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A PROPER ROLE OF SYSTEMS ANALYSIS

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A PROPER ROLE OF SYSTEMS ANALYSIS

Quade's excellent summary of the results of his exploratory study of the merits of a course in "Appreciation of Systems Analysis" suggests that the limitations as well as the proper uses of systems analysis are to be considered. The notion that appreciation is at least of coordinate importance with technique strikes a responsive chord. But what is to be appreciated? The following quotation from Quade's paper reveals a point of view, not necessarily Quade's, which raises suspicions that if the limitations of systems analysis are not appreciated, such a course could do more harm than good.

"WADC apparently now believes that, during this design stage, the pay-off from a broad systems approach might be very great. Indeed, there seems to be a feeling in some parts of the Air Force that the systems approach may provide the complete answer to all questions of development, procurement, and operation as well as those of design. As for the contractors, who seldom feel well compensated for the effort that goes into development unless it leads to procurement, the systems approach might eliminate much of the time, money, and skilled manpower that, in the past has been a required expenditure on the perfectly sound aircraft which never reaches procurement. A properly executed systems analysis might not only furnish an "optimum" choice (subject to the restriction that the requirements and assumptions on which it is based are likely to be extremely arbitrary) but also an effective means of argument to the Air Force (provided the Air Force understands systems analysis!) that the particular choice is superior to those made by competitors. Both the Air Force and the contractor should save money.

"Today, the long time from research to production, the cost, the complexity, and the diversity of future airborne weapon systems, which may depend for their

effectiveness as much on a secondary characteristic such as radar as on the preformance technically possible with airframe and engine, make the systems analysis seem particularly adapted to Air Force use. Lately, WADC design contracts for major components have required (or strongly suggested) that the contractor make his proposal as the result of a systems study. The Bell Aircraft optimum missile study, the Douglas and Martin low altitude strategic bomber studies, the Boeing large yield carrier study, and the coming strategic fighter studies are reflections of this belief in the power of the systems approach. Industry representatives* have proposed that future practice in the Department of Defense require a systems analysis in advance of all basic planning decisions for the design and procurement of future airborne weapon systems."[1]

If we review that quotation carefully it appears that systems analyses are being turned to because (1) contractors seldom feel well compensated for development effort alone, hence systems analyses are required in order to avoid unprocured development;[2] (2) resources are wasted when perfectly sound aircraft are developed and then not procured;[3] (3) superiority of particular planes proposed by competitors could reliably be evaluated by the Air Forces;[4] (4) there is too long an interval from research to production.[5] To eliminate

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* For example, see "Application of Operations-Research Techniques to Airborne Weapon Systems Planning," Robert A. Bailey (Lockheed), JORSA, August, 1953.

1. D-1991, pp. 1-2.
2. Premise true, implication false.
3. False.
4. False.
5. False.

or reduce the effect of these alleged weaknesses it has been suggested that aircraft companies use systems analyses in deriving proposed optimal weapons and that furthermore the Defense Department should use systems analyses in advance of all planning decisions for design and procurement.

Little boys and matches neither logically nor inevitably lead to fires, but the probability is distressingly high, if it's your boy and house. Similarly there is no necessity for the compounding of the above allegations and suggested remedies to lead to disaster, but the probability that they will lead to no improvement at all and may even make things worse, is in our opinion, so high that we suggest a main purpose of the systems analyses course should be directed to an appreciation of its role in different kinds of problems and to the different ways by which we can seek to improve our decisions.

In brief, there are several different categories and types of problems facing the Air Force (later we give one possible classification). Different principles of choosing actions (making decisions) may be appropriate to each -- even though the same ultimate objective is common to all of them. For some of these categories of problems, systems analyses may be a major source of potential improvement; for others systems analyses may be helpful, but other kinds of modifications in our mode of behavior may be much more effective; and finally for some categories systems analyses may be dangerous unless certain commonly held prejudices are first dispelled.

Our motive in writing this is to emphasize the last possibility, i.e., systems analyses, unless used in an environment different from that which apparently now prevails, will do more harm than good in the development decision. But we are jumping ahead of our story.

More methodically, we shall first state what we mean by systems analyses. Second we shall distinguish between two types of choice. Third we present a

classification of categories of problems according to their amenability to systems analyses. Fourth we indicate some other tactics which jointly or even independently of systems analyses can help us take appropriate actions. In preview the objective of this order of discussion is to emphasize that of the several problems calling for action, systems analysis is helpful for some, but harmful for others unless certain institutional changes are made in our airplane industry. An appreciation of systems analyses requires an understanding of what it can do, what it can't do and what it is likely to lead to if used.

