ON THE LIMITATIONS OF QUANTITATIVE ANALYSIS

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The notion that numbers and logic ought to rule the universe has been around since Pythagorus. Yet, until recently, few have had much faith that this might actually come to pass. Quantitative analysis admittedly had a place in engineering and science, and, to a limited extent, elsewhere, but certainly <u>not</u> for determining decisions and policy in the world of affairs. That attitude may be changing, however.

Today, one sometimes hears that to meet the many challenges to our society--pollution, drugs, and over-population, to name a few--one need only turn to quantitative analysis; to systems analysis, operations research, "aerospace technology," and related analytic approaches.** For the purposes of this symposium, I call these approaches

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**Cost-benefit analysis, cost-effectiveness analysis, management science, and policy analysis are also in this category; the distinctions between them and the disciplines mentioned above are largely matters of emphasis.

quantitative analysis. They are by no means completely quantitative but they aim to be. The usual practitioner is out to make them so; to introduce computers and mathematical models, along with such esoteric techniques as game theory, linear programming, and Monte Carlo simulation. There are definite limitations, however, both as to what can be done with quantitative analysis and with respect to the extent that such analysis can usefully be made more fully quantitative.

The heart of any analysis, quantitative or not, is the creation of a clear, precise, manageable description of the processes involved; one designed to predict the consequences of choice. This role is fulfilled by a "model" (or by a series of models, for it may be inappropriate or absurd to attempt to incorporate all aspects of a problem in a single formulation).

The name, model, of course, comes from science. And, in fact, in policy analysis, in systems analysis, or in operations research, the most used models, on the whole the most useful, and often the only type even considered, tend to resemble "scientific" models. That is, they seek to express the processes that determine the outcome of alternative actions by means of a set of mathematical equations or by a computer program. The objective is to obtain a simplified, stylized representation of those aspects of the real world appropriate to the question being asked. This need not be the case; in many problems, an operational game, a sequence of questionnaires, or even a purely verbal description of the situation in the form of a "scenario" can, and frequently must, replace a mathematical model.

I believe, and I assume most of you believe, that through the use of analysis (as opposed to precedent, appeal to authority, bargaining, or trial and error) one is more likely (though not necessarily) to obtain better answers to questions and solutions to problems and thus to provide better advice. This happens to a large extent because analysis is systematic, controlled, directed, organized, explicit, and, to the degree possible, objective. The central device, the creation and use of an operational model, makes efficient use of judgment and intuition. But that does not mean that the more quantitative analysis is always to be preferred to the less. For one thing, it costs more in time and money. If the costs of error are small with respect to the costs of inquiry, one might as well use trial and error. For another, its solutions may be far more difficult to accept and implement than those arising from more subjective and political processes.

Analysis would be completely quantified if the problem could be described by a mathematical model so faithfully that the decision could be made purely on the basis of the results that are obtained from the model. There are such problems* but they are not found in the domain of public policy.

The term quantitative analysis should not conjure up visions of computers and mathematical equations. Neither may be involved and mathematical analysis itself may be nonquantitative--the whole field of symbolic logic, for instance--and computers have many uses not even associated with analysis. Nevertheless, when critics speak about PPBS as a "technocratic utopia where judgment is a machine product" [1], or of people who have created "the illusion that they are capable of relating cost to military effectiveness by scientific analysis" [2], they refer to the type of activity that I am here calling "quantitative analysis."

Even though quantitative analysis is almost as old as man--the staff of one congressional committee [3] found an example of cost-effectiveness analysis in Genesis 3--it has made its most progress in both acceptance and in technique during the last twenty-five years. It is now used with success to tackle many problems: how to provide better fire protection or how to select weapon systems that will make nuclear war more unlikely. It has not, however, had the same success with other problems; how

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*For example, the problem of calculating how long it will take an object dropped from a given height to fall to the ground. For further discussion of the meaning of a quantifiable problem, look for a paper under preparation by Dr. Ralph Strauch of The Rand Corporation.

to allocate the budget between the demands of defense and domestic affairs or how to lay out a freeway route acceptable to the residents of the area through which it is to go. Why? Is it because quantitative analysis has reached its limitation here, or because, for these problems, the cost of quality quantitative analysis has risen to the point where it far exceeds the cost of error, or is it merely because politics and bargaining bar any analytic solution? Or are there other reasons?

