Constitution, Finance, Education, Chapters, Memberships, Standards, ...
c. Liason representatives

This outline contains many ambiguities. I have done this purposely since I want to attract support for the concept without getting engaged in detailed discussions about the fine structure of the proposed new organization.

The key concept behind my recommended changes is to separate Transactions editing from other technical activity of the Society. Of course, coordination among all technical activities is essential but, in a volunteer organization, work must be parceled out into manageable pieces so that tasks can be accomplished without overburdening individual volunteers. In the new structure we may initiate new technical activities in a field unsuited to Transactions paper publishing. Or, we may select a Transactions Associate Editor who has no interest or competence to organize conference sessions, workshops, etc in his technical subject. I believe the new structure will allow us to more appropriately match people and jobs and will also provide more opportunities for service and thus broaden the base of volunteer support in the Society.

I would like each of you to write me a note commenting on these proposals. Just a brief comment will be sufficient but detailed remarks are also sought. If the general response is positive, we'll begin detailed discussions and formulate specific restructuring proposals for examination by AdCom. Since we are proposing a significant restructuring, eventual membership approval will be sought for appropriate constitutional changes.

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Command Control as a Process

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Summary

Military command control is described as a process for ultimately controlling a geographic area. Some of the requirements of this process are identified and models of it suitable for developing analytic procedures are presented. Two examples which highlight possible system trade-offs are discussed. The differences in system and environmental parameters in different military scenarios are pointed out, and some promising avenues for future investigation are proposed.

Introduction

The terms "command control" and "command control system" appear frequently in military jargon these days. And, although they have both been assigned specific definitions by the Joint Chiefs of Staff, they are often used to mean whatever the speaker wants them to mean. Most often, the term command control system is used to refer to some form of computer complex which presumably "processes" information and presents it to a "decision maker" for his use.

Recently, however, a different view of what a command control system is has begun to emerge. Initiated by the apparent failure of some of these command control computer systems to satisfy their users, questions about the commander's real needs led to two interesting conclusions. First the "requirements" which had been levied on the system developers were simply the sum total of everything which the commander's staff thought might be nice to have. And second, there was no general analytic or theoretical basis for making judgments about what information was needed by whom, or how quickly and in what detail he needed it.

Rather it seemed that command was an art, which military officers learned through a combination of apprenticeship to a "commander" and the reading of military history. Unlike an airplane pilot, who has at least a smattering of the science or discipline of aeronautical engineering, a commander appeared to have no such organized body of knowledge, or theory, to draw on in the practice of his craft.

As a result of this conclusion, there are now several attempts underway to develop what could be called a "theory of command control." While motives and viewpoints may differ, the descriptive structures being built have many common features and in general are quite isomorphic. And all of the models include much more than just the commander and his computer. Without exception, they all include within the system boundaries both the instrumentalities which gather the information and the action elements which execute the commander's decision. And generally the term "sys-

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tem" is used to emphasize the functional or organizational aspects and the term "process" to emphasize the flow characteristics or time sequence of the functions, rather than the functions themselves. Thus our concept of a command control system has taken on a distinctly cybernetic flavor.

This paper first outlines the conceptual view of command control (C^2) which I have used as a basis for developing a "command control theory." Secondly, it presents a generalized model of a C^2 system and a brief look at some derivative models. Two elementary examples of how such models can be used then leads to a short discussion of some of the important system parameters. Finally, I will outline some of the more important research directions for the future development of this complex field.

The Command Control Process

The starting point for present-day descriptions of a command control system is the realization that it embodies a uniquely *military* process. The ultimate purpose of a command control system derives from a higher national or political desire to maintain, or to change, the status quo in some geographic area. Unlike a management system, a command control system seeks to bend an unwilling, and often actively hostile, external environment to its desires. In the broadest sense, some "higher authority" has specified a desired state of the environment (or geographic region) and it is up to the command control system to establish or maintain that state, employing force if necessary. (Oftentimes the threat of employing force, as in "strategic deterrence," is hopefully sufficient to control the environment.)

