COMMAND AND CONTROL--A GLANCE AT THE FUTURE

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Introduction

Problems of command and control are as old as organized warfare; but it has been only during the last five years that general recognition and a name has been given to the "new" subject matter. In that short time the field has aroused a wide spectrum of interest, ranging from philosophers who see in the subject something close to the basic theory of knowledge, but with practical applications, down to military commanders with a very immediate concern with dispelling the traditional fog of war.

During the past half decade, practical interests have dominated. The concerns were urgent: vulnerability of command posts and communications; the rapid tempo of central nuclear war, especially the extreme rate of damage that can be inflicted with nuclear weapons and ballistic missiles; the total nature of central war which requires attention to a vast amount of information about status

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and resources of each side. These problems were sufficiently immediate so that command and control systems were created more or less "blind" without theory or even well-grounded empirical generalizations to build on. One of the factors which sparked these developments was the growth of capabilities in electronic data processing-sensors, communications, and computers. The impression was rather strong and widespread that by automation at least a large gain in speed of response could be obtained. Experience in these developments has been mixed, but by and large on the disappointing side. Complete automation of current procedures has turned out to be much more difficult than was thought, and without something close to complete automation, gains in speed are overcome by the complexities of man-machine interaction.

Summarizing the major trends in command and control during the past five years: There has been a concentration on central nuclear war problems, on partial "systems", on hardware-sensors, computers, and communications--on vulnerability of communications and command posts, on centralizing decisions in a few command centers, and on information gathering systems.

Due to long development times and the large sums involved in programmed systems, we can expect these trends to resist modification. However, there are forces which will produce some major changes over the next five to ten years.

The major force that will be operative is the shift in national strategic policy from a simple retaliatory posture for deterrence to a policy of flexible response to meet a wide variety of contingencies. This policy will lead to greater emphasis on decision systems for types of conflict other than all out nuclear war, and at the same time lead to requirements for extended command and control capability for central war. It is not possible to prepare contingency plans to meet the wide variety of potential conflicts inherent in the present complex international situation. Techniques for rapidly adjusting to unforeseen (or at least not-planned-for-in-detail) conflicts will have to be developed. Undoubtedly this will require larger capacity systems. Part of this increased capability will be met by increased automation for both data systems and weapons, part will be met by larger and more efficiently organized staffs.

One of the first points where this force will be felt is vulnerability reduction. We now have command posts on land, on sea and in the air. Before long we may have them under land, under sea, and above the air. However, the present emphasis on hardening and mobility as solutions to the vulnerability problem will run afoul of a simple fact of life. More and more complex-functions cannot be crowded into smaller and smaller facilities. This constraint could lead to attempts to reduce vulnerability by techniques that are more integrally related to the structure of information systems; e.g., distributed communications, less centralized command, increased automation of lower-level functions. These modifications will be aided by the fact that in many cases they would afford positive improvements in command capabilities as well as increased survivability.

Implementation of distributed communications and increased automation at lower levels of command will depend mainly on technical advances. Distributed command, however, runs counter to the trend toward centralization. Behind this trend are a variety of powerful motivations: The strategic problem does not neatly factor into subproblems. The significance of elementary events is large--one weapon can wipe out a city--and thus tight control by the highest, most responsible authority is indicated. In the present state of the art, centralization can produce significant gains in data processing efficiency. More generally, commanders normally want as rich and complete control of forces under them as is feasible. On the other hand, there are serious drawbacks to radical centralization in addition to intensification of vulnerability. The burden of decision on the central command is increased; mistakes at the central level are amplified; over-all flexibility is sacrificed. There will be a continuing attempt to balance these conflicting considerations, but

I will hazard the estimate that for some years to come, the political advantages of centralization will outweigh the operational disadvantages.

One further factor favoring centralization relates to coherency and the multiplication of separate "systems". The hazards involved in developing a large number of more or less independently designed information handling structures was one of the earliest recognized problems in the command and control field. Originally known as the "interface" problem, the difficulties are now recognized as being more profound than just compatibility of information formats and communications. One mode of approach to the problem of coherency is centralization. However, the approach is self defeating if centralization merely means piling further separate structures on top of functionally uncoordinated subsystems.

