Some Criteria for Priorities of Research in Driving Simulation

Difficulties in Their Measurement And Application

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•PLANNING FOR simulation research priority should be undertaken with some care because of the importance and potential value of products of such research, as well as its cost. Study of unimportant side issues or of poorly productive problems, wastes effort, time, money, and potentially, suffering and lives which might have been saved with a better-ordered research program.

Many attempts have been made in industrial and government laboratories to set up priority criteria. Where feasible, quantification has been applied. Mostly it has been possible to do this where payoff leading to realization of the objectives can be quantified; e.g., where payoff is money. In the military, the value of a weapons system is more difficult to measure. On the other hand, estimates of probability of success of the research can be made; this can be done more securely, the closer to engineering the task gets. In one sense, this case is similar to that of accident prevention, where a countermeasure is also contemplated. In the latter case, however, the countermeasure is not so clearly envisaged, nor can the fact of its identification, or of its achievement as a technique, be a measure of the success of the research. The probable success to be expected if it is applied must also be estimated.

There are various ways in which research originates. In other fields the origin of the research idea is similar to that encountered in basic research. In Weschler and Brown (20, p. 20, ff.), reference is made to the consumer; in the Navy to need formulation by the Chief of Naval Operations; to conferences; to technical levels within the organization; to occasionally high-level decision where a lack of knowledge or dearth of products may be known to exist; to previous work; and to results of an evaluation team. "The evaluation team itself, in fact, may be a research project" (20). Whether or not to do certain researches in the military is most often determined beforehand at command levels by a comparison of the effects of countermeasures, if they were to be developed. In accident prevention, however, the decision to do research is often based merely on the fact that something is unknown, without determining whether the knowledge derived from the research would have any value in reducing accidents.

But in whatever way a research is chosen, in the present field there is no sense in carrying it out without knowing its consequences. By its very name, accident-prevention research has an objective. If one does not measure against that objective, there is no point in doing the research. And, in fact, everyone who does research has said by implication, even if he does not formalize the evaluation, that he thinks there is enough value in the potential outcome to be worth the cost.

It is important, therefore, to have a measure of conformity to objectives in making decisions about research priority. This implies some estimate of the product of research, the ways the product can or will be used, and an estimate of the degree to which the outcomes of research will satisfy the objectives. In the present case, intuitive implication of payoff by a researcher before the fact is not dependable. There must be objective specification of estimated payoff before the fact.

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Weschler and Brown (20, p. 29) cite the criteria mentioned most frequently in a conference on evaluating research and development: financial—cost, profit, capital risk, utilization; feasibility and the need for the product; motivation of researchers; and schemes for evaluation of proposals. The California Research Corporation (20, p. 40) names these criteria: research aspects: probability of success (relating to research results only), research cost, time and other; economics: cost, payoff, investment, time, other; manufacturing aspects: operation; probability of successful commercial development (the last three are equivalent to implementation of a countermeasure in accident prevention); and last, overall appraisal. In all cases there were three levels for each measure. This is fairly realistic, in view of the uncertainties involved.

Most of the attempts at quantification have been made by commercial organizations, which have a much easier criterion to work with than government or other nonprofit organizations (10, pp. 6-8). One example (6, referring to Olin Industries, p. 22) is

$$\text{Project Value-to-Cost Ratio} = \frac{\text{Estimated Return}}{\text{Estimated Cost}} \times \text{Prob. of Success}$$

Several companies use analogous formulas.

Another example is Feeley's own statement of numerical rating of various criteria, resulting in an overall appraisal value (6). After applying an Index of Return formula

$$\text{IR} = \text{Total Estimated Return/Total Cost}$$

the IR is weighted by a factor involving a relationship (only shown graphically) of net profit to total future cost, which is then multiplied by an original rating assigned by a review board. Different projects are passed through this procedure and acquire relative numerical ratings, leading to priority selection. If payout period is very important, this may determine the weight assigned to IR instead of the factor relating profit to future cost.

In traffic safety, very few estimates of rank of priority have been made. For example, one of these described a numerical basis for rank (15). The data came from 944 returns on a questionnaire sent to safety educators, asking for opinions about certain research needs presented to them for rating. The basis of rank for a given project was weighted-sum-of-usefulness ratings. The projects were divided into survey and experimental study results. The highest ranking experimental (sic) study was "The characteristics of drivers with continuous records of safe driving." Unfortunately, the basis of the judgment of usefulness could not be determined from the results.

In general the problem faced in a simulation research program is the same as any research priority problem, but with the assumption that certain valuable tools are available in a given research facility. Where it may be possible to create new instruments, or to use other means of research (not all organizations can do on-the-road research), the problem becomes mixed. In that case, part of the question has to do with the relative priority of carrying out researches on the existing instrument, improving it, building another, or using means other than simulation. However, the problem of such decision-making can be subsumed under the general one of ordering research, inasmuch as the values associated with building new research instruments or applying specified techniques of research are included as criteria for research priority.

Some of the steps listed in the following were implied in the commercial formulas, but because the steps are often not specifically laid out there, one can only infer what the research director intended to assume or make estimates of, and what he intended to measure carefully.

The priority-determining steps to be applied to a list of researches are set forth in a statement of general approach with the express intent that the steps be not considered either as the only ones possible or as having only this sequence. Nor are they, as given, intended to be taken as final expressions of their best form, even if the particular steps mentioned are used in any given case. After the statement of general approach, particular formulations are given, followed by an illustrative example and a discussion of some of the considerations involved in the process of deciding.

IMPORTANT CONSIDERATIONS AND ASSUMPTIONS

Research List Sources

Lists of traffic safety researches are available from many sources. Some do not consider particular researches at all, but mention only general areas, or broad questions. Almost none names particular projects. Most describe mixed types of activity, some broad problems, and some particular projects.

A few sources of suggested research can be given, with some examples. Every issue of "Traffic Safety Research Review" (19) lists ongoing studies of many kinds and reflects the tenor of current activity. A list resulted from a 1956 conference on safety education (13). Two general areas were relevant: "general safety education" (59 research questions) and "traffic safety and driver education" (50 research questions). An example, randomly chosen from the latter, is "What predriver-education instruction should be given at the elementary school level and in junior high school?" Another list can be found in proceedings of a research correlation conference (18). From many suggestions, a special high-priority list was made up by the conference, consisting of 8 items. The eighth one happens to be of greater than ordinary interest for the present discussion: "As a research tool, development of an accurate simulator for driving." Other general lists can be found coming from various sources (9, 11, 14, 15).