Viewed from this perspective, a command control system must incorporate the ability to (1) perceive (sense) the state of its environment, (2) compare that perception with the specified desired state, and (3) if there is a discrepancy, take some action to force the environment into the correct or desired state. While the traditional view of command control encompasses only the information processing and decision-making functions, this more holistic approach also includes the information-gathering (surveillance) function as well as the ultimate means of taking action to force compliance, the forces assigned to the commander. With these conceptual additions, a military command control system takes on much of the appearance of a conventional cybernetic system and, hopefully, becomes more amenable to analytic treatment.

In addition, the modern view of command control requires that any proposed model of the process be applicable to any echelon of the military hierarchy. That is, we want a representation of the process which will apply equally well to a platoon leader, a Naval Battle Group commander, or the highest National Command Authority. This, of course, implies that the model must also be "nestable" so that we can describe recursively the hierarchical relationships that must exist between the various levels of command. Thus at any level in the hierarchy we want to use a model of a control system, which is controlling (determining the objectives of) one or more replicas of itself at a subordinate level in order to achieve its objectives, while at the same time these objectives are being determined by a similar, but superior, system.

And, finally, it is now generally accepted that the most important single element of a C^2 system is the representation of the environment which it provides to the commander. This is often called the geographic display (geo-plot) or "vertical plot" in military jargon.

This is so because humans can deal with (understand) pictorial representations of geometric information much more rapidly than they can a narrative description. And obviously the commander's primary concern is with the spatial relationship of things in his environment. Therefore, charts or maps with appropriate symbols on them are the most effective means of communicating to him the state of his environment.

In some cases actual maps with movable markers are appropriate; in others, electronic, TV-like displays may be required to keep pace with the action. But, in any case, it is this facility which is crucial to the commander's performance. No matter how good the other parts of his C^2 system may be—if he does not have a current "picture" of where things are, he is completely impotent. It is from a pictorial representation of large amounts of information that he gains his perception of the environment. From this he arrives at decisions and selects courses of action.

A General Model of a C^2 System

A convenient model of the C^2 process which meets the requirements set forth above is presented in Figure 1 in its general form. An individual rifleman senses his environment with his eyes, his brain processes what he sees in conjunction with his orders, and he takes appropriate action with his rifle. At the same time, a commander higher up the chain may have available a

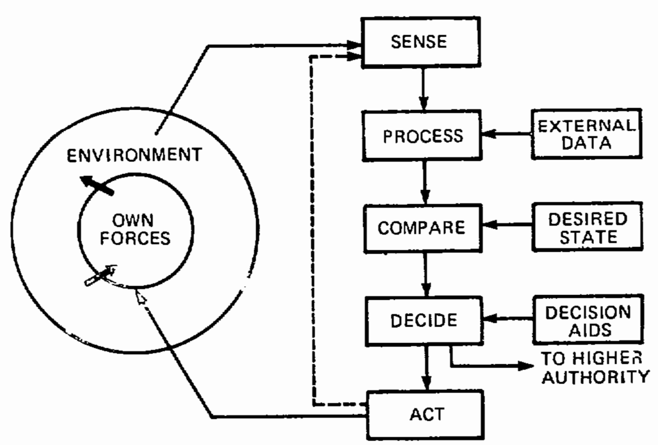

Fig. 1. Detailed model of C^2 process.

vast array of sensors, a much more complex processing and comparison function, and a whole regiment of soldiers to effect the actions upon which he decides.

The model of Figure 1 can, of course, be used recursively in a hierarchical structure, as shown in Figure 2, to elucidate the interactions between the various levels in a command hierarchy.