What are Systems Analyses?

What is a systems analysis? It is not merely another name for the scientific method in which we start with postulates and assumptions and derive implications which we then proceed to test. (1) Is it an analysis of a system of weapons rather than of merely an isolated component? (2) Is it the evaluation of a proposed weapon or component in the context of the whole complementary set of items constituting the whole air force structure, in terms of its effect on the operation of this whole organization? (3) Is it the systematic comparative evaluation of each of a whole family of weapons or items all slightly different, with the intent of selecting the particular member of the family of the weapon type proposed that is best for some specified operating situation? (4) Is it the evaluation of the weapons, just as in the preceding question, except that there is added a systematic variation in the possible environments within which the system might have to operate? It can be each of these. Each differs in the scope of the analysis and the sets of actions, a choice among which is to be influenced by information derived from the analysis. The one common characteristic worth pointing out here is the use of a

maximization (or minimization) principle for ordering the implications of the analysis. It may be costs that are minimized, or damage that is maximized, or speed, or something else, depending upon the particular problem.

Maximization vs. Diversity

Under what conditions can a maximization implication be equated with a decision or choice of action? If the assumptions were regarded as perfectly accurate forecasts and if the predictability of technological capabilities were known with perfect accuracy, then the maximization criterion, assuming one has the correct criterion, would reveal the optimal choice of action. But neither of these forecasting ability requirements are satisfied. Consequently the best that systems analysis can do is generate maximization implications of alternative sets of "ifs" or "forecasts." Choice of action then depends upon evaluating the various consequences suffered under the alternative "ifs" if a particular action is taken. In this case, where the consequence of a specified action cannot be uniquely identified in advance, there is not available any generally accepted rule for rational behavior. In fact it is difficult to tell whether a successful person—one who has a good record of making good decisions -- owes his success to blind chance, or to excellent forecasting ability, or to excellent analytic ability which enables him to maximize for specified forecasts. If our ability to forecast is good, then the source of future gains lies in improved analytical ability, i.e., improved predictions of implications. If our difficulty lies in poor forecasting ability, the impact of systems analyses is reduced. Improvement in both "forecasting ability" and "derivation of implications" must go hand in hand.

In any given situation, where more than one particular action can be taken (at increased cost), the choice might be one designed to anticipate a

wide range of potential forecasted "ifs", in the sense that while the choice is not optimal for any one future possibility, it does permit flexibility so that a fairly wide range of possibilities are covered with a degree of adequacy. The choice may be one with a narrow orientation, or it may be one with a wider orientation (but not as well adapted for the narrower range of possibilities). The decision about the choice principle will depend not upon the higher costs of diversity as compared to the lower costs of a unique best long term choice, but upon the probability distribution of costs under each type of choice.

For some problems, great gains will come from unique binding choices resulting from systems analyses; for others the gain will come from diversity of actions -- especially where diversity is cheap relative to the savings from subsequent final selections among the diverse set. At the risk of some violence we can distinguish two kinds of choices: (1) a choice of a single optimal action; (2) a choice of a diversity of actions such that subsequent selection may be made in the light of revealed developments. The first involves a longer range fixity, while the second involves a shorter range bind but purchased at the expense of higher current costs. In what situations is the latter principle of diversity preferable? And in what situations is the former appropriate? Do systems analyses help us to answer these questions? Does it help us select the diverse or unique actions? We think the answer is yes to both questions, but the point we would like to see emphasized in the course is that systems analyses also have the potentiality of misleading us. The danger we wish to emphasize is not the one arising from disputes over functional forms or details of the analysis, but from a failure to make the distinction between alternative principles of actions and from the biases built into our present Air Force attitude toward the financing of the aircraft industry.

Succinctly, we advocate that in addition to expounding the criteria problem in systems analyses we must clarify the decision problem. And we must do so because we fear that failure to remove certain built-in biases in our Air Force-aircraft industry arrangements will mean that systems analyses will do more harm than good for that class of problems in which diversity is the optimal principle of choice.

Types of Problems

To bring the discussion down to earth and make it applicable in concrete situations, the following classification of problems has been found useful.

1. The state of the world (International policy decisions)
2. Military policy (Strategic decisions)
3. Military force objectives (Tactical decisions)
4. Weapon performance characteristics (Development decisions)
5. Specific weapon alternatives (Procurement decisions)
6. Increase in set of possibilities of Category 4 (Research decisions).