Quantitative analysis is sometimes identified with scientific analysis (even though much of what goes under the cover of quantitative analysis is hardly scientific or even analytic or objective). Although there have been a number of attempts, the limits of scientific analysis have not been adequately defined. There is hardly an area today to which science has been successfully applied that, at some time in the past, was not considered to be outside the reach of scientific inquiry. Quantitative analysis faces a similar expansion. Arguing by analogy, we cannot thus expect to define a limit that can be used to distinguish between quantitative and nonquantitative analysis. We can, at most, say something about the boundary.

Thus, the struggle to fix the precise limitations of the quantitative approach is not important; the question is really irrelevant. No one claims that quantitative analysis can offer an answer to every problem and very few claim that it will do so eventually. Moreover, quantitative analysis is not only limited externally, in the sense that there are problems that we do not know how to tackle quantitatively, but it is also limited internally, in the depth to which we can make an analysis purely quantitative.

THE INTERNAL LIMITATIONS

In fact, to analyze a problem means to break it down into component parts to a stage where judgment must be used--so quantitative analysis ultimately reduces to a sequence of judgments. It is not merely a matter of time until we can attack every factor quantitatively. It is true that many parameters that could not be quantified a few years ago can be quantified today, but the process is an unending one.

Let me illustrate what I mean by means of an example [4].

Suppose we have a process for making a glue joint and wish to improve the strength characteristics.

As a first approach, we can consider variations in clamping pressure. This should produce a curve of strength vs pressure (Fig. 1).

This process gives rise to a further question. What temperature? To answer, suppose we generate a series of curves (Fig. 2).

Fine; but how long should it cure? We can run more tests but we are already getting more answers than we can illustrate on a simple chart. Possibly a set of several overlays might be prepared. But we still have more questions. How much glue? What viscosity? How long should it set before joining? How smoothly should the surface be prepared? It is clear we might as well give up on using conventional two dimensional charts to illustrate all these relationships.