It would be pleasant to predict that the multiplication of separate systems is about to be reversed; However, the probability is that in the near future there will not be a significant change in this massive trend. The creation of a national military system will, for the time being, add one or possibly several new systems. Tying all the elements together into some kind of coherent structure will be a slow and painful process. In the meantime, advances in weapons technology and richer interpretations of strategic doctrine will require new system elements. Operations in space, non-central conflicts, cooperation with a more self-sufficient European community, are some of the major perturbations that will be experienced shortly. It would appear that the theory of untying Gordian knots has not advanced beyond the Alexandrian insight.

The overemphasis on hardware as opposed to procedures, programs, and information structure (language) has already begun to change, mainly because it is becoming clear that development time and costs for software may be as great and even exceed that for hardware for command systems.

The greatest change will be in the functions assigned to data processing. Up to now, command systems have been designed primarily with the aim of furnishing commanders with timely and easily accessible information, mainly of a situational or status type. It seems fair to say that major developments have occurred in this area, although techniques for organizing and displaying collected information are still somewhat primitive. However, in the area of central war especially, the value of timely information is marginal, if all it furnishes the commander is a ringside at the spectacle. In order for the commander and his staff to make use of large volumes of data for significant choices, powerful aids to decision have to be developed.

In this regard there will be a major change in philosophy. The emphasis will shift from systems to the development of specific capabilities. Probably the most important of these will be real-time planning techniques.

By real-time planning I do not mean "on-line". The terms "real-time" and "on-line" are often interchanged in discussing decision systems. I distinguish between these two, using "on-line" to refer to the type of man-machine interaction involved, "real-time" to refer to the relationship between decision and the process being controlled. A "real-time" decision system is one in which decisions are made during the course of the conflict. Real-time systems may or may not profit from on-line computer systems; although for the kind of decision system described below, it is likely that on-line implementation will be essential.

REAL-TIME PLANNING PROBLEMS AND TECHNIQUES

Planning Facts of Life

Planning for a large organization and particularly for a military organization has several distinctive properties:

a) The process being controlled is very complex involving operations spread over large areas in space and time.

b) The process is not a steady-state, but is highly transient.

c) The process is two (or more) sided--i.e., it is only partly controlled by one participant.

d) In general, the process involves strong interactions in both space and time. The process cannot be subdivided into subprocesses.

e) Information concerning the process is generally incomplete, and transmitted with varying time lags.

f) The process is highly stochastic--i.e., many subevents are predictable only as probabilities.

g) The process is incompletely known beforehand. This is more than f), e) and c). For example, the various probabilities may not be known accurately. In many cases, the precise form of interactions is not known.

These facts of life strongly condition the feasibility of real-time planning. The planner attempting to decide on a reasonable course of future action in the middle of on-going operations is faced with the problem of accomodating his decisions to actions already set in motion and now "out of control" while at the same time being forced to make decisions that later on may turn out to be inappropriate. The problem is not completely intractable, but a complete solution is not in sight at present.

Pre-planning vs Real-Time Planning

One solution to the decision problem is to design beforehand a precise schedule of desired controllable events. This is what is usually called a plan. Predetermined plans of this sort have a number of advantages: a) They act as a feasibility check, b) they can sharply limit the amount of mid-operation communications; the limit need only be "Execute Plan." c) They allow extensive analysis and evaluation, d) they can be practiced in training exercises, e) they can be designed so as to take into account the intricate space and time interactions of the total operation.

These are very desirable characteristics. On the other hand, the major drawbacks of pre-planning are that the circumstances under which the plan is executed may be entirely inappropriate to the particular plan, and, in general, the efficiency of a plan, even if appropriate, is likely to be low compared with the efficiency of more flexible decision techniques. There are four major types of contingencies in which some kind of adaptive decision making is desirable.

a) <u>Stochastic</u>. Many events can be predicted only with a probability less than one. Being in a position to make decisions based on knowing the outcome of some stochastic events may increase the efficiency by a significant amount.

b) <u>Incorrect Assumptions</u>. As pointed out in the preceeding section, the process is not completely known. For example the probabilities of stochastic events may be incorrectly assessed, or the nature of certain interactions may be misjudged beforehand. Large gains in effectiveness can result if these assumptions can be reassessed (learning).

c) <u>Strategic</u>. The process is not controlled by one side. Actions of the other side can strongly affect the appropriateness of a pre-planned response.

d) <u>Policy</u>. At the beginning of or during the course of operations, policy (evaluation, payoff) may change radically. Policy shifts will, in general, require major changes in plans. The same comment holds for shifts in the opponents policy, or misunderstanding of the opponent's aims.

