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SYSTEMS ANALYSIS: A TOOL FOR CHOICE

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Santa Monica, California

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SYSTEMS ANALYSIS: A TOOL FOR CHOICE*

E. S. Quade
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Today, I've been asked to do the following:

1. Tell you what systems analysis is;
2. Briefly review its history;
3. Compare or contrast systems analysis with other approaches to providing advice to a decisionmaker;
4. Say something about its characteristics and procedures; and, finally,
5. Give some idea of its value and of its future.

WHAT IS SYSTEMS ANALYSIS?

Basically, a systems analysis is an attempt to aid decisionmakers in answering relevant questions about complex groupings of men and machines. The systems involved might range from hardware to social--say, from a communication satellite system to the California state welfare system. Systems analysis is a form of policy analysis, a type of analysis which generates and presents information in such a way as to improve the basis for making policy and decisions. Before we are willing to call an analysis a systems analysis, however, we usually demand a certain amount of formality and ask that it *try* to be quantitative and take an overall rather than a piecemeal approach.

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The work may involve a large organized effort, but again it may not. Computers may or may not be used. But, invariably, a systems analysis does the following: it examines the *purposes* of a policy or procedure or decision; it explores alternative ways of achieving these purposes including the design of new possibilities; it assesses the benefits and drawbacks of the various possible actions; and it compares them on one or more criteria that a choice may be made.

Systems analysis makes no pretensions of providing a complete theory of systems; that sort of thing is done in general systems theory, something entirely different. Instead it provides a framework that permits the use of a great variety of mathematical and scientific techniques. Systems analysis, moreover, does not exclude any approaches, scientific or not, that may be found useful in generating new alternatives or in investigating political and institutional factors.

In other contexts, office management or computer science, for instance, the term systems analysis is used differently. The kind of systems analysis we are discussing today, however, deals with policy. Its purpose is to help someone make a choice or a decision no matter what the context.

NOW A FEW WORDS ABOUT ITS HISTORY

Systems analysis is a new name, not a new concept or activity. Analysis devoted to comparing alternatives has been going on for a long time. In fact, ever since man first began to realize his resources were limited, he has performed calculations of some sort to compare alternatives. History is full of examples of systems thinking. Let me mention just one.

After Thomas Edison had invented the incandescent light in 1879, he wanted to convince people of its practical value [1].

He realized that to do this he had to determine the technical characteristics of a lighting system that would be satisfactory for both home and industrial use. For this he had to work out the best values that the laws of energy and economics would permit for the electrical constants of that system--lamp resistance, circuit voltage, conductor sizes, and so on. There was also a marketing problem.

To tell himself what should be done, he carried out a systems analysis. He began by deciding to establish his system in New York City in lower Manhattan where it would serve the Wall Street financial district. An early demonstration to the financial community that his lighting system was both practical and economical was important

The site of his generating station was determined on the basis of survey data. Edison's men canvassed the district thoroughly, making a house to house survey to learn the number of gas jets burning at each hour up to three A.M. A miniature network of conductors was constructed. Careful studies were made of the voltage conditions in the model network using various sizes and arrangements of conductors and other parameters. After one of his surveys in which 95% of the gas users said they would take electric light if it cost the same as gas, he worked out the price on that basis. By 1890 Edison, guided by this analysis, had achieved the goal he set some ten years earlier to see his lighting system attain widespread use.

The first treatise on systems analysis appeared about this same time. It was not called systems analysis but the 980 page volume by A. M. Wellington entitled *The Economic Theory of the Location of Railways*, first edition 1887, was an excellent treatment of the subject.

Unfortunately, early instances of systems analysis such as Edison's, as far as I can determine, did not affect the

development of systems analysis as we know it today. That developed in the late 1940's out of World War II operational analysis. Since then it has been influenced by economic theory, by the cost benefit analysis practiced by the U.S. Army Corps of Engineers in connection with their effort to improve river and harbor navigation, and by systems engineering as practiced by managers and engineers of large industrial enterprises such as telephone companies and the producers and distributors of electric power.

Operational analysis, now operations research, was the name given to quantitative methods developed during, and to some extent before, the Second World War for solving operational problems associated with radar, aircraft, and submarines. Just after that war, Rand began to apply the same approaches to broader problems, naming the effort systems analysis. The methods used soon spread throughout the defense and aerospace industries. The great boost to systems analysis, however, came later when Robert McNamara brought this new way of thinking about problems and a group of analysts and economists to apply it to Washington.