Objectives

Objectives and some criteria may be the same. In this case it is assumed that the major objectives are the same as the major payoff criterion: the prevention of death and injury and the mitigation of injury and sequelae. They need not be the same. However, inasmuch as injury is usually associated with accidents, the researcher would therefore be interested in the prevention and mitigation of accidents as a means to these ends. Some organizations are principally interested in increase of basic knowledge. Some are concerned with efficient and inexpensive traffic flow, as well as accident prevention. Some are interested in research, whether in safety or in other fields, for training and teaching purposes. Some are mostly concerned with earning money through research.

As an example of a restriction based on the kind of objective, in this discussion only human factors in traffic safety are considered. Where there is mixed research subject matter, or doubtful content, a detailed analysis is necessary in the phase requiring assignment of values to research criteria. Meanwhile, researches obviously not concerned with human factors are not considered here (e.g., road material composition which reduces skidding).

Required Characteristics

A research activity must have certain qualities to be evaluated by anyone, whether they are directly stated or implied.

The possible outcomes of the research must be specifiable in advance as to type of information to be derived. As a necessary condition for this requirement, the degree to which an answer is not impossible (this is, in a sense, a kind of confidence statement about the reality of an observed change or difference) must be determined.

An additional condition demanded in the present approach is that all researches be carried to their logical conclusion. That is, it will be assumed that any research to be carried out will carry with it the expectation of a result aimed at payoff as previously outlined. The information to be gained (as a means of approaching payoff measure) is the result of the whole series of researches in a program or area. Thus, areas of research cannot be judged here until broken down into specific programs (or occasionally projects) with a stated sequence of researches and with known types of information emerging from the research series. When that is done, an estimate can be made of possible countermeasures and their probable success. By this means, diverse areas of research can be compared. But more, without the actual countermeasure, or at least a good guess at it, no payoff measure can possibly be estimated and hence no value attached to the research. It really makes no sense to say "We work in the area of alcohol and drugs because of their known importance in relation to accidents." The statement would better be expressed if something like this were added: "In this area, the following programs and projects: 1) ..., 2) ..., will give the following information: 1) ..., 2) ...,". With this information an estimate of effective payoff can be made. Without it, there is no idea whether the researches, whatever they are, would be any more than interesting intellectual exercises.

Moreover, certain other conditions must be fulfilled. The measure of desirability or worth of any research rests on the assumption that enough information is available about the research to carry out the evaluative process. This means that for any criterion named, a measure of that criterion should be available, however gross, however vague, with whatever uncertainty. Some important criteria are personnel, money, and time needed. To specify these, the researcher must have some idea of the design of the project. In addition, an estimate must be made as to whether a research can be done at all. Only after considering the method can this be determined. For example, in trying to tell how many traffic fatalities are actually suicides, it would be quickly established that the problem is very severe, and that a good solution—at least, one which produces confidence—is not easily evident.

This imposes a difficult task, inasmuch as at least a general approach to a problem solution must be available in order to make estimates of the criterion values.

Some researches to give examples of these considerations are, as follows:

1. Determine the validity of a particular driver-trainer for training purposes. In this case, relationship to injury and death is not clear, because in order to decide to consider the question as a research project one must first (or perhaps later) show that differences in validity lead to different payoffs. This has not been shown for any instrument. In fact, the only evidence available shows, in general, no difference between driver educated with and without trainers. This information has no bearing on the problem at hand. Thus, doing the required research alone leads to complete uncertainty as to the effect of the findings on payoff. The research cannot be put through the computational mill for priority because no value is given for the major criterion, payoff. This forces one of two actions: either abandon the research or put into the program a project or some means to establish the effect of validity on payoff. The outcome of this project would be guessed in advance (as with all unresearched projects), in order to assign a measure for purposes of priority valuation. Such guesses might, for example, come from a panel of sophisticated judges. (Would not determining accuracy of such judges be a valuable study?)

2. Examine characteristics of risk-taking behavior in the alcoholized driver. This question might be proper if given a little specificity. If there were an answer, it might reveal facts about increased or decreased tendency to make assumptions about the driving environment and the driver's car at different levels of alcohol among a large enough group to allow a feeling that the data had stability. Risk-taking would have to be specified by some measure, either for a task strongly resembling driving in its risk and hazard characteristic or one where the task is actually live driving.

No decision can be made on action resulting from the research outcome without making sure that increased or decreased risk-taking is associated with accidents. Therefore, a second research must form part of the program. It must be separated, of course, from the tendency to accidents due to other effects of alchol, and would probably be better examined by itself. Thus the problem is now: "Examine the effect of various levels of alcohol on a broad sample of drivers in respect to certain defined risk-taking measures. We assume associated research—not necessarily this project, but considered as a needed concomitant—on the effect of risk-taking on injury and death." If the research results lead directly to action and need no further information before recommendations are made (whatever they may be), one important requirement for listing as a research project is satisfied. The estimate of effect of risk-taking on injury and death can be made by many means, e.g., operations research, direct experiments leading to inferences, direct estimates from statistics. The estimate of judges about payoff, if used, is also required in advance of the study for priority estimation.

Thus, in using a payoff criterion of saving lives and reducing injuries, one is forced to set down the intermediate steps which must lead to the payoff. Otherwise one only deludes oneself if he is all for research and says vaguely, "We need to know the causes of accidents before we can suggest ways of improving the situation." Only in very particular, special cases can one assume an outcome whose payoff value is likely to be high no matter what the outcome of the research.

One might cite a negative finding as being valuable but even this must be useful only in terms of the remaining action alternatives always implied.

The matter of basic research is considered in the Discussion.

GENERAL STEPS IN PRIORITY SELECTION

The decision-making steps can be arranged in various sequences, but may follow somewhat along these lines:

1. Define the research tools, including simulator(s) and field facilities on which the research may be carried out. Implied is the restriction that researches will not involve equipment beyond what already exists except when the cost of new equipment can be included as part of a project. In defining the simulator(s) to be used as research tools, their input possibilities and the kinds of measures that can be made are described. These can then be reviewed when the limiting criteria are examined for elimination of researches to be done by a given technique.

2. List the limiting criteria—properties which make a project impossible regardless of other considerations: cost, time, negative payoff, equipment, personnel, mission, policy, etc. Define these in specific terms; e.g., eliminate all projects over X dollars or those falling outside the organization's mission. It is often convenient to carry out some elimination of projects while they are being listed for consideration, inasmuch as the limiting criteria are so evident and so binding, in many cases. This process is shown in the example.

3. Set forth criteria which can be used in evaluating priority of areas, programs, and projects not eliminated. Some of them may deal with the same characteristics as some limiting criteria, but in these remaining projects the value of the characteristic has not exceeded the limiting value. A good list will take much soul-searching, as well as much detachment. The detachment is needed in order not to miss certain criteria not immediately recognized as items determining research, such as public opinion or personal leaning. Soul-searching may come into the picture in assessing and setting down for all the world to see certain unpleasant criteria such as the director's or researcher's biases

4. Examine means of applying measures to the individual criteria. The word used here is "examine" rather than "determine" because it may not be practically possible, for some cases, that one can assign measure, or afterwards even make sense of it. By "measure" is meant a numerical assignment reflecting the degree to which the project has the particular characteristic in question. It is possible to find such measures with concrete meanings rather than to do so on abstract bases, as mentioned below.

