that must be measured (estimated), (2) the degree of precision attained in the measurement (estimation) of these data elements, and (3) the reliability that can be placed in the resulting measurements (estimates). Identification of data elements is based in the theories and principles of economics and accounting which are consistent with accepted optimizing functions. Precision is gained by the selection and correct application to the data elements of appropriate mathematical and statistical routines. Reliability is largely a product of the source of the data and the procedures for obtaining it.

In seeking values for each of the data variables in the model, the goal is to obtain a point estimate which is known to occur with 100 percent certainty. Under less than 100 percent certainty, a point estimate, while computationally more convenient, cannot be considered precise. In the latter case, a range of values would at least be considered more precise. However, unless all values in the range were expected to have the same liklihood of occurrence, the estimates would still lack the desired precision. For uncertain events, maximum precision would be obtained from estimates in which the probability of occurrence is associated with each value in the range, where the range of values includes the true value with 100 percent certainty. This is entirely analogous to a probability density function (p.d.f.). But where such a p.d.f. is generated from the estimates of an individual, based on his subjective appraisal of circumstances surrounding an event, the resulting measure is referred to as a subjective probability distribution.

The subjective probability distributions generated by the estimation procedures are simply graphical transformations of "experts" mental impressions about the likelihood of uncertain events. The reasons for expressing estimates in the form of probability distributions rather than single-value estimates are: (1) The differences among research activities that exist, associated with size of effort and likelihood of achieving useful results. (2) The technique is generally concerned with processes that are inherently variable in their relationship to environmental status, that is plants, animals, and people. (3) The idea of estimating future events necessarily has variability associated with it in that it is based mostly on judgement, and cases where more than one estimator is used, there will be differences of opinion with respect to the possibilities of achieving technological change. Hence, including estimates of data elements as probability distributions simply reflects an effort to explicitly recognize in the procedures one of the two predominant difficulties of research evaluation, namely, uncertainty. The other predominant difficulty, of course, is obtaining explicit values for the products of research, which is discussed later.

While there are a number of good methods for describing subjective probability distributions of estimates of some event P(x),[2] the one used in MARRAIS

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[2]Smith (1967, pp. 236-249) has discussed several of these and associated derivation techniques and presents a technique of his own based on first differences. Morrison (1967, pp. 253-254) discusses a method which requires a simple distribution of 100 points among alternative events. Dalkey and Helmer (1963, pp. 458-467) discuss the formal DELPHI method developed by RAND. Schweitzer (1968, pp. 14-23) also discusses the use of the normal, Weibull, and beta distributions and develops a discrete subjective probability distribution method somewhat similar to the one used in MARRAIS.

is based on the beta function and was constructed in a manner such that estimates by the experts alone determined its shape. A prior distribution of a basic random variable "x" in terms of a beta distribution, with a useful modification by Schlaifer (1959, pp. 673-676) is

(8) $$P_\beta(x;\rho,\nu) = \frac{(\nu-1)!}{(\rho-1)!(\nu-\rho-1)!} x^{\rho-1}(1-x)^{\nu-\rho-1}$$

where $o \leq x \leq 1$ and $o < \rho < \nu$. The mean, mode, and variance are functions of only the two beta parameters ρ and ν. A simple transformation normalizes any range of values, say, "L" (lower bound) and "H" (upper bound) to $o \leq x \leq 1$ from $L \leq X \leq H$. Hence, the values L, H, ρ, ν uniquely define a beta function, which may have a retangular, symetric, skewed left or right, or "cubic" shape.

To obtain a subjective probability distribution of an event, experts were asked to predict

1. The values "H" and "L" for an event which they would expect to be exceeded only under very exceptional circumstances.

2. The values "h" and "l" for an event which they would expect to be exceeded only one-third of the time.

3. The value "m" for an event which they really would expect to occur (the mode).

Using techniques in MARRAIS, these five values can be used to generate the values "H", "L", ρ and ν and, consequently, a unique subjective probability distribution.[3] It is this process which is implied in the remainder of the discussion when I refer to "estimating P(X)".

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[3]Space does not permit the full development of the techniques used. For a complete discussion, see Fishel (1970, pp. 139-46).

Estimation Procedures

The principal problems of research resource allocation are associated with gauging the flows over time of both costs and benefits of alternative research activities. Other significant factors that affect allocation decisions include the feasibility of achieving research objectives, the feasibility and cost of implementing new knowledge generated, and the degree of substitutability, complementarity, and synergism among alternative research activities. Methods for obtaining estimates of all these factors except the interrelationships are described in the following. With respect to the interrelationships, the proposed CBA methodology assumes that if research activity "A" and research activity "B" are in some manner related, then activities "A", "B", and "AB" would be evaluated.

Figure 1 identifies in modular form the steps by stages involved in generating the information contained in Table 1. The order of the estimation procedures are carried out in essentially the same order depicted.

Specification Steps

The research alternatives evaluated by this system will originate with or at the discretion of the research administrator and will reflect the kind of information which he requires. The system treats research alternatives as units of comparison. That is, for each research alternative, there are clearly stated purpose and objectives. Methods of study or research may be outlined in general terms or stated in rather specific terms. In fact, experience has suggested that some very useful information is provided if method is not too rigidly specified. Treated as units, there is flexibility in the amount of aggregation or disaggregation of research alternatives or in the degree of specificity in the statement that is permitted. MARRAIS is primarily intended as a comparative procedure in which the research administrator is interested