There is no reason, today, to make a distinction between systems analysis and operations research. Originally, operations research may have been narrower and more quantitative, but its practitioners have so broadened what they consider to be operations research that today its field is now identical with that of systems analysis. In fact, interpreted broadly, both systems analysis and operations research can be considered as encompassing all policy analysis. Thus, if distinctions remain, they are merely matters of degree, with no clear line of demarcation. Similarly, cost-benefit analysis, cost-effectiveness analysis, and systems engineering can be regarded as forms of systems analysis or operations research.

OTHER METHODS

There are, of course, other methods of arriving at a choice between alternatives. One is intuition, with or without divine guidance. Here one may use help; read tea leaves or inspect the entrails of a sheep as the Romans did. Mostly, though, this approach is in no sense rational since no effort is made to structure the problem or to establish cause and effect relationships and operate on them to arrive at a solution. The intuitive process is to learn everything possible about the problem, to live with it, and let the subconscious provide the solution.

Between pure intuition on the one hand and systems analysis on the other, there are other sources of advice that can be considered analytic, although the analysis is ordinarily less systematic, explicit, and quantitative. One alternative is simply to ask an expert for his opinion. What he says can, in fact, be very helpful if it results from a reasonable and impartial examination of the facts with due allowance for uncertainty and if his assumptions and chain of logic are made explicit so that others can use his information to form their own considered opinion. But an expert, particularly an unbiased expert, may be hard to identify. An expert's knowledge and opinions are likely to be more valuable if they can be formulated in direct association with other experts. This suggests a committee or panel or other consensus device. Committees seldom do analysis or make their reasoning explicit. Their findings are usually obtained by bargaining and here personality and prestige often outrank logic. There are, however, methods of using committees, particularly panels of experts, that are systematic and can be made part of systems analysis. Various forms of the Delphi process qualify here.

Another alternative is the process sometimes known as "muddling through" or, more formally, as disjointed incrementalism. In this approach the analyst does not necessarily seek a solution to the problem as a whole. He examines only those alternatives that differ incrementally from current policy and from each other. He does not analyze all the consequences of even these limited alternatives for he assumes that policy is made in steps, that it proceeds through a long chain of political and analytic moves, and that other analyses, simultaneously conducted by the various interested parties, make it unnecessary for him to worry about completeness or fairness to other interests. While both approaches recognize that certain alternatives and consequences have to be omitted from an analysis, systems analysis attempts to make those omissions rationally, while the incrementalist is content to have them made quite arbitrarily. He feels he can afford to make only minor changes and even to make mistakes because after the decision is made, if unanticipated consequences show up, more analysis will be done. In "muddling through" analysis is seen more as a device to help the decisionmaker by contributing to his bargaining power than as a means to help him by providing the information for him to make a decision. The two approaches are quite compatible and systems analysis is beginning to improve its impact by accepting the incrementalists' view of the policymaking process and modifying its practices accordingly [2].

CHARACTERISTICS AND PROCEDURES

Most of the ideas involved are only common sense but actually doing them is often extraordinarily complex and difficult. Let me list four of the most important characteristics a systems approach should have.

1. Careful formulation of the problem. Good systems analysis must establish the boundaries of the issue under investigation where thought and analysis show them to be and not where off-the-cuff decision or convention, whether established by government jurisdiction, academic tradition, or industrial practice, would have them be. It must be aware that the solution of the problem may be the cause of others. Air pollution cannot be adequately controlled without reference to urban transportation and changes there may affect housing and jobs. Systematic investigation of these boundaries may alter perception of the issues, expose hitherto unobserved relationships, and show the way to new opportunities.

A major job may be to determine what the policymaker should want to accomplish. Objectives are hard to state and progress toward them is hard to measure but success with systems analysis requires finding a way to do both. The analyst must interrogate the decisionmaker or the manager very thoroughly and everyone involved who is likely to be able to help. Time spent here is well spent; looking for the best way to achieve the wrong objective cannot help.

In these inquiries, one must try to look at the problem as a whole, not just at its separate parts. Thus, if our problem seeks to reduce crime through an increase in police activity, we should consider the related activities of the other public agencies that affect the situation--courts, corrections, welfare, probation, and so on. Also, the analysis should consider changing training, communications, technology, work hours, the possibility of using auxiliaries of various kinds--everything that might affect the outcome. In addition, one needs to investigate the spillovers--the costs and benefits to others--as well as the direct effects--what increased police activity might do to life in the area,

for instance. Looking at the entire problem may sound like common sense, but also, if taken literally, is impossible in practice because everything in the world is connected in some way with everything else. To do analysis there must always be considerations left out. The determination of the boundaries is largely a matter of judgment. The point is we should at least think about the entire problem and deliberately decide what points we are going to tackle or include and what to leave out. Analysts and decisionmakers are often forced to suboptimize, to consider only part of the problem. What is crucial when this is done is that the criteria and objectives for the suboptimization be consistent with those that would apply to the full problem.