The criteria here will be of three types: cost criteria (in money, personnel time, machine time, removal of teaching time, etc.); payoff (in a measure suitable to the objectives); and modifying criteria (which alter the value of either payoff or cost). Most considerations which are not obviously cost or payoff fall into the modifying category: e.g., risk of duplication of research by other organizations. In general, a payoff criterion P_i will be calculated by estimating maximum possible payoff P'_i with respect to a given variable and diminishing by attenuation with factors p_i relating to likelihood of finding and implementing countermeasures, their probable success, and the length of time before implementation. The cost criteria, C_i, are expressed in common units; likewise the payoff criteria. The modifying criteria may be either additive constants, k_i (payoff), and k^*_i (cost), expressed in the same unit as payoff or cost (depending on which is modified), with zero as the normal value; or as weights, w_i (payoff), and w^*_i

(cost), with one as the normal value to be applied to the gross cost or payoff scores as multipliers. These considerations will be expanded in later sections.

5. Determine means of combining criteria into payoff and cost measures: the payoff criteria P_i (in common units) and the cost criteria, C_i (in common units), are respectively summed to raw payoff and cost scores, P_G and C_G. Now the modifying criteria w_i are applied to obtain adjusted cost and payoff scores, C_A and P_A. Finally, to arrive at one overall priority rating for the project, there are two ways in which the cost score can contribute to this overall measure:

a. In the first method (method a), a weighting value, F, in terms of probable payoff per unit of cost within the program, can be applied to the adjusted cost score so that the weighted cost score will be in payoff units and can be directly substracted from the payoff. To the extent that this weighting factor, F, really estimates payoff per cost unit expanded, the weighted cost score, FC_A, is a proper measure of how much potential payoff is lost by the consumption of this amount of cost. Problems and techniques of obtaining such a weight are discussed later. The difference between adjusted payoff, P_A, and cost converted into payoff units, FC_A, will be the priority value, R_a, and projects can be ranked accordingly.

b. In the second method (method b), the cost potential for a stated period is specified corresponding to each of the cost measures stated in 4. All sets of projects, for which the sum of the cost measures does not exceed the cost potential of the organization (or any individual cost measure) are determined. In other words, all combinations of projects possible in terms of cost in the specified period are determined. If more than one simulator is available, and/or both simulation and other research are to be considered, then the various combinations must include all different ways of doing each project.

For each project in each set an adjusted payoff score is determined, just as in method a. The sum of the adjusted payoff scores for projects within a set results in a priority value, R_b, for the set as a whole.

Of course, combining of criteria can be done in a number of ways. The foregoing seemed reasonable on first analysis.

These schemes are described symbolically in Table 1.

6. Decide on techniques of applying the priority rating, R, to set up and maintain a program. Alternative 5b results in a program immediately by choosing for each simulator the set of projects which would be done in the order of priority value. However,

TABLE 1

Item	Payoff Measure	Cost Measure
Maximum possible payoff	$P'_1,\ P'_2,\ P'_3, \ldots P'_m$	
Attenuating factors	$p_1,\ p_2,\ p_3, \ldots p_k$	
Individual criteria (in comparable units, after applying attenuating factors)	$P_1,\ P_2,\ P_3, \ldots P_m$	$C_1,\ C_2,\ C_3, \ldots C_n$
Raw combined measures	$P_G = \sum_1^m P_i$	$C_G = \sum_1^n C_i$
Modifiers:		
Multiplicative weights (positive, with normal value 1)	$w_1,\ w_2, \ldots w_r$	$w^{\#}_1,\ w^{\#}_2, \ldots w^{\#}_s$
Additive constants (positive or negative with normal value 0), and the same units as used for raw measure (e.g., deaths saved or dollars cost)	$k_1,\ k_2, \ldots k_t$	$k^{\#}_1,\ k^{\#}_2, \ldots k^{\#}_u$
Adjusted measure	$P_A = (w_1 w_2 \ldots w_r P_G) + k_1 + \ldots + k_t$	$C_A = (w^{\#}_1 w^{\#}_2 \ldots w^{\#}_s C_G) + k^{\#}_1 + \ldots + k^{\#}_u$

Weighting factor:

Priority Rating (method a), determined for each project and each research mode (field research, simulator No. 1, No. 2, etc.): $R_a = P_A - FC_A$

Priority Rating (method b), determined for each set of projects $R_b = P_A$, over projects in the set.

this may not always be possible. For example, the two projects with highest priority may be too expensive (in any of the cost measures) to do together at one time. A maximum priority combination within the cost limit can be found by method b. In some organizations the second project could be done part-time until the first is completed. However, if the organization is such that projects must be done in units of time and not on a continuing basis, the first and the second projects could not be done together and if it were decided to do the first and third, there is no certainty that that would be as good as the second and third or some other combination. The solution is provided by using method 5a in these types of organizations.

7. Define the operations which will provide numerical values of criterion measures. In general, the use of judges seems one reasonable approach at the moment, but the type and source of judges must be decided very carefully, because measures derived from their opinions are critical. Other approaches may involve operations analyses, which are minor or major research efforts themselves. The director alone may be the judge, or a panel from the organization or of outside experts in the field may be used. Different judges may be used for different measures. For example, it may be desirable to use outside judges to set raw payoff scores and judges from the organization to determine the cost and modifying criteria (e.g., policy factors). The type of average used to combine measures from several judges must be specified as well as details of the instructions to be given judges.

APPLICATION OF MEASURE AND PROCEDURE

1. List and specify the design of a set of possible researches as general areas, programs, and individual projects. Of course this implies, as mentioned above, a previous statement of objectives of research, which will set boundaries to the research list. Other boundaries will be imposed by consideration of nonobjectives and other limiting criteria. For example, an organization may be forbidden research which is another organization's prerogative. Let us assume that these objectives have been set forth and have formed a general basis for describing the list of researches. In effect, certain of the limiting criteria can be applied at this stage, saving the necessity of designing studies which will be eliminated later. But even then, often the mere research statement implies a method and an outcome, and permits a decision as to the applicability of the criterion measures. At any point in the process of design, the limiting criteria may be found to eliminate a project.
2. Eliminate all projects not meeting the limiting criteria.
3. For each project, obtain numerical estimates of criterion values on each simulator and other research mode.
4. Combine into priority ratings.
5. Determine program by methods decided on in part 6 of "General Steps."
6. Re-examine the whole picture periodically, based on developments, especially part way through projects.