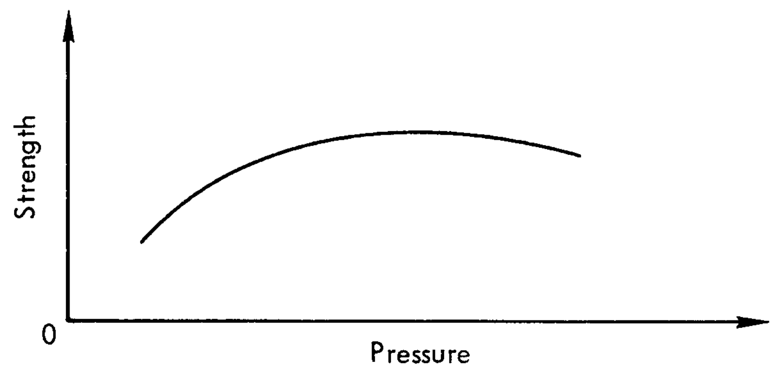

Fig. 1

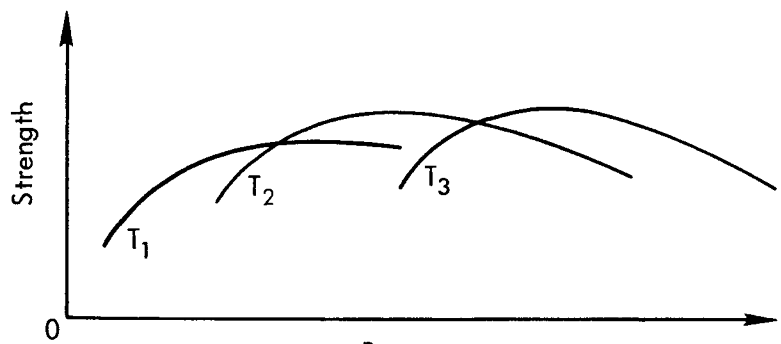

Fig. 2

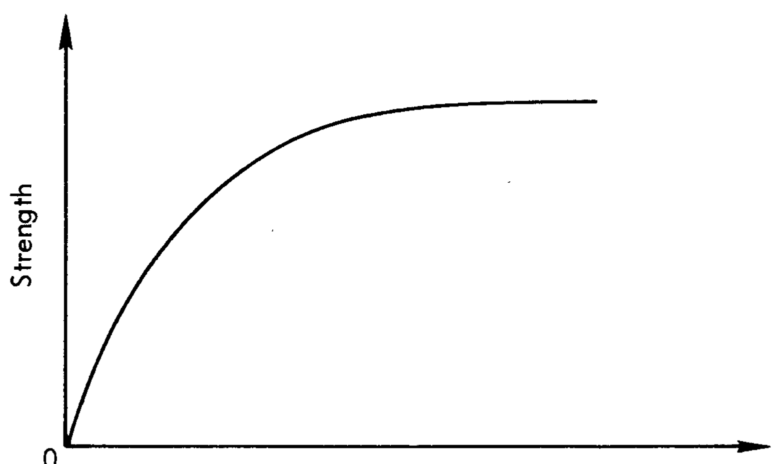

Fig. 3

There are things we can do; strategies we can adopt. For example, we can use a sequential strategy. After the first curve is computed, take the pressure for maximum strength and using this value, vary the temperature to find a maximum strength, then using these values vary the curing time, etc. It is clear that each step represents an improvement on the previously existing situation. There are many strategies that might be used, but the choice is subjective, based on the analyst's experience and his judgment about the smoothness of the functions involved.

Now suppose to attain maximum strength a three week cure is required, one that involves tying up a good deal of equipment for the period. This may make the cost prohibitive; hence one must take cost into consideration. This might yield the relationship shown in the figure (Fig. 3). But to make a choice of the point at which to operate we need to know how badly we need strength. In other words, what is the value of strength? But the value of strength is specific to a particular use, to a particular "scenario." If the uses are many and are to vary with future events, we must again depend on judgment.

Sometimes rules of thumb can be used that have general applicability. For example, when the cost-strength curve has a sharp bend (as in Fig. 3), one frequently operates close to the "knee" of the curve. But just where, and how sharp is a matter of judgment.

The point is that every quantitative analysis, no matter how innocuous it appears, eventually passes into an area where pure analysis fails, and subjective judgment enters. This is important; in making these choices the real decisions may be being made. In other words, judgment and intuition permeate every aspect of analysis: in limiting its extent; in deciding what hypotheses and approaches are likely to be more fruitful; in determining what the "facts" are and what numerical values to use, and in finding the logical sequence of steps from assumption to conclusions.

There are areas where quantitative analysis even though complete cannot give an answer. For example, game theory may be able to tell us how to behave in a probabilistic situation but not the outcome in a particular instance.

It is the external limitations that most concern the user, however.

THE EXTERNAL LIMITATIONS

Systems analysis, cost-benefit analysis, operations research, because of the quantitative nature of the models used, often appear to give precise answers to the questions they set out to answer. In reality, however, the answers provided by such approaches are only approximations (but possibly the best obtainable!) to the questions of real interest.

This is due, to a large extent, to the limitations on the capability of the analyst to build quantitative models that adequately describe the environment the models are designed to simulate. These limitations fall into two basic categories that might be called objective and subjective. Let me illustrate in the context of strategic warfare [5]. Objective limitations are limitations on the ability of the models to describe the objective characteristics of the situation being represented. This category includes the true characteristics of the enemy strategic forces, and to a lesser extent our own (for today as well as in future years), and the interactions between those forces and the targets against which they might be used. Thus our inability to know the precise accuracy of our own and enemy's missile systems, or even the adequacy with which, given the average miss distance, the distribution of misses is described by some statistical approximation, imposes objective limitations on the calculation of outcomes. Similar limitations are also imposed by our inability to know precisely what forces our enemies have in being now or will have in future years. Subjective limitations are those which are imposed by our inability to model important political or psychological factors and their place and relationship in the strategic equations. This might include, for example, such factors as what really constitutes deterrence in the minds of enemy leadership, what situations might lead to a nuclear war, or the way in which enemy leadership or our own might direct the use of strategic forces once war occurred.