2. Identification of the significant alternatives. For public policy problems, a wide range of alternatives usually exist--legislative and technical, public and private, local and national. Depending on the particular question, alternatives may be policies or strategies, or actions of any sort and they need not be obvious substitutes for each other or perform the same specific functions. Thus education, family subsidy, police surveillance, and slum clearance may, either alone or combined in varying degrees, all be alternatives to be considered in combating juvenile delinquency.

Altenatives have to be *designed* and *searched* out; one cannot select the best alternative if it has not even been recognized as a possibility. In fact, the mere identification of alternatives can sometimes lead to better policy decisions, even without further analysis, for the best solution may suddenly become obvious. In this, we have to watch our bias toward technical solutions, for we are technically oriented peoples and we are often willing to accept value-neutral technical solutions where we resist attempts to change institutions or behavior directly.

3. Thorough investigation of costs. The choice of a particular means of accomplishing an objective implies that certain resources will be required and thus no longer available for other uses. These are the costs. Costs are the negative values in the decision--the things we want to avoid just as the objectives are the positive values we seek to obtain. Many, but usually not all, costs can be expressed in dollars or other quantitative terms. For example, if the goal of the decision is to lower automobile traffic fatalities, the delay caused to motorists by schemes that lower driver speed in a particular section of road must be considered a cost. Such delay not only has a negative value in itself which may be partially expressed in dollars but it may cause irritation and more speeding elsewhere and thus lead to an increased accident rate, a chain of consequences that one may find very difficult to quantify.

The costs to society of a policy choice may take many forms: dollar costs to public and private agencies and to individuals, plus all the costs that cannot be assigned monetary values in discomfort, sickness, or lowering of the quality of life. While even the most thorough systematic work cannot account for all such costs, it can identify far more precisely than is usually done the comparative costs, both monetary and nonmonetary, of the various policy alternatives being considered. It can also help clarify the crucial issues of cost to whom.

In addition, it is important that we pay attention to the cost associated with either the failure to actually initiate a project or to successfully implement the project after we initiate it. We must recognize that some projects have a better chance than others of being successful here. Hence the project recommended should not necessarily be the one with the greatest potential for an excess of benefits

over costs unless the probabilities of successful initiation and implementation have been estimated and the expected costs that would be incurred by failure at either phase taken into consideration.

These characteristics are important; the next is essential.

4. The use of an explicit model. The heart of any systems analysis is the creation of a clear, precise, manageable process designed to predict the consequences of choice. That is, if an alternative were to be selected and implemented, we must build a device to tell us what costs will be incurred and to what extent the objectives will be attained. 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 the aspects of a problem in a single formulation).

The important function of the model is to provide a way to forecast the outcomes that follow alternative actions. A mathematical formulation with which one can optimize and thus indicate a preference among the alternatives is an extremely valuable aid to this process but it is not crucial; there are other routes; the Delphi process in which a panel of experts is used to forecast the outcomes in place of the model is an example. What is crucial to every prediction or estimate is reliance on expert judgment and intuition. This reliance permeates every aspect of the analysis--in limiting the extent of the inquiry, in deciding what hypotheses are likely to be more fruitful, in designing the model, in determining what the facts are, and in interpreting the results. A great virtue of a model is that, by introducing a precise framework and terminology, it provides an effective means of communication, with feedback, enabling the participants in the analysis to exercise their judgment and intuition in a well defined context and in proper relation to each other.

WHAT DO WE GET FROM THE SYSTEMS APPROACH?

One of the most important consequences of the systems approach is that it highlights the need for fundamental changes in the way both individuals and organizations go about their work. In particular, it demands that problem solving be carried out on an interdisciplinary basis and implies that many firms and organizations need to be organized in a more integrated way than at present. It can be a key factor in improving management practices and hence in making big improvements in efficiency.

The systems approach is not for every problem. If the costs of analysis and delay are greater than the costs of error, then trial and error may be a better approach than that of carrying out a systems analysis. One of the reasons that systems analysis has made a name for itself in dealing with strategic warfare but has had a somewhat more difficult time in the domestic field is that the costs of error are perceived as much greater in the event of war than they are in domestic affairs, so that systems analysis has had a tougher time competing with political pressures in the latter. Usually, however, systems analysis can save money.

To give you an idea of how this can be done with systems analysis let me mention a few examples. Later this morning you will hear, in detail, about two Rand policy studies--one of transportation in California, the other of housing done for New York City.