EXAMPLE OF AN APPLICATION TO A PARTICULAR ORGANIZATION

Some details of applying these steps to needs in a hypothetical organization are discussed, together with actual estimates for two research projects.

1. Formulation of Measures and Procedure (definition of research tools—specifically, modes and organization, with application of a few limiting criteria in the process).

In the given case there do not exist the personnel or capabilities of running a field facility. In addition, only one simulator will be operable by the time the project starts. It will be capable of long-term runs; it will have acceptable visual resolution at distances greater than 25 ft; it cannot deal with intersections, interchanges, or turnoffs; it can interact with moving cars, both coming toward it and overtaking; short-term runs are likely to have low validity; etc. Only contract and in-house work are possible. In-house research is not feasible now. Within the contract type of project, only research to be done on the simulator is considered. Because this is contract work, available funds limit total personnel outlay, but do not limit the numbers at any given time.

2. Some Limiting Criteria Forcing Rejection of a Project.
   - (a) Cost exceeds "X" dollars.
   - (b) The research deals with road design characteristics.
   - (c) The research does not include work for a particular personnel specialty. (Otherwise stated, a particular person must be fired.)
   - (d) Total research time exceeds "X" months.
   - (e) The research deals with another agency's bailiwick.
   - (f) Simulator hours exceed "X" hours.
   - (g) Director's time exceeds "X" hours per week.
   - (h) Expectation of zero or negative payoff.
   - (i) Design involves curves in road, or intersections, eliminating use of existing simulator.
   - (j) Project does not give a result in terms of a factor such that death or injury could be reduced by eliminating, reducing, or changing the effect of the factor.
   - (k) Design requires short-run drives.

3. Some Possible Criteria.
   - (a) Payoff criteria.
     - (1) Reduction of deaths in the next 15 years as a result of the research.
     - (2) Reduction of injuries in the next 15 years as a result of the research.
     - (3) Not used here: earning potential for profit-making organizations.
     - (4) Not used here: training potential for graduate students.
   - (b) Cost criteria.
     - (1) Cost in dollars for the project.
     - (2) Not used here: cost in injuries or lives of doing research.
   - (c) Some possible criteria modifying payoff.
     - (1) Relative importance of preventing deaths and injuries in various population groups.
     - (2) Value of project for future research support.
     - (3) Biases of organization; e.g., policy considerations at various levels, consistency with previously announced research, attractiveness to researcher, and inertia of ongoing studies.
     - (4) Unpleasantness to experimental subjects.
     - (5) Training value.
     - (6) Public opinion.

4. Measures of Criteria.

(a) Payoff criteria. (P′. Estimate the annual number of deaths in the United States caused by—not just associated with—the factor(s) studied; e.g., alcohol under given conditions, ignorance of driving techniques.)

Then estimate the annual number of injuries in the United States due to the factor(s) studied and translate these into death units by multiplying by a proportion reflecting the importance of reduction of injuries relative to reduction of deaths. Some possible ways of specifying this proportion are as follows:

   - (1) Use the ratio of number of injuries to deaths over the whole national accident picture. This figure would be changed every so often if the ratio changed appreciably in the population. The average figure is known from general statistics in the field (e.g., National Health Survey and National Vital Statistics data). If severity is included, each degree of severity could be applied to the ratio of the incidence of severity of injury to that of deaths. Care must be taken lest the objectivity with which a numerical value can be assigned to this ratio covers the fact that as a reflection of the relative importance of reducing deaths vs injuries, this value is very arbitrary.
   - (2) Ignore minor injuries, and say that if deaths and severe injuries are highly correlated, deaths predict severe injuries and will measure payoff adequately. This assigns zero value to the proportion: importance of injuries compared to that of deaths. However, injuries would be reduced to the extent that they correlate with fatalities.

(3) Judges may assign an arbitrary equivalence ratio to death and injury. For purposes of simplicity, (2) is used in this paper; i.e., only deaths are used as a payoff criterion. Thus injuries are not estimated.

(4) Use accidents as a common measure instead of deaths or injuries, because it reflects both death and injury. With this measure, the differences in death and injury ratio, say between rural and urban experiences, are ignored. A ratio similar to that in (1) would result, but with property damage as a contaminant, while on the other hand, many unreported injuries would be included, as opposed to (2) and (3). Accidents are used here because of the complexity of evaluation required. Elsewhere they may be a good criterion measure.

The figure P', deaths per year attributable to the factor, is the maximum possible reduction of deaths due to the factor. To obtain an estimate of expected reduction in deaths due to the research in the next 15 years, estimate some attenuating factors. Some take the form of probabilities in the following group of a few examples:

p_1: probability that the project as designed will be sensitive enough to demonstrate the effect in question (assuming it exists).

p_2: assuming the effect is demonstrated, the relative contribution of this project to the total information (including that coming from this project) bearing on this factor, expressed as a value between zero and one, one indicating no other information on this factor. This factor should include consideration of the possibility that the project will be duplicated after it is begun.

p_3: probability of finding a countermeasure for the factor studied.

p_4: probability of implementing countermeasures, assuming one or more to exist.

p_5: expected effectiveness of countermeasures, assuming they are implemented.

These multiply to a raw payoff value for one payoff criterion. The other payoff criteria, if not combined, must be treated similarly to get raw payoff values for each.

The product of each P' and these attenuators must in turn be multiplied by a factor reflecting the 15 years minus delay in payoff to reach the final measure—that is, expected reduction of deaths in the next 15 years as a result of the research. The time, 15 years, is arbitrary as a base and could easily be 10 years or 20 years. Estimate y, the total time in years from the beginning of the research to the implementation of countermeasures. Thus, 15-y is the effective number of payoff years. Similar time factors apply to other P' criterion values. Thus the payoff measure for each payoff criterion, assuming more than one, is

$$P_G = [p_1 p_2 p_3 p_4 p_5 P'_1 (15-y_1)] + [p_1 p_2 p_3 p_4 p_5 P'_2 (15-y_2)] + \ldots$$

in which the P' elements are maximum possible payoff associated with particular countermeasures and the y's are the estimated implementation times for these countermeasures.

(b) Cost criteria. (C = estimate of cost of the project in dollars.)

(c) Some criteria modifying payoff.

Each of these will be estimated as a multiplicative weight; i.e., a positive number with one the normal value, where values less than one are adverse and those greater than one favorable:

w_1: relative importance of the population group involved (e.g., children might be weighted greater than one).

w_2: value of project for future research support. (A study with value one neither enhances nor depresses potential for future support.)

w_3: relative importance of biases of the organization in relation to this project, including policy considerations of various levels, consistency with previously announced plans, attractiveness to the researcher, danger or unpleasantness to the subject, program training value.

w_4: relative importance of the expected public opinion about the project.