In strategic analysis, the standard approach to dealing with these limitations has been to resolve the uncertainties on the conservative side from the U.S. point of view. If U.S. forces can be made adequate to deal with that case, they are presumed to be adequate for whatever the real situation happens to be; a solution that leads to arms races and excessive budgets.

The nature of politics and the decisionmaking environment imposes an additional limitation on analysis; it simply may not be perceived as relevant. Consider, for example, how the costs and gains of a public housing project might appear to an alderman in a city such as Chicago [6]. The costs and gains most important from the nation's viewpoint (or even the city's)--those involved in the criteria used in the usual cost-benefit analysis may not even appear on his list. For him, the loss or gain of support from constituents or other aldermen, the avoidance of possible racial conflicts and troublesome issues in his ward, possible gain in support from transportation officials who might want the project site for freeway access, the loss, say, to his personal insurance business from businesses displaced, and so forth may loom much larger. In general, the criteria for good policy used by each participant in the political process is likely to differ greatly from the criteria used in cost-benefit analysis.

Value judgments are an integral part of quantitative analysis.

> "....this kind of analysis can and must be honest, in the sense that the quantitative factors are selected without bias, that the calculations are accurate, that alternatives are not arbitrarily suppressed, and the like. But it cannot be "objective" in the sense of being independent of values. Value judgments are an integral part of the analysis; and it is the role of the analyst to bring to light for the policy-maker exactly how and where value judgments enter so that the latter can make his own value judgments in the light of as much relevant information as possible [7]."

Value judgments on the part of the analyst introduce additional limitations, for how can the analyst divorce himself from--or even be aware of--the influence on his judgment resulting from his organizational and person commitments, tacit knowledge and beliefs, political leanings, etc.?

The effort to quantify may impose limitations; in the choice of the type of model, for instance, or in eliminating from consideration objectives that have no aspects that can be quantified. It also puts pressure on the analyst to choose his structure for tractibility. This may cause relevance to suffer.

IMPLICATIONS

It is important, both for the analyst and for the client, to understand that limitations on quantitative analysis exist; it is far less important, as we said earlier, to know precisely what and where these limitations are.

The decisionmaker, once he understands that, for complex questions, computers and mathematical models cannot treat all aspects of a problem, should realize that it takes more than good analysis to reach correct decisions. Also once he learns that he can never expect an answer from analysis that does not at least in part depend on someone's subjective judgment, he cannot try to shunt his responsibility for the judgments he should make himself off on the analyst.

As for the analyst, once he admits to himself that he is not going to obtain a full answer by purely quantitative and objective analysis, he can help with a clearer conscience with what he has. It does a decisionmaker very little good to be told that in two years the systems analysts will have a finished model and will then be able to give an answer. Often, before he is willing to give any answer, an analyst will plead for more time, more testing, more debugging. Yet, while he may bemoan the fact that the decision is not going to be made on the basis of the best analysis he is capable of carrying out, he knows he is never going to get a completely quantitative answer. He should thus more agreeably provide interim help. All analysis is partial but is usually far better than no analysis.

For both, a belief that analysis can lead to complete answers is likely to lead to overrun and late contracts and to a great deal of marginal work. Quantitative and scientific answers are always relative; they hold only under certain conditions. Constraints of time and staff introduce some of these conditions, the problem others. Both the analyst and the decisionmaker really know of the existence of limitations; it is just that the analyst tends to forget certain kinds and the decisionmaker others.

On account of the growing use of quantitative analysis to assist management in commerce, industry, and banking, there is a fear on the part of some managers that computers will soon take over their functions.

It is true that a large number of repetitive and routine problems--even some not so routine--can be reduced to decision rules applied by clerks or computers. Thus, for example, we can have a computer program to simulate the behavior of an investment trust officer; one that "picked such marvelously uninspired and safe portfolios for its customers that by now it may have become a member of the Union League Club" [8]. As a consequence, management can be relieved of some problems--but only of a few and they are not relegated to the hands of quantitative analysts but to less skilled personnel.