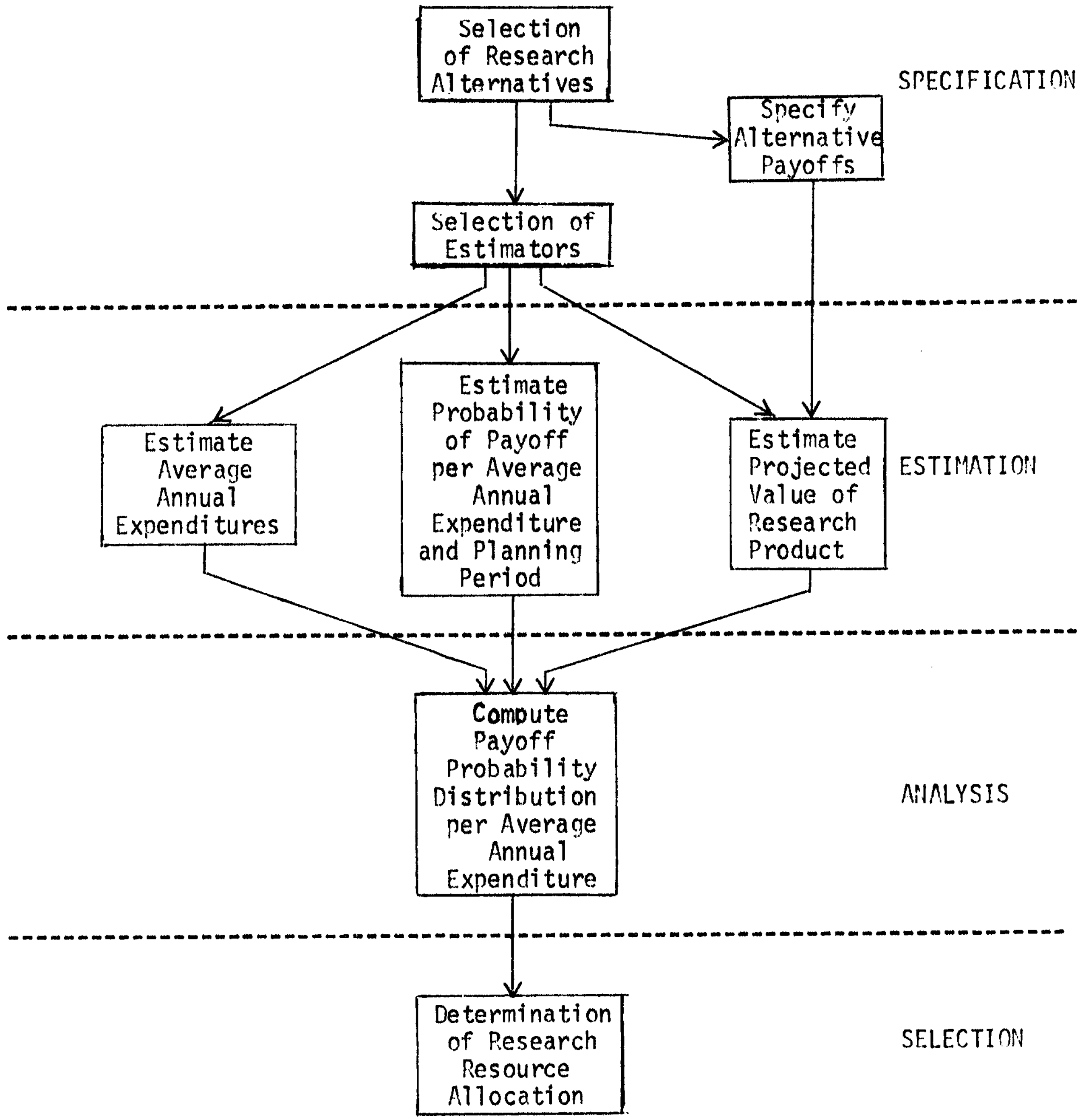

Figure 1. Modular Form of Cost-Benefit Estimation Model.

in comparing a number of alternative research activities at one time, comparing entirely new proposed research alternatives, entirely existing ones, or some combination of new and existing. But, it should be emphasized that the evaluation of a single research activity with MARRAIS in its present form, except for cases in which the value of the research results can be independently determined, would be very difficult, for reasons that will become clear.

The nature or form of the research results to be evaluated are largely predetermined by the objectives of the research activity. They are specified in final form by the administrative "planning" staff with the aid of scientists in each research area considered. The units of measure become a problem for many research results, particularly in other than the technical applied research areas--technical basic, social sciences, resource development, etc.--none of which have clearly defined units for measuring. The basis for quantification for these areas is based on consideration of the extent to which the research objective is achieved or is not achieved. This considers that there are usually some benefits emanating from the research effort even if the objectives would not be achieved. Hence, the units of measurement are percentages of total objective achievement. Total or 100 percent achievement is based on what each expert estimator or group of expert estimators visualize as "ideal" objective achievement. The "value" of benefits achieved for 100 percent achievement of objectives are then part of the estimation process.

The estimators are primarily scientists with expertise in the subject areas of the research alternatives, and may be different ones for each of the three estimation tasks indicated. However, others with particular knowledge in the specific data areas may be employed to provide certain cost data, such as business office personnel or research administration. In each estimation area, the system attempts to quantify the sum total of scientists' past experience as reflected by:

(1) Judgements about the current and likely future state of a given situation and what is technologically possible.

(2) Judgements about what sort of effort will be required to achieve the various possibilities.

(3) Judgements about the relationships between the effort required and the cost of this effort.

MARRAIS assumes that there are scientists who can relate at least parts if not all of this information and provide some estimate of the probable relationships between or among the parts.

Determining the number of and identifying estimators to provide the desired estimates is highly problematical in practice. The system requires estimates about unknown and uncertain events, such estimates being testable only after the fact at best. Hence, there is a significant concern about the reliability of the data estimates. Even where estimates are provided in the form of subjective probability distribution, the basic concern is how well the estimates represent the <u>true</u> situation. That is, the derived p.d.f. would be considered reliable in a statistical sense if repeated occurrences of the event produced values that approximately conformed to the <u>ex ante</u> p.d.f. In the context of this method, the p.d.f. would be most reliable if the value that resulted from the event were approximately equal the expected value of the p.d.f. In both cases reliability is determined by matching <u>ex post</u> results with <u>ex ante</u> estimates, indicating that reliability must be based on experience in applying the system and in evaluation of the estimators. The problem of reliability must largely be resolved in the selection of the estimators. And, despite the importance of selecting the right estimators, there are precious few rules or even guidelines that can be offered in this effort, at least at present. The "established" scientists in each subject area within an organization are usually well known, and the names of those outside the organization can easily be identified. However, there is reason to believe that these are not always the best estimators.

In MARRAIS this difficulty is handled by obtaining estimates for each data element from a number of "experts". However, while several estimators are used to predict values, the reliability of a specific p.d.f. still cannot be determined. At best, it only indicates in the variability of responses the possibility of obtaining reliable estimates. In addition, the system permits assigning weights to the individual estimates used in generating a "concensus" estimate. But, at present there appears to be no numerical method that provides a better basis for handling the problems of data reliability than the confidence placed in the judgement of known experts by the research administrator making the final decisions.

Estimation Steps

The estimation procedures developed for MARRAIS reflects the fact that there usually is a relationship between total cost, benefits achieved, and time required to complete a research activity, despite these being shown as separate estimation steps in Figure 1. First, there will nearly always be a positive relationship between the levels of benefits achieved and the level of total investment of resources for a given research activity. Because subsequent steps of a research project usually depend on results of earlier steps, the more time taken to complete a research activity, the less the total number of "replications" required in the experimental design to allow for alternative possible results at each stage. Hence, for a given level of research benefits, total research cost will generally decrease up to a point where such advantages are overcome by underutilized resources, after which it will increase.

In MARRAIS, the selection of an average annual investment and the selection of the planning period are considered interdependent and are related to each other as well as to the benefits achieved through the estimation procedure.