These weights have been limited to four factors here, but could obviously be expanded.

In assigning values to these weights the object is not to estimate the effect of public opinion, for instance, on the conduct of the project, but instead to judge the importance of the expected adverse or favorable opinion to management. Thus, if the project is expected to result in very poor public opinion, a weight of one may still be assumed if it is felt by management that public opinion is of no importance in this case. These weights can be interpreted in two ways: First, the effect of a weight of two (or one-half) will be to give twice (or half) the weight to deaths reduced by this study. Thus adjusted payoff is given by $P_A = w_1w_2w_3w_4P_G$. Second, a factor of two means that the factor is judged so favorably that this project is preferred to projects saving up to twice as many lives, other factors being equal. This last is a profoundly important aspect of the meaning of modifying criteria and is taken up in the Discussion.

5. Combining Criteria into Priority Rating.

For method a, applied here, an estimate of F, the probable payoff per dollar expended is needed. One approach would be to estimate payoff (based on the measure defined above) per dollar resulting from many researches already done, where costs are known. Then the geometric mean of these payoff-per-dollar ratios could be used as F. This value would be adjusted with passage of time as research expenditure per death and injury changed, or the value of money changed. The comparison is between several researches at any given time, hence momentary equivalence is required, and change of average cost of saving a life is permitted in later comparisons. Currently figures like a few dollars of research money per accident incurred in the population have been seen, but no figures for research money spent per life saved or injury prevented have been seen, either as a result of that research or of general research. In one agency, an estimate of $100,000 used to build a certain type of highway is quoted as the expenditure necessary to save one life.

A second possibility avoids a difficulty inherent in the foregoing approach. Because research with high priority implies high payoff per dollar, the use of the average project to estimate payoff per dollar is likely to yield too low a value for this ratio. It might be better to use estimated payoff per dollar from a series of the most likely of the various researches being considered. This measures more directly the payoff value that would probably be gained from the dollars invested in this project if it were not considered among such a group. There must be an arbitrary decision as to how many of the highest priority projects to include in computing F. Also, before the projects can be ordered in priority, a "guessed" F value would have to be used—possibly resulting from the first approach. The modifying criteria should not enter into the determination of F. F should be the ratio of P_G to C, averaged geometrically over projects. Once the program is in progress, the value for F would be computed from the actual projects which have been recently carried out in the program. For illustrative purposes the geometric mean of the payoff per dollar from the two examples to be considered is used.

The measure is computed from

$$R = P_A - FC$$

6. Applying the Priority Rating to Set Up and Maintain a Program.

It is assumed that projects will be initiated in order of priority until the support potential is exhausted. New projects will be added as support will allow. Some projects can be done part-time to allow full use of money available.

7. Procedure for Obtaining Numerical Values for Criterion Measures.

Judges are used for all measures except cost, which comes directly from the design of the project. A group of "expert judges" will be chosen. They (or their staff) must know the traffic field. They must have skill in research design. They must be able and willing to get help in particular phases of the judging where they feel need of help. They must be aware of research procedures and costs in this field. They must spend the effort to do a conscientious job in spite of possibly not believing in the feasibility of this approach or the possibility of getting good answers to the questions posed. These expert judges will be asked to assign values to the P' criteria, the P_i factors, and y for each project. They will not be given knowledge of the method to be used in combining these into priority measures. They will not estimate w's except in special cases.

Instructions will be brief; the general purpose (priority ratings) will be explained with no further details. The values to be estimated will be defined as clearly as possible and illustrated. Consultation and use of as much helpful information as possible will be suggested. Extreme emphasis will be placed on judging values for every criterion to the best ability of the judge, in spite of the difficulties involved.

From the judged values for each judge, a P_G score—raw payoff score—will be computed and the average of these, over judges, will be used as the P_G value for the project. The payoff-modifying weights will all be set within the organization by the decision of a panel. For w_1 and w_4, the panel will consist of the program's policy makers; for w_2 and w_3, the researcher will also participate.

EXAMPLE WITH NUMERICAL VALUES AND APPLIED CONSIDERATIONS

1. Choice of Researches to Be Considered.

There are difficult problems associated with selection of research questions which are to be ordered in priority. It is therefore necessary to specify, in any technique devised for ordering, whether the researches are given and only have to be operated on; whether they must be conceived as problems out of the total field, and then operated on; whether they can be selected out of a known group and then operated on; or any combination of these. In the present case some approaches to the latter two conditions are indicated, and after a half-way selective process based on rational considerations, two research problems are stated very grossly and put to the technique.

An attempt is made to distill a narrow choice of projects for ordering from a large number of possible unspecified researches. The variables to be considered should be refined from gross areas to very particular variables. From the limiting criteria, short-term driving problems would not be highly valid. The simulator cannot handle intersection problems.

The most frequent conditions associated with injury and death on rural highways (this is where most long-term trips take place) include running off the road, alcohol, rear-end collisions, head-on collisions, and the pedestrian. In the case of alcoholic driving, the length of trip is likely to be short, excluding this kind of study. Running off the road, making up about 28 percent of the fatal and 14 percent of the injury accidents on rural highways (1), is a possible candidate. Under fatigue, a leading possible element in this kind of accident, probable long-term driving is found and fatigue is therefore a possible subject for study on this simulator. It will therefore be evaluated as a research variable. Other possible causes of running off the road are glare of headlights, "highway hypnosis" (a variety of fatigue) and sleepiness (also a variety of fatigue). All of these could be studied here, and are considered.

The case of rear-end collisions may be important. They make up about 16 percent of the rural accidents, and about 5.8 percent of the fatalities (1). This is a possible kind of study on the available simulator. It may involve any of the aspects of fatigue—sleepiness, tiredness, failure of vigilance, reduced perceptual skill, lowered performance skill, etc. In respect to the car, it may involve different configurations of rear lights, opposing glare, and the like. Pedestrians cannot be inserted into the simulator. In view of the limitations of money and time, and the acceptability as research areas of the several accident causes noted, these would be examined first.

One might consider stopping for rational reasons because such researches, sufficient in quantity, may have close to maximum probable priority and others will be unlikely to come close to the priority mentioned. On the other hand, what causes fatigue—reduced perceptual skill, sleepiness, etc.? It is for the very reason that they were selected to begin with—out of experience or intuition—that they would be considered high priority.

All of the variables mentioned have countermeasures; hence, that research on effects mentioned fulfills the requirements for consideration.