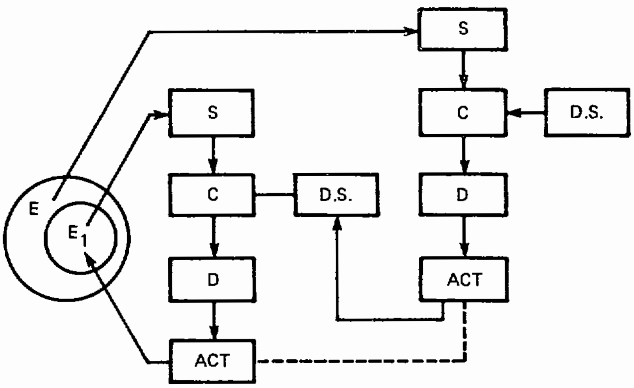

Fig. 2. "Nestled" C^2 process.

Also, in general, a commander will have several subordinates, whose "environments" may overlap, as for instance when they are using the same air space to conduct strike operations and anti-air warfare. Figure 3 depicts such a situation, and makes it obvious that an important consideration for the commander is to avoid setting goals for his subordinates which may put them in contention. That is, it is his responsibility to define, not only their individual objectives, but also the $N(N - 1)/2$ interfaces which may exist amongst them, in order to prevent fratracide within his forces.

This point is worth some belaboring. We mentioned above that C^2 was different from "management." In very few management situations can the subordinates actually destroy each other. Nor are crucial decisions often made as quickly as they must be in combat or on "the leading edge of war." Thus, the cost of a *wrong*

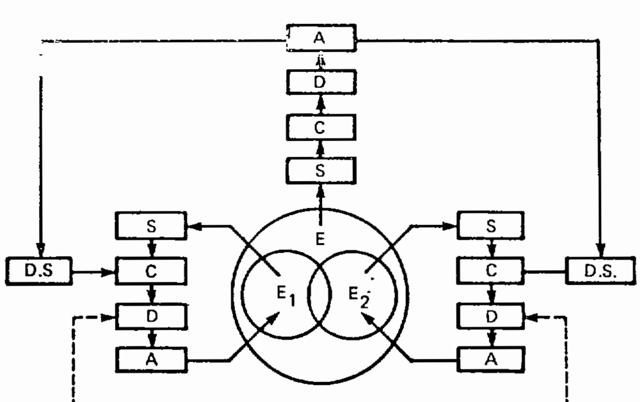

Fig. 3. Coordination of C^2 processes.

decision in a C^2 system is typically much higher than in a management system. Management might be described as the efficient use of resources *internally* to deal with a benign or neutral environment, whereas command control is the effective use of resources to deal with an *external* hostile environment.

And because this external environment can sense our activities, and respond to them, time becomes an important parameter.

Therefore, in addition to this functional model of a C^2 system, we need a representation of the dynamics of the process. Such a representation often takes the form of a "time line analysis." In this model the assumption is made that an event takes place (in the environment) at time t_0 which requires a response by the command control system. Furthermore, it is postulated that this response must be accomplished before a later time, t_p, at which it will have been effectively preempted. The intervening time between the initial event and the preemption of the desired or appropriate response is then divided into epochs as shown in Figure 4. First there is, in general, some delay before the event is

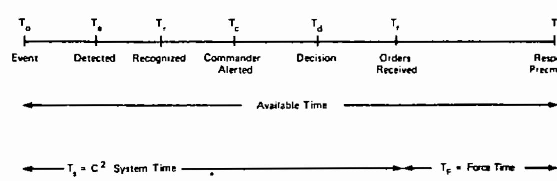

Fig. 4. Time Line Analysis.

detected. Then there is a time while the detection is evaluated or processed, leading to a recognition of its significance. Following this, the commander is alerted, formulates a response to the event, and makes his decision to execute it. Shortly thereafter, his forces will receive their orders and swing into action.

Now, in general, the forces will have to move into a new position to effectively implement their instructions, which consumes some of the time which would otherwise be available for fighting. An important part of the "Force Time" shown in Figure 4 may be devoted to simply moving. And, of course, there may be communication delays between each step of this process, which we have here included as part of the major functions.