Undoubtedly, in most cases there could be almost any number of cost-time combinations that could be used in decisions about a research activity. Practical considerations confine the estimation procedure to only a few cost-time combinations. The experiment reported in the next section used only three such combinations.

While there are a number of approaches to estimating the basic cost-time-benefit relationships, the approach used in MARRAIS is as follows:

1. The average annual expenditure $\bar{C}_{jk}$, where k = 1,...,k are alternative levels of average annual expenditures on research activity "j", which may be specified to estimators of discrete values initially estimated.

2. For each $\bar{C}_{jk}$, estimates of the time in years to complete the project are made in the form $P(T_{jk})$.

3. For each $\bar{C}_{jk}$ and Exp (T_{jk}), estimates of research benefits in the form $P(B_{jk})$ are made.

4. Using values $\bar{C}_{jk}$, $P(T_{jk})$, $P(B_{jk})$, where "K" is arbitrarily selected and other required information is given or estimated, obtain distributed solutions to equations (5) and (6), for each "j" and "k".

Theoretically, this approach provides discrete approximations to a bounded area of possible values in a plane with benefits as one dimension and total cost, assumed to be minimum-cost resource combinations for each benefit level, as the other dimension. However, $Exp(T_{ij})$ and not $P(T_{ij})$ is used in the computations, along with $\bar{C}_{jk}$ and $P(B_{jk})$. This assumes that for any k = k*, $P(B_{jk*})$ as estimated for $Exp(T_{jk*})$ is the same for all values of T_j in $P(T_{jk*})$. Intuitively, it is clear that the effect of such an assumption is a bounded density space in the cost-time-benefit space where the error of estimate increases going away from the plane cut through this bounded space as defined above. Hence, the estimation error in the solutions increases away from their expected values. As will be demonstrated, this is a small price to pay for the simplifications achieved in the estimation procedures.

In the above estimation procedures the estimation of research benefits $P(B_{jk})$ is performed in two stages: (1) the values of research products are estimated on the basis that research objectives would be achieved 100 percent, and (2) the technological feasibility of achieving the stated objectives are estimated given the constraints of each pair of $\bar{C}_{jk}$ and T_{jk}. Hence, for a given $\bar{C}_{jk}$ the resulting benefit would be computed by

(9) $$B_{jk} = F_{jk}B^*_{jk} \text{ or } P(B_{jk}) = P(F_{jk})P(B^*_{jk})$$

where F_{jk} is the estimate of technological feasibility of the research activity and B^*_{jk} is the value of research products based on 100 percent attainment of research objectives.

This two-step procedure is a logical separation of the two types of information that are inherently contained in any estimate of research benefits. In addition to permitting the obtaining of estimates of F_{jk} and B^*_{jk} from the sources best qualified to provide them, it also permits a procedure, described later, that enables B_{jk} from all types of research activities to be incorporated into a single array of relative value. Since prediction of most technological developments is not well adapted to empirical derivation, it is expected that those professionals who are most acquainted with the state-of-the-arts in each research area are the best sources of information about the technological feasibility of a research effort.

Research costs are the estimated current dollar values of all resources utilized in a research activity. These include salaries and indirect costs of scientists and supporting personnel, costs of miscellaneous supplies and specialized equipment, charges for facilities and services used, organizational overhead charges, and an allowance for the cost of disseminating and/or implementing the new knowledge generated.

The average annual resource requirements for each $\bar{C}_{jk}$, excepting overhead and dissemination costs, are estimated by scientists having the best knowledge of such requirements.[4] Except for the scientist inputs, resource requirements are best estimated in physical units with standard cost rates subsequently applied to obtain total annual costs. This eliminates variations in costs resulting solely from differences in cost rates. Also, scientists are not usually aware of cost rates for most resources. Accounting procedures in public organizations, generally based on initial-cost accounting procedures, do not allocate costs of facilities used to specific research or any other activities. Hence, standard cost rates for facilities usually have to be estimated from whatever accounting records and reports do exist. Overhead costs can be comparably allocated.

In addition to being the largest single cost category, estimations of scientist inputs reflect the efficiency and even feasibility of the research effort. Estimating scientist inputs with a specific scientist in mind presents little difficulty. On the other hand, if scientist inputs are considered as a general category, the interrelationship among quantity, productivity, and salary rates of scientists become an important factor in the estimation. To the extent that salary rates and productivity are directly proportional, estimates in dollars based on a scientist of <u>known</u> capabilities in part circumvents this estimation problem.

For a given research activity, the cost of dissemination can vary, and the rate of adoption a(t) in equation (6) is directly related to the level of dis-

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[3]In the MARRAIS experiment, three levels of resource use were requested: (1) the level that would represent a bare minimum of research effort and still hope to get something done, (2) the level that would represent an all-out effort without simply wasting resources, and (3) the level that the estimator expects to be the most likely scale of effort.

semination cost d(t). Deriving the "best" d(t) would involve simultaneously optimizing a(t), d(t) and the maximand equations. A more practical estimation procedure involves obtaining estimates of the most likely dissemination costs from qualified research and extension personnel. An existing extension structure can be assumed such that the costs estimated represent only the marginal expenditure requirements. For more basic research activities, the costs reflect requirements to get the information into publishable form and the costs of attending the usual number of professional meetings. For applied projects, the costs should reflect (1) ancillary activities required to get the product into implementable form, (2) extension and publication activities, and (3) activities to insure the existence of affiliated activities and structures that would be necessary for the product to become an economic activity.

While research inputs are considered in the context of the neoclassical economics concepts of efficiency, research outputs are usually valued on the basis of their contribution to economic growth through an improvement in the state of knowledge or economic and social organization (c.f., Kuznets, 1962).

The efficiency-ethic (distributional) dichotomy of welfare economics (c.f., Werner, 1968, p. 26) as a basis for benefit-cost analysis, also the basis for deriving the value of research output in MARRAIS, permits only a limited quantitative analysis of how research output obtains value and how this relates to research resource allocation. However, insofar as possible, the value of research output is related to values of the marketing system which, through the pricing system, are relegated the principal responsibility for allocating resources among competing alternative uses.

Much has been written elsewhere about what should or should not be included in the value of research products.[5] With the exception of expounding on one difference of opinion with these sources, I will simply describe how research products are assigned "value" in MARRAIS.

Conceptually, products of basic research obtain value through successive applications in successively less basic research activities until eventually some product or process results which has direct association with market values or equivalent in non-market situations. While possibly valid in _ex post_ analysis, the application of this concept of value in _ex ante_ analysis of value is not only vastly impractical but open to question as _the relevant concept_ of value in cost-benefit analysis. Entirely comparable to the derived values for applied research, the value of basic research results are derived from their value in subsequent, less basic research activities, a process that is seldom entirely known beforehand. Hence, the value of basic research products is what _scientists_ who use that product in subsequent research consider it to be relative to other methods for accomplishing the same thing. Hence, this view of _basic_ research treats its product as being more similar to an electron microscope, for example, than to the product of some _applied_ research activity which will have immediate impact on consumers. (I doubt that consumers of milk or milk products care a fig about the product of a research activity studying the bio-chemical characteristics of the rumen!)