First, let me say something about work on urban problems. A recent systems analysis [3], devoted to designing a large scale addition to the New York City water system indicated that economies of up to 50% were possible over the anticipated cost of the original proposal generated by the traditional engineering design process. The path to this economy became apparent through the use of a mathematical model of the system which was used, in a computer, to explore hundreds of possible

configurations. The computer also made it possible to calculate several measures of effectiveness for each trial design and to calculate tradeoffs between each of these. The planners then could specifically choose what kind of design they wanted and thus achieve significant increases in design effectiveness.

Budgetary constraints, however, limited the savings. In this case, the overall economies achieved were about one hundred million dollars or two thirds of what was estimated to have been technically possible had the optimum design been selected.

Work for New York City has also been done by the New York City-Rand Institute. Frequently this work has been relatively narrow, devoted to improving the ability of city departments to provide improved levels of service within their budgets.

> *"....The gains come from the redeployment of resources in patterns more sensitive to changing demands; from information systems which bring together information on interdependent functions; from methods for more accurately assessing the consequences of alternative procedures; and--more rarely--from the introduction of new technology. This is work readily performed by analysts whose training is in engineering, or operations research, or economics. It is the work to which quantitative analytic tools are best adapted and for which limitations of those techniques are least important. And it is work worth doing. In a city which commits some $6 billion annually to the provision of services, efficiency gains even of 1/10th of 1% can pay for a major research institute many times over. Equally important, such gains increase disproportionately the sums available in succeeding budgets for innovative and discretionary uses. By fairly conservative calculation, the implemented results of Institute studies are now saving the City some $20 million annually"* [4].

Other Rand work for New York City has been much broader, for example that on housing, but the dollar savings are much harder to determine.

Work for industry can bring similar gains but costs and estimates of savings are hard to obtain. I'll cite just one example, a study done in England for Imperial Chemical Industries Ltd. on the operation of a petrochemical plant [5]. This resulted in improvements to the process, mainly from changes in scheduling, and savings of 80,000 Pounds per annum at a total cost of 6000 Pounds.

To conclude, let me say something about the future of systems analysis.

Fortunately, it is not a static concept. The attempt to apply systems analysis to social and public policy problems is forcing changes from the way it has been practiced in the defense and aerospace industries. Some of these changes are methodological--in a greater use of judgmental techniques, Delphi for instance, and in ways of handling criterion problems such as the "scorecards" employed in the Rand transportation study. The greatest change required, however, is the inclusion within the analysis of an attempt to discover how the institutions and individuals affected may constrain the policy selected. For social problems, we must learn how to win the cooperation of both the people affected by the solution and those currently dealing with it so that the study recommendations are not only accepted at the top but by *all* interested parties and then implemented without being vitiated.

As you might expect, there is also criticism of systems analysis. I will not, however, say anything about it but merely close with an evaluation of analysis by two English economists. They were speaking of cost benefit analysis but could just as well have said systems analysis.

> *"....one can view systems analysis as anything from an infallible means of reaching the new Utopia to a waste of resources in measuring the unmeasurable"* ....[6].

REFERENCES

1. For more detail, see Harold C. Passer, "The Edison System," Chapter VII of *The Electrical Manufacturers, 1875-1900*, Harvard University Press, Cambridge, Massachusetts, 1953.

2. For an illuminating discussion of the differences in practice see K. A. Archibald "Three Views of the Expert's Role in Policymaking: Systems Analysis, Incrementalism, and the Clinical Approach," *POLICY SCIENCES*, Vol. 1, No. 1, Spring 1970, pp. 73-86.

3. deNaufville, Richard, "Systems Analysis of Large Scale Facilities: New York City's Water Supply Network as a Case Study," *JOURNAL OF SYSTEMS ENGINEERING*, Vol. 2, No. 1, Summer 1971, pp. 35-48.

4. Szanton, Peter, "Analysis and Urban Government: Experience of the New York City-Rand Institute," *POLICY SCIENCES*, Vol. 3, No. 2, June, 1972. Also in the forthcoming *Analysis of Public Systems*, A. W. Drake, R. L. Keeney, and P. M. Morse, editors, MIT Press, Cambridge, Massachusetts, 1972.

5. Jenkins, Gwilym M., "A Systems Study of a Petrochemical Plant," *JOURNAL OF SYSTEMS ENGINEERING*, Vol. 1, No. 1, Autumn 1969, pp. 90-99.

6. Prest, A. R., and R. Turvey, "Cost Benefit Analysis: A Survey," *THE ECONOMIC JOURNAL*, December 1965, Vol. 15, No. 300, pp. 683-735.