This fact suggests a convenient distinction which may sometimes be useful to make. We can consider the "command" part of a command control system as the planning function, (which affects how much the forces have to move), and the "control" part as the actual monitoring and directing of the plan's execution. This allows us, at least conceptually, to examine the effectiveness of the planning function separately from that of the control function. This is important because both functions are inherent in a military C^2 system, but usually operate on quite different time scales, and in response to quite different kinds of events.

For instance, a brilliant commander may have prepositioned his forces so well in response to the enemy's posture that they don't have to move to execute his orders subsequence to an "event." So he may achieve the same overall success with a slower C^2 *support* system than could a less gifted commander whose forces were not in the right place.

This we arrive at a dualistic model of a C^2 system. One representation is a structural or spatial model that looks very much like a feedback control loop. The other representation is a cyclical one in the time domain in which the response to one event triggers another event (through the opponent's C^2 system) which in turn is detected and causes yet another response. In this way, our model, although basically simple, provides us with the "richness" required for application to the analysis of real world problems.

Highlights of Other Models

As mentioned in the Introduction, the "model" I have proposed is not unique in the present-day search for a "unified command control theory." There are many others, of which two are of particular interest.

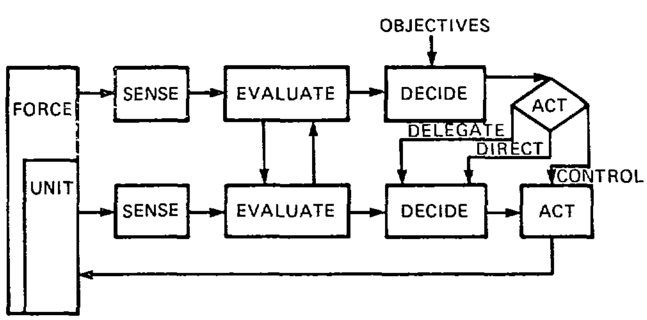

Fig. 5. APL Model.

First, there is a model developed by Carol Fox and her colleagues at the Applied Physics Laboratory of Johns Hopkins University which is reproduced in Figure 5. This model is an extension of the generic one proposed above which focuses attention on two important possibilities in a hierarchical structure. First, providing a capability for "evaluators" at different levels to exchange data, information, and "hunches" may make an important contribution to the uniformity, correctness, and understandability of the "perception of the environment" (geo-plot) which they present to their respective commanders. But this additional communications network between the analysts at different levels will require an investment in communications capacity. How much improvement does it provide?

Secondly, this model also makes *explicit* the fact that a commander may delegate some authorities to a subordinate, or may provide him direction (set a "desired state"), or may simply bypass him and take direct control of an action. By delegation, a commander can reduce *his* required information flow. What effect does this delegation have on the communications and information processing capacity required at the various levels of command?

The second model worthy of particular note is one due to the work of Dr. Tom Rona of Boeing Aerospace. His particular interest is in the field of what is colloquially known as "Counter C^2" or, as he describes it, "the information war."

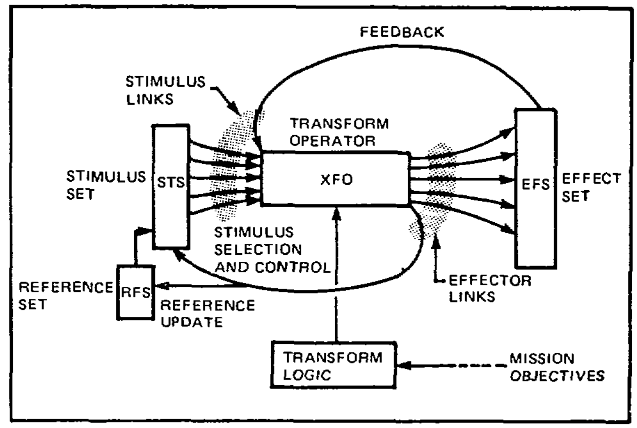

Fig. 6. Rona's Canonical Model.