I. State of the World.

With time, power positions will be revised. Since we cannot forecast with perfect accuracy we must use a spectrum of possible future alternative situations. For example, three reasonably likely states of the world in 1960 are: (a) Russia and U.S. are in still the same relative power position, with their satellities. (b) A Franco-German power has risen on the continent, turning the present bi-polar status into a three cornered situation. (3) Communist infiltration has succeeded in controlling all of Europe and Asia. Any choice among current actions, to be indicated below in the subsequent categories, must not be predicated on a single most probable world forecast.

II. Military Policy.

Suppose that event (c) in the above category were to be true in 1960. Our military policy might be to fight limited scope-limited objective wars, both parties fighting for limited objectives or it might be to talk about a direct strike against Russia. Again, the purpose here is not to suggest a set of well reasoned policies that is appropriate to each state of the world but rather to emphasize that there are alternatives.

III. Form and Use of Military Power.

For any given military policy for exerting power and influence, there are several forms of military power that can be utilized. If limited scope-limited objective wars are a policy, the type of Air Force mission will be different than if our policy rests on the threat of all-out attack against Russia. But within each of these, there are alternative possibilities. An all-out attack policy can be based on (a) strong home defenses, (b) SAC city offensives. Essentially category three comprises the various different military functions.

IV. Weapon Performance Characteristics.

For a specified status in category III, there are several alternative useful weapon types. For example, for SAC city attacks in Category III, there are in Category IV, (a) long range big bomb carriers, (b) long range guided missiles for big targets, (c) high altitude bombers, (d) low altitude small bombers. Category IV comprises general families of weapons.

V. Particular Weapons.

The B-52, B-60, B-47, Atlas, Snark, etc. and all types specifiable by blueprints or design specifications are included here. Given a specified class of weapons in Category IV, there is a choice among the competing weapons

available now or predicted as available at some future date.

Regardless of the category of problem within which one is being asked to make a decision, systems analyses are useful, if for no other reason than that systems analyses use logical methods of deriving implications of postulates and of finding optimum (in the sense of maximum) implications (distinguished from choices). But the way the results of the analysis are to be used in reaching a decision does depend very much upon which category one is concerned with; all this for the reasons given above. Some call for flexibility, some call for diversity, and in some case foresight and prediction may be so accurate as to permit unique choices based on maximizing conditions. How can one tell in which categories or situations diversity is appropriate and in which flexibility was appropriate? How would one know how much diversity or flexibility is in order?

If echoes are permitted, we can note the distinction between types of problems and choice criteria have been noised about earlier.[1] It was argued that the development decision warrants diversity and that the informational basis for choosing development work was different from procurement. With the proposal that systems analyses appreciation be taught to the Air Force and possibly to airframe companies, it is appropriate to resurrect these points in order to ensure that the use of systems analyses in these various categories is not taken to imply similar bases of choice.

The insurance principle of diversified investments in development is superior to the principle of developing and procuring one flexible weapon. This assertion is refutable. But so strong is our conviction in this, that we strongly recommend this theorem as a basic part of the systems analysis.

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1. RM-798, "The Chef, Gourmet and Gourmand," Armen Alchian, 24 March 1952, Confidential.

In all frankness, we are obstinately insistent that this is true for research and development decisions; we are of an open mind on the issue of whether or not it is true for procurement and other categories of decisions.

This conviction was based at one time on the uncertainty of the future and on large procurement and operational cost economies resulting from research and development expenditures. Now a second source of uncertainty is recognized, viz., the uncertainty of the performance capabilities of proposed weapons. This is not a criticism of aircraft designers or producers. It is a criticism of those who fail to appreciate the inaccuracy of prediction of weapon performance. Case histories of our past weapons provide abundant evidence, cf. B-36, for example. Officials of aircraft companies also attest to this. One official, L. J. Atwood, President of North American Avaiation Company, was so chagrined by rosy predictions about airplane performances prior to their flight, that he recommended penalizing any aircraft developer for over-optimistic claims. He complains that by overstating the case for a proposed weapon the manufacturers win procurement contracts. (Unfortunately, validity of Atwood's charges does not warrant that penalties be imposed. More on this below.) Earlier we had argued only that uncertainty about the specified task justifies the insurance principle. Now we argue in addition that our technological information is not good enough to predict performance characteristics of specified projected weapons with accuracy sufficient to make a unique choice of the best weapon even for specified military operations.