Theoretically, all of these contingencies, except (d) can be met by a sufficiently rich set of preplans. The first three can be dealt with by generating a strategy (in the game-theoretic sense) rather than a plan. This means pre-selecting a course of action for each possible pattern of information over time. (d) cannot be handled within the confines of a single strategy. If the policy change takes place prior to the execute order, then (d) can be dealt with by a set of strategies, each designed for a specific policy (on either side!) However, if the policy shift or recognition of the opponents policy occurs after the initiation of action, a major re-planning process is required to take account of the new situation.

Although the first three types of contingencies can theoretically be dealt with by designing strategies; in practice this procedure is completely impossible to implement. The complexity of military operations is such that a single strategy would require astonomical storage space to write down (even if the storage were a computer memory). The evaluation of a strategy, or the attempt to pick an optimum, would be, of course, even less feasible. In addition, although alternatives can be specified for each pattern of information as affected by (b), incorrect assumptions, there is no way known at present to evaluate beforehand a selected strategy, even if all the other contingencies are well understood. In some cases this can be done if enough is known to assume a distribution of values of the unknown parameters, thus reducing to the stochastic case; but for the general case no satisfactory approach has been proposed.

Stochastic variations are the easiest to deal with, both for pre-plans and for real-time planning. In pre-plans, redundant allocation can be employed to maintain expected outcomes at a desired level. In real-time planning, serial allocation can be employed, providing enough information can be made available, communications to operational units exist, and the operational units have sufficient flexibility to accept the revised orders.

Contingencies arising from incorrect assumptions can be accounted for in real-time planning providing enough information can be accumulated sufficiently rapidly to allow reassessment of the parameters in time to affect a significant part of the operation, and providing the capability exists to reassess the consequences of earlier decisions.

In pre-planning, various kinds of "hedges" can be employed to smooth out the effects of variations in the opponent's actions. The simplest technique is to assign to the least vulnerable units the actions with highest priority. Redundant allocation can be used to cover some enemy actions where the results are considered to be roughly predictable. A further degree of sophistication which is feasible but has not been realized in practice, is to make the value of the opponent's resources a function of time, which "discounts" payoffs at a later (more uncertain) phase of the conflict.

Policy variations can be dealt with to some extent in the pre-planning context by designing separate plans for each of several gross variations in policy. This technique can rapidly get out of hand, especially when variations in the opponent's aims is also taken into account.

Organizational Aspects

Planning is a function conducted within an organization. There is a mutual interaction between the structure of the organization and the structure of the planning problem. For our purposes it will be useful to distinguish the planning problem in the abstract, from the planning process as imbedded in an organization. We can think of the subgroup of the organization that is concerned with planning as a black box and discuss the flow of information into this box, the transformation of that information necessary to produce operations orders, and the stream of orders from the box, in isolation from the organizational structure. This will result in some lack of realism, but should not be serious if the abstraction is kept in mind. The problem of unpacking the inward information flow into many recipients, of factoring the decision problem among several units, and of distributing the internal communications channels is a severe one. Furthermore, there are many aspects of the organizational flow of information that are not directly related to the decision problem, but involve "human factors." Many questions such as the level of detail which should be available to a commander are more closely related to the support the commander needs in order to exercise his authority than to the military decision problem. These considerations are extremely important for the over-all design of a decision system, but they are apt to obscure the form of the planning problem. Although a planning procedure designed in isolation from organizational constraints is likely to require major modifications to be applicable; it is also the case that organizational forms will mold themselves to improved planning techniques.