Reflecting this approach, he isolates the "receptors" (sensors in my model), the "transform" function (analogous to my processing, comparison, and decision functions) and the "effectors" (the "forces assigned" in my model) for special emphasis. His basic model is displayed in Figure 6, and emphasizes the feedback to, and control over, the "transform" function. In analogy

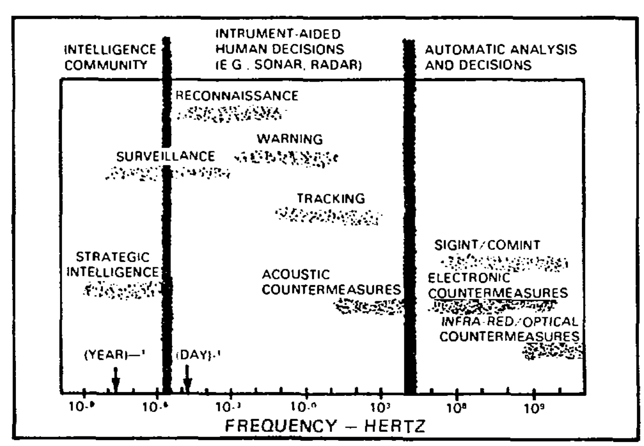

Fig. 7. Event Spectrum.

with the "time-line analysis" above, Dr. Rona proposes a non-dimensional "frequency spectrum" shown in Figure 7. This presentation focuses our attention on the fact that effective Counter-C^2 includes not only electronic jamming during an attack, but also misperceptions which have been carefully nurtured over a long time span to disrupt what I have called the command or planning function.

Application of the C^2 Model

As we said before, our view of a C^2 system has an assumption that the commander has before him a representation of his environment (a "vertical plot" or a map with pins in it) which provides him with an understanding of the spatial relationship of the objects (his own, the enemy's, and neutrals) within his area of concern. It is the responsibility of the sensing and processing functions of the C^2 system to keep this representation up to date and accurate. And an obvious question is: "how up to date and accurate is good enough?"

Let us examine, as a specific example of such a calculation, the case of firing a long-range cruise missile at an enemy vessel. We assume the missile has a velocity V_m, the enemy ship has a velocity V_s, and is at a range R from the firing platform. If we further assume that the "shipping density" (assumed uniformly randomly distributed) in the vicinity of the target is ρ and that the missile will atack the first ship it "sees," it is easy to show that the probability of correctly attacking the desired target, (P_{ca}), is given by:

$$P_{ca} = \{1 + \Pi\rho(RV_s/V_m + \sigma)^2\}^{-1} \qquad (1)$$

where RV_s/V_m is the distance which the target can move during the missile's flight and σ is the initial uncertainty in its position. That is, the *area* of uncertainty within which the target is located grows as the *square* of the missile's flight time and encompasses more and more of the "background" shipping density, reducing the probability of a correct attack.

This relationship can best be examined by presenting it in the form of a nomograph, Figure 8. There we have plotted with a solid line the result of firing at a 20-knot ship from a range of 250 miles with a 500-knot missile in an environment which has a shipping density of 2 × 10^{-3} ships per square mile when the target's location (but not course) is known exactly at the time of firing. The resulting P_{ca} is seen to be about .93.

Now it is asserted without proof that the cost in resources to provide a surveillance (sensing) capability such that the locations of potential targets are known exactly and continuously is more than can be afforded. However, for a reasonable cost, an ocean surveillance