Institutional Biases Affecting Systems Analyses

But we have another axe to grind. If desirability of the possibility of diversity is accepted, then organizational and institutional biases against it should be detected and removed. So long as they exist, with no counter biases

the amount of diversity will probably be too small. If systems analyses show that development diversity is a source of big savings in total military costs, and we think it does show this, then removal of biases and obstacles against diversity is desirable. Or from the other side of the coin, their presence is prima facie evidence of insufficient diversity.

Consider the following facts:

1. The aircraft company that develops a plane typically receives a contract to produce it. This rule is subject to the following amendments:

a. Other producers may be brought in if the developer cannot produce at the rate desired by the Air Force.

b. Other producers may be brought in in order to have secondary sources of production available in case of an emergency.

c. Other producers may be brought in because they have been unsuccessful in the development of a plane the Air Force desires to produce but it is deemed advisable to keep this potential source of successful development in business.

2. Development is customarily a losing business for aircraft companies and development losses are recouped by production work.

What are the implications? Clearly losing money on development work must be a willful act on the part of aircraft companies, given the kinds of contracts the Air Force makes for development work. In the normal course of events, one would expect R & D work to be as profitable as any other type of activity carried on by aircraft companies. Why should aircraft companies choose to lose money on development work? It turns out that R & D work constitutes only a small proportion of the source of aircraft company receipts. The primary source of income is production work.

Because successful development work is a necessary condition for success as a producer, it would seem sensible for aircraft companies to view development as a vehicle for obtaining profitable production contracts. This suggests that the "losses" incurred in development are in effect "loss leaders" or devices whose cost is more than recouped in other activity, in this particular case production. The foregoing implies that we should find a state of hyper-competition in the development field and a corresponding state of hypo-competition in production.

However just as development is a bar to admission to production work, design competitions or study contracts constitute a bar to admission to development work. The function of these competitions is to sort out potentially good from bad designs and submit the good designs to the test of development. Therefore the hyper-competition we would expect to find in development is in fact shifted forward to the design state. How does this hyper-competition manifest itself? Companies compete by outbidding one another in stating expected performance characteristics and understating development costs in design competitions - study contracts.

Separating the wheat from the chaff by means of design competitions is a difficult task. On this point the President of North American Aviation says: "There is a disproportionate premium attached to winning a design competition. It is the ticket of admission to the production show, but after all a design is just a list of promises based on calculations, which in turn are predicted on assumptions that can vary with the optimism of the producer.

"Rarely if ever have there been any real penalties when the glowing forecasts of the design proposal were adjusted downward to the physical facts of the airplane. And it is then too late to change."[1] If we can believe

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1. Air Force, October 1953, "Airframes," by J. L. Atwood, p. 58.

this statement, then we must accept the conclusion that effective discrimination between good and best designs is not something which can be done reliably.

In the main, designs for military aircraft, unlike automobile designs for example, aim at achieving about as much as is possible in the way of performance given the technical knowledge on hand. Unfortunately, no clear line of demarcation exists that separates what is and is not technically feasible. Aircraft companies in attempting to capture in their designs the upper limits of what is possible often overshoot their mark and what comes out of development are weapons of inferior performance characteristics relative to what was proposed in designs. This is a natural kind of systematic error which results from the economic stress laid upon winning design competitions, the inability to distinguish good from best designs, and the lack of penalties for failure to meet design specifications.

The way to weaken the importance of winning design competitions is simply to bring enough competitive designs through the development stage so that the probability of accepting a developed plane for production is not high enough for aircraft companies to feel that the battle is won once a design is accepted. If such a procedure were adopted, the importance of predicting which designs will turn out best and which will not, a process which apparently is not very reliable, becomes relatively less important. The stress is then put upon the airplane companies to turn up with airplanes, not designs, which have a high performance capability.

A positive incentive in the form of rewards should be considered as a means for getting aircraft companies, and others, to go into development work for what they can get as profits in development rather than as a vehicle for obtaining production contracts. These rewards could be royalties for successful development paid in terms of number of planes produced or some kind of

prize for outstanding development work.

Along these lines, it seems worthwhile breaking the link between development and procurement. Procurement contracts should and could be awarded not for successful development work but for efficiency in production. Therefore there should be no necessary relationship between the developer and producer. Such a measure would force the aircraft companies to consider development as an end in itself and bring about lower costs of production simply as a result of the direct competition for production contracts.