We can roughly divide a decision system into formal and informal parts. The formal part is that part of the information handling which is characterized by more or less well defined procedures and more or less formatted information. The informal part is much more difficult to characterize. It consists of material of a very wide variety: the newspaper item read at breakfast by a commander, the intimate acquaintance of a technician with the peculiarities of a given bomber, the understanding of an analyst of the limits within which an attrition computation is reliable, the estimate of a bomber commander of the "readiness" of his crew, and the like. Much of this material cannot be expressed in terms of precise elements in a decision procedure.

A somewhat more useful distinction is in terms of the formalized, the formulizable, and the unformulizable part of the information base of a decision system. In a dynamic look, some elements in the decision situation are not formulated, but could be, others, for various reasons, cannot--e.g., there is no theory to express interactions, the information is too vague or the volume is simply too great. The formal part of the information system is generally "tractable"--i.e., it can be expressed in models, it can be measured, it can be coded in various ways. The informal part is likely to be elusive (in much the way that informal channels of communication are elusive in organizational studies.) Some of the informal base can be expressed in language, and is, in the form of speech, telephone conversation, written memorandums, etc. Other elements may not be verbalized, and even other parts may not be verbalizable (although here we are treading on thin ice!) The distinctions are not sharp, and roughly we have the situation in Fig. 1.

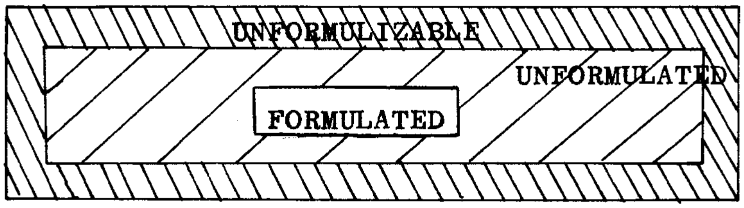


Fig. 1

Within a formal scheme for real-time planning, such as the model-family discussed in the next section, room can be made for influence from informal channels by allowing a fairly rich man-model interaction. This can be accomplished by giving the planner freedom to guide the compution by on-line resetting priorities, modifying parameters, and the like.

Model Families

In the real-time planning problem the two sharpest constraints are time, and incomplete information. Because of the complexity of military operations, what appear to be small changes can ramify into many dependent changes. Rapidly changing information will require frequent modifications. These two together pose the requirement for rapid reassessment of the situation, and rapid generation of operations orders. These requirements for rapid reassessment of the situation, and rapid generation of operations orders. These requirements can be met in part by the utilization of a family of models at different levels of abstraction.

In its simplest expression, the model family can take the form of a hierarchy of models, arranged in increasing level of aggregation:

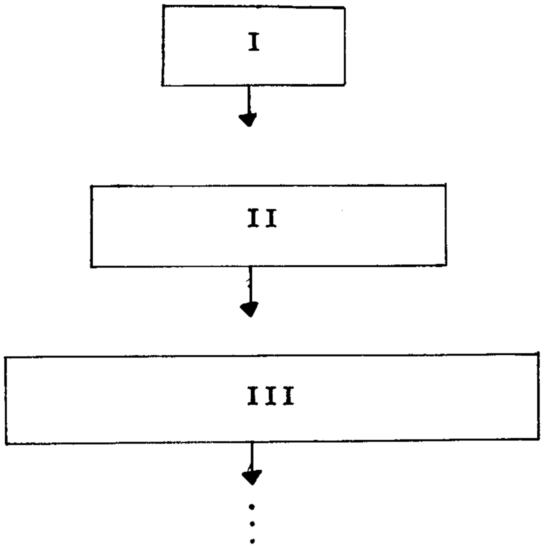
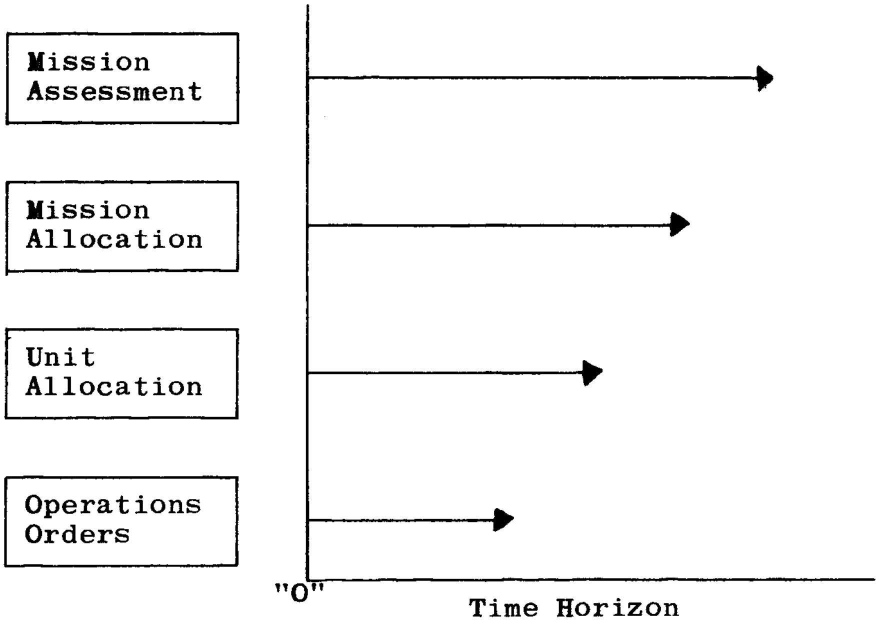