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[5]Werner (1968, pp. 26-51) has discussed the adequacies of both neoclassical and welfare economic theories as desirable constructs for evaluative analysis. Spengler (1962, p. 439) refers to comments by Pareto, Marshall and others which strangly suggest that the influence of the market place might be much greater than superficially evident in allocating resources in non-market situations. Arrow (1962, pp. 609-619) discusses the case where the research product is an invention which becomes potentially a marketable commodity. Prest and Turvey (1965) discuss various secondary effects and under what conditions and how these should be added to or deducted from research benefits. Carroll (1967, pp. 1010-1024) has drawn a distinction between _product_ values and _process_ values, the latter defined as value derived from the research activity itself. Also, other papers in this volume have discussed or alluded to various facets of this subject.

Because of the degree of variability in the nature of the types of research and resulting research products, no single procedure is appropriate for estimating the B^*_{jk} of equation (9). However, there are some general characteristics which provide a sufficiently uniform basis for classifying approaches to deriving research product value. For this purpose, two types of research are identified:

1. Usually applied research which has research products readily expressible (a) in physical units, such as yield increases, or (b) as a percent increase or improvement over existing conditions.

2. Usually basic research which does not have research products that are readily expressible as above, but which are expressible in terms of percent of objective achieved. In some cases the research product value at 100 percent level of achievement (a) may be directly estimated while (b) in most cases it cannot be directly estimated.

The estimation procedures for assigning values to research products are carried out in two steps. For those research activities of the first type above, values are obtained by direct evaluation of increased value, resources saved, etc., in the form $P(B^*_{jk})$. The procedure will nearly always involve both economic and technical scientists who are most familiar with the area as well as industry specialists for certain of the information.

The second type of research product generally cannot be directly evaluated. In the few cases where the value of the objectives, if they were 100 percent achieved, could be estimated, then the procedure would be the same as for the first type above. The remainder of this type would require an alternative to expressing the value of the research product. The method for deriving such values presupposes that any research activity has anticipated positive value from its product, regardless of whether or not such value has expressible form. It assumes that both research activities with expressible positive value of the first type above and those without can be ordered in a common array by a set of preference criteria which reflect subjective estimates about the relative worth of the research products to the achievement of organizational objectives. Further, estimates of "first differences" provide the basis for computing relative indexes of value for the second type of research products in terms of the positive values of the first type of research products.

As an example, suppose that among a set of research alternatives being preordered three projects e_1, e_2, and e_3 are ordered accordingly,

$$P_K\ (e_1, e_2, e_3) = e_1 \succcurlyeq e_2 \succcurlyeq e_3$$

where P_K is a selected preference criterion. Further suppose that e_1 and e_3 have expressible positive values such that $V(e_1) > V(e_3)$, and e_2 does not have an expressible positive value. The implied value of the research product of e_2 resulting from this information can be considered to be bounded between $V(e_1)$ and $V(e_3)$. A specific implied value for the research product of e_2 can be derived by selecting values for "a" and "b" first differences until

$$V(e_1) - a = V^*(e_2) = V(e_3) + b. \quad (10)$$

The method is comparably applicable to a number of e_m and to circumstances where the second type e_m are not so distinctly bounded.

The validity of the resulting ordered array and implied indexes obviously depends on the appropriateness of the selection criteria P_K specified and the selection of the evaluators who determine the ordered array. There are several equally valid alternatives to both of these P_K requirements. For example, where the number of e_m are large, subarrays might be determined on distinctly different P_K and evaluators. A single array would then be determined from these separate ordered subarrays utilizing particularly qualified evaluators and a P_K which represents the total organizational objectives. Basically this method has been described by Bartee (1967, pp. 28-40) in the selection of payloads for scientific satellites.

In MARRAIS, the first differences "a" and "b" are obtained by asking the estimator to specify approximately how valuable (in percentages) he expects the product of a research activity would be relative to the value of the product of the research activity ranked (on the basis of P_K) immediately above it, if all research objectives were 100 percent achievable. Hence, where even only one research activity has expressible dollar benefits, implicit benefit values can be imputed to all other research activities by equation (10). Where more than one research activity has expressible dollar benefits, a weighting scheme based on ranks and first differences is used to impute these values (c.f., Fishel, 1970, pp. 158-161). But, the benefit values B^*_{jk}, whether obtained by direct computation or imputed, are assumed to be the research benefits that would result if research objectives were achieved with 100 percent success and they were fully adopted.

Analysis Steps

The analysis steps include generating "consensus" estimates from the individual estimates of $\bar{C}_{jk}$, $P(T_{jk})$, $P(F_{jk})$, and $P(B^*_{jk})$, and carrying out the Monte Carlo solutions of equations (6) and (7) to generate the distributed maximands R_1 to R_3 based on these variables and other estimated information.

There are actually several methods of obtaining consensus estimates from the individual estimates, each equally valid depending on the information one wishes to convey in the process.[6] While alternatives are available in MARRAIS, the primary method is using either equal or unequal weights, which are specified by the user, to obtain concensus values for "L", "H", "l", "h", and "m",

[6] In the MARRAIS experiment, three different methods each with three different weighting schemes were tested (c.f., Fishel, 1970). There were considerable differences in resulting consensus estimates.

as previously defined, and computing $P(T_{jk})$, etc., by the same method as used to compute individual $P(T_{jk})$. A second method is one discussed by Winkler (1968) in which the weights are applied to "L", "H", ρ, and ν. The latter method includes judgements about the relative dependence-independence of individual estimators by specifying the sum of the weights ω_i to be some value between 1 and $\Sigma\omega_i$. Consensus estimates of each average annual expenditures $\bar{C}_{jk}$ are "double" weighted, by $Exp(T_{ijk})$ and by ω_i for each $\bar{C}_{ijk}$ provided by estimator "i".

The three forms of the maximands given by equations (1) to (3) are computed by obtaining solutions for equations (6) to (7) utilizing the Monte Carlo procedures and distributed values $P(T_{jk})$, $P(F_{jk})$, and $P(B_{jk})$ for each average annual expenditure $\bar{C}_{jk}$, along with other information previously indicated. The method involves repeated random sampling from the cumulative density functions of the distributed variables and computing solutions for equations (6) and (7) using these randomly selected values.