Obviously this enhanced development program is going to be more expensive than the previous one. However if this expansion is initiated with a program that awards production contracts using the criterion of price as the basis for who gets what contracts, then money would be saved in the procurement field. A second source of savings would be of course having a greater range of better choices when the procurement decision is made thereby providing more effective forces for a given level of procurement expenditures or forces of equivalent effectiveness for a lower level of procurement expenditures. Thirdly, this development program will buy insurance against the effects of changing states of the world that produce changes in weapon requirements. These changes can be more easily coped with if ready alternatives are available that can be easily put into production.

If this predisposition to fixing procurement contracts by trying to optimize at the development stage is ignored in Air Force planning we have the following possibility ("actuality" in view of a recent contract requesting the Boeing Aircraft Company to recommend optimal weapons for the future):

If the aircraft companies all look to the kind of analysis performed at RAND, each firm will, after frustrating itself trying to predict the future state of the world, pick what it thinks is the most likely, or most acceptable

to conventional Air Force thinking. They will do so because their motives (sources of profit) are in developing a weapon that will ultimately be purchased in large numbers by the Air Force. They will regard the most likely future state of events as the one on which to place their development money. If the possible future states under Category I were predicted with probabilities .6, .2, and .2, it would be a little difficult to believe that any companies would design for the .2 contingencies. Their interest is in procurement; it is not in providing a balance of developments. And that is as it should be; from the point of view of the stockholders of the airframe companies. Thus their motives are not in conformance with the Air Force's, and secondly, even if they were (and we shall later indicate a method for bringing this about) their knowledge about events and problems of choice within Category I and II is at a comparative disadvantage relative to other agencies. For that matter, even the Air Force is at a comparative disadvantage in these categories, relative to higher civilian agencies. (And to compound matters even within the Air Force the incentives put upon it by the annual budget justification process direct its attention to cost reductions in present operations even if they increase subsequent costs.) In a nutshell, aircraft companies should not be asked to perform systems analyses which at once range over all of categories I-V. They have neither the proper motivation to reach helpful answers, nor do they have the knowledge. Any course in system analyses which fails to emphasize this will be doing a disservice.

But this does not mean that there is no role for systems analyses by airframe companies. They should be confined to Category V problems. They can be asked to ascertain best weapons, i.e., choose within Category V, for specified elements of Category IV. This analysis could be done along the lines of a systems analysis. And we assume that the aircraft companies are

well equipped to do this task; maybe they are capable of assembling a staff and doing it better than RAND. If they can't, then they should continue to serve as sources of specialized information in the RAND systems analyses.

Conclusion

If we now look back and examine the assertions on page 2, the basis for the footnote judgments will be evident.

1. Inadequate compensation for development work is the reason developers feel inadequately compensated. It's not because of some other technological or natural fact of life. Therefore the cure is not in using systems analyses, however desirable that may be for other reasons; the cure is to break the link between development and procurement and make development pay.

2. Resources are not wasted when perfectly sound aircraft are developed and then not procured. In fact, such an outcome is a necessary result of an adequate development program. Failure of such an outcome is absolute proof of inadequate development.

3. Superiority of particular planes cannot be ascertained by systems analyses; the ignorance giving rise to this inability is not the kind that systems analyses will remove.

4. The time from research and development to production is not too long. This view confuses the time required to perform a task with the completion date. We want early completion dates, and this can be achieved despite a lengthening of the interval between development and procurement, if we can arrive at given states of technical knowledge even earlier. An expanded research and development program promises more in the way of achieving earlier producibility than do attempts to shorten the period.

If these popular beliefs and fallacies are not thoroughly demolished

prior to the use of systems analyses, we predict that we shall soon find these beliefs being regarded as facts of life which systems analyses are supposed to offset. Erroneous belief that they can be offset will divert attention from them thereby resulting in systems analyses' self-frustration. If these beliefs are removed and replaced by a proper system of incentives and institutional organizations, systems analyses will have the opportunity of yielding fruitful information.

We may summarize our conclusions:

1. Systems analyses are machines for generating implications of postulated initial information; they do not generate decisions.

2. Under uncertainty, the criterion of decisions is not simple maximizations; the essence of the decision process is to affect the scope of random factors so as to give a "good" probability distribution of outcomes. The insurance principle is to decisions what maximizations are to analytic implications.

3. Insurance requires diversity of investment — not variety of possible environments or flexibility of particular weapons.

4. Optimal diversity in concrete situations cannot be ascertained. But institutional arrangements, wherein biases are created against diversity and toward identification of analysis with decision, are prima facie evidence of a system that yields suboptimal diversity.

5. Stratification of the military problem into categories according to those in which diversity is economical and not optimal will facilitate an appreciation of purpose and usefulness of systems analyses.

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