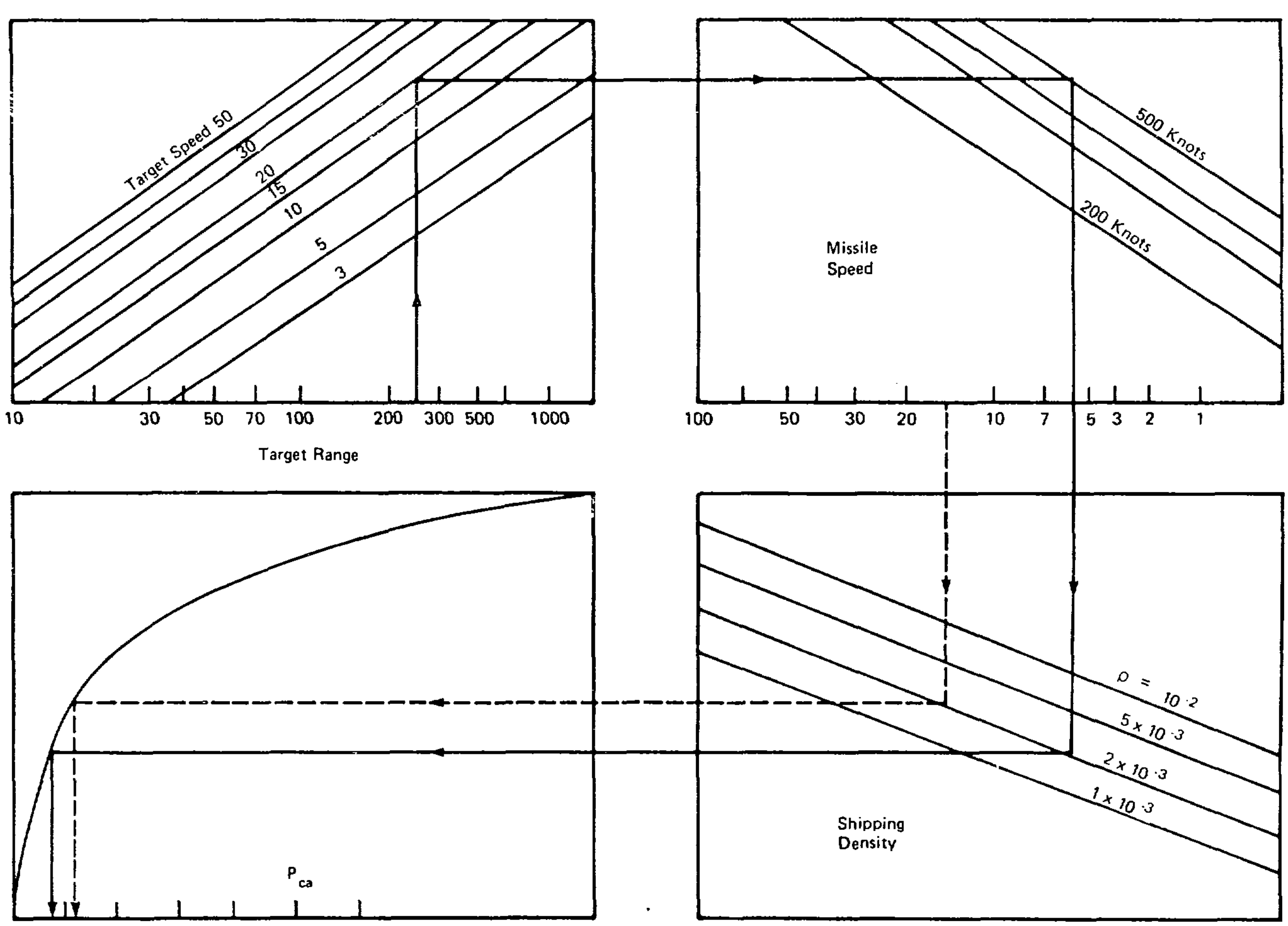

Fig. 8.

system might be able to achieve a ten mile uncertainty in object locations over a fairly broad area. Introducing this location uncertainty is equivalent to moving ten miles left on the abscissa of the second box in the nomogram, and the result is plotted with a dotted line, leading to a P_{ca} of about .88.

Note that if the commander had the time available, he could direct the firing platform to close to a shorter range and recover some of the lost performance. Or, on a longer term basis, an investment in a faster, and presumably more expensive, missile could produce the same result. Alternatively, an ability on the part of the missile to discriminate between ship types—perhaps on the basis of length—would reduce the apparent shipping density and again produce an improved P_{ca}. (Or he might have prepositioned the firing platform at a shorter range—if he had *planned* better.)

Thus in one fairly simple example we can begin to see the direct interactions and trade-offs between investments in different parts of a command control system when both the sensors and the active forces are included as part of the system.