In this simulator, C3 can be eliminated (Table 2). A broad countermeasure resulting from simulator study is less easy to conceive for a permanent characteristic of the

TABLE 2

CONDITIONS AND THEIR COUNTERMEASURES ASSOCIATED WITH ACCIDENT BY TYPE

Item	Variable and/or Countermeasure		
A. Type of accident	Running-off-road	Rear-end collision	Head-on collision
B. Examples of conditions possibly associated with accidents not eliminated by limiting criteria, so-called immediate accident causes (2, 4, 7).	1. Inattention 2. Sleepiness 3. Tiredness 4. Glare of headlights 5. "Highway hypnosis" 6. Drugs 7. Skill decrement 8. Perceptual decrement 9. Unexpected curve in road 10. Speed too high for conditions 11. Skid 12. Others are not considered here	1. Inattention 2. Sleepiness 3. Tiredness 4. Glare of headlights 5. "Highway hypnosis" 6. Drugs 7. Skill decrement 8. Perceptual decrement 9. Unexpected curve in road 10. Speed too high for conditions 11. Poor perception on closing	1. Inattention 2. Sleepiness 3. Tiredness 4. Glare of headlights 5. "Highways hypnosis" 6. Drugs 7. Skill decrement 8. Perceptual decrement 9. Unexpected curve in road 10. Speed too high for conditions 11. Skid
C. Some other possible associated conditions, so-called intermediate and distant accident causes (2, 4, 7).	1. Age 2. Sex 3. Weather 4. Experience 5. Exposure 6. Personality 7. Driver training 8. Personal characteristics	1. Age 2. Sex 3. Weather 4. Experience 5. Exposure 6. Personality 7. Driver training 8. Personal characteristics	1. Age 2. Sex 3. Weather 4. Experience 5. Exposure 6. Personality 7. Driver training 8. Personal characteristics
D. Countermeasures	1. Rest pauses 2. Pep pills 3. Attention-arousing or differently organized rear lighting 4. Differential enforcement 5. Alertness indicators 6. Inside-the-car-radio reminders 7. Sleep sidings 8. Monotony breakers 9. Unknown	1. Rest pauses 2. Pep pills 3. Attention-arousing or differently organized rear lighting 4. Differential enforcement 5. Alertness indicators 6. Inside-the-car-radio reminders 7. Sleep sidings 8. Monotony breakers 9. Unknown	1. Rest pauses 2. Pep pills 3. Attention-arousing or differently organized rear lighting 4. Differential enforcement 5. Alertness indicators 6. Inside-the-car-radio reminders 7. Sleep sidings 8. Monotony breakers 9. Unknown

driver, but seems to be more approachable for a behavior of the driver. Such a position is obviously subject to discussion, but for this case, C1 and C2 are dropped. Hypothetically C4 would be used, but these accidents are not, on the face of it, restricted to the young or old. They may contribute more than their share, but to determine why would involve too much of a research project for the present facilities. C5 is irrelevant to a simulator test. C6 could be tested, but it is extremely unlikely that this can be discriminated in such a small research project. Until one can get a sample of driver training groups who have not been selected by their volunteer status, this variable would better be avoided. C8 is possible, and could be considered. A more elaborate analysis could be made of C8.

Meanwhile, fatigue can be produced, possibly covering B 1-10, except 6 and 9, for running-off-road. The same holds for rear-end collision. If, in addition, one can get at B11, the range of this type of variable seems to be covered, even though many other intermediate, associated, or other dimensional variables are ignored. The choices (somewhat arbitrarily, it is true) are therefore personal characteristics, countermeasure evaluation, drugs, any of the separate elements involved in the fatigue process (such as B1, 2, 3, 5, 7, 8, and 10), B4 for all accident types, and B11 for rear-end collisions.

The countermeasure considered for falling asleep may not be the best one, but until one can find a better one, an existing one is best (D). Pep pills are already used, but so much abused that this cannot be used as a possible public countermeasure. Enforcement is irrelevant here in a simulation research. Alertness indicators thus far do not work well (but should not necessarily be discarded for another research). Radio reminders inside the car may work. Others are developing this work, however. Sleep sidings exist, but are not used enough. Monotony breakers self-imposed are not used much, but if someone invents a good external one it will be very useful. One cannot test it here because it has not yet been developed. There remain rest pauses, changed rear-lighting, and examination of as many of the items under B as can be studied incidentally during the test runs. The alternative is to study the items under B separately, the idea being that this information may permit better choice of countermeasure later, or even intensive research or development of a countermeasure not now particularly successful.

There are thus some countermeasures now to be examined. However, because it is known that many run-off-road accidents take place at curves and intersections, it may be better to emphasize rear-end collisions, which are less dependent on road configurations that this simulator cannot produce.

After going through much travail of the foregoing type, it may be possible to eliminate many more research possibilities and get down to a few. Some of the aforementioned reasons were given for examplary purpose, and not necessarily because of a tightly logical elimination process—see, for example, the consideration mentioned in the preceding paragraph. Assuming all the researches have finally been eliminated, the following two remain:

1. Misperception (not sleep) leading to rear-end collisions on turnpikes, with rear-end lighting countermeasures.
2. Drowsiness and sleepiness on turnpikes, with countermeasure a drowsiness-detecting and alerting device.

Project 1.

1. The research would consist of presenting several rear-end configurations in vehicle V_2, which is being approached at various speeds by vehicle V_1, in conjunction with different speeds of V_2, V_3, and their combinations. Countermeasures (e.g., rear-end lighting changes) would be pinned down, validations and cross-validations carried out, and programs initiated.

2. Limiting Criteria.

Most of these have already been mentioned in the foregoing discussion on choice.

3. Criterion Measures.

For Study I, several sources could have been consulted for probable number of lives lost due to the factor: the Pennsylvania Turnpike study (3), the Northwestern study (2), the estimates of some recent studies (e.g., 1, 12), and the like. A value of 3,000 lives/year was used as an arbitrary (probably not correct) number for P'. There is only one payoff criterion, P'. Thus p_1 will be the same as P_G. The attenuating factors mentioned here are p_1 through p_5. For p_1 it is not difficult to detect with confidence the effect of a moderate to strong countermeasure. The value of p_1 is therefore given as 0.90. This research, although important, will probably lean heavily on other parallel work. Hence $p_2 = 0.25$. Countermeasures are known. But even if not known, it is suspected that a highly effective one is feasible. It has been conceived, and no known objections prevent its application. Hence $p_3 = 1.00$. If the countermeasure is found effective, there is a good likelihood that it can be adopted, but not certainly, hence $p_4 = 0.80$. If implemented, the countermeasure might not be wholly effective because other elements enter the picture of rear-end collision based on misperception. The problem cannot be solved completely by this means, hence $p_5 = 0.50$. It is not expected that the countermeasure can begin to be implemented for 7 or 8 years. It should take 5 years or so to saturation. Hence, effectiveness within the 15 years is given as beginning at the midpoint of beginning and end of saturation, 10 years, with an effective duration, 10 years, with an effective duration of 5 years. Raw payoff can be computed now:

$$P_G = p_1 p_2 p_3 p_4 p_5 (P')(15-y) = (0.90)(0.25)(1)(0.80)(0.50)(3,000)(5) = 1,350$$

4. Modifying Criteria.

It is felt that for different laboratories or organizations, a large variety of modifying criteria exist, and only a few can be mentioned here, let alone dealt with. For any single group of researchers, however, the number is probably not particularly prohibitive. Criterion w_1, importance of study, is not biasing in one direction or another in this case. Hence, $w_1 = 1.00$. Criterion w_3, organization bias, is negative, because in this case there is some question about future problems with vehicle regulations, making countermeasures more sticky to deal with; therefore, $w_3 = 0.60$. Criterion w_4, public opinion, is not likely to favor or reject this more than other researches, hence $w_4 = 1.00$.