A decisionmaker who is aware of the limitations may call on analysts for help even when the latter have nothing to contribute beyond their judgment and intuition; because these analysts are ordinarily smart and well educated, their judgment is frequently very good. Here lies a danger. Not in the use of judgment but in the failure to emphasize the difference in results and recommendation based on judgment alone. An analyst's judgment is more likely to be in error than his research, and the use of his unaided judgment is likely to reflect on quantitative analysis unless the processes are kept distinct in the user's mind.

COUNTERING THE LIMITATIONS

To counter to some extent and get along in spite of the limitations on quantitative analysis imposed by the use of computers and mathematical models, one can employ "partially quantitative" techniques that surrender some of the features of the traditional model.

Operational gaming, that is to say, exercises in which the participants interact by playing roles that simulate individuals, or factions in a society, or even such things as sectors in an economy, is a first step away from computers and mathematical models. Its predictive quality is very clearly a function of the intuitive insight provided by the participants. By allowing for the introduction of judgment at every stage, a game provides an opportunity to take into account intangibles often considered completely beyond the reach of analysis. Both the expert on the control team and the player can let their decisions be influenced by their appraisal of the effects of the simulated environment. For example, the player can take into account how the success or failure of an economic action may depend upon assumptions about a population's willingness to accept a change in diet or the flexibility of the political structure to accommodate a new power bloc. In any mathematical formulation or computer simulation, factors of this type must be anticipated and decisions about them made in advance; in a game they can be made *seriatim*, and in context, as the need arises.

But gaming--even though it sacrifices both the capability to replicate exactly and to optimize--is still, like the traditional model, a simulation. There sometimes are advantages in sacrificing this also.

When faced with issues where there is uncertainty, doubt, disagreement, and seemingly no way to build any sort of model, common practice has been to turn to a committee or a panel of knowledgeable people or "experts," for advice. Systematic techniques for eliciting group judgments, employed by such a group, may also serve to replace the traditional model [9]. Let me describe one such approach.

The Delphi procedures [10] are designed to improve the forecast or estimate one obtains from a committee or panel by using controlled information channels, such as a series of questionnaires, to avoid the drawbacks associated with face-to-face confrontation. Three simple ideas are involved: anonymity, iteration and controlled feedback, and statistical group response.

(1) Anonymity. The participants are queried by a formal mode of communication, usually a questionnaire or a computer. The answers are not matched with the respondent, and even the identity of the participants may be concealed.

(2) Iteration and Controlled Feedback. Discussion is replaced by an exchange of information controlled by a

steering group or exercise manager. After each questionnaire, the information, or part of it, generated in the previous stages is fed back to the participants in order that they may use it to revise their earlier answers. In this way "noise"--irrelevant or redundant material--can be reduced.

(3) Statistical Group Response. Group opinion tends to converge with iteration but the normal outcome is a spread of opinion even on the final round. Rather than making an attempt to force unanimity, some statistical index, usually the median, is used to represent the group response. This way of defining the group judgment reduces pressure for conformity and insures that the opinion of every member plays a role in determining the final response.

Experimental work has shown that the Delphi procedures lead to convergence of responses, reproducible results using similar groups of respondents, and, where results can be checked, improvement in accuracy more often than not. The formal properties of the estimation process (convergence, reliability, well-defined distributions) carry over in the area of value judgments (objectives, priorities). It is clear that by asking each respondent to assign a numerical value, say on a scale of 0 to 10, to a quality such as the beauty associated with an object, one can arrive at a measure of beauty. Also, preliminary work leads one to believe that using such methods it may be possible to identify and measure the underlying dimensions that provide life its quality. [11].

Although Delphi procedures are becoming widely used for forecasting, for resource allocation, and for determining objectives and goals, much more experimental work needs to be done before its superiority over standard methods is established. Large gains seem possible with respect to increasing the accuracy obtainable by group judgment and with respect to creating procedures more responsive to the information needs of decisionmakers. There are difficulties also; panel resistance for one thing and undue influence or inept direction by the exercise manager another.