The final step is the reporting of the analysis in a form useful to research administrators. Several forms are possible, including the form and information shown in Table 1. In addition, MARRAIS can graphically plot the three maximands R_1-R_3 for each research activity and level of support $\bar{C}_{jk}$. Finally, a "consensus" budget for each $\bar{C}_{jk}$ can be provided, in dollars for personnel and supply requirements and in physical terms for land, facilities, and major equipment requirements both by subcategories.

An Experimental Application

MARRAIS was experimentally applied to nine alternative research projects at the Minnesota Agricultural Experiment Station to establish the likelihood of or extent to which ex ante types of cost-benefit analysis and methodologies have a place in the decision-making processes of public research administration and in what manner they might fit into the administrative framework. By means of the experiment, it was hoped that some substantive conclusions could be reached regarding the efficacy of the various estimation and analytical techniques developed for MARRAIS, in particular those techniques designed to reflect scientists' judgements about the feasibility of inducing changes in the current state of knowledge and the liklihood of success in doing so. It was also hoped that some conclusions could be made regarding whether or not these methods, designed either to reduce or specify the degree of uncertainty in research resource allocation processes, actually represent an improvement in information over that generated by less formal means, and whether or not the information would, in fact, be used by research administrators.

The nine "model" research project statements were developed from a review of approximately 300 active research project reports which in total include about every aspect of research dealing with soybeans. These were provided by the Smithsonian's Science Information Exchange. The nine projects include three that are essentially "basic" (modulation morphology, radiation genotypes, and fat synthesis), three that are "applied" or "developmental" (storage deterioration, minimum tillage, and breeding genetics), and three that generally fall somewhere in between these two categories (soil effects on root growth, herbicidal selectivity, and rotation effects on diseases). Each model project statement consisted of its title, a statement of purpose, the objectives of the research, and a general statement regarding the method of study. The statements were neither so general as to be meaningless nor so specific that scientists would be prevented from injecting some individual interpretation about the scope and method of conducting a project. Also, while most of these projects did have multiple objectives, each project still presented a singular type of "benefit" to be achieved.

The estimates on which subjective probability distributions were generated for the various data required were obtained from scientists located throughout the eastern half of the United States. These scientists either conduct or administer research on soybeans in public research organizations. While such a general survey procedure in practice would likely be much less desirable for obtaining the necessary estimate than of obtaining the estimates from a few highly competent individuals, neither the identity of competent scientists nor any guidelines or method to identify such scientists were or are known. In addition, for this initial effort, it was considered desirable to investigate the variability of responses that might be encountered under actual applications and associate with this variability any characteristics of the estimators that could be readily identified. In particular, it was of interest to examine the question of weighting of estimates based on relative "competence" of the scientists.

An initial mail survey was sent to 170 scientists, 23 of which are located in Minnesota, explaining the experiment and requesting their cooperation and, at the same time, requesting certain professional data from them. This data related primarily to several measures of their experience and of their publication record and a self appraisal of where they visualize their own scientific orientation between "mostly basic" to "mostly applied". A total of 120 scientists responded to this first survey. However, there was a notable rate of attrition over the next two surveys such that only 55 scientists outside of Minnesota and 14 scientists within the State actually provided all of the information requested of them. No formal sampling design was attempted and no statistical significance was attached to the results obtained.

During the early stages of the experiment, while the initial survey and estimation procedures were progressing, a "side" experiment was performed to develop some logical foundation for "weighting" estimator responses. Research administrators at or above the Department Head level in the Institute of

Agriculture, University of Minnesota, were asked to identify and weight those characteristics each associates with those scientists in whose judgement they would place the most confidence, with respect to (1) estimating costs and resource requirements for a project and (2) estimating the relative worth (benefits) of alternative research projects. The one characteristic they all included, personal acquaintance with the scientist, was arbitrarily excluded because not all the scientists providing estimates were known by the administrators. While the answers were quite diverse, there was a general tendency to associate experience and publication record with good judgement in both cases.

A second phase of this "side" experiment had one research administrator, who was acquainted with all of the Minnesota scientists included in the survey, rank those scientists according to the relative confidence he places in their judgements with respect to the same two areas. A comparison of the ranks computed from the several administrators' abstract weightings of scientists' capabilities above and the ranks from the single administrator's subjective evaluation of the scientists' relative ability to make judgements in these two areas provided highly _insignificant_ results, to say the least. In fact, several attempts were made to identify _any_ sort of relationship between the subjective ranking obtained from the single administrator and the characteristics of the scientists ranked. Medial, rank, and sequential correlation tests (_c.f._, Quenouille, 1952, pp. 44-46) as well as regression analysis were applied to both individual and combinations of characteristics, all with no significant levels of confidence in results obtained. Hence, assuming that the single administrator's ranking accurately reflects the scientists' capabilities to predict project benefits, there would appear to be no objective weighting scheme more justifiable than to assign equal weights to the scientists' estimates about the various events included in the experiment. However, despite these results, some alternative weighting schemes were tested.

The second survey requested the scientists to rank the nine projects and provide "first differences" in the rank. Two rankings were requested: (1) rank each subgroup of basic, basic-applied, and applied projects (3 each) according to the criteria--relative contribution to scientific knowledge for basic, relative contribution to the soybean industry for applied, and some composite of these two for basic-applied; (2) rank all nine projects with respect to the relative contributions the research results, if 100 percent successful, would make to the long run well-being of the soybean industry.

Many interesting observations resulted from analysis of the rankings. With only a few exceptions, the rank did not differ much whether equal or unequal weights were used or whether the ranks provided by 20 "experts", those with the highest experience and publication scores, were used. Agreement among scientists in different disciplines, geographical regions, or scientific orientation (basic-to-applied) as to rank was almost totally lacking. The only agreement seemed to be that research on Breeding Genetics offers the most potential and research on Fat Synthesis or on Rotation Effects on Diseases offers the least potential. Of special interest was a rather striking *negative* relationship between the discipline of the estimator and the discipline of the research topic, *i.e.*, to some extent, at least, it would seem "ignorance is bliss" in judging the relative worth of research projects. There also was a notable tendency to reflect the relative importance of problems to specific regions of the country in the rank assigned to a project, which should be expected. Somewhat surprising was the lact of any relationship between the rank of the alternative projects *explicitly* categorized as basic, basic-applied, and applied, with the scientific orientation of the scientists, again as judged by themselves. Finally, in comparing the results of the two different ranking procedures, separately by the basic-to-applied classification and collectively, the results strongly suggest that scientists generally consider that what is best for the soybean industry also best contributes to the stock of knowledge in their scientific discipline.