Now, adjusted payoff for Project 1 is therefore:

$$P_A = w_1 w_2 w_3 w_4 P_G = (1)(1)(0.6)(1)(1,350) = 810$$

Project 2.

1. The proposal would consist of first testing a theory about a means of detecting oncoming drowsiness in advance of its happening, and then, if it is correct, developing and applying a countermeasure. One theory for an approach to this already exists, with supporting data, and estimates can be made of its probable correctness and of the liklihood of developing and applying countermeasures. Tests of long-term driving would be conducted, sleepiness induced, the technique tested, validating and cross-validating studies run, and programs initiated. The method of detecting drowsiness in advance is to use a multiple-electrode device (16). From this, a cheaper detector would be sought, or one which indicated corollary information with the same end product. It would be made available and put up for sale. Among those who drive much, it might find a ready market. Among those who do not, it could be rented.

2. Limiting Criteria.
These have been dealt with in selecting the project.

3. Criterion Measures.
As in Project 1, an arbitrary value was selected for P' (again, only one payoff criterion). In the actual case a best estimate of P' would be made.

4. Modifying Criteria.
As in Project 1, the attenuators p_1 to p_5 are evaluated. First, $p_1 = 0.75$, because there is not complete confidence that the variable in question, discrimination of drowsiness, will be reliably detected if present. The present research is almost the only work of this nature being done, hence $p_2 = 0.80$. It is not likely that a countermeasure will be found; therefore, $p_3 = 0.30$. If it is found, it is not likely to find widespread use: $p_4 = 0.05$. If it is used, it must work well for it to be commercially useful, so $p_5 = 0.98$. The timing arguments lead to y of 7 years and 15-y = 8. P' is estimated at 4,000 lives/year.

Now raw payoff for Project 1,

$$P_G = p_1 p_2 p_3 p_4 p_5 P' = (0.75)(0.80)(0.30)(0.05)(0.98)(4,000)(8) = 180$$

The modifiers w_i, which, as opposed to the p's, can exceed a value of one, are considered. Again, no bias attaches to drowsy drivers: $w_1 = 1.00$. Also, no positive or negative aspects of the work will affect future research support: $w_2 = 1.00$. The organization favors research on degrading processes in the driver, and supports attempts at overcoming them, hence $w_3 = 1.2$. Assume that the public will be slightly more favorably inclined to this than other research, and $w_4 = 1.05$, because the organization attaches importance to public opinion.

Now adjusted payoff,

$$P_A = w_1 w_2 w_3 w_4 P_G = (1)(1)(1.2)(1.05)(180) = 227$$

5. Measures of Criteria.
The research costs for Project 1 are estimated at \$300,000 (probably understated), and those for Project 2 at \$400,000 (similarly understated, perhaps more so). No estimate is made of countermeasure cost because both will involve commercial ventures, and the figures for probability of funding and implementing countermeasures p_3 and p_4 have, in essence, taken into account the costs of production. Where such costs fall to the researcher, or to a public agency in which there is direct cost, not investment, they may be estimated. This portion of the problem requires much consideration (see Discussion).

6. Combining Criteria.

Ordinarily, F, the payoff/cost ratio, would come from a number of high-priority researches. But because there are only two here, they were used. F is obviously common to all researches being ranked. Here F is derived from P_G, not P_A, because the payoff is independent of w_i; e.g., organization bias (although possibly not of judges' fallibility), which only affects the researcher's payoff value, not the true payoff, P_G. Thus

$$F = \left[(P_{G_1})(P_{G_2})/(300,000)(400,000)\right]^{1/2} = 0.0014$$

Remembering that the priority of any research is expressed as

$$R = P_A - FC$$

separate values are derived for each research in question:

$$R_1 = 810 - (0.0014)(300,000) = 390$$
$$R_2 = 227 - (0.0014)(400,000) = -335$$

Hence, Project 1 is preferred to Project 2.

DISCUSSION

The present paper is felt to have particular use—whatever other values it may have or lack—in emphasizing the existence and importance (unrealized in many cases) of certain criteria in making decisions about what research to do. However poorly one may regard the validity or even the feasibility of the present approach, if one goes through the motions of estimating values for the various criteria, certain assumptions made about relative value come startlingly into view.

1. In estimating P', extent of the problem, one must examine just how much of a dent would be made if the problem were solved and a countermeasure implemented. For certain problems P' is quite unbelievably small. Only by specifically asking and answering, or making a best guess if the data are not available (as is usually the case), does one get to a feeling for one P' compared to another.

2. In determining p_1, values must be included for various elements of research which ordinarily are considered under evaluation of quality of research. Among other things these include researcher quality, motivation (20, p. 37ff.), excellence of research design, proper research team makeup, adequate statistical planning, and research know-how. At a secondary level these may themselves be evaluated by a process involving p's and w's. They have not been dealt with in this way for reasons of space, but the procedures can easily be seen in this context.

If one were asked specifically, it would often not be obvious that research quality of much of the literature is poor. It takes one kind of sophistication to know that one is knowledgeable. It takes another, equally important, to know that one does not know. One major value of carrying out these procedures may be that it might lead a researcher to question his own research competence (or that of his team) and to try to get an external evaluation of it. This particular field—accident prevention—has many examples of utterly useless projects because of this factor (echoed in 5, 9). The sad part is that because of the lack of insight, some people will, even if exposed to the necessity, be reluctant to put their competence to the test; and, if not so exposed, will not know that their research products are worthy of very little confidence.

3. For p_2 one may ask, as well as its major intent, about duplication of effort, and the likelihood that information developed by others will form the central basis of the outcomes of research. A fundamental element is how much the information being developed is needed for solution of the problem. If it cannot be solved at all without the

research, $p_2 = 1$. If an approximate solution cannot be obtained, p_2 has a lesser value. A difficulty arises when several researches are necessary, but none is sufficient. Does this necessary piece of work still retain its value of 1?