CONCLUDING REMARKS

It is not merely a matter of time until we can attack every question quantitatively or even approach it with analysis. To use Herman Kahn's illustration, no type or amount of analysis in 1910 on the impact of the motor car on the future of American life would have been likely to uncover its impact on the dating habits of American youth--nor, for that matter, would expert judgment and intuition have been of much help. The perspective of a group of teen-agers might have worked, however. Moreover, of the major issues facing the nation today, it is hard to think of any that can be resolved purely by what we know. Analysis, consequently, should be viewed more as a method for investigating problems than for solving them.

So long as the nature and limitations of quantitative analysis are kept firmly in mind, there is little cause for concern. But dangers exist. One is the failure, in the pressure to quantify, to recognize the unsuitableness of quantitative analysis for the problem at hand. Another is that attention will be focussed on efficiency, rather than on goals and on selecting as preferable one pattern of results over others. James Schlesinger put it well:

> "Operational research is a new field, and in the early years practitioneers of new arts tend to regard them as panaceas....
>
> ....The ordinary practitioner of a discipline must be expected to accept the formulas of discipline uncritically and to apply the methods mechanically. In quantitative analysis, a long run threat to

> optimal decision-making exists in the pressure for quantification and in the failure to recognize not merely the qualitative but the inherently subjective nature of the decisions that must be made. While estimates of exchange ratios can be made more or less accurately on the side of costs, they cannot be on the side of objectives. Precise utility maps exist only in the textbooks. In quantitative analysis, energy is diverted to the search for numbers, and, what is worse, a decision may be distorted because of the disproportionate weight given to those aspects of a problem that are quantifiable" [12].

On the other hand, even though in broad problems, say involving the choice of objectives as well as resource allocation, quantitative analysis can do no more than provide relevant information on performance and costs, such analysis is almost always useful. It counters the purely subjective approach on the part of advocates of a program and may force them to change their line of argument and talk about the realities rather than merely expressing their personal opinion with statements of noble purpose. Yet, on the whole, it is remarkable that quantitative analysis has gotten as far as it has in policy making and in government--since politics is geared to winning the voters by promising the benefits of programs before their quantitative aspects--the costs and the means--are determined.

NOTES

1. "Stacked Analysis" Editorial, New York Times, 27 August August 1967, p. 14 E.

2. Vice Admiral H. G. Rickover in Planning Programming Budgeting, Senator Henry M. Jackson, Subcommittee on National Security and International Operations, Government Printing Office, 1970, p. 600.

3. Initial Memorandum in [2] above.

4. I am indebted to Dr. W. C. Randels, Lockheed Missiles and Space Corporation, Sunnyvale, California for this example.

5. This discussion closely follows that in an unpublished paper by Dr. Ralph Strauch of The Rand Corporation.

6. Roland N. McKean, "Cost and Benefits from Different Viewpoints" in F. J. Lyden and Ernest G. Miller (eds.) Planning Programming Budgeting, Markham Publishing Co., Chicago, 1967, pp. 199-220

7. Alain C. Enthoven, "Operations Research and the Design of the Defense Program," Proceedings of the 3rd International Conference on Operations Research, Dunod, Paris, 1964, pp. 530-534.

8. Martin Shubik, "A Curmudgeon's Guide to Microeconomics," Journal of Economic Literature, v. 8, No. 2, June 1970, p. 419.

9. E. S. Quade, "An Extended Concept of 'Model'" in OR69: Proceedings of the 5th International Conference on Operations Research, John Lawrence (ed.), Tavistock Publications, London, 1970, pp. 173-180.

10. Norman Dalkey, "An Experimental Study of Group Opinion: The Delphi Method," Futures, September 1969, pp. 408-429.

11. Norman C. Dalkey, Measurement and Analysis of the Quality of Life: with Exploratory Illustrations of Applications to Career and Transportation Choices, The Rand Corporation, RM-6228-DOT, August 1970

12. James R. Schlesinger, "Quantitative Analysis and National Security," World Politics, Vol. XV, No. 2, January 1963, pp. 295-315.