As a second example, let us consider a case which shows more explicitly the importance of the performance in the time domain of the information-processing part of a C^2 system. Suppose we expect to be attacked by 600-knot aircraft which carry missiles with a 200-mile range and we know that there is a 20-minute delay from the time a raid is detected until the defensive aircraft are vectored to intercept. If the interceptors also fly at 600 knots and the goal is to intercept the enemy before he can launch his missiles (at 200 miles), then the vectors must be given when the enemy is at 400 miles, and the first detection must take place at 600 miles.

If our first detection is being provided by airborne early warning (AEW) aircraft whose radars have a 200-mile range, it will take nine of them to provide surveillance all the way around the perimeter of the 600-mile circle.

However, if we can improve the time delays in our sensing, processing, and decision functions so that it only takes five minutes from detection to the commitment of forces, we shrink the required detection radius to 450 miles, under the same assumptions, and the reduced circumference can be adequately covered by only seven AEW planes.

A 75 percent reduction in C^2 time delay has allowed us to make a 22 percent reduction in men and materiel devoted to the surveillance function. And equally important, the AEW planes now would fly 300 miles less going to and from their posts, which might double their time on station, requiring only half as many flights per day. So we have decreased not only the number of forces required, but their operating tempo by reducing the time delays in what is conventionally regarded as the C^2 system. Obviously, as we saw in the first example, providing faster interceptors (which are generally more expensive) could probably accomplish the same result. But it is by no means clear that increasing the aircraft's mobility is a more cost effective solution than reducing the information processing time delays.

While such analyses cannot define an optimum command control process, they do point out a methodology by which different configurations of a command control system can be compared in quantitative terms.

The Parameters of a C^2 System

In our simple examples of Command Control Theory analyses given above, the results clearly depended on certain generic properties of the equipment used to implement the C^2 process.

It is worth a moment's digression to examine what values these parameters may assume under different scenarios.

TABLE 1
Some Typical Environmental Parameters

Parameter	Army	Navy	Air Force
Size of Area	5×10^3	10^6	10^4
Nature of Terrain	Rolling	Flat	Free Space
Clutter	High	Low	Low
Total # Objects	10^5	10^3	250
No. of Hostiles	10^4	50	100
No. of Friendlies	10^4	50	100
Object Speed (mph)	30	30	500-1000
Object Value ($)	10^5	10^8	10^6

TABLE 2
Some Typical Force Parameters

Parameter	Army	Navy	Air Force
No. of Force Elements	500	10-50	25-200
Weapons Range (mi.)	2-20	15-150	2-10
Platform Speed (mph)	10-30	10-30	100-1000
Platform Radius	150	3000	300
Weapons Cost ($)	10^3	10^5	10^4
Combat Duration	Continuous	Intermittent	Short
No. of Targets	10^3	50	200

In particular, Table 1 gives some representative values of the "environmental parameters," with which the sensing and evaluating part of a C^2 system must deal, for the case of land, sea, and air warfare.

And in similar fashion, Table 2 portrays some of the "force parameters" for these three cases.

Examination of the data in these two tables should make it clear that, while the models we have adopted (e.g., Figure 1 or 5) are adequately general to apply to any C^2 system, when we go one step further, and discuss the implementation of the functions, we must take account of the wide differences in the environments to be sensed and the forces available to deal with them. Thus a C^2 system which is wholly adequate for the Navy may have serious deficiencies for the Army problem and vice-versa.

For instance, in the Army case there are typically thousands of objects on the battlefield, each one of relatively low value. By contrast, the Navy has to deal with only hundreds of objects, each of high value, scattered over a much larger area. And the forces at the commander's disposal show a similar disparity. The result is that, to first order, a naval C^2 system must deal with relatively few, but high cost decisions, while an army system has to deal with many more decisions, each one of lower economic cost.

And herein lies a major challenge. At the "fighting level" the systems must perforce be very different—yet at higher command levels we would like them to become more similar and blend into one "system" for the National Command Authority.