4. The values for p_3, p_4, and p_5 involve making an estimate of the existence, effectiveness, and probable implementation of a countermeasure. A process of evaluation must go into a value for countermeasures as well as for research. Note that in a fully developed scheme for research, the cost of countermeasures should be included, not only as to payoff, but also as to time and money cost. This consideration is not impossible to develop, but is quite complicated.

5. An important factor here, hardly to be overemphasized, is that when one is forced to estimate the value of the w's, one is doing so in terms of the payoff, lives. In this case, the question resolves itself ultimately to: by what factor is one multiplying the expected number of lives saved (after the p's are applied) in order to take into account the w's? If P_{G_1} is 500, and P_{G_2} is 550, and researcher preference leads to values of $w_{3_1} = 1.4$ and $w_{3_2} = 1.0$, then the researcher equates his positive bias to 150 lives. He is saying, "If I had two researches with the given values, I would do one where $w_{3_1} = 1.4$, since the effective criterion value is 700 in the one case and 550 in the other." Because the preference factor is applied to lives, in the long run, if these estimates of P_{G_1} were to be correct, the meaning of researcher preference or of the other w's would seem on the face of it to be impossible to gage—lives vs whims or administration policy. In the actual practice of research choice, however, this consideration is almost never seen as an equation of lives with policy or with preference, etc., by the researcher Calica et al. (4) specifically note this point. It is more often clearly seen as such by the countermeasure practitioner, such as the road builder, the traffic engineer, and the police administrator (4), who are forced into the recognition of their decision processes by realistic need. The same judgment should govern the decisions of research, given the stated objectives.

6. And so with the other criterion elements of w_3. Among them must be included inertia of the organizational structure. It is messy and personally distasteful and troublesome to replace people; e.g., two engineers testing seat belts might be replaced by two sociologists, who could possibly find out the why's of poor seat belt use and might come up with a countermeasure, or vice-versa, where a psychologist is trying to develop a driving licenses selector with a paper and pencil test. In another criterion case, administration may be against involvement in a particular research area. This refers to research areas where no absolute stricture exists, because where one does exist, it is regarded as a limiting criterion. The bias of administration is often treated as a limiting criterion if the researcher does not even consider bucking such a position. One kind of administration bias results from the probability that research support will be radically reduced if a glamorous effort is given the normally lesser priority in terms of lives that may be saved. Here one must look to administration for decisions on the weight to be attached, inasmuch as a balancing of ultimate outcomes is involved. Often the priority of the glamorous work rises not because of bias, but because realistically, ultimate payoff is then greater for that effort than any other.

Many other criteria can be thought of. When conceived, they should enter as basic payoff or cost criteria, or as modifiers with appropriate weight.

Another way of emphasizing the full meaning and impact of modifiers such as the w's is to ask, what weights would the w's have been given if the number of deaths due to traffic accidents were 400,000 per year instead of about 40,000 and if all the expected hoopla were to accompany such a high figure?

A good aspect of this process is that when a researcher writes down the modifiers, certain undesirable administrative policies will be eliminated because they would be brought formally to the attention of administration, which may not have recognized them as having the weight they did. In essence, the researcher and administration would be forced to face their own objectives and the values assigned to them.

Of course, dishonesty in assigning values is always possible. But then, no system will work in that case.

Some General Problems

It is known that accidents are caused by combinations of multiple factors. When priority of one variable only is evaluated, how is this problem handled?

Validity of the technique for estimating research priority needs to be checked in each of the value-assigning phases, also the reliability.

If a countermeasure is already being implemented, an expression is needed to take account of the fact. It does not exist in the present scheme. It might be a function which can operate on the other implementation functions or weights.

If there is a range of time from beginning to end of implementation, there is a problem of estimating the correct single implementation time, or at least, of dealing with the problem in some way. This is important because in most cases the course of implementation probably does not increase linearly from none to full over the time involved, whereas such linearity is a simplifying assumption in the present formula.

How shall the arbitrary time period for implementation (here, 15 years) be chosen? Is there a rationally derivable value?

What if several countermeasures exist? What if, as is almost always the case, there are several research designs with different costs and different payoffs? How can one get around the necessity of bulky time investment to check out all these possibilities by deriving priorities for each separately?

In cases of in-house research where the people available cannot be increased, and permanent personnel are already paid for, cost figures for them are fixed for all studies. How shall their contribution be counted? This question is important because, conceivably, an optimal set of studies could leave a person idle. What then?

Where does basic research come in? Obviously, some basic research will have value for beyond some applied research. Here basic research is defined as that type of investigation in which the objective is a general increase in the knowledge of the given field. Implied is the absence of a specific goal such as lives saved. The present technique is applicable to basic research only if one can quantify the ways in which one measures the achievement of the stated objectives. On the other hand, it is possible to assign worth to any research in terms of other objectives, whether or not it was originally intended to satisfy those objectives. Keeping to the objective of basic research, no investigation is better than any other, so long as it brings new information. If the statement of objectives is refined to include generalizability of information, or perhaps scope of the dimensions of life that might be affected, or the like, then it becomes easier to quantify the criteria reflecting achievement of the objectives of basic research. By and large, it appears as if the present method would have to be altered considerably, and many simplifying assumptions applied, before it could deal effectively with the question of basic research priorities.

Originally the concept of evaluating priorities took the form of a linear equation. The independent variables were to be factors affecting decisions about priority; the dependent variable was to be a priority score; each variable was to have a weight reflecting its importance in the scheme of priority allocation (e.g., public opinion might have a smaller intrinsic value in an "absolute" sense than that of project cost); and in a given case of research, each independent variable was to be assigned a coefficient reflecting how strongly it applied in the given case. Here, each variable had to be equated to a common measuring unit, presumably also lives or injuries lost or saved. In such an equation, it is obvious that payoff variables are positive and cost variables negative. The independent variables—personnel, time, research effectiveness, inertia of organizational structure, public opinion, policy, etc.—are additive primary variables in this scheme, rather than multiplicative modifiers, as in the scheme developed above.

In considering the factor relating to how much a given research contributes to the total solution, it might be better to assign a value less than one to a project if it only picks up a portion of the total necessary research, even though it may be an essential portion. An alternative way of handling the question may be to split the factor into an importance factor and a proportion-of-effort-required factor. How these would work together has not been examined in detail. At least the problem is recognized.

The present work was not intended in any way to be more than a speculative approach to a problem needing some thinking. There are obviously other approaches (see, for example, the implications of questions and procedures in 4); the technique depends partly on unavailable information; circuitous routes must be taken to arrive at many numbers; refinements are obviously needed for many of the measures; validation will take a long time; the technique is, for some researches, cumbersome; the problem of predicting and evaluating countermeasures effectively is very troublesome; etc.

However, if the paper has led anyone to think about the value system under which he has worked, and to consider the value system under which he may in the future operate, then it will have accomplished one of its own objectives.

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