Fig. 2

The model of highest level can be utilized to perform over-all optimization and to express the strongest interactions among operations. Lower-level models then "unpack" the results of the preceeding levels, and perform suboptimizations on elements "aggregated out" in supra-models. As applied to the real-time planning problem this scheme takes the form:



The mission assessment model would be, ideally, a two-sided game which, at each significant change in information--"0" time, in quotes to indicate that it is a moving reference--would replay the entire conflict starting from the present situation. It would thus have an extended time horizon, but being highly aggregated could have a rapid compute time.

The intermediate models could have more restricted time horizons; and the lowest level, operations orders, could be restricted to just those actions which, for strategic reasons required immediate implementation. In this fashion a concordance is achieved between <u>scope</u> of the computation and computation time, the more scopic models being at the same time smaller.

The system presupposes continuous updating of information in terms of the <u>elements</u> of the models. One way to introduce learning into the system is to allow for rapid change of parameters at the planner's option. Since the computation cycle is repetitive, introducing such changes would not overturn the logical structure. Changes in policy could be effected to a first approximation by allowing rapid revision of the value scales and/or priorities. It is clear that to implement these learning and policy variation techniques, methods of rapidly generating appropriate inputs for the entire hierarchy would be needed.

In a less sophisticated exemplification of the model hierarchy, the highest level model could be replaced by a summary of desired operations, written by the planner. This would allow reflecting policy changes in a more direct fashion. A model family of this sort, called STRAP, is now under development at RAND.

The model hierarchy is only a first approximation to a planning system. Operational constraints at the implementation level can invalidate a plan, or sharply reduce its effectiveness. Feed-back from lower levels is needed to "reset" the parameters of the more scopic routines. This leads to the concept of a model family which contains a certain amount of self-adaptation.

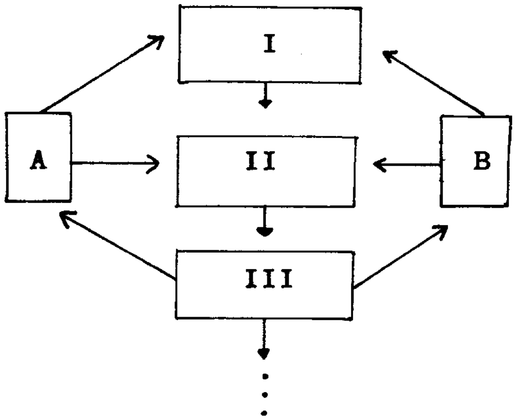


Fig. 3

In the illustration, A and B represent routines which reaggregate constraints uncovered in the lower levels. To reduce the amount of iteration that would result with such a system, a first approximation would be to reset only for operations called for in the next cycle.

A prototype of a model family like the one illustrated can be constructed using the subroutines of STRAP, and is now in the design stage.