The third and by far the most difficult survey requested estimates of the resource requirements (costs), time required to complete the project, and the feasibility of achieving a successful outcome, by the process described in the last section. Out-of-state scientists were requested to make these estimates for only one project each, the subject matter of which was most closely related to their individual area of expertise. Minnesota scientists generally were requested to make estimates on two projects, using the same assignment criteria--one by mail survey and one by one of four panel configurations, namely

1. Panel A met and discussed at some length the nature and scope of the proposed project, after which they arrived at (if not agreed on) a single set of estimates.

2. Panel B, after discussing the proposed project, agreed on a single set of cost estimates, but independently estimated the time and technological feasibility estimates.

3. Panel C, after discussing the proposed project, independently estimated the cost, time, and technological feasibility estimates.

4. Panel D, after making independent estimates of the three required data, met to discuss the proposed project as previously. They then independently modified their original estimates based on their reactions to the discussion.

While the panels were not of sufficient size nor the experiment sufficiently controlled to provide a data base that could be statistically analyzed, the results of the effort did provide useful information about how the estimation procedures should be conducted. The method used by Panel D proved to be the most useful, because it tends to minimize the influence of "dominant" individuals on panel estimates. And, it is preferable to the method used in Panel C, which is similar, because it forces some opinion to be formed by each estimator before the estimators discuss the project. Modified estimates did tend to differ from first estimates, except for the "dominant" estimator on the panel.

There was a great amount of variability among estimates of $\bar{C}_{jk}$, $P(T_{jk})$, and $P(F_{jk})$, as was realistically expected before hand. The variability mostly reflected the generality in the experimental projects statements and the basic differences in how estimators tend to visualize a research effort. Some think in terms of grandiose efforts to solve a problem with everlasting finality; others tend to think in terms of neat little packages, solving one piece of the total problem before moving to the next piece; and, there were several gradations between these two extremes. The extent of this difference, revealed in the panel experiments, in terms of size of the cost estimate was substantial and somewhat surprising. This indicates the necessity of either more specificity in project statements administered or, preferably, a repeated feedback procedure, such as the DELPHI method (c.f., Dalkey and Helmer, 1963) or an extended version of Panel D method, to at least narrow the scope of research activities being evaluated.

Other sources of, or reasons for, the observed variation in cost estimates were sought in the professional data provided by each scientist. There was some difference in the realtive level of cost estimates among disciplines. Scientists in botany, plant pathology, bacteriology, entomology, and biochemistry tended to provide estimates well above the average for the more basic research topics and near average or below for the applied projects. Exactly the reverse occurred for scientists in the agronomic and soil sciences. Differences in cost estimates among scientists with different basic-applied orientations were less conclusive. For every project, scientists who rated themselves as being basic-applied consistently provided cost estimates that were relatively higher than those who considered themselves either more or mainly basic or applied.

Variability in the estimates of time required to complete the research activities $P(T_{jk})$ and the feasibility of successful outcomes $P(F_{jk})$ tended to follow the pattern of cost estimates. Two tendencies were readily evident: Expected time required to complete a project decreased and the level of feasibility increased, as well as the degree of certainty in the estimates of time and feasibility, as average annual costs increased. Also, the consensus estimates for all projects and cost levels except three were skewed to the left for time estimates and skewed to the right for feasibility estimates, the three exceptions being symmetric distributions. This latter characteristic seems to suggest that scientists are basically an optimistic lot!

A number of other estimates were made in the experiment. These are only briefly discussed here, because of limited space and because the estimation procedures generally followed traditional methods. The adoption rate used in this experiment was based on findings by Evenson (1968, pp. 53-54), which indicates a 12-year inverted "V" cycle of adoption for research results, but modified by some calculations by Peterson (1969, pp. 18-19), who points out that assuming "in perpetuity returns" actually has negligible effects on computed rates of return to research. Lacking even intuitive foundation for determining adoption-rate parameters for each project, a common rate equation was assumed for all projects: $a(t) = 1 - .775^{t-\hat{t}}$, where $\hat{t}$ is the number of years to complete the project, approximating Evenson's inverted "V".

The direct estimation of dollar benefits, on which imputed benefits for other research activities were based, was carried out on only one project, the topic concerned with storage deterioration of soybeans. With the assistance of technical scientists, marketing economists, and industrial soybean specialists, ranges of estimates were made of the proportion of stored soybeans affected by deterioration losses, the proportion of losses declining 1, 2, or 3 grades, price differences among grades or levels of quality, the difference in loss rates between farm and commercial storage, and the average annual on-farm and off-farm stocks of soybeans expected during the coming years. This information provided the basis for generating a probability distribution of the total dollar benefits that would be expected under nearly ideal conditions.

The two process values included in the experiment--the added value resulting from the increased experience and research capabilities of the research scientists involved, and the value of the training of graduate students resulting from participation in the research project--were computed from the National Science Foundation's National Register of Scientific and Technical Personnel reports for 1966 of agricultural scientists. For scientists, the added value was $300 per added year of experience; for graduate instruction, the added value was $1000 per graduate student.

Because resource requirements for other than personnel and supplies were estimated in physical units, it was necessary to derive some standard cost factors for these. A standard budgeting procedure was used in deriving a use-rate cost for each facility or equipment required, including land (plots), buildings, and major equipment. The use-rate reflected the total cost for using a unit of a resource, such as the amortized value of land, buildings, and small equipment, plus associated labor, maintenance, and utilities costs per unit of resource use. Charges were calculated at different rates for direct overhead (office space and associated services, fringe benefits, etc.) and indirect overhead (libraries, research administration, etc.), neither including costs of the above resources used.

In deriving dissemination costs, several sources of costs were recognized and estimated, namely: a proportion of an extension specialist's time (plus overhead, supporting activities, and travel costs), professional activities of the scientists (mainly speech preparation and travel), publication of results, and implementing facilitative operations or organizations. With the assistance of an Extension administrator, rates for each of these activities and costs were estimated for each project, along with estimates of implementation rate coefficients.

An additional experiment, using the results of the analysis of this estimated information by MARRAIS, involved a three-step presentation of the information to a research administrator for the purpose of determining what effect, if any, additional information to that normally available would have on his decision-making processes. While the experiment was very artificial and quite limiting in many respects, it did provide some useful and interesting information.

The first experiment presented the research administrator with the same project statements presented to the scientists-estimators. In addition, each project statement included a breakdown of personnel and miscellaneous supplies requirements in dollar units and of facility requirements in physical units, a similar format to the typical research proposal. In each case the data used were the mean values of the most-likely cost levels. The administrator was requested to rank the projects according to their relative acceptability, based on the enclosed information and whatever other information he normally would consider and that was available to him.

The second experiment presented the research administrator with the same information as above but also included for each project the annual total cost of all resources, the projected total costs and expected benefits, and the respective B-C and B/C maximands. The derivation of the benefits data was explained, stressing the fact that it was primarily based on information provided by 20 highly qualified researchers experienced in soybean research.