The Intellectual Challenge of C^2

In this brief exposition, I have attempted to explain how the concept of a C^2 theory came into existence, what the present state of the art in C^2 theory is, and something of the complexities of its subject matter. Now I would like to conclude by pointing out some guidelines for future work in the field.

First, and perhaps most important, is that, to be effective it must be simple. Geometry and algebra are understood by admirals and generals, not set theory and triple integrals.

So "cookie cutter" radars, whose detection probability is unity out to a fixed range, and zero beyond that, are the order of the day. Simplifying assumptions must abound in order for the major relationships to be apparent.

Secondly, while the cybernetic nature of the system as I have described it is obvious, we need to examine the effect of changing some of the conventional procedures and interactions. For instance, many investigators are attacking the problem of taking a series of observations of the location of things and turning them into a continuous "track history."

But what would be the effect of scheduling the surveillance assets to produce an optimum "report stream" for the purposes of developing track histories? More specifically, for instance, in the naval environment, with fixed surveillance resources, two quick looks, followed by a long "coasting period," followed by two quick looks, etc., may be more effective than a *uniform* "sampling rate." If the "quick looks" came within an interval so short that there was almost no possibility of confusing two objects, the resultant estimates of course and speed should make it possible to correctly "associate" the third "look" much more easily. We need a theory of surveillance akin to the existing theories of "search" or tracking.

Third, I would draw your attention to the problem of how one should manage the data flow. With a multiplicity of sensors examining the environment, how, where, and under what circumstances should their individual observations be merged to produce a "percention of the environment"?

This raises questions which concern such subjects as availability of the information to commanders at all levels, the requirements for additional communications capacity, and the "survivability" of the system in the face of both battle damage and natural perturbations.

The fourth major gap in developing a sound C^2 theory is in our understanding of what information is needed, at what level, in order that a hierarchical system operate effectively. The work already done in the area of "team decision making" is a start. But it seldom deals with a *hostile* environment, so it is of limited use in developing a (military) "Command Control Theory."

Finally, from the examples cited above, it should be clear that, while we call it a "C^2 system," we can't really write down an "equation of state" for the system with which we are concerned. Work on developing "closed loop" expressions of military effectiveness, in terms of some of the generic parameters I alluded to earlier, and in the context of a "generic model" of a C^2 system is badly needed. So, it seems to me that for a control system theorist, an operations researcher, a system engineer, a decision theorist, or even an applied psychologist, the field of (miltary) command control offers powerful challenges.

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Previously he was the Director of Navy Laboratories from 1968 to 1974. As such, he was responsible for the management of the Navy's in-house RDT&E complex. He represented the Assistant Secretary of the Navy (Research and Development) on all policy matters regarding the Laboratories, controlled the manage-

Continued on page 16

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Pierre R. Belanger was born in Montreal. He received the B.Eng. from McGill University in 1959, and the S.M. and Ph.D. degrees, both in Electrical Engineering, from M.I.T. in 1961 and 1964, respectively. After a two-year period with the Foxboro Company, he joined McGill in 1967 and has been there since that time. He is currently a Professor in Electrical Engineering and Chairman of the department. He is currently Vice President (Finance and Administration) of the IEEE Control Systems Society.

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ment and support funds of the Navy's research and development appropriation, established the Navy's RDT&E military construction program, and sponsored certain technical programs carried out by the Laboratories. From 1967 to 1968 he was Research and Engineering Consultant to Commander-in-Chief, Pacific. From 1965 to 1967 he served as Special Assistant (Electronics) to the Assistant Secretary of the Navy (Research and Development). From 1958 to 1965 he was with Scientific Engineering Institute, a small nonprofit research organization in Boston, Massachusetts. From 1953 to 1958 he was with the Control Systems Laboratory, University of Illinois.

He received his B.A. with honors in physics and did his graduate work in nuclear physics at the University of Illinois, receiving his M.S. in 1949 and his Ph.D. in 1953 from the University of Illinois.