The third experiment confronted the administrator with all of the information generated by the estimation procedures. This included the information contained in the preceding section for each of the three average annual expenditures, the Predictability Indexes, and a graphical presentation of the data on the range of benefits net of costs (B-C), by

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which indicated the mode in the block, the mean in the circle and the mean plus and minus one standard deviation at the end points.

The administrator's reaction to the first experiment was one of reluctance, because significant pieces of information he normally relied on very heavily were not made available to him, namely a review of literature, which scientists would actually conduct the research, what departments would be involved, and what cooperation could be expected in the conduct of the research. The administrator stated that without any of this information on each project, any decision on his part would be meaningless.

The second experiment initially brought the same response as the first experiment and essentially for the same reasons. But, after some discussion about the projects and estimates, the administrator was asked if he could use the benefit-cost information to eliminate certain of the projects from consideration rather than attempting to specify the most important. Once started, the selection process continued to an eventual ordering of all the projects as indicated in Table 2. He emphasized that these were only his <u>inclinations</u> and that many factors would affect his decisions if these were actually proposed. Frequent referencing by the research administrator to the benefit-cost data during the evaluation of the projects suggested that these data were influential to the extent that they provided the administrator some substantiation independently for the conclusions reached by his own logic and information.

While the information in the third experiment did not result in any reordering of the nine experimental projects, several facets of the information did gain the administrator's interest. This interest was directed mainly toward intra-project comparisons and mainly was concerned with the nature of the expected changes in research performance resulting from changes in levels of support.

Table 2. Research Administrator's Ordering of the Nine Experimental Research Projects.

Verbal rating	Research project		Benefit/cost ratio
	Code[a]	Subject	
Highest	A	Nodulation morphology	7.4
Very high	C	Breeding genetics	14.3
Moderately high	B	Soil effects on root growth	13.3
High-service	B	Herbicidal selectivity	18.4
Medium-high	C	Storage deterioration	5.1
Medium	C	Minimum tillage	6.6
Low-medium	B	Rotation effects on diseases	8.2
Low	A	Radiation genotypes	3.2
Lowest	A	Fat synthesis	5.3

[a]A: basic; B: basic-applied; C: applied.

Especially for those projects he considered overcosted in the previous experiments, the alternative of support at a lower average annual expenditure made the information generally more palatable to him, such as the size of the increase in annual costs to achieve the results more quickly. However, he did not relate this to any effect it might have on decisions regarding resource allocations. The research administrator was emphatic that he would like to have this information and that it would be useful, but that it could never constitute the only decision criterion.

It did appear that the information about the projects other than the maximands themselves would be used by the research administrator to gain a better understanding about what sort of research response he could expect from manipulating the annual level of support. These results only suggest that the measures probably would be relied on more as the research administrator became more experienced in using them and as he learned the extent to which he could associate the information they convey with the information he requires for resource allocation decisions.

Implications of the Experiment

There are two questions raised by the experimental application of MARRAIS. The first is a methodological question regarding whether or not and how well information aimed at improving resource allocations could be generated. The second question is concerned with the application of the information generated for research administrators: whether the information would be used in the decision-making process and the impact this information would have on the resulting decisions.

An overall evaluation of the estimation techniques would seem to indicate that these do collectively outline an information system that demonstrates potential for facilitating and improving information used in resource allocation decision making in public research organizations. Despite an obvious need for some further refinement of procedures and techniques, the system could be implemented in a form at least similar to that used in this study. However, acceptability of these conclusions hinges on the acceptability of certain key assumptions on which MARRAIS was based and the relative precision and efficiency of the estimation techniques employed.

A major fault of the system as it is now constructed is in the handling of interrelationships among projects, both with respect to effects on uncertainty and with respect to levels of costs and benefits. An attempt will be made to develop a more effective way of handling this problem, for example, by generating a covariance matrix of research characteristics analagous to that used in comparison of alternative investments (*c.f.*, Hurter and Rubenstein's discussion on the subject elsewhere in this volume).

While the results of the experiment indicated that reasonably acceptable information about research costs and benefits can be generated using MARRAIS, the extent to which the generated information would be applied by research administrators was less conclusive. There was reason to believe that the information would be used, but determining whether or not resulting decisions would actually have been improved as a result of using this information was well beyond the limit and scope of effort of the experiment. The only practical methods for making such judgments would have been to reevaluate the results of the decisions made under this system and contrast them ex post to the results of the decisions made under conventional systems.

Whether or not the proposed information system would notably affect administrative behavior depends largely on the answers to four questions (possibly among others): (1) Does the information generated address itself to a significant problem area of research administration? (2) Is this an area that the research administrator can do something about? (3) Does the information system efficiently perform the task set forth for it? (4) Does the research administrator have the capability to use the system effectively? These questions can only be briefly discussed here.

Regarding the first question, there are many who consider the principal problem facing research administrators is not so much an efficiency issue in resource allocation, which is the primary concern of MARRAIS, but the relevancy issue--what outputs are desired by society and in what priority--which is handled essentially "outisde" of the system. It possibly is true that the principal problem facing nearly all public research organizations is the relevancy issue, but relevancy is only broadly defined. What might be considered a relatively contained consideration at one administrative level may be a relatively broad consideration at another. There may be many alternative methods of satisfying a "relevant" area of research. Hence, while relevancy may be viewed as the predominant problem to some administrators, there still remains the task of allocating research resources in an efficient manner among alternative demands for these resources. Obviously, the one problem cannot wait for an adequate solution to the other, even if the other does have a solution.

The relevancy issues confronted by MARRAIS have to do with the gains that can be made with improvement in the information about proposed research activities. This has several dimensions. First, at an elementary level, there should be a substantial improvement in communications, both within the organization among scientists and administrators and outside the organization with legislatures and client organizations. Communications are simply put on a more tangible, less suppositional foundation. Second, even if a research administrator could not point to specific gains by using the information, he should feel more confident that he is at least reducing the changes of making a wrong decision. Third, knowledge about the uncertainty of research alternatives would tend to increase the environment of research alternatives considered by the research administrator. Knowing the pattern of returns and the uncertainty associated with these returns might make some research efforts acceptable that were formerly not acceptable. The principal gainer here should be basic research, which has been described by Tweeten and Schultz (among others) as being relegated the "hind tit" as far as the allocation of resources are concerned, because basic research would be meeting applied research on an even level of comparison.

One very relevant issue brought to light in the experiment was the fact that resource allocation decisions are currently being made on the basis of only two-thirds (and in some cases substantially less) of the total cost of conducting research projects. And, even this cost basis is notably distorted by existing accounting practices. The difference between the cost estimates generated by MARRAIS and those normally found on project proposals is demonstrated in Table 3 by comparing the total costs to the costs included in the first two cost categories for one of the experimental projects. In practice, the costs of other resources are hidden under the practice of charging a flat percentage of personnel (or scientist) salaries to cover all of the indirect costs, regardless of the amount of "indirect" resources used.

Table 3. Comparison of Cost Categories for the Experimental Research Project About Rotation Effects on Diseases.

Resource cost category	Costs		Percent of total	
	(thousand dollars)			
Personnel	24.9		54.1	
Miscellaneous supplies	4.1		8.9	
Total annual costs		29.0		63.0
Land	2.6		5.7	
Facilities	6.4		14.0	
Other miscellaneous	.2		1.1	
Total non-annual costs		9.3		20.8
Total direct costs		38.3		83.8
Overhead costs		7.7		16.2
Total costs		46.0		100.0

The practice of accounting or not accounting for costs of all resources used could result in a different relative order of project selection under a formal selection scheme such as MARRAIS. For example, it was observed that the "reported" costs (personnel plus miscellaneous supplies expenditures) as a percent of "total costs" varied by as much as 7.2 percentage points among cost levels for one project and as much as 11.1 percentage points among different projects for the same cost level. The implications become even more significant when comparing low-facility-using social science research with high-facility-using hard science research in selection scheme that uses a common indirect cost rate for both.

Regarding the second of the four questions, there are several factors which suggest that the research administrator may be substantially limited in his capacity to reflect in his decisions the efficiency information provided by MARRAIS. Some of these are only mentioned here. First, there is a duality of objectives in conducting research by scientists in a university setting. While research conducted even in private colleges increasingly can ill afford to disregard social relevance in topics investigated, still the values attached to research selection in universities are variant from those attached to state experiment station research. Second, one of the realities of administering a public research organization is to justify to legislatures the continued support of the research plant, which in turn requires maintaining a broad base of support from among the clientele served. Some activities justified on this basis would be difficult to justify on the basis of their benefit-cost maximands. Third, a seemingly universal objective of research administrators is the growth of their organizations, measured by the amount of resources available, can also be the source of non-optimal allocations based on benefit-cost criteria. The basic reason for this is that funds for research originate from several sources, some of which represent "extra" research opportunities that are marginal to the on-going research supported by core budgets. A distinctly different set of selection criteria are applied to these marginal funds. Fourth, it does take time to phase out existing research programs and tool up for new ones. In addition, the research administrator must balance what he considers the long run cost of maintaining a less than optimum research mix against the expense of dismantling and subsequent tooling up in specific area of competence. Finally, there would be internal pressures to resist the application of MARRAIS on a broad scale, because its application would require that scientists and other individuals outside of a given department evaluate proposed projects. It is doubtful that such a loss of autonomy would be very palatable.

Regarding the third of the four questions, a general reaction would be that MARRAIS can do some evaluative efforts efficiently. The relevant question is: How big an evaluative effort can be justified on the basis of efficiency? The real cost of applying the estimation procedures would be in the amount of time taken from scientists to make the estimates required, not in operational costs. For the relatively simple projects included in this study, it was estimated that on an average, about 20-30 minutes per scientist were required to do the ranking and first difference estimates and as much as 40-45 minutes were required per scientist for each project to complete the cost-time-technological feasibility estimates. Additional time would be required to evaluate the direct benefits that would be expected for the applied projects or program efforts which serve as the payoff value base. Even with experience the time required for the first two estimates would not be expected to diminish and in all likelihood would be greater because projects would be more complicated and scientists undoubtedly would devote more serious attention to making the estimates. The total cost in time and effort would be dependent on the number of projects and programs evaluated, the number of estimators making the evaluations on each one, and the frequency with which each of the projects or programs would be reevaluated.

Considering that the research administrator would restrict his selection of estimators to a relatively limited proportion of all scientists within the organization, the application of the proposed benefit-cost estimation procedures in their totality and to all research efforts that might be considered by the research organization would be an obvious unrealistic drain of the better research talent. The discrepancies between the benefit-cost maximands of current versus possible research efforts would have to be quite enormous to justify such a cost. Hence, from this standpoint alone it could be expected that the application of the system would be limited to only the more important comparisons as determined by the research administrator.

Regarding the fourth question, it would be my observation that the research administrator, himself, would have to go through some possibly agonizing changes in order to make the application of MARRAIS effective. First of all, he would have to be willing to give up more of his control overthe allocative process, which is implied in the delegation of information generation procedures. (Control of decisions and control of the information on which decisions are based is synonomous.) In addition, because the familiar characteristics of the basic estimates are "lost" during transformation in the analytical procedures, the administrator would have to learn to <u>trust</u>, almost at face value, both the sources of the estimates and the products of the analytical processes. Many of the currently implicit decision criteria <u>would</u> become explicit, whether or not the administrator wished it to be; the administrator must be willing to live with this "baring of the soul" and all that it implies. Finally, research administrators would have to gain the skills of professional investors in order to effectively interpret the information presented him. Hence, it is just not the bench scientists that would have to change with the implementation of such methods as MARRAIS.

In view of the forgoing, will techniques such as MARRAIS be used by administrators of public research organizations? If they are, to what extent will they be used? As a minimum, it can be concluded that we are a long way from seeing such techniques being employed as <u>the</u> allocator of research resources. Neither the current state of development of allocative techniques nor the temperament of the research establishment in the public sector are up to what would be required of them. At the same time, if nothing else, management information systems of this type do have considerable potential for relieving research administrators from a large portion of their information generation activities and at the same time improving the scope and quality of the information used in decision making, leaving them more time to be administrators rather than information collectors. In addition, studies such as the MARRAIS experiment, can provide knowledge about the research process which, I doubt, is even available to administrators through intuition gained from many years of experience. Such advantages as these and an increasing pressure on research administrators to make correct decisions suggest to me that some sort of method like MARRAIS cannot be ignored by administrators much longer.

I would suspect that the nature of MARRAIS-type applications for the next few years will be in the nature of experiments or special studies of the kind described here. This will be applications to rather specific and bounded topics where impending critical policy decisions require substantially more information than is available at present or by traditional methodologies. However, with refinements in techniques, there will be venturesome administrators willing to gamble on applying advanced management information systems in their organizations, across the board. And, as so familiar to those of us in agriculture, the rest will follow.

As a final comment, the proper role of quantitative techniques in the decision-making process of agricultural research administrators has by no means been finally determined as a product of this experiment. Undoubtedly, it will evolve only from a gradual chipping away at our rather formless rock of unknowns through many individual efforts like those reported here. Although the composition of this rock, as so frequently suggested, may well be granite rather than limestone, even granite will eventually take form under a patient hand. It seems to me that a more difficult problem may be convincing enough scientists and administrators that the number, magnitude, and complexity of the problems encountered are indeed penetrable and that the outcome is well worth their support.

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